SOUTH NATION RIVER
BASIN DEVELOPMENT STUDY

VOLUME 1

SOUTH NATION RIVER
CONSERVATION AUTHORITY

SOCIETE D'AMENAGEMENT DE
LA RIVIERE NATION-SUD

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14 October 1982

The Manager
South Nation River Basin Development Study
South Nation River Conservation Authority
P.O. Box 69
Berwick, Ontario
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Report on Water Resources Study Component:
South Nation River Basin Development Study

Dear Sir:

We take pleasure in submitting the final report outlining findings and recommendations of the Water Resources Study Component. This information is based on a thorough investigation of streamflows, water quality and groundwater within the basin. The effects of various land use changes, agricultrual drainage practices and water management alternatives have been evaluated as further background information for the Basin Management Plan.

All of which is respectfully submitted.

Yours very truly,

MacLAREN PLANSEARCH INC.

J.V. Morris
President

R.B. Wigle
Project Manager

Encl.
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EXECUTIVE SUMMARY

INTRODUCTION

The South Nation River Conservation Authority has undertaken a comprehensive river basin study under the Canada/Ontario Eastern Ontario Subsidiary Agreement which will produce a Plan for the integrated management of land and water resources. Several resource related studies were authorized by the Authority in order to provide background information for the Basin Plan.

This report outlines the findings of a water resources investigation which forms an integral component of the Basin Plan. A thorough review of the natural water system including low and high flows, water quality and groundwater is provided.

Stream discharges in the South Nation River and its tributaries are characterized by an almost annual occurrence of widespread flooding which impacts agricultural lands together with low summer flows that constrain water supply, waste assimilation, and recreational opportunities. Earlier studies have identified capital works schemes which can reduce agricultural flooding and provide a low flow augmentation capability. Nevertheless, an increased awareness that land use practices directly affect water resources of the basin has given rise to concerns that increased agricultural production and land drainage may further aggravate water management problems. An integrated package of hydrologic and water resource operations models was used during the study to investigate these problems.

ANALYSIS OF STREAMFLOW AND PRECIPITATION

Available flow data in the South Nation River Basin consists of 15 records with only six having a sufficient duration for flood frequency analysis. A number of graphical and statistical analyses which were conducted to check the adequacy of the data base provided the following insights:

- Double Mass Curve analyses of the streamflow stations on the South Nation River at Plantagent Springs and Spencerville, the Castor River at Russell and the East Branch of the Scotch River near St. Isidore confirm the consistency of the data base. An investigation of annual precipitation at Ottawa CDA, Ottawa International Airport and Kemptville stations yielded similar conclusions.

- Graphical analyses including the cumulative moving mean discharge, and temporal distribution of normalized discharge of the South Nation River at Spencerville and Plantagenet Springs and the Castor River at Russell when compared with the Ottawa CDA precipitation station, show that the time series are stationary and do not exhibit trends. There is some indication of persistence in the annual discharge data since both high flow and low flow years tend to be followed by flow years of similar magnitude.

- Further statistical checks of streamflow data indicate the data sequence may be considered trend-free at the three foregoing streamflow stations for the annual, May, and June to October period flood and time series of discharge. The flow data for annual discharge and flood exhibit some persistence which is attributed to the basin precipitation in view of the high correlation between annual precipitation and annual discharge.

- Based on the analysis of flow records within the South Nation basin, historical changes in runoff and flood patterns cannot be attributed to the introduction of tile and outlet drains in the watershed. However, floodplain storage upstream of flow gauges will attenuate flood peaks and may tend to moderate any changes in the flow regime which are caused by agricultural drainage. Further investigations were carried out to substantiate this conclusion.

- Available flood records at six stations, South Nation River at Spencerville, Chesterville and Plantagenet, Castor River at Russell, Bear Brook near Bourget and the East Branch of the Scotch River near St. Isidore, were fitted with the Log-Normal (LN), Three Parameter Log-Normal (3LN) and the Log-Pearson Type 3 frequency distributions.

- It was found that the Log-Pearson Type 3 distribution by the method of moments is an appropriate distribution for flood frequency analysis in the South Nation River Basin. The added advantage of using this distribution lies in its ability to incorporate information from regional skewness in order to increase the reliability of estimating the magnitude of rare flood peaks.

- The skewness coefficient for those streamflow stations immedately downstream from major floodplains was found to be negative, while those stations unaffected by major flood-plain storage exhibit positive skewness. It is suggested that large natural floodplains act as storage reservoirs which attenuate the high flood peaks and effectively set an upper bound on flood discharge rates.

- One-day and seven-day flow duration curves were computed for the June through November and December through May periods at the following flow stations: South Nation River at Plantagenet, Chesterville and Spencerville, Castor River at Russell, Bear Brook near Bourget and the Scotch River near St. Isidore.

HYDROLOGIC MODELLING

The Hydrologic Simulation Program - Fortran (HSP-F) was selected for use in the modelling of the water resources of the South Nation River basin. The comprehensive simulation capabilities of the program, its operation in a continuous simulation mode, and its deterministic representation of the hydrologic cycle and water quality processes are attractive features of this model. The model of the South Nation River Basin was used to:

- Extend available records of streamflow at gauged locations.

- Develop streamflow records at ungauged locations of interest.

- Examine the impact of structural water management options on the basin hydrology.

- Evaluate the impact of land use scenarios including land drainage on the basin hydrology.

• A period of 22 years, from 1957 - 1979, was chosen to simulate streamflows within the South Nation River basin. This period was primarily dictated by the availability of hourly meteorologic data records at stations in Ottawa for the temperature, wind speed, radiation, dew point temperature and lake evaporation input data series. The primary driving force of the hydrologic simulations is the input precipitation series. The greatest effort was therefore expended in developing an accurate and areally representative record of hourly precipitation inputs. A total of 12 hourly records 22 years long were developed and then applied to individual sub-areas of the watershed using appropriate Thiessen polygon weights.

• The data record from fifteen existing streamflow stations in the South Nation River Basin was used for purposes of the HSP-F model calibration and validation process. Accuracy of the records was established through discussions with Water Survey of Canada personnel and is detailed in the report.

• For purposes of the hydrologic modelling, the South Nation watershed was divided into 15 land segments corresponding to points at which streamflow records are available. Since simulated flows were required at other points within the watershed each of the land segments was further partitioned by the use of channel routing reaches. Flows were generated at thirty-seven points. A number of model parameters including drainage area, overland slope, percent forest cover and waterway cross-section and slopes were obtained by direct physical measurement or field surveys while remaining parameters were established by a calibration procedure.

- The term 'calibration' refers to the adjustment of a model's parameters which cannot be measured directly in order to match the model's simulated streamflow to observed values. Validation refers to the checking of the model's performance using an independent set of flow data from that used for calibration.

- Calibration of the HSP-F model was carried out using streamflow data collected at six Water Survey of Canada gauge points between 1 October 1974 and 30 September 1979. At the remaining nine streamflow gauges, the available period of record prior to 30 September 1979 was used. Validation was possible at four points: South Nation River at Plantagenet and Spencerville between 1957 and 1979; Castor River at Russell between 1968 and 1974 and Scotch River near St. Isidore de Prescott between 1970 and 1974.

- A comparison of simulated and observed streamflows depicted by continuous flow hydrographs, mean daily and 2-hour peak flow frequency distributions, runoff volumes, and flow duration curves indicated an accurate representation of streamflows and an acceptable calibration. Some divergence of simulated and observed flows was evident at the 50 year and 100 year recurrence interval.

- Extreme minimum flows established by Log-Normal frequency distributions of seven-day low flows tended to be larger than recorded values, due to problems caused by simultaneously calibrating the HSP-F model at the upper and lower flow range. Adjustments were made to simulated low flows based on recorded data in order to improve forecasts.

- From the calibration of the HSP-F model, it is evident that additional streamflow and precipitation data would be useful for further investigations of this nature. Continuous precipitation recorders maintained by the Conservation Authority at Casselman, Spencerville and Plantagenet can provide a more synoptic representation of hourly precipitation over the basin, therefore, their continued operation is advised. The foregoing stations are listed in order of funding priorities. For flood forecastng purposes, both Spencerville and Casselman have considerable merit if converted to real time operation.

The existing streamflow gauging network within the South Nation basin is comprehensive and upgrading of the station at Chesterville to a continuous operation is the only improvement which is recommended. If specific wetland areas are identified as important contributors to stream baseflow, it would be worthwhile to install stream gauges at their outlet to provide further insight into their hydrologic behaviour.

- Following completion of calibration and validation, the HSP-F model was used to generate a daily streamflow record for the 22 year period from 1957 to 1979 which reflects current runoff conditions in the watershed. From this flow series both high flows and low flow frequency characteristics were defined at the following locations:

i) <u>Daily Peak Discharge</u>

Period: Annual and Growing season (May - October)

Return Period: 5, 10, 20, 50 and 100 years

Location: a) South Nation River at Plantagenet, Chesterville and Spencerville, Bear Brook near Carlsbad Springs and South Castor River at Vernon.

b) Outlet of proposed municipal drainage channels designated as Payne Creek, Van Camp, Ferguson, Mullen (Gannon) and South Castor drains.

ii) <u>Seven Day Low Flows</u>

Period: Annual

Return Period: 2, 5, 10 and 20 years

Location: South Nation River at Chesterville, Casselman and Plantagenet, Bear Brook at Bourget and Castor River at Embrun.

- Estimated streamflows over the 22 year period at thirty-seven points within the South Nation River Basin are stored on magnetic computer tape for future use.

IMPACTS OF AGRICULTURAL DRAINAGE PRACTICES

The effects of future agricultural drainage within the South Nation River Basin involving both sub-surface tile and municipal drain outlets was assessed on a watershed scale with the HSP-F model. Insight into model parameter changes due to agricultural drainage was obtained by detailed investigations carried out on small catchments with the HSP-F model for natural drainage and the DRAINMOD model for tile-drained conditions. The DRAINMOD model developed at the University of North Carolina is a continuous simulation model formulated to simulate tile drainage conditions explicitly.

- Field data used for model calibration purposes was collected by the Conservation Authority within eight drainage basins ranging in area between 7.3 hectares (18 acres) and 898 hectares (2,218 acres) starting in September 1980 and continuing during the spring and summer of 1981. Six outlet drains and two tile drain outlets were monitored in the subcatchments with varied soil conditions and degrees of agricultural drainage. Analysis of the limited field data from the spring period indicated higher run-off volumes during and immediately following storm events with increased tile drainage. The peak runoff ratio was not affected by the degree of tile drainage for the events which were studied.

- Due to limitations of the field data including remote location of rainfall recorders and inaccuracies of flow rating curves for the drains, a true model calibration verification procedure was not possible. However, the models are reliable simulators of agricultural drainage processes and they adequately reproduce the trends resulting from drainage improvements on a watershed scale.

- Due to questionable accuracy of base flows measured within municipal drains and limitations in simulating low flows with the detailed tile drainage model (DRAINMOD) when waterlevels fall below tile drains, it was not possible to verify the impacts of subsurface drainage improvements on low flows.

- Increased confidence in predicted effects of agricultural drainage on flows within the basin may be gained by a continuation of the monitoring program for agricultural test watersheds. This data will provide additional information for calibration of the agricultural drainage models. It is suggested that a sample should be selected from the eight gauged watersheds previously established by the Conservation Authority that will give a representative cross-section of soils, tile drainage conditions and drainage areas. Every effort should be made to use continuously recorded rainfall data which is near the test watershed. On-site gauges plus Authority gauges previously established at St. Elmo, Casselman and Plantagenet should be considered for this purpose.

- In view of the inability to obtain a low flow calibration of hydrologic models for tile drained agricultural areas, further field monitoring is recommended. A drainage area of sufficient size should be selected to permit measurement of low flows. Ideally, this catchment will now be used for agricultural purposes with a low percentage of tile drainage but with an anticipated major installation of subsurface drainage in the future.

- An inventory of future municipal drain improvements within the South Nation River basin and investigations of proposed agricultural drainage on a representative 35 square mile sub-watershed with meteorological input from 1972 to 1976 indicates:

i) Modification of existing drains with tributary areas of 0.5 hectares (1.25 mi^2) miles or less involving deepening to permit tile drainage is the most common future drainage improvement. This will have negligible impact on peak flows.

ii) A smaller number of municipal drains with tributary areas greater than 0.50 hectares (1.25 m^2) will be enlarged to provide increased capacity. The maximum number of drains to be enlarged within a sub-watershed will result in a 5 to 7% increase in flood peaks at the outlet of the catchment.

iii) Installation of tile drainage results in a more rapid draw-down of soil moisture thereby creating a larger soil storage capacity and reducing peak runoff. The tiled condition results in a smaller runoff response particularly during the summer and early winter period when increased storage capacity in the soil may eliminate runoff altogether. If several large rainfall events occur in close sequence, the effectiveness of the tile drainage in attenuating peak flows is reduced. If tile flow contributions from an earlier event are superimposed on the surface runoff peak, maximum flows may be slightly higher than the untiled condition.

- Impacts of agricultural drainage flows at the four major flood prone sites within the South Nation basin are discussed under Flood Control and Land Use Scenarios.

SECONDARY FLOOD PLAIN AREAS

Due to the relatively flat topography and limited channel capacity throughout the South Nation Basin, extensive annual flooding has been reported in many parts of the watershed, particularly during the spring. The flood plain delineation component of the study identified flood-prone areas under open water conditions which have not been mapped by the Conservation Authority. The extent of the flooding in these secondary areas was estimated.

The procedure employed to identify secondary flood-prone sites used 1978 aerial photographs taken under flood conditions; field surveys of representative waterway and overbank cross-sections together with conveyance characteristics; flow estimation of the 10 year and 100 year events at the flood sites based on existing streamflow data and; a normal depth calculation of flood stage at the sites.

In general, little flood damage potential was identified outside of known flood-prone areas which have been mapped by the Authority. This appears to be in agreement with local experience. Sites that will have local flooding under 100 year flood conditions but with little damage potential are:

- Town of Limoges, South Indian Creek
- Town of Kenmore, South Castor River
- Town of Spencerville, South Nation River
- Town of Embrun, Main Castor River
- Payne River, near Finch
- Scotch River, West Branch near St. Elmo
- South Nation River, North Branch near Van Camp
- South Nation River, Main Branch near Hyndeman
- Castor River, near Embrun
- South Nation River, near Crysler
- Castor River, near Russell
- South Nation River, near Chesterville

Additional flooding at Hammond due to inadequate culvert capacity on the small waterway was also pointed out during the study and may warrant detailed flood plain mapping to define the hazard area. Further, while open water flooding at Crysler was not deemed significant during the screening of secondary hazard areas, inundation caused by ice jams in 1982 pointed out the need for further investigation of this problem.

FLOOD CONTROL AND LAND USE SCENARIOS

The calibrated watershed model was used to investigate a number of proposed structural measures which control flooding plus the potential hydrologic impacts of land use changes including agricultural drainage.

a) Municipal Drain Improvements

The hydrologic impacts resulting from the improvement of the following major municipal drains was investigated separately from the effects of agricultural drainage within the South Nation River basin: South Castor, Payne, Mullen, Van Camp and Ferguson Drains. Modifications to existing watercourses were incorporated into the flow routing portion of the HSP-F model in order to compute the effect on the continuous flow sequence between 1957 and 1979. Flood frequency plots illustrate:

- After drain improvements are completed, peak instantaneous runoff rates at the downstream limits of the drains will be increased from 12 to 55 percent.

- The drains ranked in order of their percentage increase in peak flows are:

  i) Payne Drain
  ii) Mullen Drain
  iii) South Castor Drain
  iv) Van Camp Drain
  v) Ferguson Drain

- Flood prone lands at Chesterville and Plantagenet will only marginally be affected by the combined flow impact of the five drains since peak flows at these locations will be increased by less than two per cent.

- Annual minimum 2-hour low flows were unchanged by the construction of the five municipal drains.

b) Agricultural Drainage

Future agricultural drainage improvements were represented by the installation of subsurface drainage within seventy-five per cent of existing agricultural lands plus associated municipal drain improvements. Agricultural lands were inventoried by Township and the foregoing percentage of future tile drainage in agricultural areas was defined as the optimal level for economic return during the Agricultural Component Background Study. Expected improvements in municipal drains were assembled by the Conservation Authority in conjunction with the Ontario Ministry of Agriculture and Food during this study. Future outlet drain improvements included the proposed Mullen, Ferguson and Van Camp Drains as well as the Chesterville channelization completed in 1981 to Cass Bridge.

In order to evaluate the hydrologic impacts of the future drainage practices, the watershed model was used to simulate continuous streamflows between 1957 and 1979 incorporating changes in drainage related parameters. Flood frequency plots for both the annual period and growing season from May to October indicate significantly lower peak flows at the four major flood prone areas: Plantagenet and Chesterville on the South Nation River, Vernon on the South Castor River and Carlsbad Springs on Bear Brook. Reductions vary from three to fourteen per cent during the annual period involving spring snowmelt events while peak flow attenuation is more dramatic during the May to October period ranging from six to thirty-eight per cent.

c) Channelization Works for Flood Control

Major channel works that are proposed for flood control were investigated on the Payne, South Castor and Bear Brook in addition to the Chesterville channel which was extended to Salters Bridge. Simulation of hydrologic impacts on peak flows were carried out together with future agricultural drainage improvements outlined in the foregoing report section and impacts were assessed as an incremental effect.

Channelization of natural waterways which improves the flow capacity of a cross-section and reduces the volume of floodplain storage will commonly increase flood peaks at downstream locations. This effect was generally observed within the South Nation River basin at the four major flood prone areas, Plantagenet, Chesterville, Vernon and Carlsbad Springs, due to the flood control channelization.

The incremental effect of the flood control channelization on flood peaks will be:

i) South Castor River at Vernon. Peak flows are increased during the annual period and growing season by 4% for more severe flood return periods.

ii) Bear Brook near Carlsbad Springs upstream of South Indian Creek. No change in flood peaks.

iii) South Nation River at Chesterville. During the summer growing seasons, peak discharges larger than the 10-year event will be increased by 5 to 9 percent. Annual peak flows reflecting spring snowmelt plus possible rainfall occurrences are only marginally affected.

iv) South Nation River at Plantagenet. Peak flows remain unchanged for the annual period indicating spring runoff events will not be affected. Summer flood flows will increase by 2 percent.

For both the annual period and the growing reason from May to October flood peaks are reduced from those experienced under current agricultural drainage practice due to the attenuation of high flows provided by tile drains. This reduction varies from 0 to 14 percent for the annual period and 6 to 34 percent during the growing season at the four flood prone areas.

d) Expansion of Forest Lands

Within the South Nation River basin about 39 percent of the drainage area is currently forested. Maximization of forest lands in the watershed was evaluated by converting all marginal farm land and suitable idle land to forest production and subsequently modelling the effects on flows between 1957 and 1979. Hydrologic parameters within the HSPF model were altered to reflect increased forestry. No drainage improvements were considered in conjunction with this alternative.

It is emphasized that reforestation of the foregoing magnitude represents an upper limit that was selected to clearly illustrate the impact of this land use change on streamflows within the South Nation River basin.

Flood frequency analysis indicates the following change in the peak flow regime:

i) For the annual period including spring snowmelt, annual peak flows tend to increase for more severe return periods with the largest effects experienced at Vernon on the South Castor River.

ii) During the summer growing season, the four flood prone locations, Plantagenet, Chesterville, Vernon and Bear Brook, experience a wide range of peak flow variation but a trend of larger flow increases with larger events is noted. At Plantagenet and Chesterville for example, the 20 year peak flow is intensified by approximately 10 percent. Review of the continuous flow simulation reveals that larger tracts of forest lands will often delay spring snowmelt and flood peaks into May and the summer growing season, thereby increasing the occurrence and magnitude of larger flood events.

iii) More frequent runoff events with a smaller magnitude are caused by mid-summer thunderstorms for which forest cover has the opposite effect. The deep rooted vegetation depletes the soil moisture storage by increased evapotranspiration which reduces base flows and increases the soil storage capacity. These effects result in 5 to 17 percent reductions for more frequent flood events at the four major flood prone locations within the South Nation basin.

e) <u>Flood Control and Low Flow Augmentation Measures</u>.

Previous water resource investigations of the South Nation River basin have identified eleven reservoirs for purposes of flood control and low flow augmentation. However, most authorizations have dealt with analyses of site specific rather than basin-wide water management problems. During this study, proposed reservoirs were assessed in terms of their flood control and low flow capabilities with the assistance of a reservoir operations model. Existing soils information at proposed dam sites was reviewed as a further aid in evaluating the viability of the projects.

A two step procedure was adopted during the hydrologic screening of reservoir efficiencies:

i) A preliminary investigation during the initial phase of the project which assisted the Authority in establishing priorities between reservoirs.

   Specific flow sequences were selected from historical streamflow records and transferred to the proposed reservoir sites by drainage area pro-rating techniques before they were used in the HEC-5 reservoir operations model.

ii) A detailed evaluation of more attractive flood control reservoirs during the final phase of the project.

   Critical flow sequences were selected from the continuous simulation provided by the HSPF model at the proposed reservoir sites and used in the reservoir simulation model to evaluate flow reductions at Plantagenet.

The preliminary investigation provided the following ranking of reservoir sites:

1. North Castor Reservoir: flood control and low flow augmentation.

2. Scotch Reservoir: flood control.

3. Spencerville Reservoir: low flow augmentation.

4. Bear Brook Reservoir: flood control and low flow augmentation.

Computations relating to the low flow augmentation capability of the Spencerville Reservoir revealed that the previously proposed site development is not compatible with the volume of spring runoff which is available for storage. Preliminary examination suggests that the optimum live storage would be in the order of 55.5 to 61.7 Mm^3 (45 000 to 50 000 ac-ft) for low flow purposes.

A number of points were identified which influence any decision to construct the reservoirs for flood control:

- More agricultural land would be inundated at the reservoir sites than removed from the flood hazard zone at Plantagenet.

- Geotechnical conditions at the Bear Brook site are poor and potential foundation problems may be insurmountable.

The final reservoir operations investigations included the three foregoing flood control reservoirs plus storage developed at Lemieux on the South Nation River. Findings confirmed the preliminary investigations and pointed out that the flood reduction capabilities of the reservoirs during the growing season are mainly limited to flow events smaller than a 25 year magnitude.

Diversion schemes that have been suggested for flood control purposes were eliminated from further consideration. The Spencerville Diversion was considered unnecessary due to the limited flood reduction potential of the Spencerville Reservoir while the Cobb's Lake Diversion was found to be disproportionately expensive in relation to the benefits derived at Plantagenet.

Local protective measures including channelization and dyking emerged as the favoured alternatives to reduce flood damages at the four major flood prone areas. Calculation of the average annual flooded area within these sites provides the Authority with further background data to evaluate the economics of flood control measures. For the flood prone area upstream of Chesterville, the average annual agricultural area which is subjected to subsurface soil saturation due to flood stages in the South Nation River was also computed for existing conditions and after the channelization is extended to Salters bridge. Average annual flood area reduction benefits at Chesterville resulting from this channelization will be significant but will be partially offset by increased flooding at Plantagenet.

WATER QUALITY STUDIES

In general, water quality in the South Nation River Basin does not satisfy provincial water quality objectives for bacterial and total phosphorus concentrations.

Total phosphorus concentrations throughout the basin have frequently been measured to be higher than twice the provincial guideline for streams of 0.03 mg/L. Approximately 95% of the phosphorus losses to the stream originate from non-point agricultural sources. The point sources in the basin, which include 2 industrial lagoon discharges and 6 municipal lagoon discharges, contribute the remainder of the annual basin phosphorus export.

About 70% of the annual total phosphorus losses are exported during the months of March, April and May. The total average basin export rate for phosphorus is calculated to be 0.49 kg P/ha-yr (0.44 lb P/ac-yr). The majority of the phosphorus export emanates from the northern half of the basin which includes the Castor Rivers and the Bear Brook, with unit area losses about twice that of the southern half of the basin. Higher phosphorus losses in the northern half of the South Nation River basin can be attributed to the higher sediment yield and an apparently greater livestock contribution.

A previous study of the South Nation River basin concluded that most of the sediment is being produced in the northern half of the basin with the Bear Brook and Castor River systems contributing the most sediment. The sources of sediment are closely related to the distribution of red and grey banded sensitive marine clays in the northern half of the basin.

The three major sediment producing sources were ranked as follows:

i) mass wasting
ii) open channel drains
iii) sheet erosion of fields

Once mass wasting has been accounted for, total annual basin sediment losses are comparable to mean sheet erosion losses reported for permanent pastures in Southern Ontario.

Total phosphorus "potency factors" for bank material developed in PLUARG studies, coupled with the high bank erosion losses reported in the South Nation River basin, imply phosphorus losses associated with eroded bank material may be as high as 30-50% of the total annual basin phosphorus export. This suggests control of bank erosion is equally important as control of field erosion in reducing phosphorus loadings to the river system. By comparison, subsurface drainage, which includes tile drain effluent, interflow and active groundwater recharge, is estimated to contribute approximately 15% of the phosphorus export.

The contribution of phosphorus losses associated with livestock activities is estimated to be between 7% to 35% of the total basin phosphorus export attributable to non-point sources. This range is based on applying unit area livestock losses and loss rates per animal unit extrapolated from other Southern Ontario agricultural watershed studies. While these studies demonstrate that management of livestock activities is more important in determining nutrient loss rates than animal densities per se, the larger animal inventories in the northern half of the basin may account for some of the higher phosphorus losses found in the north.

The available data base is insufficient to determine the mechanism by which nutrients attributable to livestock activities reach the streams. Cattle access to the streams, feedlot runoff and poor manure management are likely sources and warrant closer examination on a farm by farm basis.

For the other major land uses in the basin other than livestock activities, the following ranges of average unit area phosphorus losses were developed:

	kg P/ha-yr	lb P/ac-yr
Row crops	0.9 - 1.7	0.8 - 1.5
Grains	0.45 - 0.81	0.4 - 0.72
Pasture/hay	0.34 - 0.59	0.3 - 0.53
Woodland/idle	0.045- 0.09	0.04 - 0.08

Ranges and not absolute values were developed due to the inability to accurately estimate both livestock contributions and the amount of phosphorus export associated with bank erosion which is not totally dependent on the adjacent land use.

Continuous corn cultivation usually results in the greatest unit area phosphorus losses compared to the other agricultural cultivation activities. An increase of 10 000 hectares (25 000 acres) of continuous corn cultivation at the expense of pasture/hay acreage would result in an increase in total basin phosphorus export of approximately 6 percent. Since most of this increase would occur in the spring and originate from a wide drainage area, no significant deterioration in instream quality with respect to phosphorus would be expected.

Tile drain effluent quality is better than that of surface runoff quality with respect to most parameters, except nitrate nitrogen. Increased subsurface drainage with tile drains would lead to decreased surface runoff and hence lower in-stream total phosphorus concentrations.

Instream bacteriological quality exceeds Ministry objectives of 1000/100 ml and 100/100 ml for Total and Fecal coliforms, respectively. The objectives are exceeded throughout much of the basin, notably in the northern areas. While this fecal contamination is animal in origin, the available data is insufficient to distinguish the mechanism by which this contamination reaches the stream. Other studies have shown that the level of bacterial contamination cannot be related to livestock density since manure management practices are the controlling factors.

While point source discharges are not important on a basin scale, they may be important on a local scale. Dissolved oxygen modelling results for $7Q_{20}$ low flow conditions suggest that potentially unacceptable dissolved oxygen concentrations downstream of the point sources may result;

i) In the East Castor River during late summer continuous industrial lagoon discharges in Winchester.

ii) In the Casselman impoundment during fall emptying of the industrial lagoons in Winchester.

iii) In the Crysler impoundment due to continuous summer discharges from the industrial source in Chesterville.

No monitoring programmes have been undertaken to verify whether the simulated dissolved oxygen problems actually exist under the low flow conditions modelled.

Ministry objectives for instream total phosphorus would have little bearing on point source discharges due to the high background levels upstream of all the point sources. Of the other nutrient forms, free ammonia concentrations downstream of the point source discharges may exceed Ministry objectives during low flows, particularly in the East Castor River.

Based on the findings of the non-point source water quality related studies, the following conclusions can be made with respect to improving instream conditions in the South Nation River basin:

i) Efforts to control sediment erosion and phosphorus losses to the stream would best be directed to the northern half of the basin where potential for reductions are the greatest.

ii) Bank and channel erosion sources should receive attention equal to field erosion sources.

iii) Buffer strips and grassed waterways, while not particularly effective in reducing field erosion, would minimize bank and channel erosion and hence, should be considered as integral parts of good surface drain design.

iv) Cattle access to the streams should be controlled to maintain the integrity of the stream banks. This would reduce erosion related phosphorus loadings to the stream, as well as nutrient and bacterial contamination due to animal defecation into the waterways.

v) Since generalizations cannot be made on nutrient and bacterial instream contamination resulting from each livestock operation in the basin, the implementation of improved manure management techniques should be evaluated on a farm by farm basis.

vi) Although representing a small fraction of the basin area, row crop cultivation represents a disproportionately large source of phosphorus losses to the stream. Best management practices (BMP) such as strip cropping, contour ploughing and terraces, with the exception of a few localized areas, would not be applicable on a basin scale since they are more suited to controlling runoff from steeper slopes. Reductions in sediment and nutrient losses associated with no tillage, conservation tillage and crop rotation systems would require further evaluation with respect to the inherent lower crop or monetary yields associated with each. Similarly, winter cover crops and spring ploughing would have to be further evaluated due to the possible associated decrease in the effective crop growing season.

Increasing tile drainage may be considered as a BMP since this would decrease surface runoff and phosphorus losses. The increase in nitrate levels associated with tile drainage could be tolerated since instream nitrate levels are currently well below legislated guideline levels.

GROUNDWATER RESOURCES AND WATER SUPPLY

Groundwater is the most important source of water supply in the South Nation River Basin. Most municipalities and rural residents, as well as several industries, obtain their water supplies from groundwater sources.

The groundwater in the basin is obtained from both carbonate bedrock and overburden aquifers. In the northern part of the basin, the major supply is from sand and gravel deposits, while in the southern portion, the carbonate bedrock formations provide the bulk of the groundwater supply. The yields of most wells are low; the overburden wells have slightly higher yields 0.30 - 0.38 l/s than wells in bedrock 0.15 - 0.23 l/s.

Total withdrawals by all users currently are much less than estimated total annual recharge to the groundwater system. More than 95% of total recharge replenishes two surficial sand and gravel aquifers, referred to as the Rideau Front and

Champlain aquifers. These aquifers are, mainly recharged directly from local precipitation. The bedrock aquifers receive recharge from outside the basin.

The surficial Rideau Front aquifer shows the best potential for the development of large groundwater supplies. A number of buried sand and gravel aquifers, as well as several bedrock formations have the potential for moderate groundwater development.

With respect to quality, groundwater throughout the basin is generally hard to very hard and sulphurous and saline waters are common in bedrock aquifers that underlie thick marine clay deposits and/or shale layers. Poor quality groundwater may also be found in discharge areas near rivers and creeks.

An estimation of community water requirements including industrial demand was carried out during the study and was compared to the firm yield of current supplies plus potential groundwater sources. Location of additional groundwater suppies to be investigated for communities with a shortage of water are detailed in the report.

Problems are recognized at Winchester, Chesterville, St. Isidore, Bourget, Hammond and St. Pascal where supply deficiencies will most likely be encountered after additional groundwater sources are developed. Nearby watercourss were investigated as a source of supply which would augment the groundwater resource. An estimate of the reliability of surface water supplies based on Ministry of the Environment withdrawal guidelines, maximum day supply rates required by the communities and low flow frequency data for the watercourses indicate that the communities of Winchester, Chesterville , St. Isidore and St. Pascal are most susceptible to shortages. The following observations are made regarding supply problems at these communities:

- St. Pascal is considered too remote from a watercourse with adequate summer flows to make surface supplies a viable alternative.

- The surface water supply at Winchester was obtained from the South Nation River at Chesterville which is the nearest watercourse with a significant firm yield. The existing impoundment at Chesterville has sufficient storage to supply the requirements of Chesterville and Winchester with maximum day shortfalls anticipated less than once every twenty years. Water demands by Nestle were not available to the study and may considerably shorten the recurrence of water supply deficiencies.

- Additional water supplies at St. Isidore must be provided by a surface water impoundment on the South River or individual domestic wells in the northern part of the village.

A review of the potential impacts of future development scenarios within the South Nation River basin on the groundwater resource provides the following observations:

- Future growth scenarios for urban rural communities do not pose a potential long-term problem in reducing groundwater recharge. The essentially clayey nature of most of the soils in the basin and the negligible acreage of high infiltration soils involved in any development scenario make the potential for construction related impacts on the groundwater regime at any locale negligible.

- Impairment of groundwater from the disposal of domestic wastes is of primary concern especially in the shallow surficial sand Champlain, Rideau Front and Maple Ridge aquifers.

- De-icing salts used in the maintenance of roads during winter months may pose a problem in areas of exposed surficial sand aquifers such as the Champlain and Rideau Front aquifers.

- Although, there are no documented instances of major contamination problems arising out of the operation of landfill sites within the South Nation River basin, particular attention should be paid to the proper siting of proposed waste disposal facilities.

  i) Flood prone areas associated with river flood plains should be avoided.

  ii) Areas encompassing the Rideau Front, Champlain and Maple Ridge aquifers should be protected and waste disposal sites permitted only after extensive hydrogeological investigations indicate no adverse impacts.

- Any aggregate extraction operations in the basin will probably locate within the Rideau Front and Maple Ridge aquifers where aggregate materials constitute very good aquifers and significant recharge areas. Proper management of these operations especially in the Rideau Front aquifer is mandatory if its potential for large supplies of good quality water is to be realized.

- Spray irrigation of municipal wastes offers a number of benefits in the South Nation River basin from an agricultural perspective and environmental viewpoint since water availability and the lack of assimilative capacity in many watercourses are pressing concerns. Municipalities and small communities are mainly dependent on groundwater for public and private supplies therefore protection against contamination is imperative.

  Efficient spray irrigation procedures usually require level soils with good permeability such as loamy sands and sandy loams. Although the Champlain aquifer apparently offers the best potential in terms of soil capability for treatment of municipal wastewaters by spray irrigation, a number of concerns can be identified:

  - The existence of near surface water table conditions.

  - Most households in the area obtain their water supplies from individual dug and drilled wells completed in the surficial fine-grained sands which are highly susceptible to contamination.

Channelization schemes which have been suggested as local flood protection measures at the four major flood prone areas within the South Nation River basin were assessed in terms of potential groundwater impact. With the expection of the Chesterville channelization which has been the subject of an earlier comprehensive study conclusions are subject to a program of field instrumentation and monitoring. Suggested groundwater impacts of the other three schemes are:

Vernon Channelization

Channelization should not have any significant or widespread impact on the groundwater regime. Most wells are completed in bedrock overlain by clays and silts and therefore should not be affected. Excavation of the river bottom to bedrock potentially may result in the degradation of water quality in the underlying bedrock aquifer.

A few wells in the Kenmore area are completed in buried sand and gravel aquifers. Although, there is no evidence that this aquifer is connected to the river, any link will cause dewatering of wells and possible contamination during periods of high flows in the channel.

Bear Brook Channelization

Channelization can be expected to impact to varying degrees on the groundwater resource in the area. Most wells are constructed in shallow surficial sand deposits that constitute the Champlain aquifer and hydraulic connection of the aquifer with the river will result in local interference with well supplies. Deep wells completed in the Carlsbad Springs shale aquifer are not expected to be affected by the channelization.

Plantagenet Channelization

Most wells in the area are shallow dug, bored or jetted and completed in the surficial Champlain sand aquifer. Where this shallow groundwater system or buried sand/gravel lenses are in hydraulic connection with the river, channelization can be expected to dewater the aquifer and interfere with local well supplies. River borne contaminants may be induced into the aquifer during high flow periods.

In order to ensure that ample potable groundwater will be available to meet future demands, it is recommended that a regional water management plan should be developed. The plan should include a detailed survey of groundwater resources of each community, investigation of potential areas of groundwater supply by test drilling and test pumping, and a groundwater level monitoring programme. A model of the groundwater system, using input data obtained from the management plan, could be used to simulate effects of alternative development schemes on the system. In addition to the regional water management plan, it is recommended that an assessment of water consumption be carried out in areas where such data is lacking.

Investigations of wetland areas are also recommended, to establish whether these include either potential groundwater sources or areas suitable for secondary treatment of sanitary wastewaters. Field instrumentation and monitoring are required to quantify the impact of land drainage on groundwater recharge. Finally, it is recommended that hydrogeological evaluations of the potential impacts of channelization should be carried out.

CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.0 INTRODUCTION

1.1 General

The South Nation River Conservation Authority has commissioned several resource related studies to provide background information that will aid in the development of a comprehensive River Basin Management Plan. The water resources investigation is an integral component of this Plan which is being undertaken to establish the optimum management of land and water resources in the basin.

The preparation of a Basin Plan for the South Nation watershed area must necessarily be based on a thorough knowledge of the natural water system including low and high flows, water quality and groundwater. Stream discharges in the South Nation River and tributaries are characterized by an almost annual occurrence of widespread flooding which impacts agricultural lands together with low summer flows that constrain water supply, waste assimilation and recreational opportunities. Serious water management problems exist which may limit the economic and agricultural potential of the watershed.

Earlier studies have identified capital works schemes which could reduce agricultural flooding and provide a low flow augmentation capability. Nevertheless, an increased awareness that land use practices directly affect water resources of the basin has given rise to concerns that increased agricultural production together with land drainage may further aggravate water management problems.

An integrated package of hydrologic and water resource operations models was used to investigate these problems and to provide a systematic evaluation of management alternatives.

1.2 Location and Extent

The South Nation River drainage basin encompasses an area of some 3910 km^2 (1510 mi^2) in eastern Ontario. The study area lies east-southeast of Ottawa and occupies parts of the Counties of Leeds, Grenville, Dundas, Glengarry, Stormont, Prescott and Russell, and the Regional Municipality of Ottawa-Carleton. The economy is primarily agricultural and the population is predominantly rural. There are no major urban centres.

1.3 Physiography and Drainage

The landforms in the South Nation River basin are a direct result of glacial and post-glacial erosional and depositional processes. An essentially subdued topography with low relief features characterizes the basin. Surface elevations vary from a high of 122 m (400 ft) above mean sea level in the south to a low of 46 m (150 ft) in the north.

The low lying Winchester Clay Plain physiographic region (1) occupies nearly one-half of the basin in the central and eastern area. The Prescott and Russell Sand Plains predominate in the north.

The physiography reflects an essentially marine and lacustrine depositional environment which is reflected in the extensive sand and clay plains. Superimposed upon these are minor beach and morainic deposits.

The South Nation River and its major tributaries, Castor, Scotch and Payne Rivers, and Bear Brook, drain the basin and discharge to the Ottawa River near Wendover. Drainage in many parts of the basin is poor and extensive annual spring flooding is associated with very low stream gradients in the clay plains above Chesterville and Plantagenet. Drains and ditches have been constructed in many areas to improve the inherently poor drainage conditions. Numerous bogs and swamps are associated with the topographically low depressional areas of which the Alfed, Mer Bleu, Winchester and Moose Creek bogs are the largest.

1.4 Previous Investigations

Many studies have been conducted in the basin involving various aspects of geology, groundwater resources, land use, and flood control.

All of these relevant studies have been reviewed and utilized in the course of this study and are referenced throughout the report. In particular, the flood line mapping studies in the Brinston, Plantagenet, Vernon and Bear Brook areas, the many municipal drain reports, the FARINEO studies and a recent Ministry of the Environment report on water resources in the basin provided a great deal of information. This literature was supplemented by field programs to obtain stream channel cross sections, flow monitoring data for model calibration and other information on drainage and land use.

1.5 Study Overview

The principal phases of the study are detailed the following sections:

1. Existing hydrometeorological data have been reviewed and analysed to determine the flood frequencies, trends and statistical characteristics of the existing flow and meteorological record.

2. A preliminary screening of previously proposed water management alternatives (reservoirs and channelization works) has been conducted to determine those which warrant further considerations. This screening employed a simple watershed model which considered the overall watershed implications of the various proposals.

3. Secondary floodplain areas have been investigated using simplified analyses and inspection of aerial photos to identify flood-prone areas and determine the need for further floodplain mapping outside the major areas previously studied.

4. A continuous simulation hydrologic model was prepared and calibrated to flow records in the basin. This model formed the basis for evaluating the impacts of future land use practices and drainage improvements in subsequent analyses.

5. The effects of agricultural drainage practices on flood flows was investigated through a field monitoring program conducted on a number of test watersheds. A detailed subsurface drainage model was calibrated to this data and used as the basis for determining the impacts of agricultural drainage improvements.

6. The watersheds impacts of selected future land use and flood control alternatives were investigated using computer modelling methods. The scenarios which were considered included agricultural drainage improvements, major flood control works, several reservoir proposals, and increased forest production.

7. An overview study of water quality in the basin was completed employing literature review, in-stream monitoring, empirical analyses and computer modelling. Both existing water quality and estimates of impacts of future land use changes were evaluated.

8. Groundwater studies were conducted to characterize the existing groundwater regime and determine its present availability and potential for future water supply. The potential for ground water use at many specific town sites was analysed. The impacts of future land use and drainage system changes and possible groundwater management schemes has also been evaluated.

9. The implications of existing low flow conditions upon water supply were investigated.

Each of these study phases are discussed fully in the following chapters.

CHAPTER 2

ANALYSIS OF STREAMFLOW AND PRECIPITATION

CHAPTER 2

ANALYSIS OF STREAMFLOW AND PRECIPITATION

2.0 ANALYSIS OF STREAM FLOW AND PRECIPITATION

2.1 Available Data

The watershed drainage area and location of existing hydrometric stations in the South Nation River basin are shown on Figure 2.1. While 15 hydrometric records are available in the basin, only 6 have a sufficient length of record for flood frequency analysis. A summary of the data available for each station is given in Table 2.1.

The average annual runoff from the watershed is about 355 mm (14.0 in) based on measurements at Plantagenet. During the same period from 1950 to 1978 the average annual precipitation over the watershed is estimated to be about 865 mm (34.0 in). The resultant basin average evapotranspiration is therefore about 510 mm (20.0 in) per year.

The preliminary analyses of available discharge data included the following items.

- tests for trend and persistence in the data that check for changes in the hydrologic regime
- double mass analysis for data consistency
- flood frequency analyses
- flow duration analyses

During successive stages of the study, various monthly durations were used for investigative purposes. These were:

Figure 2-1

Location of Gauging Stations and Flood-Prone Zones

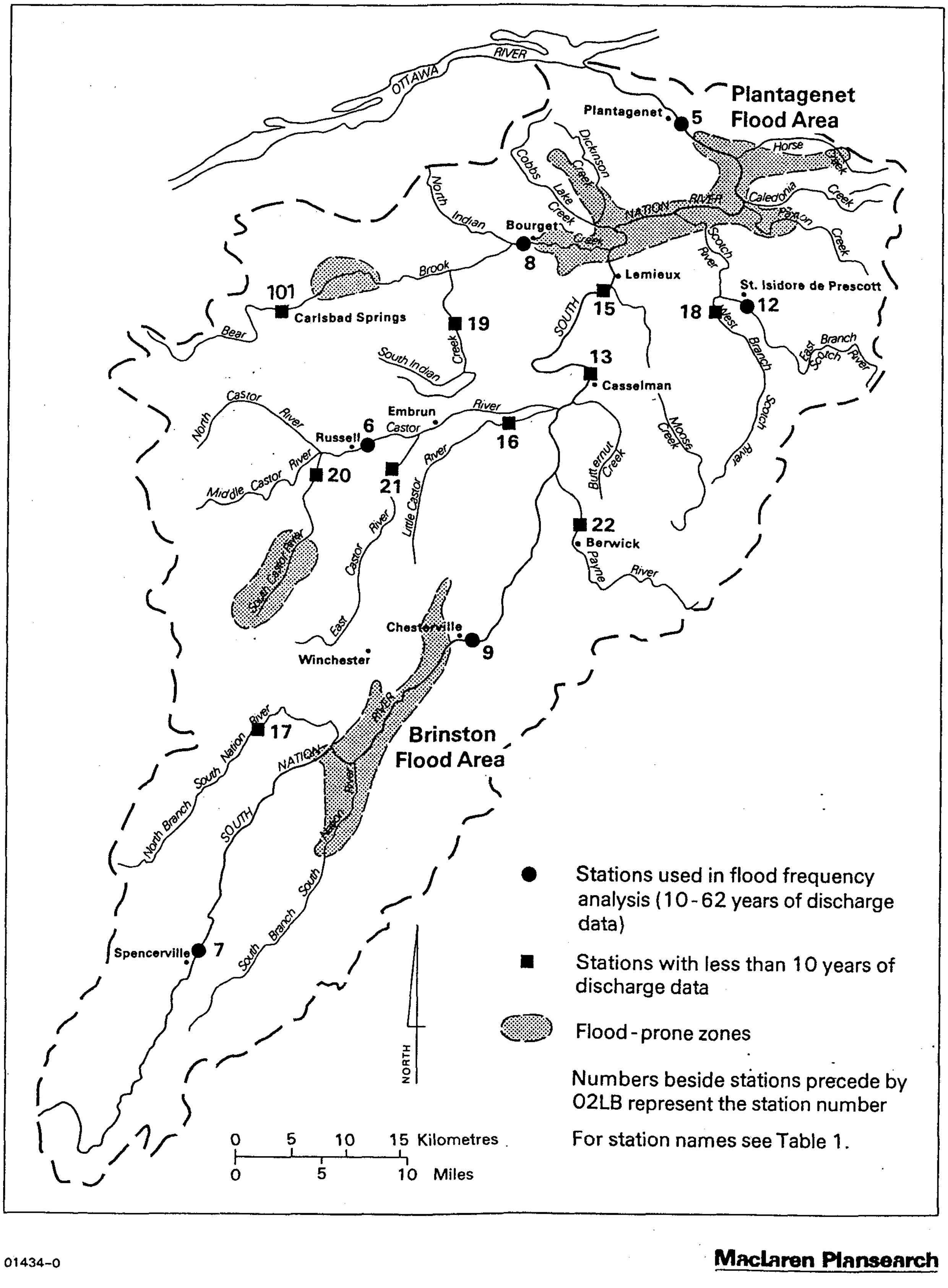

TABLE 2.1

SUMMARY OF AVAILABLE DISCHARGE DATA

Station Name	Station Number	Location Latitude N °	'	"	Longitude W °	'	"	Drainage Area, km^2 (miles^2)	(1) Mean Annual Flood m^3/s(cfs)	(2) Mean Annual Discharge m^3/s(cfs)	(3) Mean December to May Discharge m^3/s(cfs)	(4) Mean June to November Discharge m^3/s(cfs)	Record* Length N. for (1)	Record* Length N. for (2)	Record* Length N. for (3)	Record* Length N. for (4)
South Nation River Near Plantagenet Springs	02LB005	45	30	23	74	57	20	3810 (1470)	735 (25 950)	42.3** (1490)	71.7 (2530)	12.9 (456)	1916-43 45,47-79 N = 62	1916-33 49-79 N = 49	1916-33 49-79 N = 49	1915-38 45-79 N = 59
Castor River at Russell	02LB006	45	15	43	75	20	40	433 (167)	112 (3969)	5.02** (177)	8.40 (297)	1.67 (59)	1948-79 N = 32	1968-79 N = 12	1968-79 N = 12	1948-49 1968-79 N = 14
South Nation River at Spencerville	02LB007	44	50	32	75	32	38	246 (95)	49.6 (1752)	3.04** (107)	5.25 (185)	0.847 (29.9)	1948-79 N = 32	1950-79 N = 30	1950-79 N = 30	1948-79 N = 32
Bear Brook near Bourget	02LB008	45	25	33	75	09	12	440 (170)	111 (3935)	6.67 (236)	11.3 (399)	1.95 (68.9)	1949-53 55-69 76-79 N = 24	1977-79 N = 3	1977-79 N = 3	1976-79 N = 4
South Nation River at Chesterville	02LB009	45	06	08	75	13	47	1050 (404)	180 (6373)	16.6 (586)	27.7 (978)	5.56 (196)	1950-52 55-79 N = 28	1972-74 N = 3	1972-74 N = 3	1972-74 N = 3
(East Branch)Scotch River near St. Isadore de Prescott	02LB012	45	22	11	74	54	00	76.7 (29.6)	17 (600)	1.05 (37)	1.71 (60.4)	0.416 (14.7)	1970-79 N = 10	1970-78 N = 9	1970-78 N = 9	1970-79 N = 10
South Nation River at Casselman	02LB013	45	19	01	75	05	32	2410 (929)	714 (25 215)	30 (1059)	52.1 (1840)	7.99 (282)	1976-79 N = 4	1976-79 N = 4	1976-79 N = 4	1976-79 N = 4
South Nation River at Lemieux	02LB015	45	23	42	75	03	56		DATA INCOMPLETE							
Little Castor River near Embrun	02LB016	45	16	17	75	13	06	76.1 (29.4)	29 (1024)	1.05 (37.1)	1.91 (67.5)	0.195 (6.89)	1978-79 N = 2	1978-79 N = 2	1978-79 N = 2	1978-79 N = 2
(North Branch)South Nation River near Heckston	02LB017	44	59	40	75	31	00	62.9 (26.7)	11.6 (410)	0.904 (31.9)	1.69 (59.7)	0.129 (4.56)	1978-79 N = 2	1978-79 N = 2	1978-79 N = 2	1978-79 N = 2
(West Branch)Scotch River near St. Isadore de Prescott	02LB018	45	22	33	74	56	51	99.5 (258)	35 (1236)	1.69 (59.7	2.45 (86.5)	0.927 (32.7)	1979 N = 1	1979 N = 1	1979 N = 1	1979 N = 1
South Indian Creek near Limoges	02LB019	45	21	47	75	15	00	72.3 (27.9)	26 (918)	0.894 (31.6)	1.53 (54)	0.264 (9.31)	1979 N = 1	1979 N = 1	1979 N = 1	1979 N = 1
South Castor River at Kenmore	02LB020	45	13	40	75	24	46	189 (73)	44.8 (1582)	1.98 (69.9)	3.46 (122)	0.517 (18.3)	1979 N = 1	1979 N = 1	1979 N = 1	1979 N = 1
East Castor River near Russell	02LB021	45	13	43	75	19	32	145 (56)	49.3 (1741)	1.36 (48)	2.23 (78.8)	0.491 (17.3)	1979 N = 1	1979 N = 1	1979 N = 1	1979 N = 1
Payne River near Berwick	02LB022	45	11	30	75	06	20	152 (58.5)	70.7 (2497)	2.54 (89.3)	4.55 (161)	0.710 (25.1)	1977-79 N = 3	1977-78 N = 2	1977-79 N = 2	1977-79 N = 4
Bear Brook at Carlsbad Springs	02LB101	45	22	30	75	28	20	65 (25.1)	22.6 (798)	1.12 (39.6)	1.75 (61.8)	0.483 (17.1)	1976-78 N = 3	1976-77 N = 2	1976-77 N = 2	1976-77 N = 2

* N stands for the number of periods with complete discharge records

** Computed by using all available monthly discharge records

Discharge Data were obtained from the Inland Waters Directorate of the Water Resources Branch, Water Survey of Canada at Ottawa, Ontario

a) Data Base Review

Spring flood: December to May
Summer season: June to November

b) Screening of Flood Control Alternatives

Spring flood: March to April
May flood: May
Summer season: late May to October

c) Hydrologic Model Calibration:

Summer season: June to September

d) Final Hydrologic Simulations
Agricultural Damage Analysis

Growing season: May to October

2.2 Analysis of the Data Base

2.2.1 General

In undertaking various statistical analyses of hydrologic data, including flood frequency analysis, it is commonly assumed that the discharge records are drawn from a random sample and from a single (unknown) probability distribution.

This assumption of randomness can be disproved by some feature of a non-random nature such as trend or persistence.

2.2.2 Graphical Analysis

In this preliminary analysis, the data from the gauging stations and precipitation stations with the longest period of record were tested for randomness and trend.

Graphical analyses were undertaken as indicated at the following stations:

(a) South Nation River Near Plantagenet Springs (02LB005)

- cumulative moving mean discharge (annual, May, October)
- temporal distribution of normalized discharge (annual, May, October)
- cumulative moving mean flood peak* (annual)
- temporal distribution of normalized flood peak (annual, May)

(b) South Nation River at Spencerville (02LB007)

- cumulative moving mean discharge (annual, May, October)
- temporal distribution of normalized discharge (annual, May, October)
- cumulative moving mean flood peak (annual)
- temporal distribution of normalized flood peak (annual, May)

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* Flood peak = Maximum (peak) daily discharge (see Sections 2.3.1 and 2.3.2)

(c) <u>Castor River at Russell (02LB006)</u>

- cumulative moving mean discharge (annual, May, October)
- temporal distribution of normalized discharge (annual, May, October)
- cumulative moving mean flood peak (annual)
- temporal distribution of normalized flood peak (annual, May)

(d) <u>Ottawa CDA, Ottawa Airport and Kemptville</u>

- cumulative moving mean annual precipitation at each station and the three station average
- the cumulative moving mean precipitation for Ottawa CDA for May and October
- the temporal distribution of the normalized Ottawa CDA precipitation series (annual, May, October)

To examine the stationarity of the time series, the temporal distribution and the progressive mean, were plotted for each of the time series (Appendix A). The annual precipitation series from the Ottawa CDA station was also plotted for comparison with the annual flow series. The overall results of the graphical analyses are summarized in Tables 2.2 to 2.5.

Examination of the cumulative moving mean plots for the long record stations (Figures A1.1, A1.2, A1.3, A1.7, A2.1, A2.2, A2.3, A2.7) shows, in general, that the time series are stationary; that is, they do not exhibit trends. However, there is indication of some persistence in the annual discharge

TABLE 2.2

SUMMARY OF GRAPHICAL ANALYSES FOR CUMULATIVE MOVING MEAN DISCHARGE AND PRECIPITATION*

	ANNUAL	MAY	OCTOBER
South Nation River near Plantagent Springs (Discharge)	(Fig. A1.1) - mean annual discharge generally decreased 1957 to 1967 and has generally increased to 1979 - variation follows similar pattern in precipitation	(Fig. A1.2) - slightly below the long term mean from 1950 to 1974 (within 10% of long-term mean) - less than 5% higher than the long-term mean for 1974 to 1979 - conclude total May discharge relatively stable and consistent and generally reflects variations in precipitation	(Fig. A1.3) - generally decreasing from 1954 to 1971 and generally increasing 1971 to 1979
South Nation River at Spencerville (Discharge)	(Fig. A.2.1) - mean generally decreasing 1963 to 1967 and then generally increased to 1979 - pattern consistent with Plantagenet and overall trends in annual precipitation	(Fig. A.2.2) - generally decreasing mean from 1956 to 1968 - increasing 1969 to 1976 then decreasing again - similar overall pattern to precipitation	(Fig. A.2.3) - decreasing mean runoff from 1954 to 1969 and increasing thereafter

* Precipitation Data were obtained from the Climatological Application Branch of the Atmospheric Environment Service. Canadian Climate Centre, Environment Canada, at Downsview, Ontario.

TABLE 2.2 (cont'd)

SUMMARY OF GRAPHICAL ANALYSES FOR CUMULATIVE MOVING MEAN DISCHARGE AND PRECIPITATION*

	ANNUAL	MAY	OCTOBER
Castor River at Russell (Discharge)	(Fig. A3.1) - record starts 1968 and discharge increases to 1972 (consistent with generally increasing precipitation in this period)	(Fig. A3.2) - generally close to or above the long-term (12 yr) mean for the period 1969 to 1979	(Fig. A3.3) - generally below long-term (12 yr) mean except for 1977 to 1978.
	- generally slight decreases in discharge from 1973 to 1979 (less than 5% of long-term mean)	N/A	N/A
Ottawa CDA (Precipitation)	(Fig. A1.1) - above the long-term mean from 1923 to 1962, then dropped below it, generally decreasing from 1954 to 1966, then increasing in general to 1979	(Fig. A4.2) - precip. trend high in 50's, lower in 60's and increasing again in 70's; flow variations are generally consistent with these trends	(Fig. A4.3) - generally at or below long-term mean from 1956 to 1971; generally increasing after 1971 - fairly stable mean in range 61 to 66 mm/month (2.4 to 2.6 in/month)
	(Fig. A4.1) - average of CDA, airport and Kemptville indicates the same general trend - decreasing from 1954 to 1966, then increasing in general to 1979		

TABLE 2.3

SUMMARY OF GRAPHICAL
ANALYSES OF TEMPORAL DISTRIBUTION
OF NORMALIZED DISCHARGE AND PRECIPITATION

	ANNUAL	MAY	OCTOBER
South Nation River near Plantagent Springs (Discharge)	(Fig. A1.4) - discharge below the mean for 1955 to 1968; generally above or near the mean from 1969 to 1979 - generally reflects persistence in the normalized precipitation pattern	(Fig. A1.5) - 1957 to 1968 below avg. with exception of 1963 - precip. and runoff trends generally correspond 1970 to 1979	(Fig. A1.6) - lows are generally limited - below mean 1949 to 1971, except 1952, 1954 and 1965, 1967 - generally above mean 1972 to 1979 except for 1974 and 1978 which correspond to below average precipitation
South Nation River at Spencerville (Discharge)	(Fig. A2.4) - at or below avg. 1956 to 1968 with exception of 1960 which was slightly above - at or above avg. 1969 to 1979 which is consistent with the corresponding precip. series	(Fig. A2.5) - generally below mean 1961 to 1968 with exception of 1963 - 1969 high runoff corresponds to high precip. in the month - 1970 to 1979, runoff and precip. correspond except that 1979, 1977 show lower runoff than precip. would indicate	(Fig. A2.6) - below mean 1949 to 1971 except 1952, 1954, 1955, 1959, 1970 - lows generally limited to 0.60 SD (SD = stndard deviation) - general correspondence with precip. 1971 to 1979

TABLE 2.3 (cont'd)

SUMMARY OF GRAPHICAL
ANALYSES OF TEMPORAL DISTRIBUTION
OF NORMALIZED DISCHARGE AND PRECIPITATION

	ANNUAL	MAY	OCTOBER
Castor River at Russell (Discharge)	(Fig. A3.3) - below average precip. and below average discharge correspond for 1968, 1969, 1970 and similar for above average in 1972 and 1973, period from 1976 to 1979 shows somewhat less correlation of streamflow and precipitation	(Fig. A3.4) - lows generally limited to about 1 SD below mean (SD = Standard Deviation) N/A	(Fig. A3.5) - lows generally limited to about 0.8 SD below mean N/A
Ottawa CDA (Precipitation)	(Fig. A1.4) - below mean from 1955 to 1970 with exception of 1967 - generally above or near the long term mean from 1970 to 1979 (Fig. A4.1) - average of CDA, airport and Kemptville indicates the same	(Fig. A4.4) - high precip. in 1952, 1956, 1960 - little indication of persistence in May precip. amounts, generally random highs and lows around the mean with exception of 1961 to 1968 which had below average precip.	(Fig. A4.4) - more random than discharge which is also reflecting base flow - no general trends, but there are a few more low years than high years

TABLE 2.4

SUMMARY OF GRAPHICAL ANALYSES
OF CUMULATIVE MOVING MEAN FLOOD PEAK

	ANNUAL	MAY	SUMMER
South Nation River near Plantagent Springs	(Fig. A1.7) - moving mean from 1916 to 1979 shows repeating patterns of highs and lows. Therefore increasing trend in recent years (similar to previous trends) cannot be attributed to land use changes based on this analysis	N/A	N/A
South Nation River at Spencerville	(Fig. A2.7) - higher peaks 1950 - 1965 correspond to same general tendencies in the 1950's at Plantagenet - generally increasing from 1969 to 1977, similar observations at Plantagent; therefore both are likely a function of meteorologic conditions rather than land use changes - mean flood, above average from 1950 to mid 60's; below average mid 60's to 1969 and increasing since 1969, similar to Spencerville and Plantagenet	N/A	N/A
Castor River at Russell	(Fig. A3.6) - generally decreasing from 1955 to 1966 (exception 1963), then increasing from 1969 to 1979, similar pattern at Plantagenet for the above period	N/A	N/A

TABLE2.5

SUMMARY OF GRAPHICAL ANALYSES OF TEMPORAL DISTRIBUTION OF NORMALIZED FLOOD PEAK

	Annual	May	Summer
South Nation River near Plantagenet Springs	(Fig. A1.8) - random tendencies in flood peaks indicated by positive and negative excursions - some persistence evident - period 1967 to 1979 generally above mean flood (exception 1969 to 1974)	(Fig. A1.9) - lows are limited to less than 1 SD below the mean. Extreme occurred in 1945 (SD = Standard Deviation)	N/A
South Nation River at Spencerville	(Fig. A2.8) - pattern not consistent with Plantagenet Springs - 1970 to 1979 has equal number of highs and lows; highs correspond to Plantagent for 1970, 1971, 1972; opposite for 1973, 1974, 1976, 1977, 1979, possibly due to distribution of rainfall or snowmelt	N/A	N/A
Castor River at Russell	(Fig. A3.7) - generally above mean from 1970 to 1979; consistent with Plantagenet - may be reflecting land use changes; however, earlier peaks in this record are higher	(Fig. A3.8) - lows are limited to 0.8 SD below the mean - high flow years 1969, 1973, 1974, 1976 - consistent with pattern at Plantagenet Spring	N/A

data; that is, high flow years have a tendency to be followed by high flow years and low flow years tend to be followed by low flow years.

It is noted that in general the observed patterns seem to reflect changes in the precipitation regime as opposed to changes in runoff due to watershed modifications. In this regard, a high correlation has been found between annual precipitation and annual discharge at various locations in the watersheds with the correlation coefficient at Plantagenet equal to R = 0.78 (Figure A1.4).

It is also noted that the annual and flood runoff patterns at the Spencerville gauge were found to be similar to the Plantagenet data. The fact that drainage modifications have not been as extensive in the watershed upstream of Spencerville compared to the watershed upstream of Plantagenet may indicate that drainage modifications have tended to result only in minor changes in the flow regime at downstream locations.

2.2.3 Statistical Analysis

Each time series was checked for trends by utilizing the Kendall Rank Correlation Test and the Rank Order Correlation Test. The results are summarized in Table 2.6. It was generally found that application of these two tests confirmed the earlier conclusions that there are no overall trends in the data base.

The temporal distribution plots for the Plantagenet and Spencerville annual flows (Figures A1.4 and A2.4), give some

TABLE 2.6

TEST FOR TREND AND PERSISTENCE IN HYDROLOGIC TIME SERIES

Station	Plantagenet	Plantagenet	Plantagenet	Plantagenet	Plantagenet	Spencerville	Spencerville	Spencerville	Ottawa CDA	Ottawa CDA	Ottawa CDA	Castor Riv at Russel
Hydrologic time series	Annual Flood	Annual Discharge	May Discharge	Jun-Oct. Discharge	Jun-Oct. Flood	Annual Flood	Annual Discharge	May Discharge	Annual Prec.	May Prec.	Oct. Prec.	Annual Flo
Period	1916-43	1916-33 1949-79	1915-33 1948-79	1915-38 1945-79	1915-38 1945-79	1948-79	1950-79	1915-50	1951-50 1952-79	1950-79	1950-79	1948-79
Years of Record	62	49	51	59	59	32	30	31	64	30	30	32
Kendall Rank Corr. Test for Trend Z Statistic	0.9293	0.6206	0.4467	0.6997	0.0719	- 0.3243	0.4817	- 0.4589	- 0.9617	0.8742	1.3738	0.5189
Significance	No	No	No	No	No	No	No	No	No	No	No	No
Rank Corr.Test for Trend T Statistic	1.0220	0.6443	0.3609	0.7656	- 0.0117	-0.5387	0.2794	- 0.5468	- 0.9397	- 1.0906	- 1.8021	1.4887
Degree of Freedom	60	47	49	57	57	30	28	29	62	27	27	29
Significance	No	No	No	No	No	No	No	No	No	No	At 10% Lev.	No
Spearman Corr.Coef. Test for Persist. T Statistic	2.0900	4.3152	- 0.0715	- 1.1851	- 0.9962	0.1586	3.3804	- 0.5325	1.3200	1.0427	1.5561	0.4564
Degree of Freedom	59	46	48	56	56	29	27	28	61	28	28	30
Significance	At 5% Lev.	At 1% Lev.	No	No	No	No	At 1% Lev.	No	No	No	No	No

NOTE: At 1% level: Z critical = ± 2.58
At 5% level: Z critical = ± 1.96
At 10% level: Z critical = ± 1.65

t critical = function (degree of freedom, level of significance)
Z = normal variate
t = student t variate

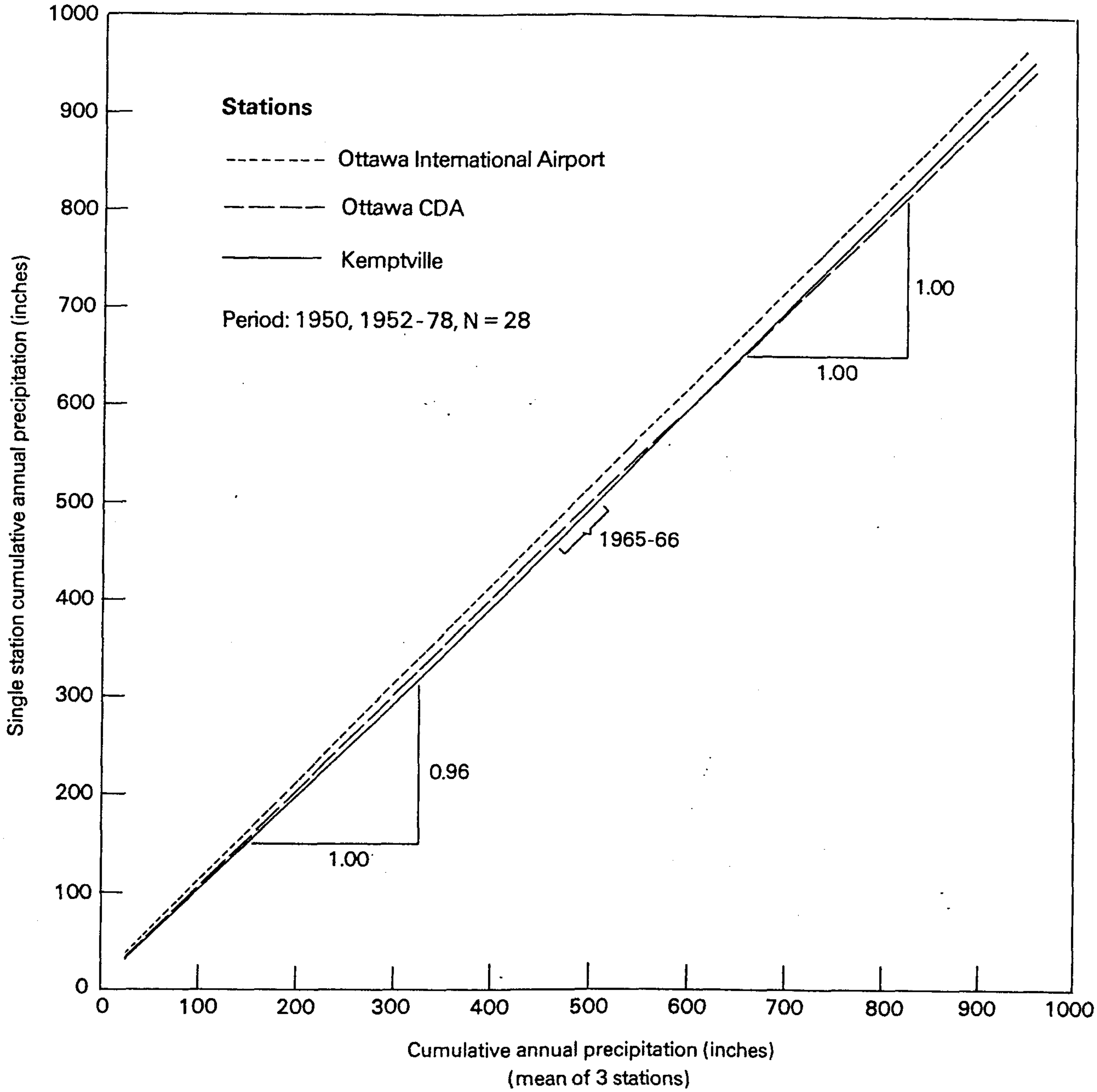
evidence of persistence in that high flows tend to be followed by high flows, and low flows followed by low flows. This was further assessed by utilizing the Spearman Correlation Coefficient Test, and the occurrence of persistence in the data was indeed found to be highly significant (at the 1% level). The annual precipitation plot shows the same type of temporal pattern (Figure A1.4) but in the statistical tests this trend does not appear so prominently. However, the persistence in the annual flows does appear to originate primarily from the annual precipitation pattern for the time period analyzed.

2.2.4 Double-Mass Analyses

Double-Mass Analyses were used to test the consistency of station records. The cumulative values of annual precipitation at station Ottawa CDA, Ottawa International Airport and Kemptville are plotted against the cumulative mean of the three stations in Figure 2.2. The plot for Ottawa CDA and Ottawa International Airport appear as straight lines, indicating the consistency of the data. The plot for station Kemptville shows a slight change of slope (from 0.97 in/in to 1.00 in/in) occurring at about 1966 or 1967. It is not certain that this change has a physical cause for there may have been a minor change in the location of station Kemptville in the year 1968. Since the change in slope is small, it cannot be concluded from this study that the precipitation data at Kemptville is inconsistent.

The cumulative monthly discharges for the stations South Nation River near Plantagenet Springs and Spencerville, Castor River at Russell and East Branch Scotch River near St.

Double Mass Analysis: Annual Precipitation



Isidore de Prescott are plotted against the cumulative mean of the four stations in Figure 2.3. All the plots appear as straight lines, showing the consistency of the data base.

2.3 Frequency Analyses of Peak Discharge Rates

2.3.1 General

Flood events in the South Nation River basin are normally caused by snowmelt and/or rainfall events. Analysis of existing data shows that snowmelt events mainly occur in the months December to May, and rainfall events are predominant in the months June to November. Therefore, for the purpose of reviewing the data base, the spring flood has been defined as the peak daily discharge in the months December to May and the summer flood as the peak daily discharge in the months June to November.

The growing season in the basin is from May to October. A flood occurrence in May could delay crop planting and a flood occurrence in the summer could reduce crop yield. Therefore, the frequencies of occurrence of May and summer floods are important to the assessment of flood management alternatives during the growing season. The frequencies of annual and spring floods are also important in delineating flood hazard areas. The historical statistics of available long-term flood discharge data are summarized in Table 2.7.

2.3.2 Flood Frequency Characteristics

The magnitude of the spring flood was found to be consistently higher than that of the summer flood except at Planta-

Figure 2-3

Double Mass Analysis: Monthly Discharge
Period: 1970-78

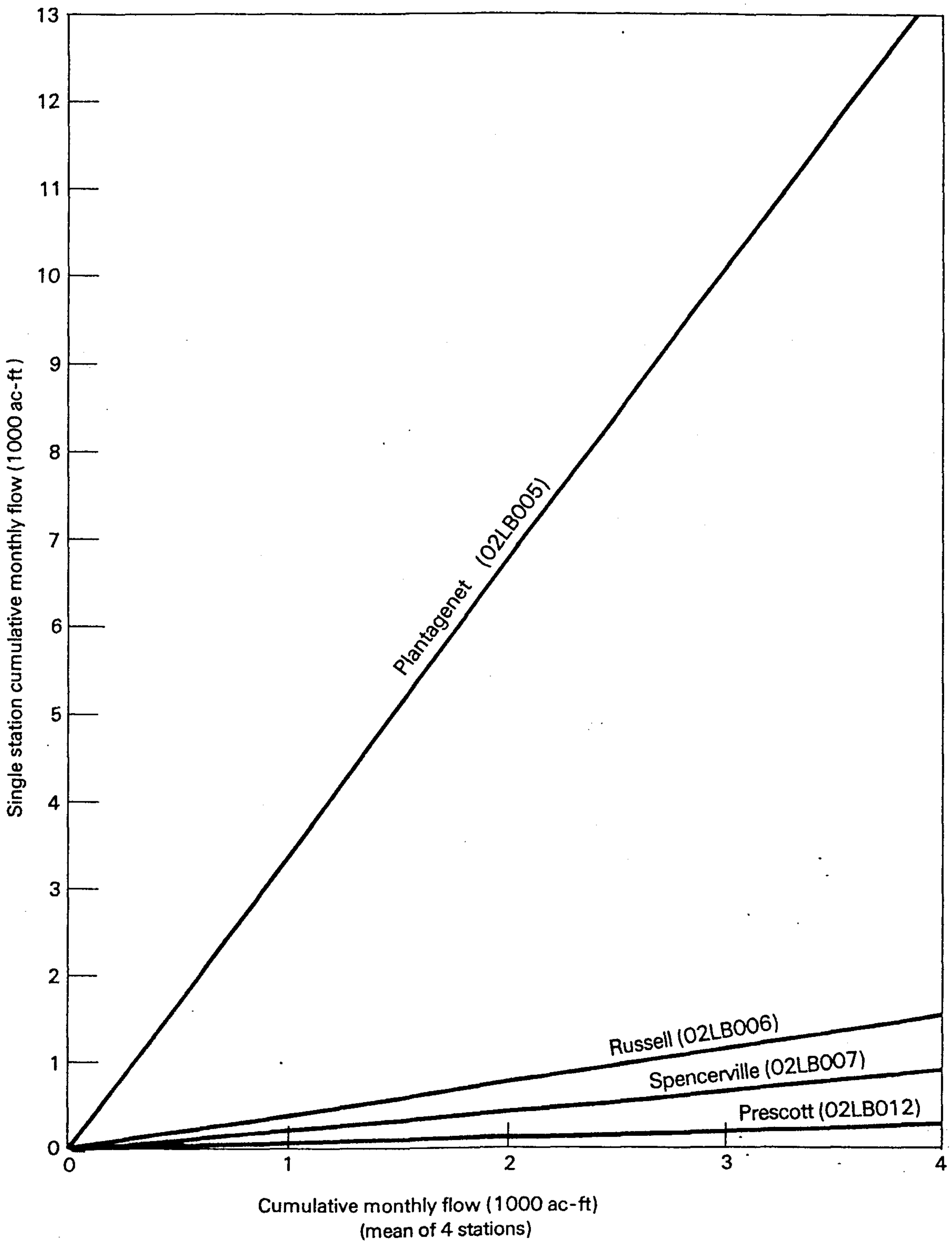


TABLE 2.7

SUMMARY OF HISTORICAL STATION FLOOD STATISTICS

	Annual Flood Sample Statistics						Summer Flood Sample Statistics						May Flood Sample Statistics					
				(Log-Transformed Data)*						(Log-Transformed Data)*						(Log-Transformed Data)*		
	Mean cfs	SP** cfs	CS	Mean In (cfs)	Mean In (cfs)	CSL	Mean cfs	SD cfs	CS	Mean In (cfs)	SD In (cfs)	CSL	Mean cfs	SD cfs	CS	Mean In (cfs)	SD In (cfs)	CSL
S.N.R. at Spencerville (02LB007)	1752	748	0.61	7.3725	0.4624	-0.49	266	219	1.03	5.1684	1.0184	-0.45	266	194	1.4	5.3521	0.6835	0.3
S.N.R. at Chesterville (02LB009)	6373	2085	-0.27	8.6972	0.382	-0.95	INCOMPLETE RECORDS											
Castor River at Russell (02LB006)	3969	1363	-0.25	8.2132	0.4193	-1.21	605	629	1.66	5.8534	1.1817	-0.25	573	622	1.16	5.7712	1.1184	0.4
Bear Brook near Bourget (02LB008)	3935	2028	1.11	8.1517	0.5242	-0.25	INCOMPLETE RECORDS											
East Branch Scotch River (02LB012)	600	133	-0.05	6.3738	0.2355	-0.80	INCOMPLETE RECORDS											
S.N.R. near Plantagenet Springs (02LB005)	25950	7883	-0.24	10.1078	0.362	-1.23	5005	4224	0.96	8.0483	1.1112	-0.61	4678	4241	1.12	7.999	1.0095	-0.06

NOTE: * Log to the base e
** All SD, CS, CSL are unbiased estimates
SD Standard deviation
CS Skewness coefficient of natural data
CSL Skewness coefficient of log-transformed data
S.N.R. South Nation River
1 cfs 0.028317 m^3/s

genet Springs in the year 1965, where the summer flood was recorded to be only slightly higher than the spring flood. Hence, for all practical purposes it can be assumed that the spring flood is identical to the annual flood for the six stations with long-term records.

Independent flood frequency analyses were also undertaken utilizing the May and summer time series of flood peaks. The sample statistics of the annual flood, the summer flood and the May flood are given in Table 2.7 for both the natural data and the log-transformed data. These statistics (mean, standard deviation and skewness coefficient) can be used to fit various theoretical flood frequency distributions to the available flood series.

The Log-normal (LN), the three parameter Log-normal (3LN) and the Log-Pearson Type 3 (LP3) distributions were chosen for comparison of their relative accuracy in fitting the flood data. The Log-Pearson Type 3 distribution has been widely used in flood frequency analysis in the United States and in the United Kingdom. In a recent study (1) based on 32 gauging stations in Ontario with long-term records, it was found that the 3LN and LP3 distributions generally resulted in a better fit to the annual flood events than other extreme value distributions. The parameter estimates of the 3LN and LP3 distributions depend on the sample mean, standard deviation, and skewness coefficient.

The sample skewness coefficient is very sensitive to extreme events and the length of record. If a regional pattern of skewness coefficients exists, the 3LN and LP3 have the advantage of utilizing regional skewness information in predicting flood events. However, when the skewness coefficient of the untransformed (natural) data is negative, the 3LN distribution is not applicable and the LP3 distribution may yield negative flood flows for short return periods and has an upper bound. A regional skewness pattern has been found in the U.S. (2) and a preliminary skewness prediction equation has been determined for the Province of Ontario (excluding St. Lawrence Lowlands) (3).

2.3.3 Peak Discharge Estimates

The available historical flood records are plotted for the six stations using the Weibull plotting position (see Appendix B). The fitted Log-normal (LN), three parameter Log-normal (3LN) by the method of maximum likelihood and the Log-Pearson type 3 (LP3) by the method of moments and by the method of maximum likelihood were also plotted and compared to the historical data (see Appendix B, Log-normal not shown). The above distributions were superimposed and the best fitted distribution was selected. In some cases (Figures B5.1 and B5.2) the LP3 curves by the method of moments and the method of maximum likelihood are almost identical. For stations South Nation River at Chesterville and near Plantagenet Springs, Castor River at Russell, and East Branch Scotch River near St. Isidore de Prescott, it was noted that the 3LN distribution data could not be fitted to the annual flood data because the sample estimate of skewness was negative.

The overall comparison of the selected "best-fit" distribution for each station is summarized in Table 2.8. From this comparison, it was concluded that Log-Pearson Type 3 (LP3)

TABLE 2.8

SUMMARY OF SELECTED BEST FITTING DISTRIBUTION

Station	Annual Flood	Summer Flood	May Flood
Spencerville (02LB007)	3LN LP3 (Moment)	LP3 (Moment)	LP3 (Moment)
Chesterville (02LB009)	LP3 (Moment & M.L.)	Incomplete Records	
Castor River at Russell (02LB006)	LP3 (Moment)	LP3 (Moment)	3LN
Bear Brook near Bourget (02LB008)	LN	Incomplete Records	
East Branch Scotch River (02LB012)	LN	Incomplete Records	
Plantagenet Springs (02LB005)	LP3 (Moment & M.L.)	LP3 (Moment) & M.L.)	LP3 (Moment & M.L.)

Symbols:

LN = Log-normal distribution
3LN = 3 parameter log-normal distribution
LP3 = Log-Pearson type 3 distribution
(Moment) = by the method of moments
(M.L.) = by the method of maximum likelihood

distribution by the method of moments is an acceptable distribution for flood frequency analysis in the South Nation River Basin. Table 2.9 summarizes the flood estimates for different recurrence intervals based on the LP3 distribution (moments) at each location.

2.3.4 Station Skewness Coefficient

For unregulated flood sequences, the sample skewness estimates are generally positive for streams and rivers in Ontario (3, 4). This is due to the fact that natural floods are bounded at the lower end (i.e. at zero or values higher than zero) and unbounded at the upper end of the flood frequency distribution. However, for regulated flood sequences, the sample skewness estimate may be negative because the floods may be bounded at the upper end due to flow regulation. The sample skewness estimate may also be negative for short data sets.

The sample skewness estimates are summarized in Table 2.7, and it is evident that the annual flood series at Spencerville on the South Nation River, and Bear Brook near Bourget, are positively skewed, while those at Plantagenet and Chesterville on the South Nation River, Russell on the Castor River and the East Branch of the Scotch River near Prescott are negatively skewed.

The negative skewness on the East Branch of the Scotch River is attributed to the relatively short period of record. In any case, statistical tests have indicated that this value is not significantly different from zero. The other stations exhibiting negative skewness all have large floodplain storage zones immediately upstream from the hydrometric gauge location, and have limited channel capacities in the vicinity of the stream gauge. Therefore, it is postulated that when the annual flood is high, a large portion of the flow enters the floodplain storage zones due to the restricted channel capacity, thus reducing the magnitude of flood flow at the streamflow station. In other words, the natural floodplain acts as a storage reservoir which attenuates the high flood peaks and effectively sets an upper bound on flood discharge rates. Therefore, it is believed that this phenomenon results in negative skew coefficients at these locations.

On the other hand the flood series at Spencerville does not appear to be significantly affected by floodplain storage or channel constrictions, which is consistent with a positive value of the sample estimate of the coefficient of skew at this location.

Although there exists some floodplain storage upstream of Bourget, the control of flow at Bourget is relatively small due to the downstream inflows from the North and South Indian Creek.

The sample estimates of the skew coefficient of the May and summer flood series are all positive. This could be due to the fact that subsequent to the spring runoff the flood discharge rates tend to be lower than in the spring and tend to be closer to the natural channel capacity. Hence, the relative magnitude of floodplain storage effects is smaller for May and summer flood events and the flood peaks at downstream locations are not limited to the same degree as the larger magnitude spring events. Therefore, the coefficient of skew for these events is generally found to be positive, which is consistent with the majority of Ontario streams.

Table 2.10 gives the standard error (6, 7) and the 95% confidence interval (CI) on the sample estimates of the skew coefficient at the long term station locations. The 95% confidence interval implies that there is only one chance in 20 that the true skewness lies outside this interval. If the interval does not contain zero, we may conclude that the true skewness is significantly different than zero at the 5% level of significance.

From Table 2.10, the station summer and May flood skews are all positive in magnitude and significantly different from zero. For the annual floods, only the sample estimate of skewness for the station Bear Brook near Bourget is significantly different from zero.

2.3.5 Inter-correlation of Annual Flood Peaks

The available period of concurrent discharge records and the simple cross-correlations of annual flood peaks for each pair of stations were determined and are summarized in Tables 2.11 and 2.12 respectively. Table 2.12, shows that the annual flood peaks are highly inter-correlated at many of the stations (The results for the East Branch of the Scotch River should be ignored due to the relatively short record of 10 yr or less). This is consistent with annual floods that are normally generated by a combination of snowmelt and rainfall conditions which occur at the same time over a large area of the watershed.

TABLE 2.9

ESTIMATED FLOOD PEAKS FOR THE 1:5, 1:50 AND 1:100 YEAR RECURRENCE INTERVALS*

Station/Return /Period	Annual Flood						Summer Flood						May Floor					
	5 Yr		50 Yr		100 Yr		5 Yr		50 Yr		100 Yr		5 Yr		50 Yr		100 Yr	
	m^3/s	%**	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%
S.N.R.*** at Spencerville	66.8	8.3	102.8	14.2	111.6	17.3	11.9	18.4	31.1	31.6	37.9	38.5	10.5	15.2	27.0	32.1	34.0	39.0
S.N.R. at Chesterville	234.5	6.1	303.0	13.3	317.2	16.7	INCOMPLETE RECORDS											
Castor River at Russell	148.7	5.6	186.9	15.5	192.8	19.4	27.0	34.5	95.1	60.2	124.0	72.3	22.6	35.0	114.4	77.3	170.2	94.4
Bear Brook Near Bourget	153.5	11.7	268.4	20.4	303.0	24.5	INCOMPLETE RECORDS											
(East Branch) Scotch River near St. Isidore de Prescott	20.3	6.7	24.3	13.0	25.0	16.3	INCOMPLETE RECORDS											
S.N.R. near Plantagenet Springs	940.1	3.4	1141.2	9.8	1172.3	12.2	329.4	14.2	597.5	25.0	713.6	30.8	197.9	15.0	65.1	27.7	846.7	33.1

* By Log-Pearson Type III Distribution (Method of Moments)
** Standard error of flood in percentage at the prescribed return period
*** S.N.R. = South Nation River

Flood estimates were computed by Program FDRPFFA from Reference 5.

TABLE 2.10

STANDARD ERROR (SE)* AND 95% CONFIDENCE INTERNAL (CI)**
ON STATION FLOOD SKEW (CS)

Station	Annual Flood					Summer Flood					May Flood				
	N	CS	SE	95%	CI	N	CS	SE	95%	CI	N	CS	SE	95%	CI
Spencerville	32	0.61	0.416	1.45,	-0.24	32	1.03	0.415	1.88,	0.18	32	1.40	0.415	2.25,	0.55
Chesterville	28	-0.27	0.441	0.63,	-1.17			I N C O M P L E T E					R E C O R D S		
Castor River at Russel	32	-0.25	0.415	0.60,	-1.10	14	1.66	0.597	2.94,	0.38	17	1.16	0.550	2.32,	0.00
Bear Brook near Bourget	24	1.11	0.472	2.08,	0.14			I N C O M P L E T E					R E C O R D S		
East Branch Scotch River	10	-0.05	0.687	1.48,	1.58			I N C O M P L E T E					R E C O R D S		
Plantagenet Springs	62	-0.24	0.304	0.37,	-0.85	58	0.96	0.314	1.59,	0.33	60	1.12	0.309	1.74,	0.50

NOTE:

$$* \quad SE = \left[\frac{N\,(N-1)}{(N-2)\,(N+1)\,(N+3)} \right]^{\frac{1}{2}}$$

$$** \quad CI = [\,CS \pm t * SE\,]$$

t = student t statistic at 95% level of significance

TABLE 2.11

CONCURRENT RECORDS OF ANNUAL FLOOD

	Spencerville 02LB007 1	Chesterville 02LB009 2	Castor River at Russell 02LB006 3	Bear Brook near Bourget 02LB008 4	East Branch Scotch River 02LB012 5	Plantagenet Springs 02LB005 6
Spencerville 1	1948-79 (N=32)					
Chesterville 2	1950-52 1955-79 (N=28)	1950-52 1955-79 (N=28)				
Castor River at Russell 3	1948-79 (N-32)	1950-52 1955-79 (N-28)	1948-79 (N=32)			
Bear Brook near Bourget 4	1949-53 1955-69 1976-79 (N=24)	1950-52 1955-69 1976-79 (N=22)	1949-53 1955-69 1976-79 (N=24)	1949-53 1955-69 1976-79 (N=24)		
East Branch Scotch River 5	1970-79 (N=10)	1970-79 (N=10)	1970-79 (N=10)	1976-79 (N=4)	1970-79 (N=10)	
Plantagenet Springs 6	1948-79 (N=32)	1950-52 1955-79 (N=28)	1948-79 (N=32)	1949-53 1955-69 1976-79 (N=24)	1970-79 (N=10)	1916-43,45, 1947-79 (N=62)

TABLE 2.12

SIMPLE CORRELATIONS OF ANNUAL FLOOD

		Spencerville 02LB007 1	Chesterville 02LB009 2	Castor River at Russell 02LB006 3	Bear Brook near Bourget 02LB008 4	East Branch Scotch River 02LB012 5	Plantagenet Springs 02LB005 6
Spencerville	1	1					
Chesterville	2	0.80	1				
Castor River at Russell	3	0.55	0.71	1			
Bear Brook near Bourget	4	0.26	0.45	0.73	1		
East Branch Scotch River	5	-0.06	-0.26	-0.43	-0.01	1	
Plantagenet Springs	6	0.45	0.46	0.83	0.71	0.12	1

However, it is noted that for hydrometric stations not directly connected by stream channels that the cross-correlation for peak flows are generally lower. This indicates some spatial variation in flood producing characteristics and points out the need for accounting for the spatial characteristics in the watershed simulation model. (Parameters with spatial variations include precipitation, snow accumulation, temperature, physiographic and drainage characteristics)

2.4 Flow Duration Curves

The 1-day and 7-day flow duration curves for the stations South Nation River near Plantagenet Springs, Castor River at Russell, Bear Brook near Bourget, South Nation River at Chesterville, South Nation River at Spencerville and (East Branch) Scotch River near St. Isidore de Prescott were plotted on Figures 2.4 through 2.9. Since low flows usually occur during the summer months June through November (dry season), and high flows in the months December through May (wet season), only these periods (including the annual period) were considered in the flow duration analysis. The record length for the periods is given in Table 2.1. These duration curves are useful in studying the frequency of high and low flows. For example, in Figure 2.6, point A indicates that for the South Nation River at Plantagenet Springs within the period June 1 to November 30, the daily flow for any day was greater than 0.28 m^3/s (10 cfs) in 96.7% of the time. Similarly, point A in Figure 2.9 shows that for the same station and period the daily flows for any seven consecutive days were all greater than 0.28 m^3/s (10 cfs) in 96.6% of the time.

The flow duration curve also reflects the variability of the regime of the river. A flat curve with high minimum values is most likely derived from rivers with a large baseflow component, and a steep curve with low minimum values tends to indicate rivers with quickflow component. Low minimum flow values also suggests that agricultural development may require storage to provide water during periods of low natural flow.

2.5. Conclusions

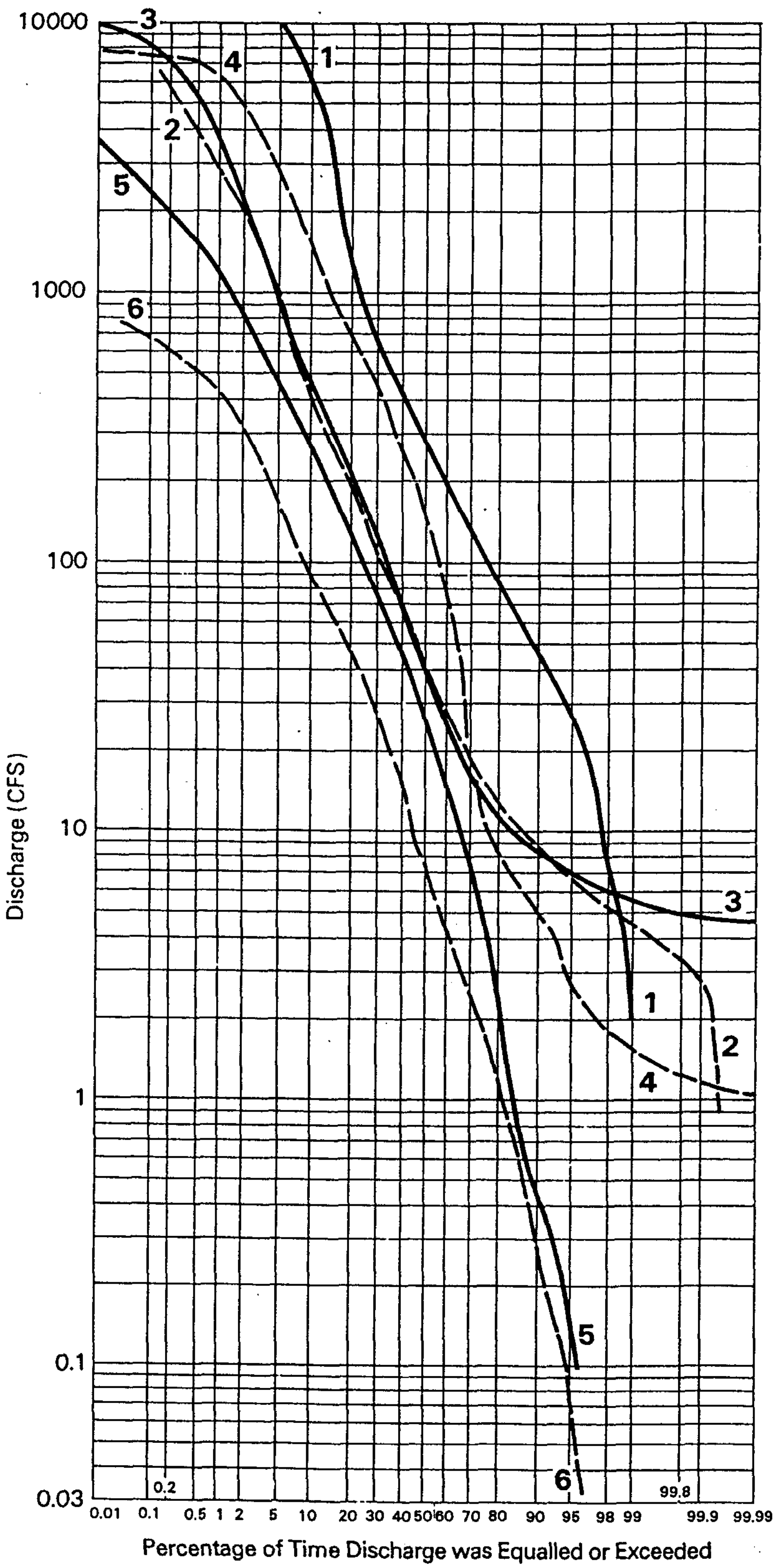
(1) The streamflow data sequence may be considered as trend-free for the hydrometric stations at Plantagenet Springs and Spencerville on the South Nation River for the annual flood, annual discharge, and the June to October and the May monthly time series of discharge. The data available for annual discharge exhibit some persistence, which is presently attributed to the precipitation over the basin. However, further checks into the nature of persistence of the annual flow series are recommended for other locations in the watershed using precipitation data which has been collected together with the simulation results from the HSP-F model.

(2) The skewness coefficient for those streamflow stations immediately downstream from major floodplains was found to be negative, while those stations unaffected by major floodplain storage exhibit positive skewness. It is suggested that large natural floodplains act as storage reservoirs which attenuate the high flood peaks and effectively set an upper bound in flood discharge rates.

(3) It was found that the Log-Pearson Type 3 distribution by the method of moments is an appropriate distribution for flood frequency analysis in the South Nation River basin. The added advantage of using this distribution lies in its ability to incorporate information from regional skewness in order to increase the reliability of estimating the magnitude of rare flood peaks.

(4) On the basis of the analyses of flow records within the South Nation basin, historical changes in runoff and flood patterns cannot be attributed to the introduction of tile and outlet drains in the watershed. It is acknowledged that floodplain storage upstream of the streamflow stations on the Castor River at Russell and the South Nation River at Plantagenet will attenuate flood peaks and may tend to moderate any changes in the flow regime which are caused by agricultural drainage. These effects are further assessed by using the HSP-F watershed model and a detailed drainage model.

1 - Day Flow Duration Curves (Annual)



1 South Nation River Near Plantagenet Springs (02LB005)

2 Castor River at Russell (02LB006)

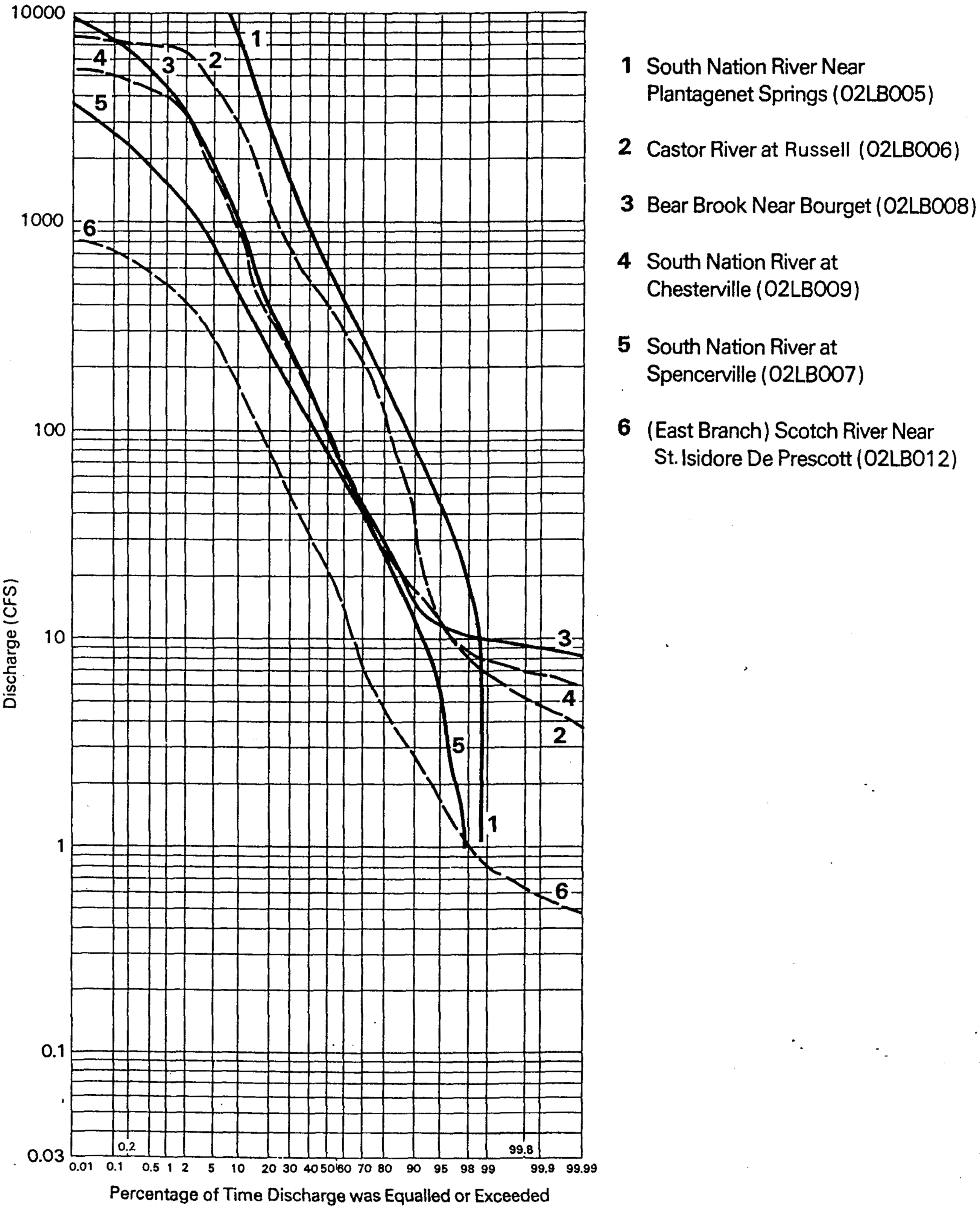
3 Bear Brook Near Bourget (02LB008)

4 South Nation River at Chesterville (02LB009)

5 South Nation River at Spencerville (02LB007)

6 (East Branch) Scotch River Near St. Isidore De Prescott (02LB012)

1 - Day Flow Duration Curves (December To May)



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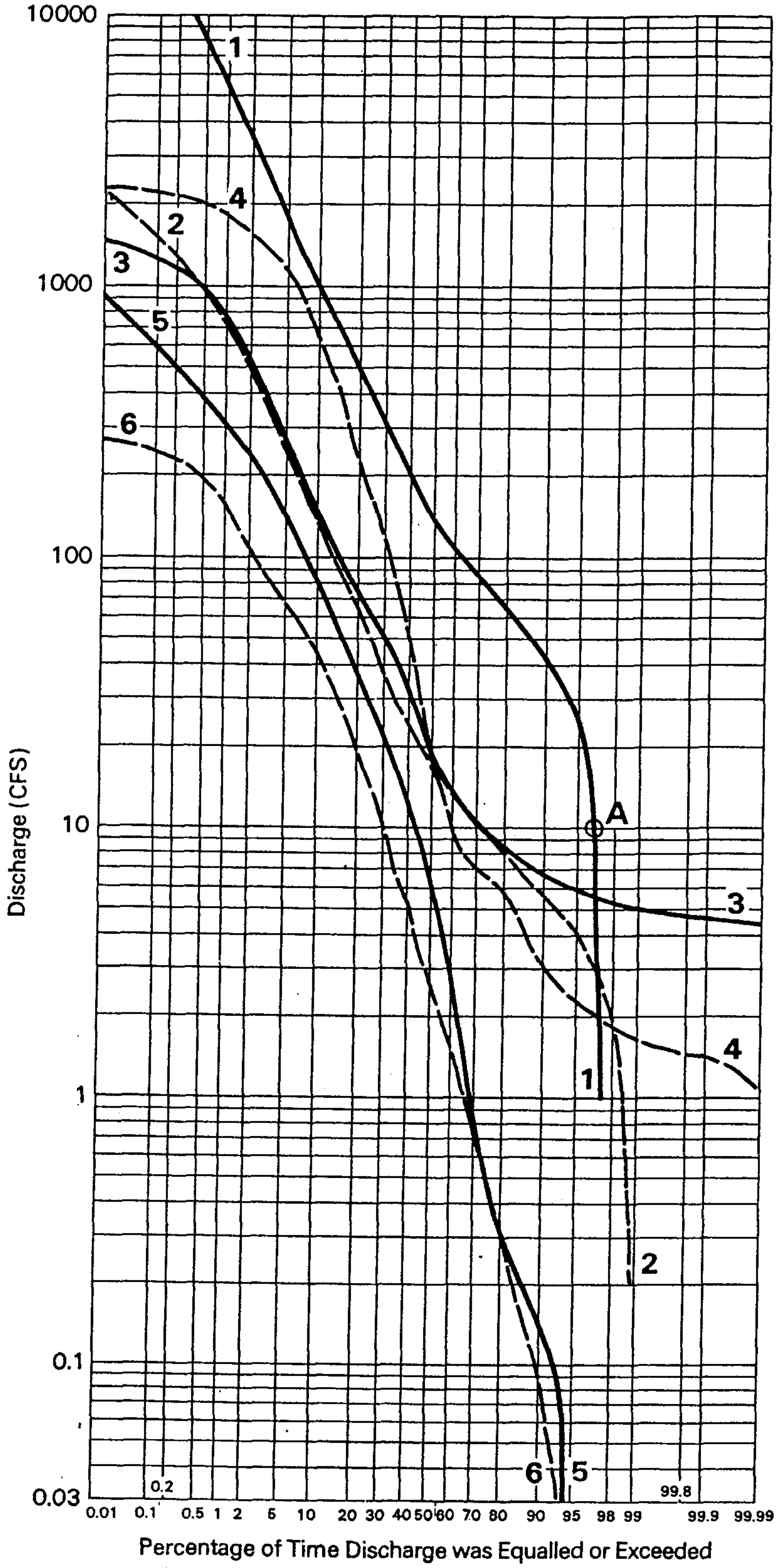
1 - Day Flow Duration Curves (June To November)



1 South Nation River Near Plantagenet Springs (02LB005)

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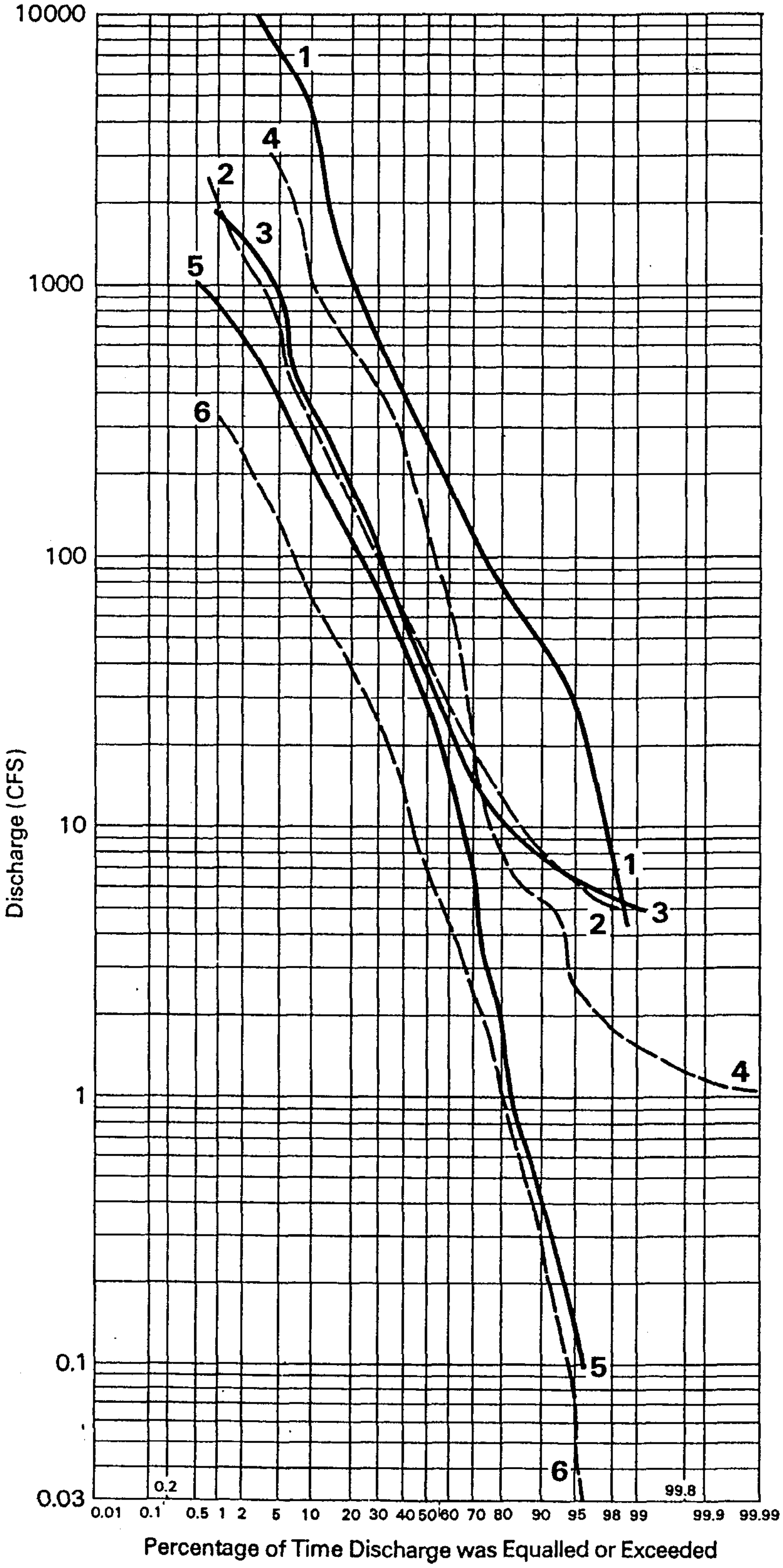
3 Bear Brook Near Bourget (02LB008)

4 South Nation River at Chesterville (02LB009)

5 South Nation River at Spencerville (02LB007)

6 (East Branch) Scotch River Near St. Isidore De Prescott (02LB012)

7 - Day Flow Duration Curves (Annual)



1 South Nation River Near Plantagenet Springs (02LB005)

2 Castor River at Russell (02LB006)

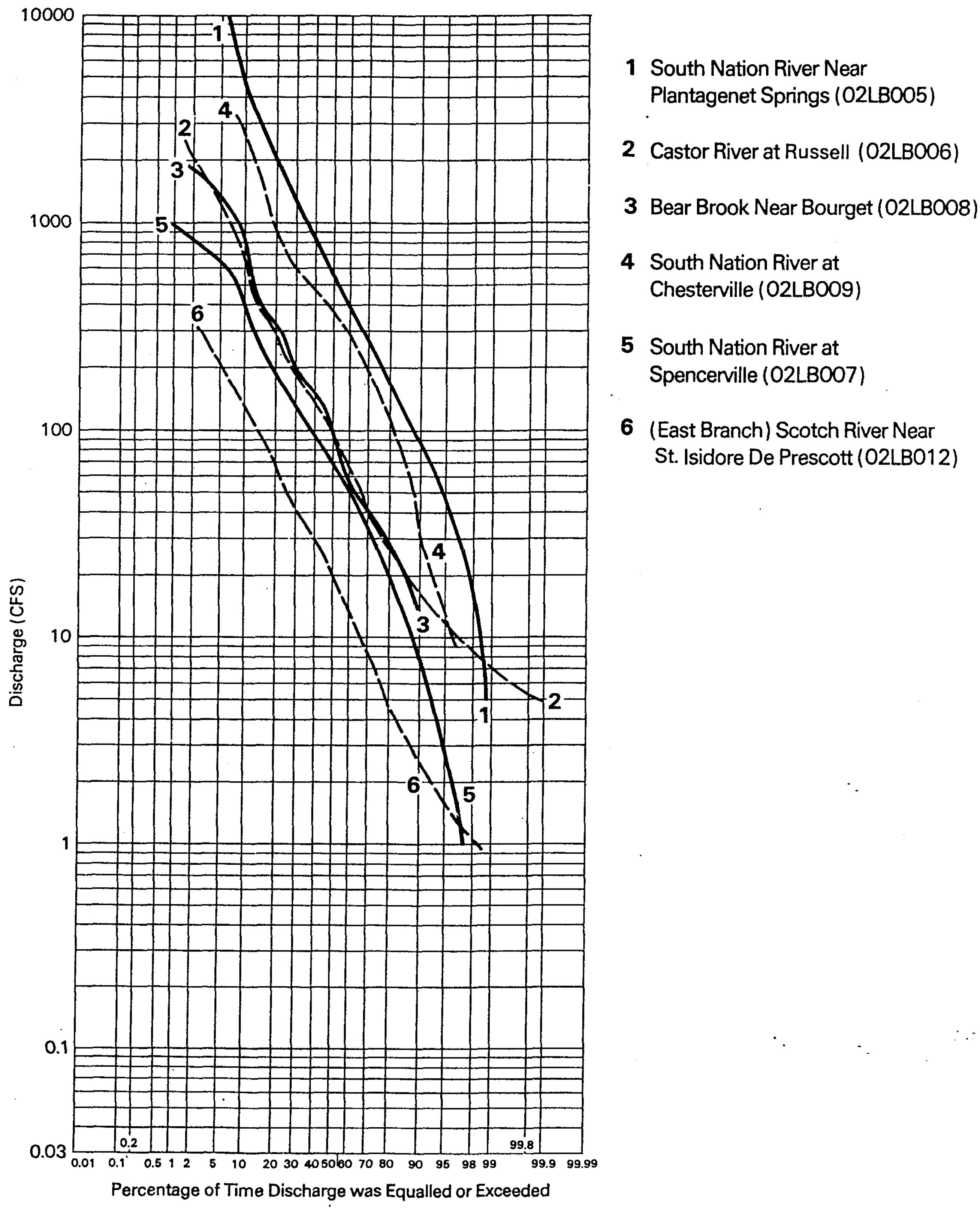
3 Bear Brook Near Bourget (02LB008)

4 South Nation River at Chesterville (02LB009)

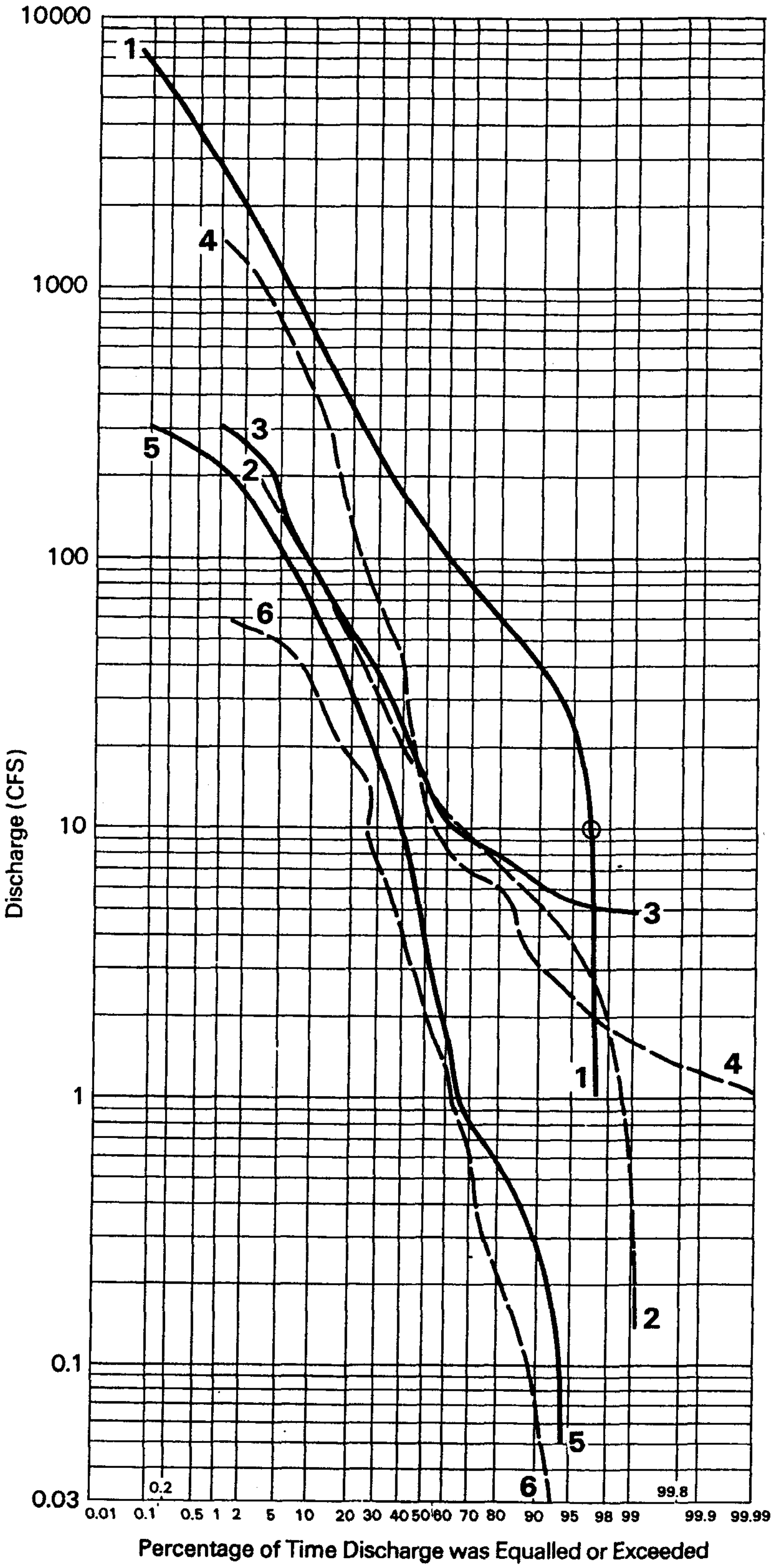
5 South Nation River at Spencerville (02LB007)

6 (East Branch) Scotch River Near St. Isidore De Prescott (02LB012)

7 - Day Flow Duration Curves (December To May)



7 - Day Flow Duration Curves (June To November)



1 South Nation River Near Plantagenet Springs (02LB005)

2 Castor River at Russell (02LB006)

3 Bear Brook Near Bourget (02LB008)

4 South Nation River at Chesterville (02LB009)

5 South Nation River at Spencerville (02LB007)

6 (East Branch) Scotch River Near St. Isidore De Prescott (02LB012)

CHAPTER 3

PRELIMINARY SCREENING OF WATER MANAGEMENT ALTERMATIVES

CHAPTER 3

PRELIMINARY SCREENING OF WATER MANAGEMENT ALTERNATIVES

3.0 PRELIMINARY SCREENING OF WATER MANAGEMENT ALTERNATIVES

3.1 Introduction

Since 1948, numerous studies have been undertaken by various agencies in the South Nation River basin. As a result of these studies, several structural remedial works have been proposed to alleviate flooding and to improve the water quality by flow augmentation from reservoirs during dry summer periods. The structural alternatives proposed thus far consist of eleven reservoirs, two diversions and three channel projects.

Most of the investigations undertaken in the past have dealt with analyses of site specific rather than basin-wide water management problems. Consequently the previously proposed structural alternatives were screened with the assistance of a computer model during this phase of the study to assist the Authority in the preparation of the basin Plan. The merit of the structural alternatives, depended on their ability to reduce downstream flooding and to increase summer low flows by flow augmentation. Those structural alternatives that provided some definite benefits were selected for further numerical evaluation during subsequent stages of the study.

3.1.1 Flooding Problems

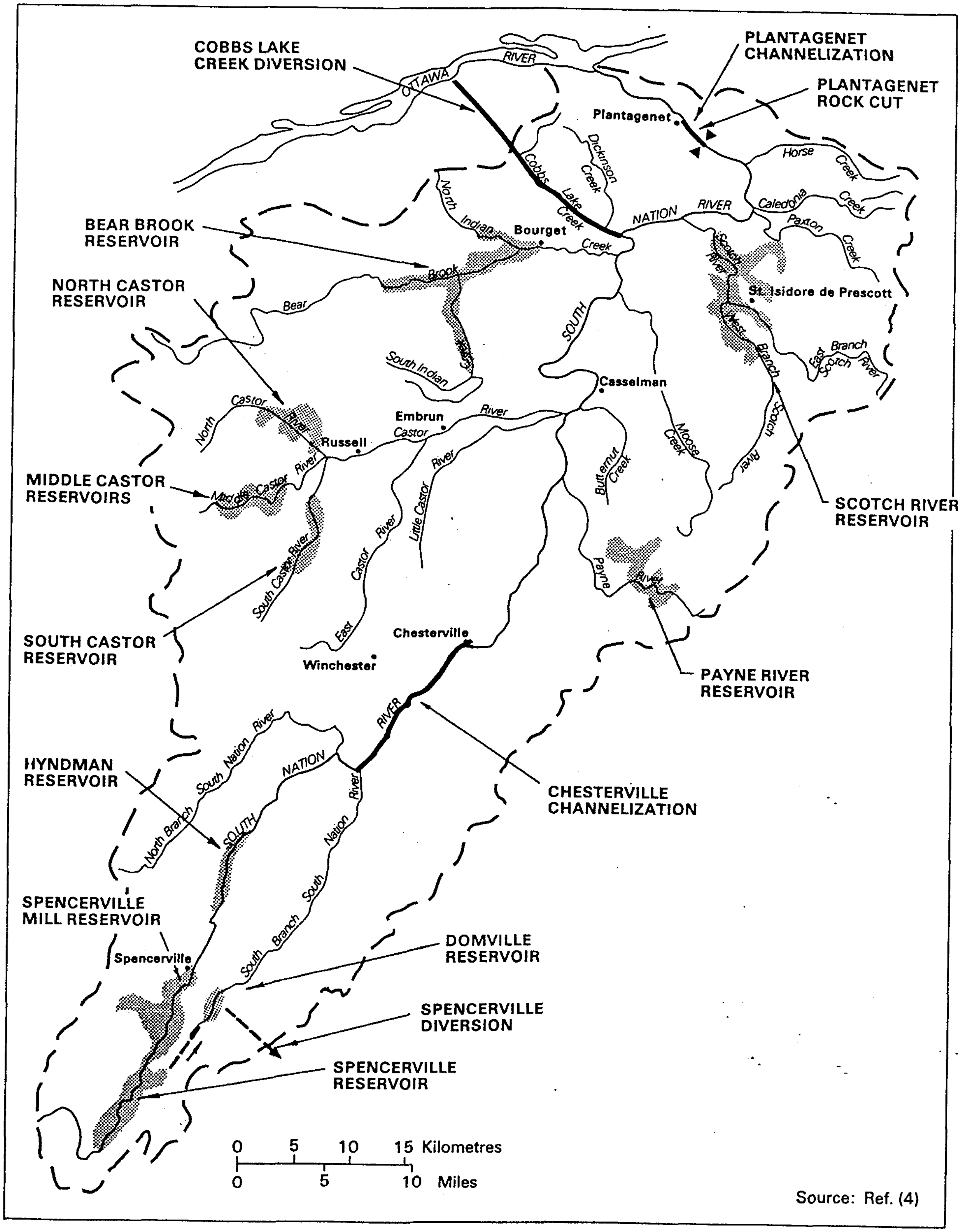
The two major flood-prone areas in the South Nation River basin are the Brinston area upstream of Chesterville and the Plantagenet area between Lemieux and Plantagenet Springs. During the highest recorded discharges of 1190 m^3/s (42 200 cfs) at Plantagenet and 280 m^3/s (9820 cfs) at Chesterville, it has been estimated that approximately 5828 ha (14 400 ac) and 1720 ha (4250 ac) of farmland, respectively, have been flooded. Flooding generally starts when the bankful capacities of 14-17 m^3/s (500-600 cfs) in the Brinston area and 230-280 m^3/s (8000 - 10 000 cfs) in the Plantagenet area are exceeded(1). The extent of the major flood prone areas within the watershed is depicted in Figure 3.1.

The Brinston and the Plantagenet areas are subject to flooding during three distinct events identified as Spring Floods, May and Summer Floods. Spring flooding is generally caused by snowmelt and normally occurs between mid-March and mid-April. The flows generated during this period can be quite high and may interrupt some dairy operations. Generally, the flooding is considered a nuisance but it does not substantially affect the agricultural production in the basin. Flooding in May is generally caused by the addition of surface runoff from rainfall events to relatively large base flows in the river. Since May is the planting season, flooding during this time period may delay planting or cause damage to seeded fields. Flooding due to excess rainfall during the growing and harvesting season from late May to October is critical. If damage to crops is severe, replanting is no longer possible and crop loss can be significant.

3.1.2 Summary of Proposed Remedial Works

Brinston and Plantagenet represent, the two major flood prone areas within the South Nation River basin. The Brinston area is located within the upper watershed and computer simulations indicate that the proposed storage measures for this

Structural Proposals for the South Nation River Basin



Source: Ref. (4)

area reduce the peak flow at Plantagenet by less than five percent. Consequently, each area was considered separately during the screening exercise.

3.1.2.1 Brinston Flood Area

In an effort to relieve flooding in the Brinston area, the following remedial works have been proposed:

Reservoirs

1) Spencerville (2)
2) Spencerville (3)
3) Spencerville Mill
4) Domville
5) Hyndman

The drainage area, surface area and gross storage of each reservoir are presented in Table 3.1. Additional reservoir data is documented in Appendix C.

Diversion

The Spencerville Diversion was proposed to relieve flooding in the Brinston area by diverting a maximum flow of 84.9 m^3/s (3000 cfs) from the basin to the St. Lawrence River(2).

Channelization

The Chesterville channelization project is currently under-way. It involves the channelization of a 19 km (12 mi) reach of the South Nation River upstream of Chesterville. The channel has been designed with a 102 m^3/s (3600 cfs) bankful capacity to convey the 1:10 year May event without flooding (4).

The location of the proposed remedial works for the Brinston area are shown in Figure 3.1.

3.1.2.2 Plantagenet Flood Area

Previously proposed remedial measures which alleviate flooding in the Plantagenet area are:

Reservoirs (3)

Payne River
North Castor River
Upper Middle Castor River
Lower Middle Castor River
South Castor River
Bear Brook
Scotch River

The drainage area, surface area and the gross storage of each reservoir are presented in Table 3.1. Additional reservoir data is documented in Appendix C.

Diversion

The Cobbs Lake Creek Diversion was proposed to relieve flooding in the Plantagenet area by diverting flows along Cobbs Lake Creek and Clarence Creek into the Ottawa River (4).

Channel Modification/Channelization

The Plantagenet Spring rock outcrop has been modified to reduce flood levels in the Plantagenet flood area. However, due to the low lying upstream areas, the channel's bankful capacity still remains at about 230-280 m^3/s (8000-10 000 cfs) (1).

In conjunction with the channel modification, channelization of a 3.2 km (2 mi) reach downstream of the rock cut was proposed since this reach would now constitute the main outlet control (1).

Dyking

Dyking has been suggested to prevent overbank flooding in the lower reaches of the Scotch River, Bear Brook, Cobbs Lake Creek and Caledonia Creek tributaries before they discharge to the main South Nation River (4).

The location of the proposed remedial measures for the Plantagenet area are shown in Figure 3.1. Although not shown, two separate reservoir sites have been identified for the Middle Castor River. The proposed control structures are located 7.2 km (4.5 mi) and 13.0 km (8.0 mi), respectively, upstream of Russell.

TABLE 3.1

PERTINENT DATA FOR PROPOSED RESERVOIRS

Name of Reservoir	Name of Reservoir	Drainage Area km^2 (m^2)	Flooded Area at Max.WS Elevation Hectares(acres)	Gross Reservoir Storage 10^6m^3(ac/ft)
South Nation River above Spencerville	Spencerville (ODPD 1948)	238 (92)	1082 (2673)	15.8 (12 776)
South Nation River at Spencerville	Spencerville (Acres 1966)	246 (95)	2830 (6993)*	88.8 (72 000)
South Nation River near Spencerville	Spencerville Mill	246 (95)	N/I	2.2 (1748)
South Branch of South Nation River near Domville	Domville	18.1 (7)	N/I	3 (2449)
South Nation River near the Village of Hyndman	Hyndman	297 (114)	N/I	2.2 (1760)
North Branch of Castor River above Russell	North Castor River	135 (52)	1546 (3820)*	21.7 (17 600)
Middle Branch of Castor River above Russell	Upper Middle Castor River	85 (33)	809 (2000)*	15.1 (12 240)
Middle Branch of Castor River above Russell	Lower Middle Castor River	96 (37)	318 (785)	2.9 (2320)
South Branch of Castor River above Russell	South Castor River	176 (68)	2125 (5250)*	11.6 (9440)
Castor River above Russell	Castor River Combined (excluding Lower Middle Castor River)	N/A	4480 (11 070)	48.4 (39 280)
Payne River above Finch	Payne River	119 (46)	1360 (3360)*	16.5 (13 400)
Bear Brook near Bourget	Bear Brook	430 (166)	332 (820)	11.1 (9000)
Scotch River at Riceville	Scotch River	285 (110)	2400 (5930)*	45.6 (37 000)

SOURCE - (Ref. 3)
N/A - Not Applicable
N/I - No Information
* - Figures derived by MacLaren from 1:50 000 scale topographic mapping

3.2 Hydrology

3.2.1 Selection of Flow Sequences

3.2.1.1 High Flow Events

In view of the importance of agricultural flood damages, the historical flow event which was selected for the evaluation of flood control alternates has caused severe flooding at Brinston and Plantagenet during the growing season. A review of the historical streamflow data indicated that a major flood occurred on 19 May 1945. This was a rainfall generated event which produced a peak flow of 470 m^3/s (16 600 cfs) at Plantagenet Springs. A frequency analysis carried out for maximum daily discharges for the month of May established that the above flow has a recurrence interval of about 1:20 year. Floods occurring in May have a higher magnitude than those occurring in the summer for similar recurrence intervals; therefore, structural alternatives which control a May design flood will provide greater protection during the summer period.

3.2.1.2 Summer Low Flows

The proposed dams and reservoirs may also be used to provide low flow augmentation during the summer. Table 3.2 shows the severity of the low flow problem from June to November for selected locations based on the historical flow record. The South River at Spencerville and the Scotch River at St. Isidore de Prescott have experienced zero flows during many years. In order to evaluate the effectiveness of the pro-

TABLE 3.2

RECURRENCE INTERVAL FOR VARIOUS FLOW DURATIONS
(Based on Historical Flows from June to November)

Station Name	1-day low flow (cfs) m^3/s	Recurrence Interval (years)	7-day low flow (cfs) m^3/s (cfs)	Recurrence Interval (years)	30-day low flow (cfs) m^3/s (cfs)	Recurrence Interval (years)
South Nation River at Spencerville	0.003 (0.1)	3	0.003 (0.1)	3.4	0.003 0.1	5.3
Castor River at Russell	0.016 (0.58)	20	0.54 (1.9)	20	0.14 (4.9)	20
South Nation River near Plantagenet Springs	0.30 (10.5)	30	0.35 (12.5)	30	0.51 (18)	30
Scotch River at at St. Isidore de Prescott*	0.0	4.3	0.0	4.4	Not Available	-

Source: Ministry of the Environment, Dischargep-Average Recurrent Interval Curves for the South Nation River. 1976.

* Analysis performed by MacLaren Plansearch Inc. based on ten (10) years of data for station 02LB012 located on the East Branch of Scotch River near St. Isidore de Prescott.

posed structures for low flows augmentation, a flow sequence in 1962 was selected which produced an average spring runoff followed by low summer flow. As shown in the flow-duration analysis on Figures 3.2 to 3.5, the 1962 low flows were more severe than the historical record.

3.2.2 Methodology for Flow Distribution

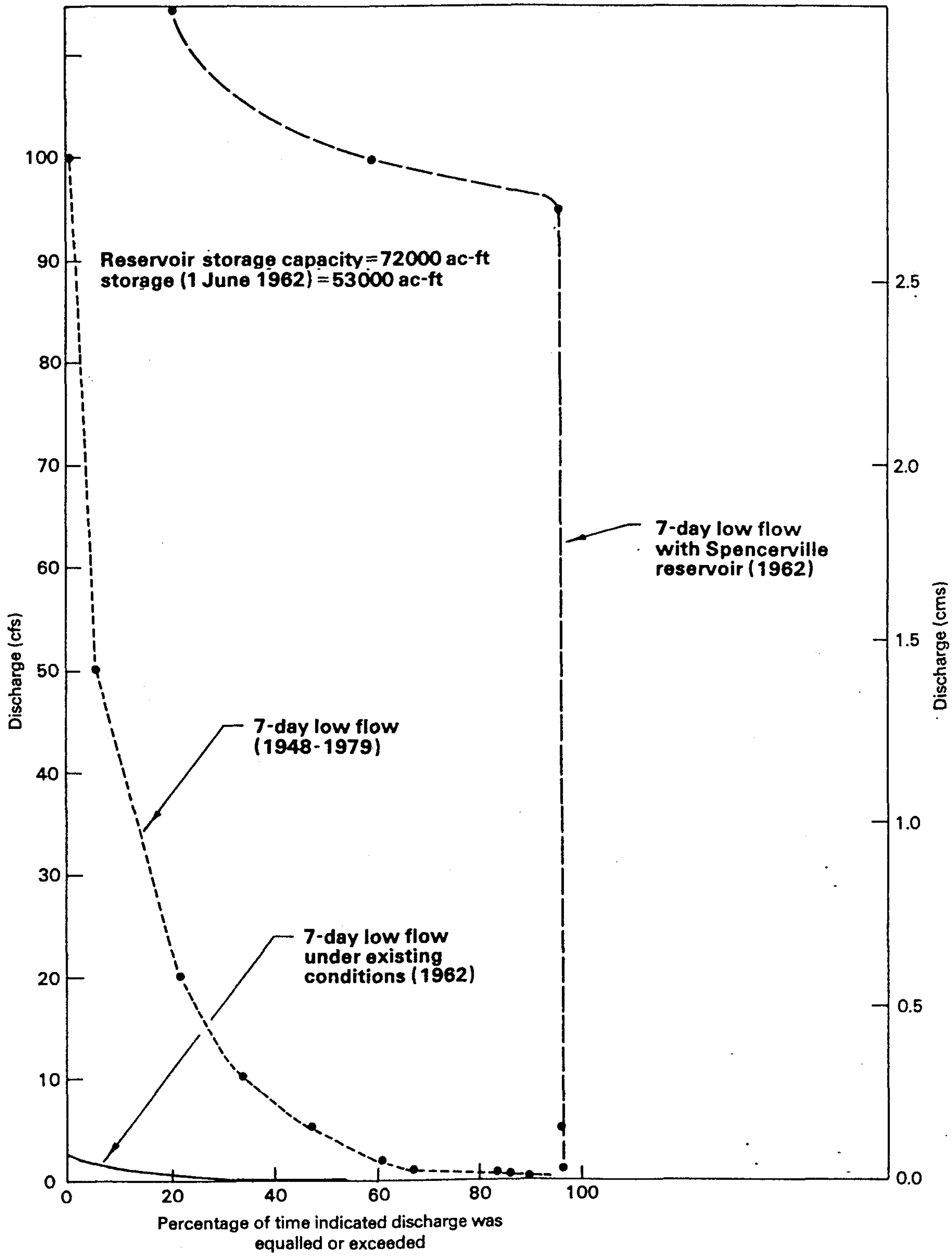
3.2.2.1 High Flow Event

In 1945, the only active streamflow station in the South Nation River basin was on the South Nation River near Plantagenet Springs (02LB005). Fortunately, an event similar to the 1945 flood occurred in 1973. The two events have comparable timing of the peak and volumes of runoff as shown in Figure. 3.6.

In 1973, flow records were available from six stations: South Nation at Spencerville (02LB007), South Nation at Chesterville (02LB009), South Nation at Casselman (02LB013), South Nation near Plantagenet Springs (02LB005), Bear Brook near Bourget (02LB008) and Castor River at Russell (02LB006). The drainage areas for the above stream gauges are summarized in Table 3.3.

The foregoing 1973 records were used to distribute 1945 flows to selected points of interest throughout the basin. First, the estimated volume of runoff at the gauge sites was determined for the spring period in 1945 by pro-rating the 1945 Plantagenet record with the 1973 volume ratios for each sonth. A typical relationship which was used to estimate the volume at Spencerville in 1945 is presented below.

South Nation River at Spencerville Flow-Duration Analysis for Low Flows (1 June-30 September)



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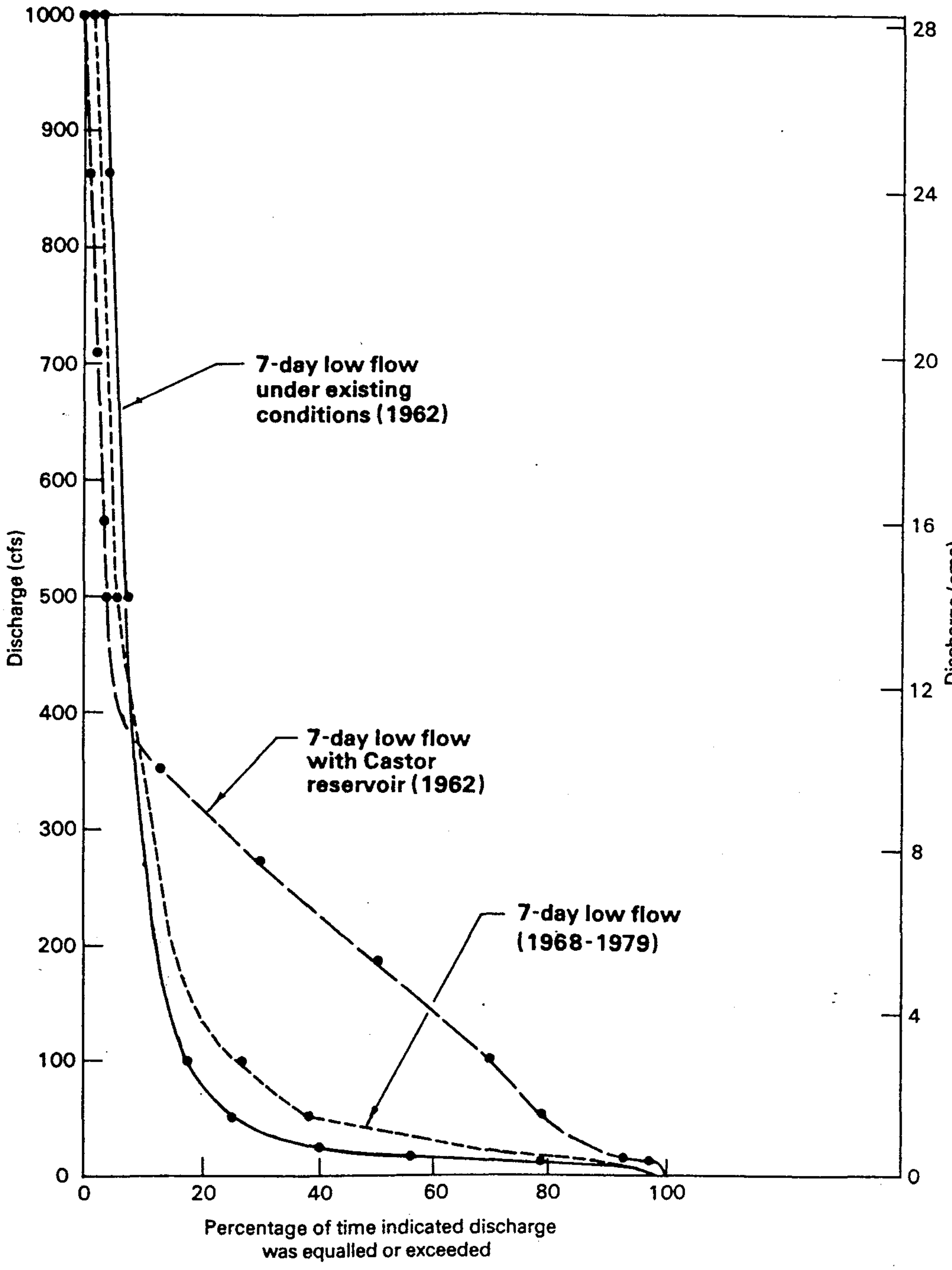
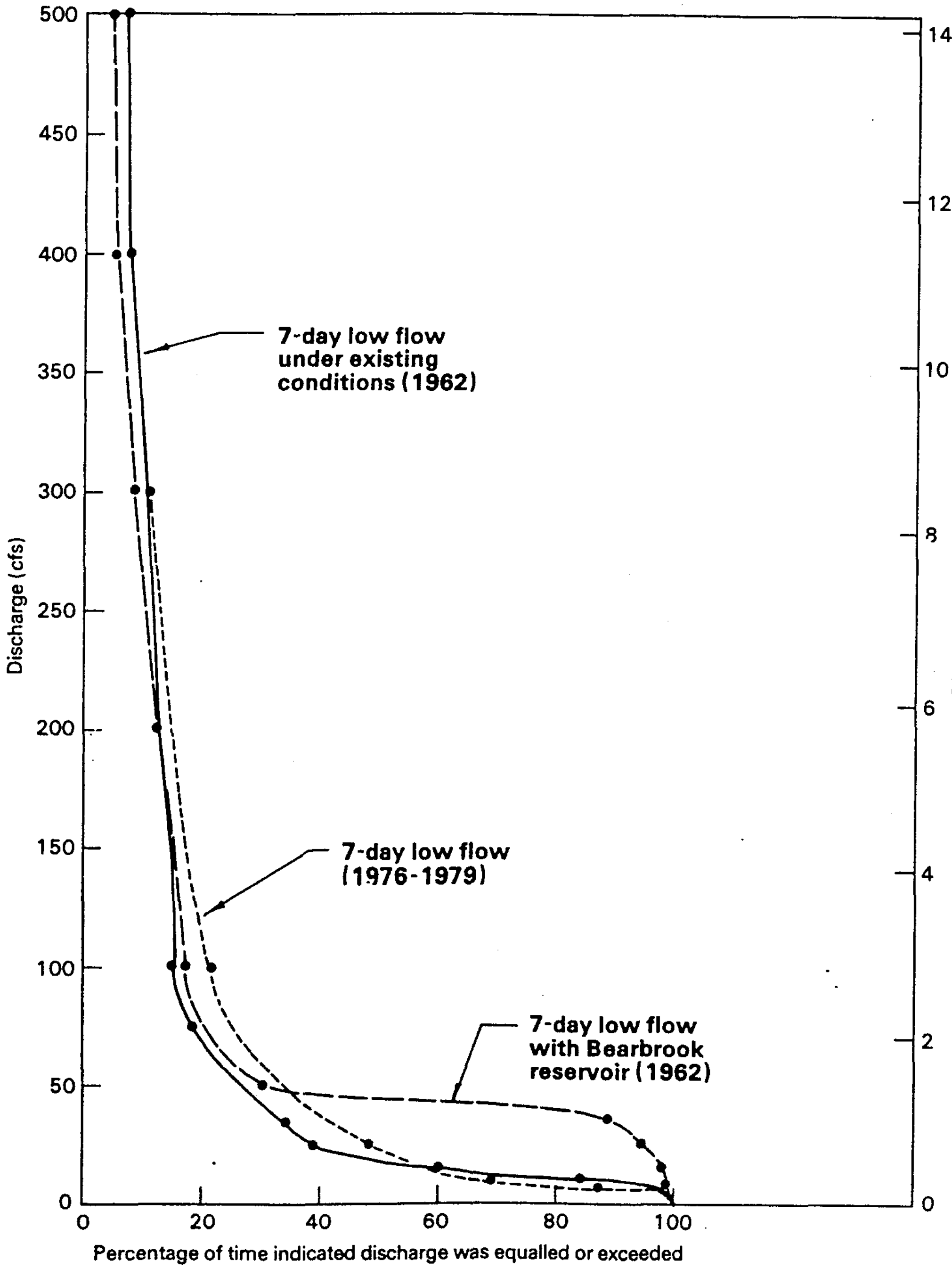
Castor River at Russell Flow-Duration Analysis for Low Flows (1 April - 31 October)

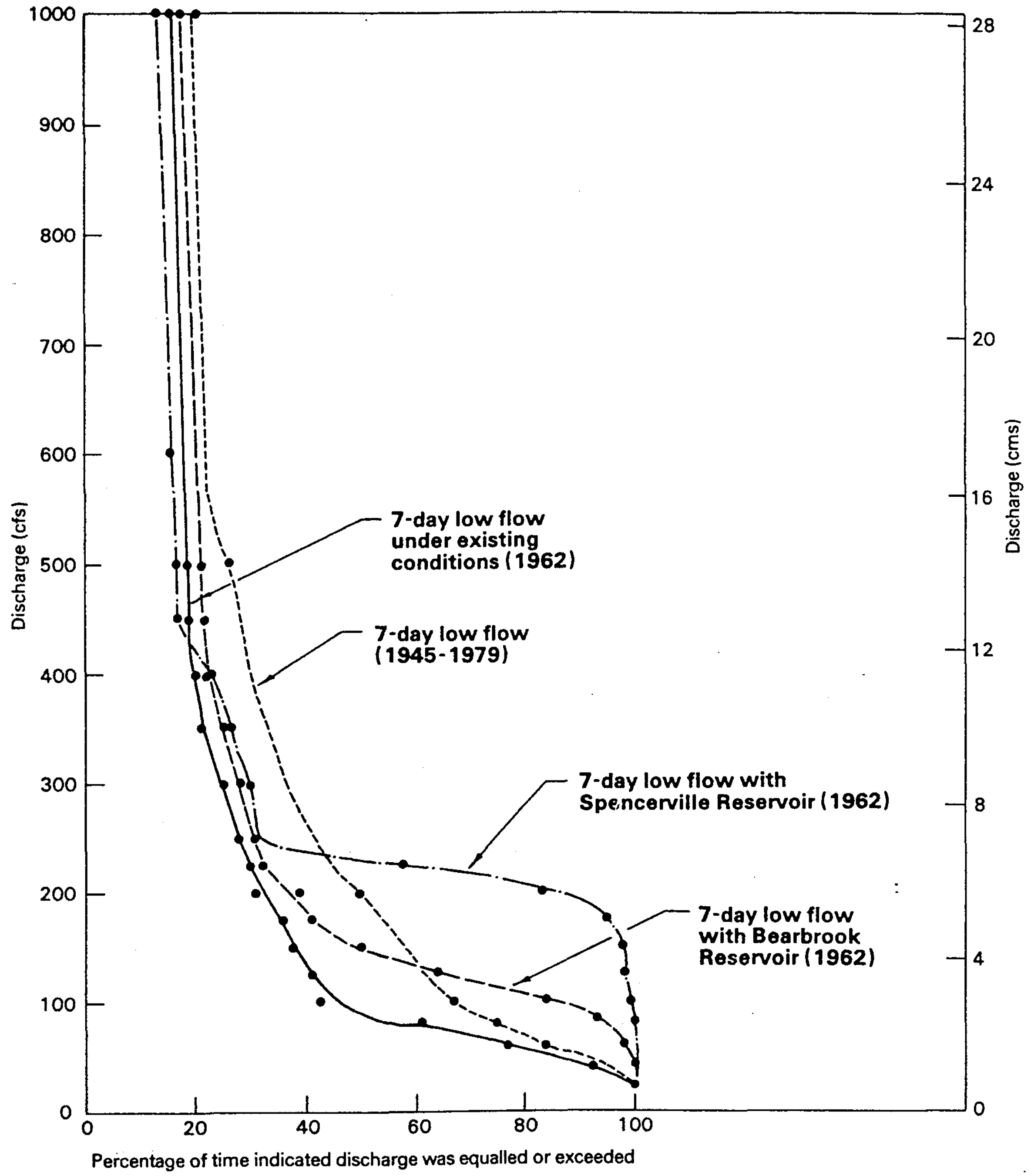


MacLaren Plansearch

Bear Brook at Bourget
Flow-Duration Analysis for Low Flows
(1 April - 31 October)



South Nation River at Plantagenet Flow-Duration Analysis for Low Flows (1 April - 31 October)



South Nation River Observed Flows at Plantagenet Springs for Years 1945 and 1973

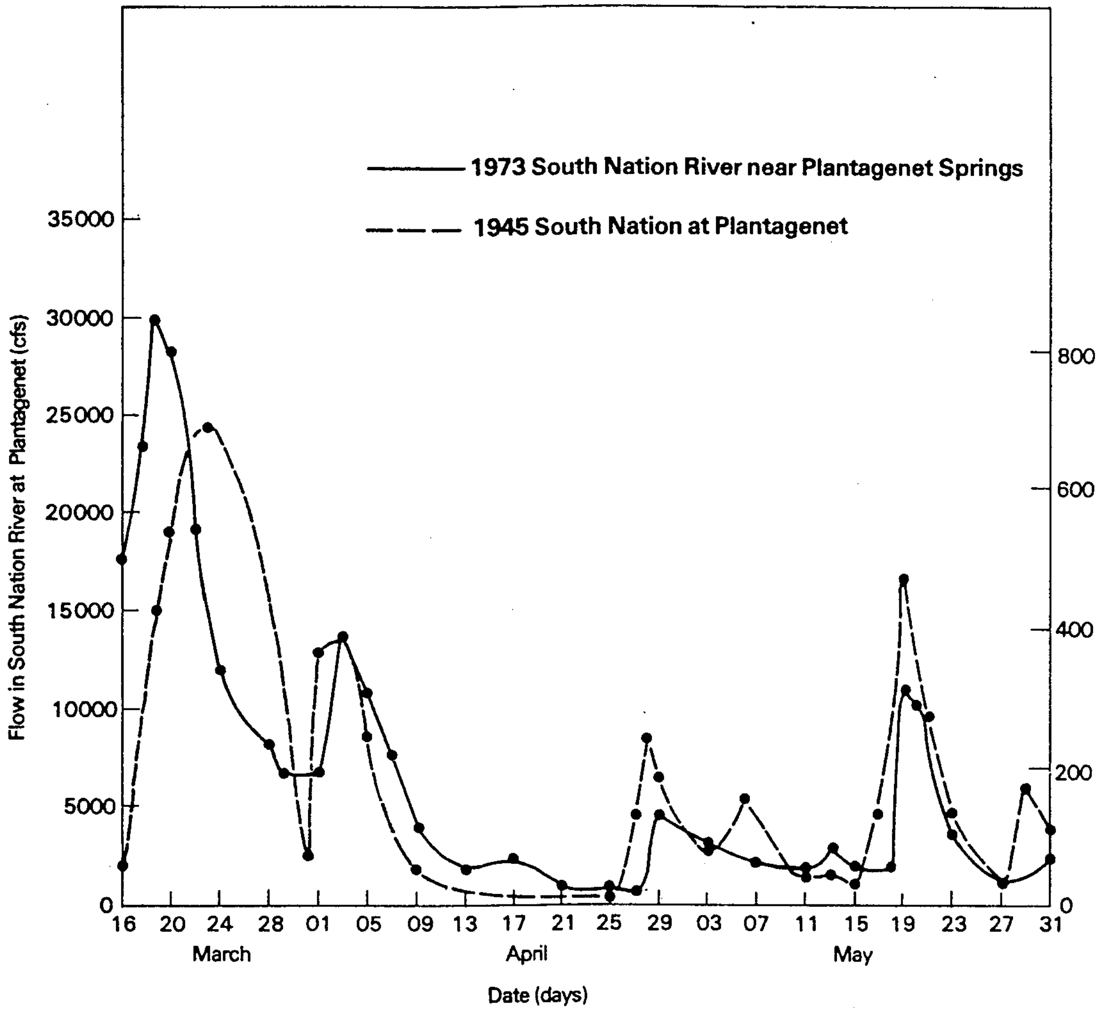


TABLE 3.3

DRAINAGE AREAS FOR SELECTED STREAM GAUGES

Station Name	Drainage Area km^2 ($miles^2$)
South Nation River at Spencerville	246 (95)
South Nation River at Casselman	2410 (929)
South Nation River near Plantagenet Springs	3810 (1470)
Bear Brook near Bourget	440 (170)
Castor River at Russell	145 (56)

$$\text{Volume at Spencerville in March 1945} = (\text{Volume at Plantagenet in March 1945}) \times \frac{(\text{Volume at Spencerville, March 1973})}{(\text{Volume at Plantagenet, March 1973})}$$

The daily flow at Spencerville during the spring of 1945 was subsequently established for each month by the following relationship:

$$\text{Daily flow at Spencerville in 1945} = \text{Daily flow at Spencerville in 1973} \times \frac{(\text{Volume at Spencerville in 1945})}{(\text{Volume at Spencerville in 1973})}$$

Discharges at intermediate locations were computed by a drainage area pro-rating technique.

A comparison of 1973 volume ratios with those based on the entire record period in Table 3.4 indicates that the areal distribution of 1973 flow is quite representative of runoff patterns throughout the basin during a typical spring period. Simulations of reservoir operation and resultant flow reductions would, therefore, be representative of flood control benefits.

3.2.2.2 Low Summer Flows

Since the streamflow records from the six stations identified in Section 3.2.2.1 are available in 1962 the volume of runoff and the recorded daily flows were used directly. The procedures outlined in Section 3.2.2.1 were used to develop flow sequences at points of interest.

3.3 Computer Simulation

3.3.1 General

Several computer models are available for use in water planning studies. Mathematical programming-based models including linear, dynamic and quadratic programming techniques are formulated to determine the best set of decision variables within a single utilization of the model given a series of constraints. In solving the problem, a number of approximations are usually required so that the full realities of the problem are not truly reflected. In comparison to these models, simulation models represent a mathematical description of the ongoing processes that "simulate" the performance of the real system. Simulation models are more rigorous than the mathematical programming models because there is no inherent requirement to force the mathematical structure of the equation to be solved into a procedure amenable for solution by an optimum-seeking algorithm. Nevertheless, when using a simulation model, considerable emphasis must be placed on determining a complete set of planning options that are to be analysed to ensure the most beneficial scheme is selected.

A simulation model which has been used in water planning studies to evaluate a large number of structural and non-structural alternatives is the HEC-5 program. This model was selected for screening purposes and is described in the following section.

3.3.2 Description of HEC-5 Model

The HEC-5 model is a computer simulation model developed by The Hydrologic Engineering Center, U.S. Corps of Engineers (5).

The model was developed to simulate the sequential operation of a system of reservoirs of any configuration for flood events and to assist in determining:

a) Flood control and conservation storage requirements for each reservoir in the system.

b) The influence of a system of reservoirs on the spatial and temporal distribution of runoff in a basin.

c) Operational criteria for both flood control and conservation (including hydro power) for a system of reservoirs.

d) The expected annual flood damages, systems, costs, and system net benefits for flood damage reduction.

e) The combination of existing and proposed reservoirs or other alternatives including non-structural alternatives that result in the maximum net flood control benefits of the system by making simulation runs for selected alternative systems.

The HEC-5 program is a useful tool that can be used to simulate the sequential operation of various storage reservoirs and water diversions. Once sequential flow data, reservoir rule curves and physical linkage of watercourses data are coded for input in the HEC-5 program, detailed simulations can be made easily for numerous combinations of reservoirs and other alternatives including non-structural alternatives.

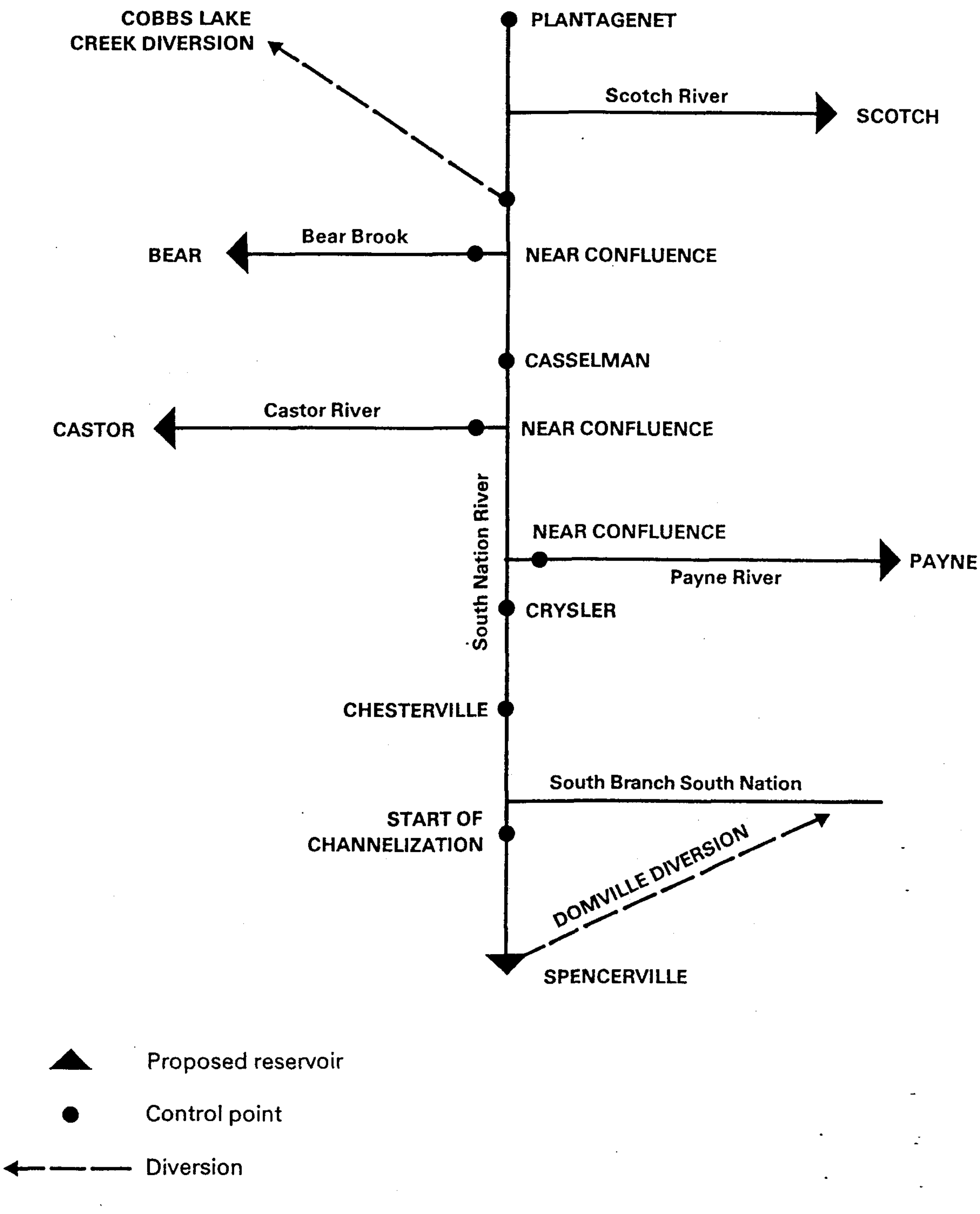
TABLE 3.4

RATIO OF MONTHLY VOLUMES FOR THE 1945 EVENT AND THE LONG-TERM STATION FLOW RECORD

Ratio of Flow Points	Period Under Consideration	Ratio of Monthly Volumes		
		March	April	May
Spencerville / Plantagenet	1945 Event[1]	0.036	0.061	0.067
	Long-Term	0.079	0.061	0.084
Chesterville / Plantagenet	1945 Event[1]	0.24	0.30	0.40
	Long-Term	0.26	0.27	0.49
Castor River at Russell / Plantagenet	1945 Event[1]	0.13	0.11	0.11
	Long-Term	0.11	0.11	0.11

(1) Based on 1973 volume ratios.

Schematic of South Nation River System for Input to the HEC-5 Model under High Flow Conditions



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To set up the model, the available reservoir storage is apportioned by the user into conservation storage and flood control storage for each monthly period. The system is then operated by the model based on an operational rule curve specified by the user. The rule curve is specified in terms of beginning-of-month storages. The program then interpolates linearly to attain the next month's storage level.

Releases from the reservoir are based on the inflows to the reservoir, storage level in the reservoir, outlet capacity of the dam structure and specified non-damaging channel capacities at downstream points. For each reservoir, stage/storage, stage/discharge, stage/surface area relationships are required.

The schematic input for the program consists of a series of links and nodes. The node can be either a reservoir or a control point (point of interest). Each node is identified by a unique value and is linked to other nodes by the travel time in the channel. At each node, the incremental local flow and the non-damaging channel capacity must be specified.

The 1979 HEC-5 version was used in this study. In this program version, a maximum number of fifteen points of interest can be modelled. This consists of a maximum of five reservoirs with the remaining points being control points. Up to eleven diversions can also be modelled.

3.3.3 Schematic of the System

3.3.3.1 High Flow Event

The drainage areas, surface areas at maximum water surface elevation and the gross storages of all proposed reservoirs in the basin are shown in Table 3.1. However, due to the dimensional limits of the present HEC-5 program, some of the smaller reservoirs are not included in the analysis. These include the proposed Hyndman, Spencerville Mill and the Domville reservoirs. This procedure represents a reasonable approach since, as shown in Table 3.1, the storage volumes of these reservoirs are small in comparison to the other reservoirs. Since the Spencerville reservoir proposed in 1948 ODPD report is in the same general location as the one proposed by Acres, only the latter reservoir was modelled.

In addition, the total storage of the reservoirs on the North, Middle and South Branch of the Castor River have been combined and modelled as one facility.

The reservoirs modelled in the system are: Spencerville (as proposed by Acres), Castor River, Payne River, Bear Brook and Scotch River. These reservoirs were modelled alone and in combination with others to evaluate their effectiveness in reducing areas flooded and in augmenting low flows.

The schematic diagram of the South Nation River system showing the input points into the model under high flow conditions is shown in Figure 3.7. Some points of interest have been chosen at the confluence of the major tributaries with the South Nation River in order to determine the effect of the reservoirs in altering the timing of the peaks and the reduction in downstream flooding.

The channel capacities used to determine the threshold values at which flooding starts are 102 m^3/s (3600 cfs) in the Brinston area, with channelization, and 226 m^3/s (8000 cfs) in the Plantagenet area.

3.3.3.2 Low Flow Event

The number of points of interest were reduced for the low flow modelling since timing of peaks is not a concern during low flow periods. The schematic diagram of the South Nation River system showing the input points into the model under low flow conditions is shown in Figure 3.8.

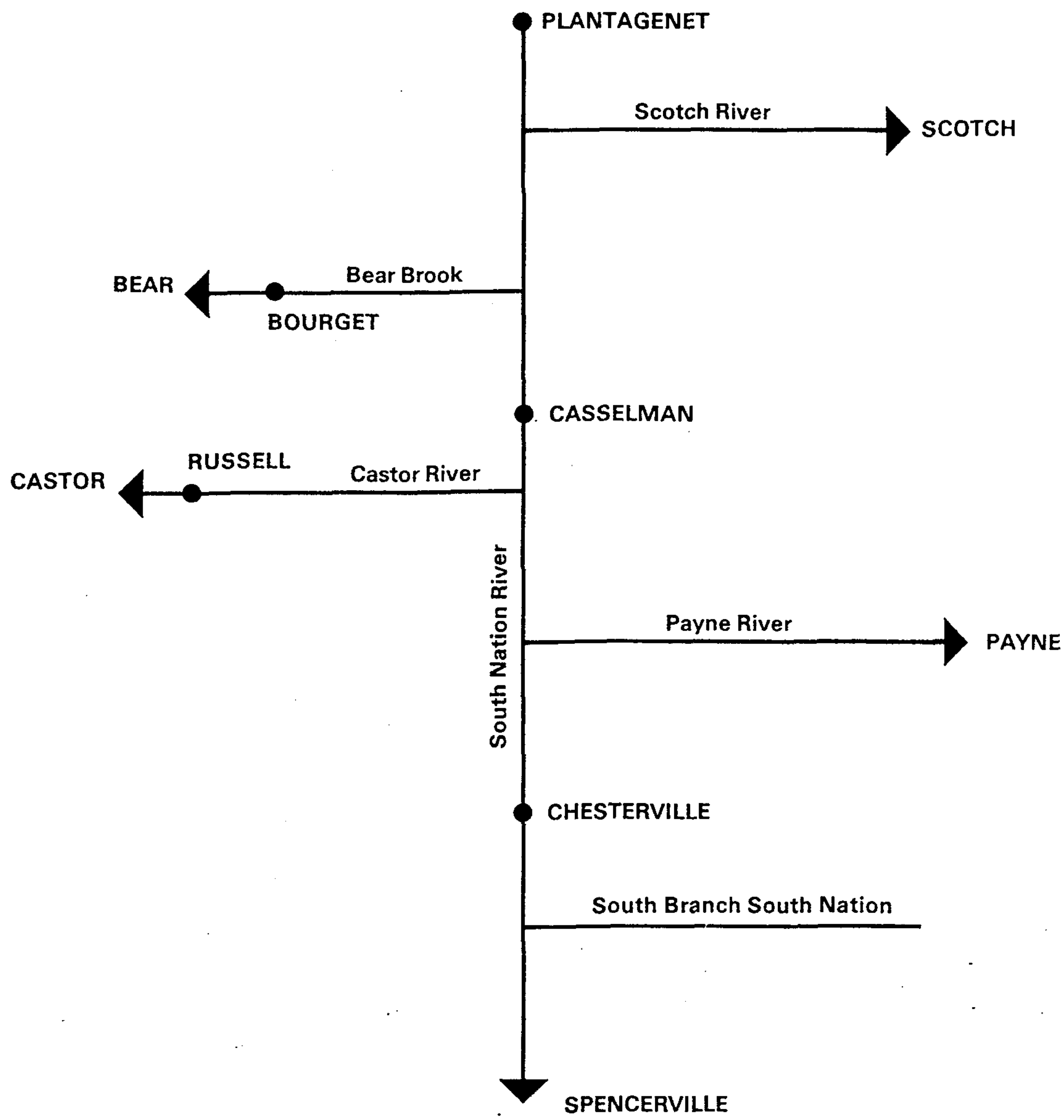
3.3.4 Alternatives Modelled

3.3.4.1 High Flow Event

The flow sequence modelled consists of daily flows extending from 16 March to 31 May 1945. The peak flow for this event has a recurrence interval in May of 1:20 year. In order to evaluate the flood reduction capacity of the proposed structural works, flow sequences with a peak discharge equal to the 1:10 year, 1:20 year and 1:50 year event were also simulated.

Figure 3-8

Schematic of South Nation River System for Input to the HEC-5 Model under Low Flow Conditions



▲ Proposed Reservoir

● Control point

01434-0

MacLaren Plansearch

The 1945 flow sequence was adjusted by the appropriate factors in order to provide flood magnitudes equal to the selected recurrence interval. The magnitude of the simulated peak flows at Spencerville, Chesterville and Plantagenet for the various recurrence intervals are presented in Table - 3.5. Adjusting the May flows also adjusts the magnitude of the March peak flows. The flow sequences and the recurrence intervals for the March and May events at Plantagenet are shown in Figure 3.9.

The computer simulations were carried out to evaluate the effect of the proposed reservoirs on the larger spring floods and their ability to reduce May floods to non-damage levels in the Brinston area [102 m^3/s (3600 cfs)] and at Plantagenet [226 m^3/s (8000 cfs)]. Resevoir combinations which were investigated are noted in Table 3.6. Two methods of operation were simulated. In one alternative, the reservoirs remained empty until 1 May and were then allowed to fill. Reservoirs were filled after 1 March in the second alternative in an attempt to attenuate the spring flood but were drawn down by 1 May in preparation for the May event. It was found that the latter method of operation provided some degree of protection during the spring period while the reservoirs could be emptied by 1 May without causing additional flooding at Brinston or Plantagenet.

3.3.4.2 Low Flow Event

The alternatives shown in Table 3.6 with the exception of the Spencerville Diversion were also modelled for the 1962 low flow year. The flow sequence consists of daily flows extending from 1 March to 31 October 1962. Each alternative

TABLE 3.5

MAGNITUDE OF SIMULATED MAY PEAK FLOW AT SELECTED FLOW POINTS

Flow Point	Recurrence Interval (years)	Simulated Peak Flow m^3/s (cfs)	Flows for Corresponding Recurrence Intervals (from Statistical Analysis) m^3/s (cfs)
	1:10	14.4 (509)	16.0 (565)
Spencerville	1:20	19.7 (697)	19.5 (688)
	1:50	31.0 (1094)	28.0 (988)
	1:10	112.2 (3964)	106.2 (3750)
Chesterville	1:20	153.8 (5431)	144.4 (5100)
	1:50	241.4 (8526)	203.9 (7200)
	1:10	308.6 (10 900)	310 (10 950)
Plantagenet	1:20	424.7 (15 000)	440 (15 540)
	1:50	665.3 (23 500)	665 (23 487)

Flow Sequences Modelled (based on 1945 event)

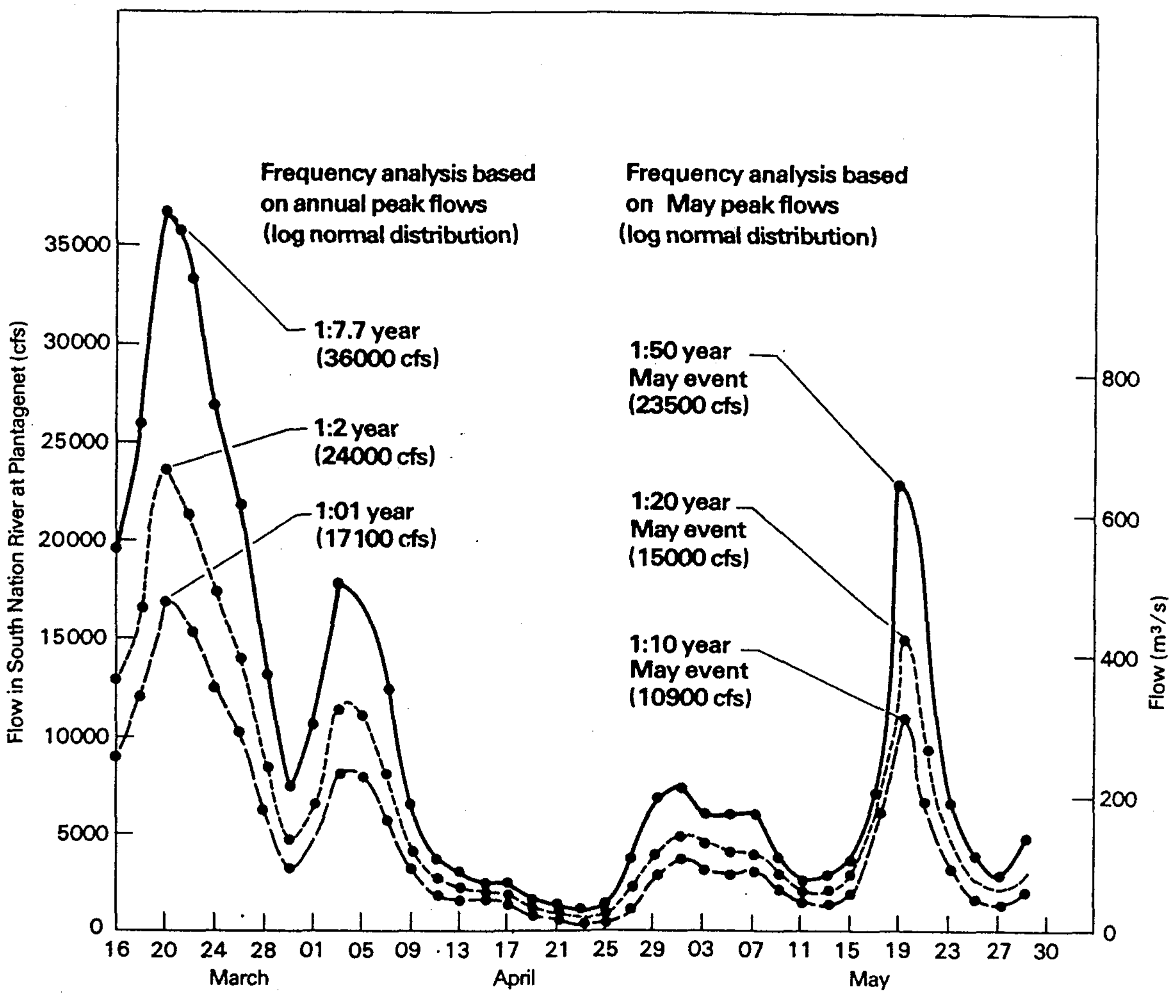


TABLE 3.6

ALTERNATIVES MODELLED USING HEC-5

	Structural Alternative					
Alternative Modelled	Spencerville Reservoir	Spencerville Diversion	Payne River Reservoir	Castor River Reservoir	Bear Brook Reservoir	Scotch River Reservoir
1	X					
2	X	X				
3			X			
4				X		
5					X	
6						X
7				X		X
8				X	X	X
9			X	X	X	X

was modelled by filling the reservoir(s) during the spring freshet according to rule curves established for operation during the analysis of high flow conditions; the water was then released from the reservoir(s) starting on 1 June until the reservoir(s) was empty by 1 October.

3.3.5 Tabulation of Results

3.3.5.1 High Flow Events

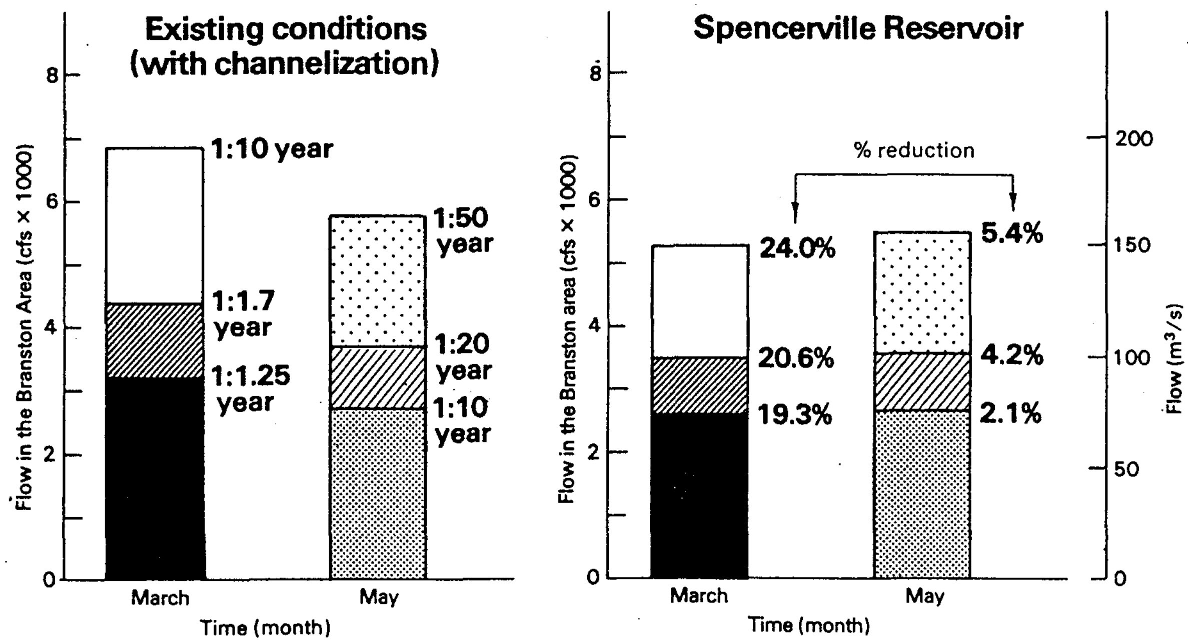
Brinston Flood Area

Since the Chesterville channelization is currently underway, all computer simulations were undertaken with the full channelization in place. The channelization, with a non-damage channel capacity of 102 m^3/s (3600 cfs) provided the base condition against which other structural alternatives could be evaluated in reducing the area flooded in the Brinston area.

Figure 3.10 indicates the magnitude and frequency of spring and May floods simulated under existing conditions for the Brinston area and the percent reduction in peak flows due to the proposed Spencerville Reservoir. The May events have recurrence intervals of approximately 1:10 year, 1:20 year and 1:50 year.

The Spencerville Diversion has not been included in the analysis because it was found to have limited use. This diversion was originally proposed to divert excess flows from the Spencerville Reservoir to the St. Lawrence River but simula-

Flow Reduction in the Brinston Area due to the Proposed Structural Alternatives



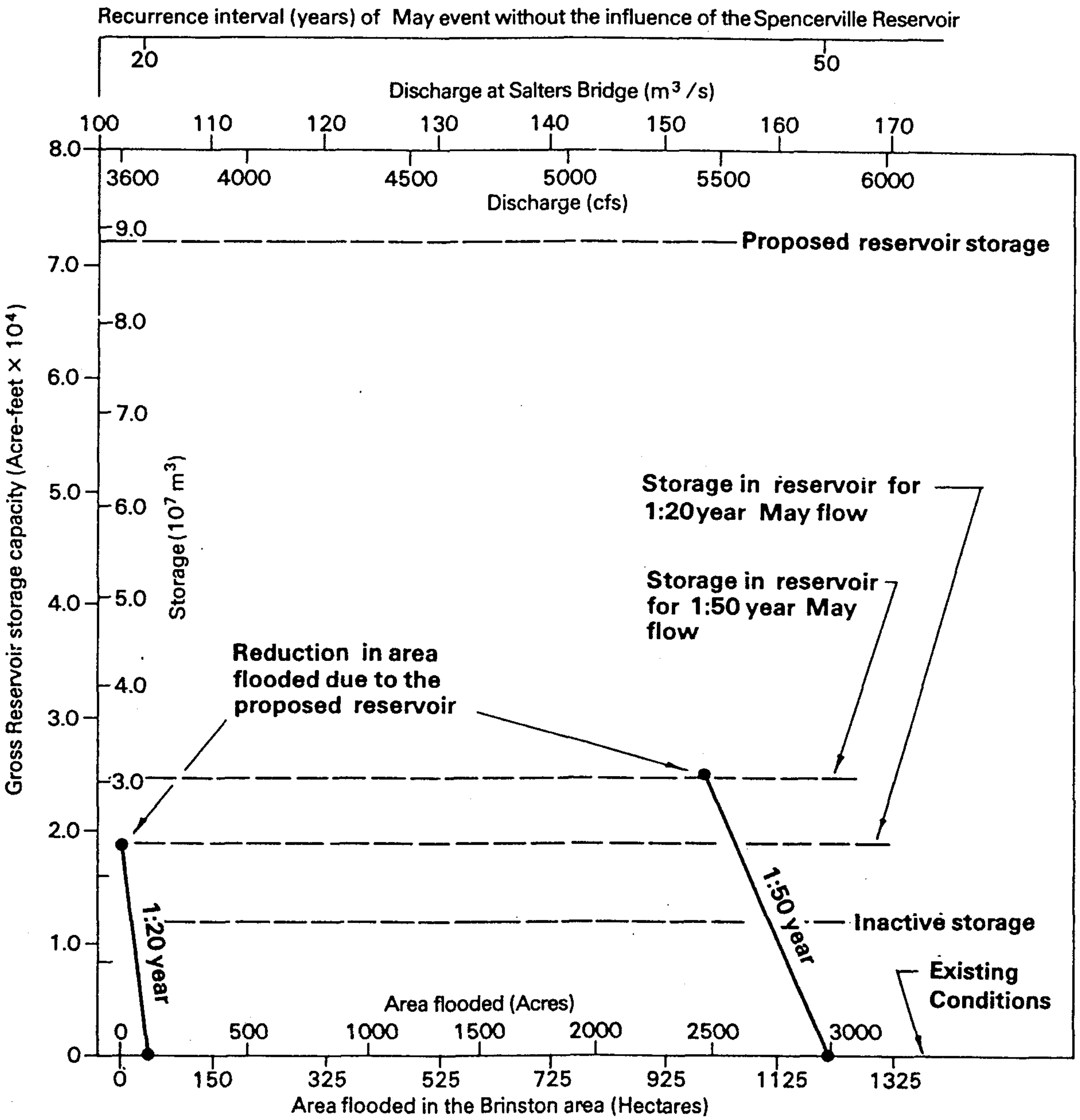
tions revealed that the reservoir is only partially filled during flood conditions. Twenty percent of the live storage was used during the 50 year event with progressively smaller storage volumes retained during less severe flood discharges.

The Spencerville Reservoir is not effective in reducing flooding in the Brinston area due to runoff from the drainage area below the Reservoir. Less than 20 percent of the monthly runoff volume recorded at the Chesterville gauge for the months of March, April and May is contributed by the catchment area upstream of Spencerville; therefore, approximately 80 percent of the storm runoff from the watershed above Brinston is uncontrolled. This results in minimal flood reduction in the Brinston area as illustrated in Figure 3.11.

During the 1:10 year event, the flow is contained in the channel, through the Brinston area but during the 1:20 year event, some flooding will occur downstream of Salter's Bridge. For the 1:20 year event under existing conditions, a flow of 104.4 m^3/s (3687 cfs) would flood approximately 40 ha (99 ac) of land. However, with the addition of the Spencerville Reservoir the flow would be reduced to 100.5 m^3/s (3550 cfs) and flooding would be minimal since the flow would be contained within the channel. For the 1:50 year May event there is reduction of 200 ha (494 acres) in the area flooded.

The flow/area flooded relationship for the Brinston area was developed from the flood plain mapping study conducted by DeLCan Ltd. (6). This information represents flooding with

Effect of Spencerville Reservoir in Reducing Area Flooded in the Brinston Area



the natural waterway through the Brinston area. The effects of channelization were accounted for by shifting the stage/-flooded area relationship to reflect the new threshold of flooding at 102 m^3/s (3600 cfs).

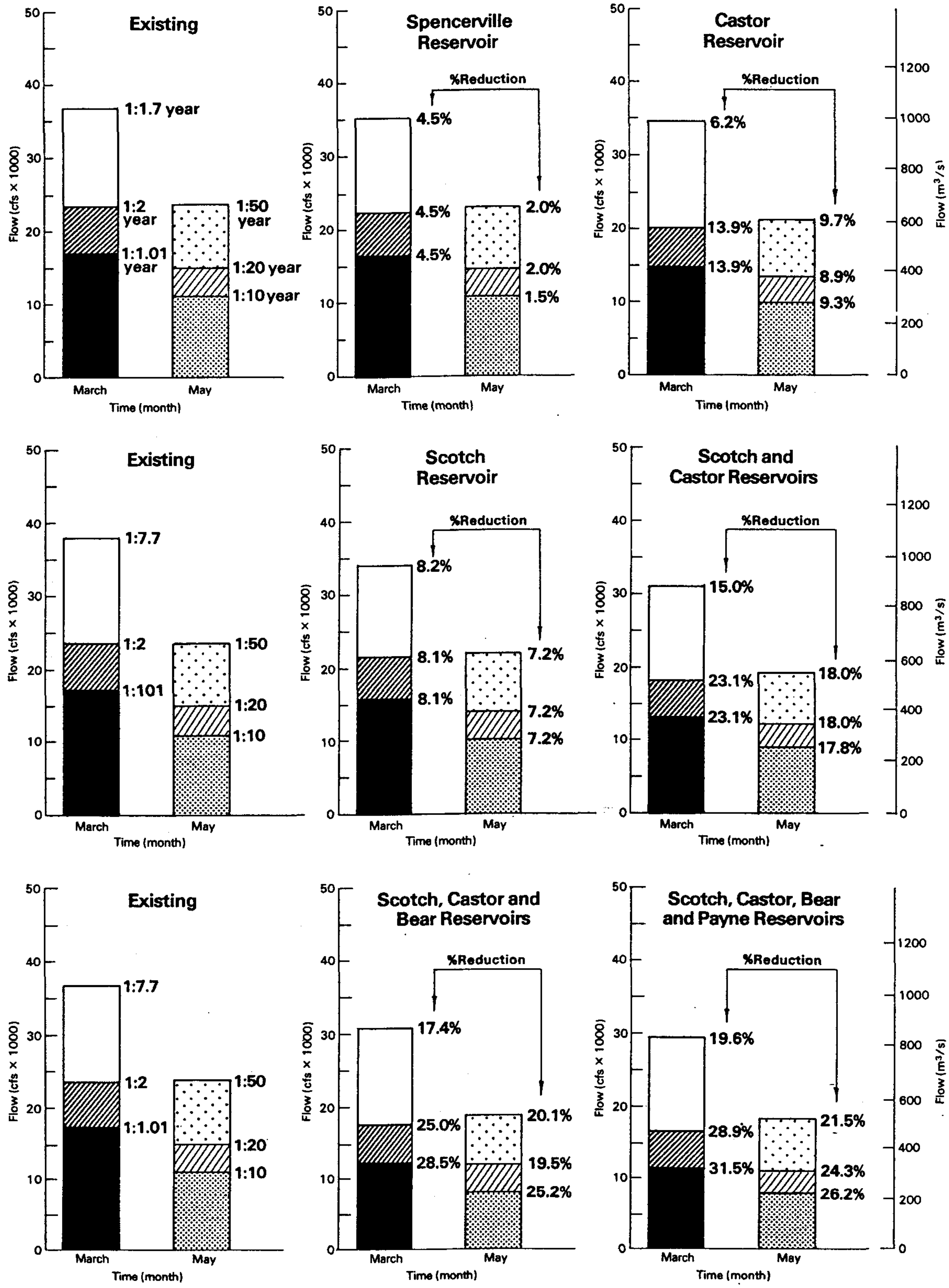
Plantagenet Flood Area

Computer simulations illustrating the flood reduction potential in the Plantagenet area are shown in Figures 3-12 to 3-15. The magnitude and frequency of the simulated events during March and May are documented together with the percent reduction in peak flow due to the various proposed structural alternatives.

The impact on the flooded area at Plantagenet is further illustrated in Figures 3.13 and 3.14. As expected, the analysis indicated that the location and storage capacity of reservoirs are critial factors in determining their ability to attenuate flood peaks. Both the Scotch River and the Castor River reservoirs appear to provide some flood control benefits; however, any significant reduction in flood duration is limited to frequent events as noted in Figure 3.15.

Two earlier studies of flooding within the Plantagenet area have been conducted by DelCan(6) and McNeely Limited-Proctor and Redfern Limited(1). Information used to estimate agricultural flooding in the former study was considered more comprehensive and was, therefore, used to establish the flow-flooded area characteristics of the hazard lands. Subsequent detailed review of the two foregoing studies revealed that the DelCan estimates of flood levels were too low for selec-

Flow Reduction in the Plantagenet Area due to the Proposed Structural Alternatives



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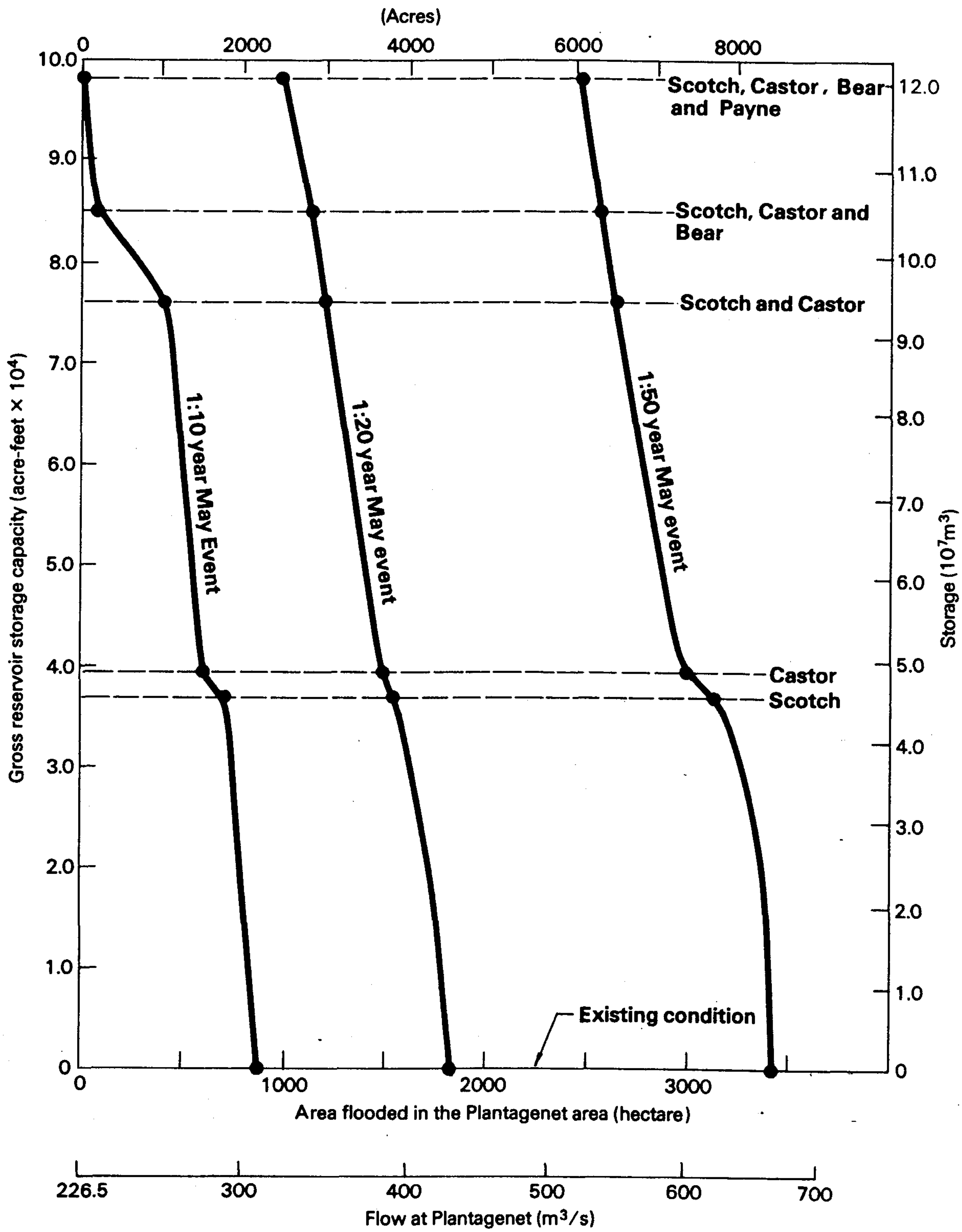
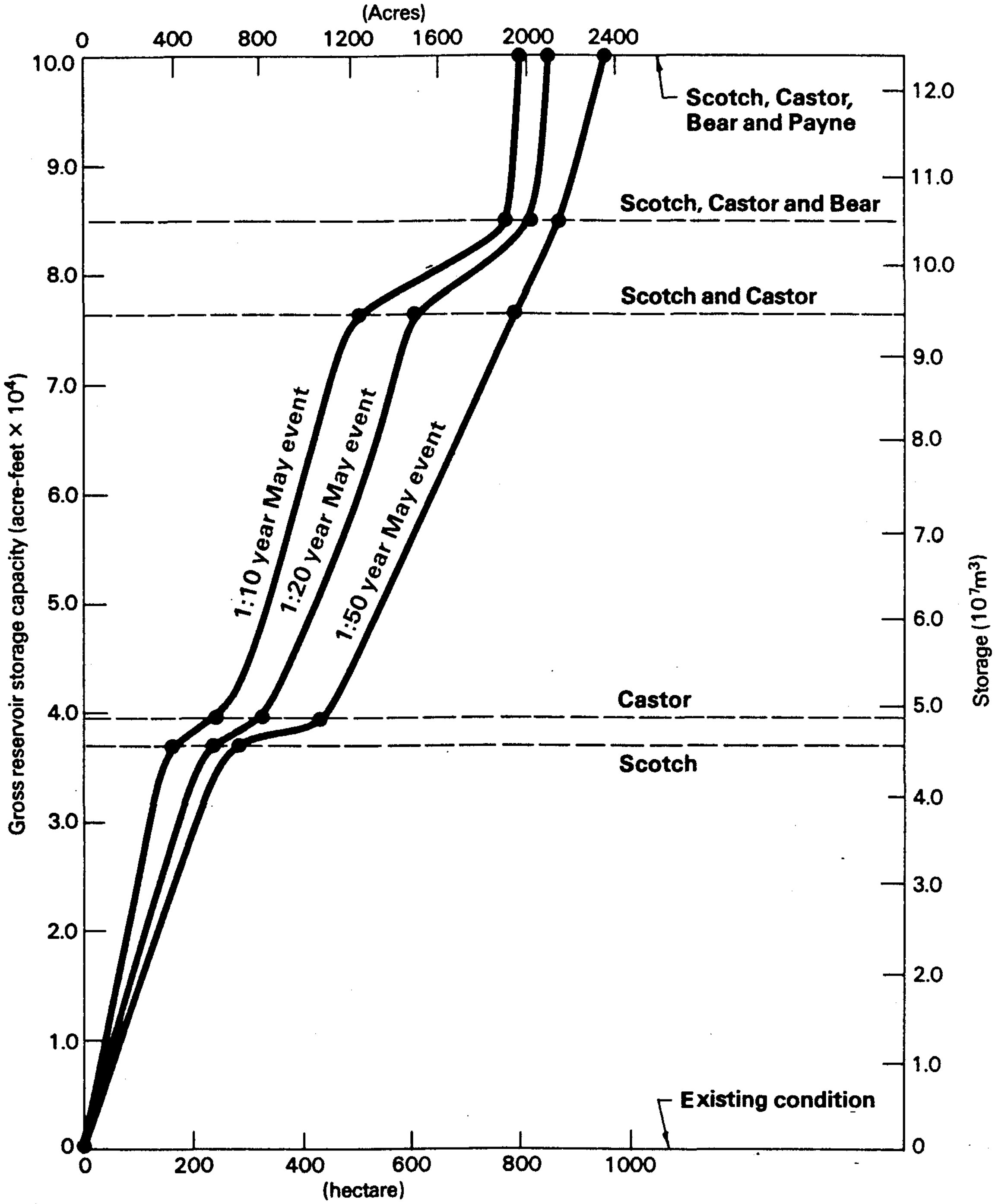
MacLaren Plansearch

Effect of Reservoir(s) in Reducing Area Flooded in the Plantagenet Area

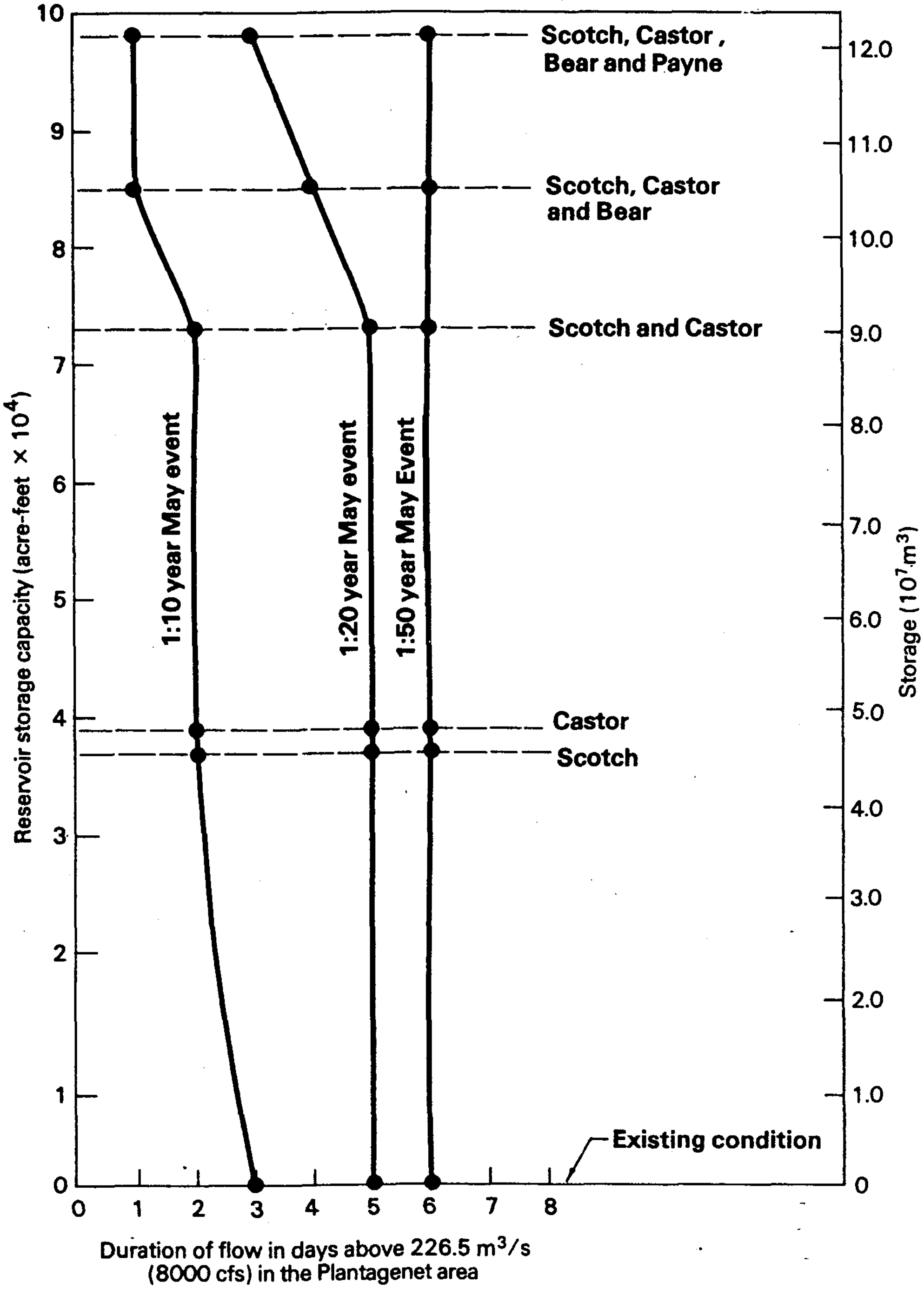


Reduction in Area Flooded in the Plantagenet Area due to the Proposed Reservoir(s)



Reduction in area flooded in the Plantagenet area

Reduction in the Duration of Flooding in the Plantagenet Area due to the Proposed Reservoir(s)



ted flood frequencies; therefore, flood areas and reduction of flooding used in the preliminary screening of alternatives in this phase of the Water Resources Component study are in error. While general findings and conclusions are valid, an accurate determination of flooded areas was only carried out in the latter stages of the investigation and reported in Chapter 7.

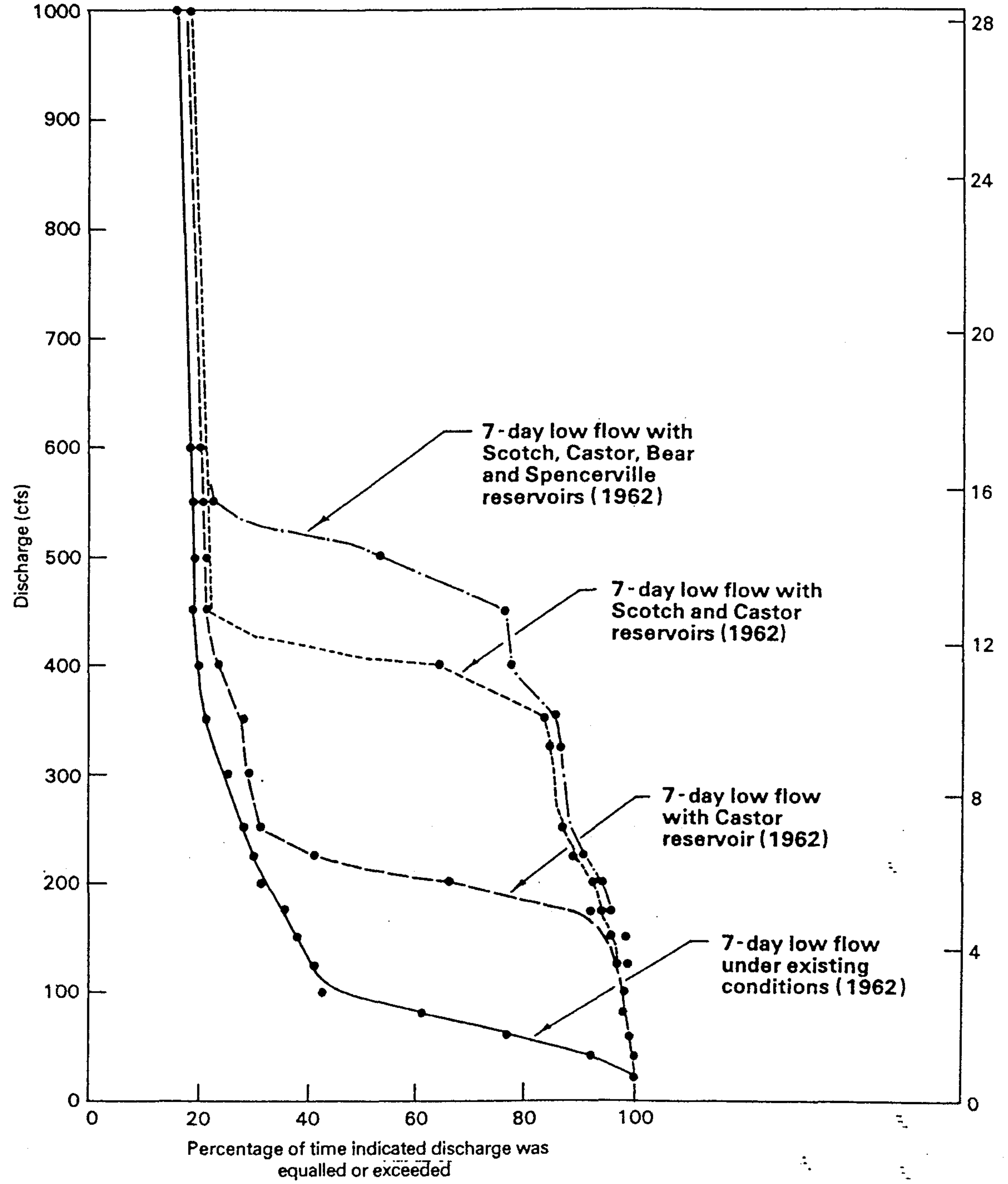
3.3.5.2 Low Flow Events

The five reservoirs considered for flood control purposes were also investigated for low flow augmentation. In an effort to assess the effectiveness of these reservoirs, low flow-duration analyses were carried out for selected time periods:

(i) historical flow record, (ii) summer of 1962 under existing condition, and (iii) summer of 1962 with proposed reservoir(s). The flow-duration curves for the seven-day low flows for the conditions outlined above are shown in Figures 3.2 to 3.5 and 3.16 for the flow points at Spencerville, Bourget, Russell and Plantagenet Springs.

The low flows during the summer of 1962 were more severe than the historical record; however, the addition of the reservoirs, results in a substantial increase in flows. For example, during the summer of 1962 with the addition of the Spencerville Reservoir, the flow at Spencerville would equal or exceed 2.7 m^3/s (97 cfs) 90% of the time as compared to 0.003 m^3/s (0.1 cfs) under the existing condition. Similarly, with the addition of the Castor River Reservoirs, the flow at Russell would equal or exceed 0.57 m^3/s (20 cfs) 90% of the time as compared to 0.20 m^3/s (7 cfs) under the existing condition.

South Nation River at Plantagenet Flow-Duration Analysis for Low Flows (1 April - 31 October)



A summary of the low flow magnitude for 1-day, 7-day and 30-day duration for existing conditions and for the proposed reservoirs are shown in Table 3.7.

3.3.6 Discussion of Results

3.3.6.1 Flood Control Structures

Brinston Flood Area

As noted in Section 3.3.5.1, Spencerville Reservoir controls less than 20% of the runoff volume observed at Chesterville since 77% of the drainage area above Chesterville is not controlled by the reservoir. In addition, the suggested reservoir capacity is not used since it is disproportionately large in relation to the tributary drainage area.

The effectiveness of the Spencerville Reservoir in reducing peak flows and area flooded is summarized in Table 3.8 as a function of the reservoir's live storage and surface area. The reduction in peak flow and area flooded are minimal for all events shown. Since the flood control benefits derived from the Spencerville Reservoir are small, this structural alternative should not be built for flood control purposes. The Spencerville Diversion is also not required for the control of high flows because the storage capacity of the Spencerville Reservoir is not fully utilized. These two alternatives were not considered further for flood control.

TABLE 3.7

LOW FLOW MAGNITUDES FOR VARIOUS FLOW DURATIONS FOR PRE-RESERVOIR AND POST-RESERVOIR CONDITIONS

(Based on 1962 Summer Flows from 01 June to 01 October)
m^3/s (cfs)

Location	River System Condition	1 Day Low Flow	7-Day Low Flow	30-Day Low Flow
South Nation River at Spencerville	Existing	0.003 (0.1)	0.003 (0.1)	0.003 (0.1)
	Spencerville Reservoir	3.5 (122)	3.5 (122)	3.51 (124)
Castor River at Russell	Existing	0.17 (6)	0.19 (7)	0.23 (8)
	Castor River Reservoir	3.2 (113)	3.2 (114)	3.4 (119)
South Nation at Plantagenet Springs	Existing	1.2 (43)	1.3 (45)	1.5 (54)
	Spencerville Reservoir	5.2 (184)	5.3 (188)	5.7 (200)
	Payne River Reservoir	2.5 (89)	2.6 (93)	2.9 (102)
	Castor River Reservoir	4.6 (163)	4.7 (167)	5.2 (183)
	Bear Brook Reservoir	2.1 (74)	2.2 (77)	2.4 (85)
	Scotch River Reservoir	3.6 (132)	3.8 (133)	3.9 (139)
	Scotch and Castor Reservoir	10.4 (367)	10.7 (378)	11.4 (401)
	Scotch, Castor, Bear and Payne Reservoir	10.6 (375)	10.8 (383)	11.5 (405)

TABLE 3.7 (Cont'd)

LOW FLOW MAGNITUDES FOR VARIOUS FLOW DURATIONS FOR PRE-RESERVOIR AND POST-RESERVOIR CONDITIONS
(Based on 1962 Summer Flows)
m^3/s (cfs)

Location	River System Condition	1 Day Low Flow		7-Day Low Flow		30-Day Low Flow	
Bear Brook at Bourget	Existing	0.17	(6)	0.19	(7)	0.23	(8)
	Bear Brook Reservoir	1.0	(37)	1.1	(38)	1.1	(39)
South Nation River at Chesterville	Existing	0.014	(0.5)	0.014	(0.5)	0.037	(1.3)
	Spencerville Reservoir	3.5	(125)	3.5	(125)	3.7	(130)
South Nation River at Casselman	Existing	0.62	(22)	0.68	(24)	0.88	(31)
	Payne River Reservoir	0.68	(24)	1.5	(54)	2.2	(79)
	Castor River Reservoirs	1.4	(49)	1.8	(62)	3.5	(123)
Scotch River	Existing	0.11	(4)	0.14	(5)	0.20	(7.0
	Scotch River Reservoir	0.11	(4)	0.22	(8)	0.71	(25

Plantagenet Flood Area

Similar analyses were carried out for the structural alternatives which can reduce flooding in the Plantagenet area. Although the Castor River reservoirs were modelled as one facility, separate analyses were carried out for the North Castor, Upper Middle Castor and the South Castor Reservoirs as shown in Table 3.8. The effectiveness of each reservoir in reducing peak flows and flooded areas is indicated in Table 3.8 as a function of the total live storage and flooded area at each reservoir site.

The tabulated results for each reservoir indicate that the Upper Middle Castor River, North Castor River and Scotch River Reservoirs have a definite effect in peak flow and flooded area reduction especially for the more severe events. These proposed reservoirs are effective due to their storage capacities and strategic locations within the South Nation River basin.

The Bear Brook Reservoir appears to reduce flows during the 1:10 year event, but is not as effective for the 1:50 year event, due to storage limitations. Results indicate that the Payne River Reservoir is not instrumental in flood control at Plantagenet and therefore should not be considered for this purpose.

A number of criteria were used to assess the relative flood control benefit of the reservoirs for events as large as the

TABLE 3.8

EFFECTIVENESS OF THE PROPOSED STRUCTURAL ALTERNATIVES IN REDUCING PEAK FLOWS AND AREA FLOODED IN THE BRINSTON AND PLANTAGENET AREAS

Alternative	Area Affected	Reservoir Live Storage(2) 10^6 m^3 (ac-ft)	Peak Flow Reduction (m^3/s) Reservoir Live Storage (m^3)(2)			Area of Flood Reduction (ha) Area of Reservoir (ha)(2)		
			1:10 Year(1)	1:20 Year(1)	1:50 Year(1)	1:10 Year(1)	1:20 Year(1)	1:50 Year(1)
Spencerville	Brinston	74.0 (60 000)	2.03×10^{-8}	7.43×10^{-8}	12.03×10^{-8}	No Flooding	0.006	0.036
Payne River	Plantagenet	15.6 (12 650)	25.3×10^{-8}	36.7×10^{-8}	45.9×10^{-8}	0.01	0.06	0.06
North Castor River	Plantagenet	21.7 (17 600)	59.4×10^{-8}	84.8×10^{-8}	132.7×10^{-8}	0.08	0.10	0.21
Upper Middle Castor River	Plantagenet	15.1 (12 240)	57.6×10^{-8}	83.4×10^{-8}	131.8×10^{-8}	0.10	0.12	0.24
South Castor River	Plantagenet	11.6 (9 440)	60.3×10^{-8}	84.4×10^{-8}	132.8×10^{-8}	0.03	0.04	0.05
Bear Brook	Plantagenet	9.9 (8 010)	206.7×10^{-8}	114.8×10^{-8}	91.8×10^{-8}	0.48	0.30	0.30
Scotch River	Plantagenet	44.7 (36 260)	45.9×10^{-8}	68.9×10^{-8}	114.8×10^{-8}	0.08	0.10	0.13

(1) Recurrence Interval for May Event
(2) Fully developed reservoir site

TABLE 3.9

Comparison of Flood Reduction at Plantagenet with Inundation at Reservoir Sites

Flood Prone Area - Hectares (Acres)

	1:10 Year(1)				1:20 Year (1)				1:50 Year (1)				Full Reservoir Inundated at Reservoir	
	Reduction at Plantagenet		Inundated at Reservoir		Reduction at Plantagenet		Inundated at Reservoir		Reduction at Plantagenet		Inundated at Reservoir			
Reservoir	Agric*	Total	Agric	Total	Agric	Total	Agric	Total	Agric	Total	Agric	Total	Agric	Total
Scotch	182 (450)	202 (499)	490 (1210)	627 (1550)	218 (539)	242 (598)	712 (1760)	915 (2260)	291 (719)	323 (798)	1184 (2925)	1518 (3750)	1872 (4625)	2400 (5930)
North Castor	106 (262)	118 (292)	769 (1900)	961 (2375)	131 (323)	146 (361)	903 (2232)	1129 (2790)	172 (425)	191 (472)	1214 (3000)	1501 (3720)	1237 (3056)	1545 (3820)
Bear	146 (361)	163 (400)	259 (640)	331 (820)	91 (225)	101 (250)	259 (640)	331 (820)	91 (225)	101 (250)	259 (640)	331 (820)	259 (640)	331 (820)

* Agricultural

(1) Recurrence Interval for May Event.

20 year flow. Their efficiency in attenuating flood peaks may be judged as the flow reductions at Plantagenet per unit of reservoir storage during the 20 year event. This index produces the following ranking for the reservoirs: Scotch River, North Castor River and Bear Brook. A similar priority was obtained when capital cost of the reservoirs was estimated per area reduction in flooding at Plantagenet although the Scotch River and North Caster reservoirs were quite similar when screened by this criteria.

Geotechnical investigations (Appendix D) of reservoir sites based on existing data have provided further insight into the relative merit of each project. While the Castor River sites are considered fairly good subject to additional confirmatory data, the Scotch River was designated only fair and the Bear Brook site was deemed poor from a geotechnical point of view.

Costs of purchasing these reservoir sites based on inventories of land use and land costs assembled by the Conservation Authority are estimated to be:

1.	North Castor River	\$1 890 000
2.	Scotch River	\$3 100 000
3.	Bear Brook	\$ 495 000

The actual reduction of flooding on the South Nation River at Plantagenet for various return periods does not compare favourably with the area that would be flooded at each reservoir site. As shown in Table 3.9, agricultural lands which would be required for reservoir storage will exceed the flood reduction at Plantagenet for all levels of flooding which were investigated.

Additional reduction of flooding at Plantagenet beyond that which is achieved by the Castor, Scotch and Bear Brook Reservoirs can be realized by the construction of the Cobb's Lake Creek Diversion or local protective measures including channelization and dyking of the South Nation River downstream of Lemiux. The required capacity of the diversion for various degrees of reservoir development is shown in Figure 3.17 for the 20 year protection level.

Preliminary investigations of the Cobb's Lake Diversion which would follow Cobb's Lake Creek from its confluence with the South Nation River to the drainage divide and then to Clarence Creek, have indicated that the capital cost of the scheme would be in excess of $120 M. From hydraulic computations between the South Nation River and the Ottawa River, diversion of 200 m^3/s (7000 cfs) representing the damaging flows at Plantagenet during the 1:20 year May event would require 13.0 km (8.15 mi) of grassed lined channel with water depth 3.7 m (12 ft) and bottom width 28.7 m (94 ft) and 8.0 km (5.0 mi) of tunnel at the drainage divide consisting of four 4.9 m x 6.1 m (16 ft x 20 ft) box culverts. In view of capital costs of the diversion, the foregoing reservoirs or channelization and dyking on the South Nation River appear to be more economically attractive.

3.3.6.2 Low Flow Augmentation

As shown in the flow-duration analyses for low flows on Figure 3.3 and 3.5, the Castor Reservoir has a significant effect in augmenting low flows at Russell and also at Plantagenet Springs. Since this reservoir can also improve the low flows in the Casselman and Lemieux area, it is assigned a high priority among reservoir alternatives for low flow augmentation.

The Spencerville Reservoir cannot be filled in an average spring runoff. During the 1962 spring runoff, the reservoir would have filled to about 65 400 Ml (53 000 ac-ft) by 31 May or about 68% of the previously proposed reservoir's live storage. Nevertheless, a smaller reservoir at this location would provide significant improvement in low flow flows in the Spencerville area and throughout the main stem of the South Nation River. The flow-duration curves for Spencerville and Plantagenet are shown in Figures 3.2 and 3.5, respectively. Because of its effectiveness in providing low flow benefits throughout the South Nation River, the Spencerville Reservoir site is ranked second.

The Bear Brook Reservoir provides low flow benefits for Bourget and Plantagenet and has been ranked third. Figure 3.4 shows that this reservoir is especially effective in augmenting very low flows.

The Scotch River Reservoir has not been given high priority for low flow augmentation because it affects only Plantagenet Springs.

3.4 Recommendations/Conclusions

The tentative ranking for each reservoir together with its function is:

1. North Castor Reservoir - for flood control and low flow augmentation

2. Scotch River Reservoir - for flood control

3. Spencerville Reservoir - for low flow augmentation

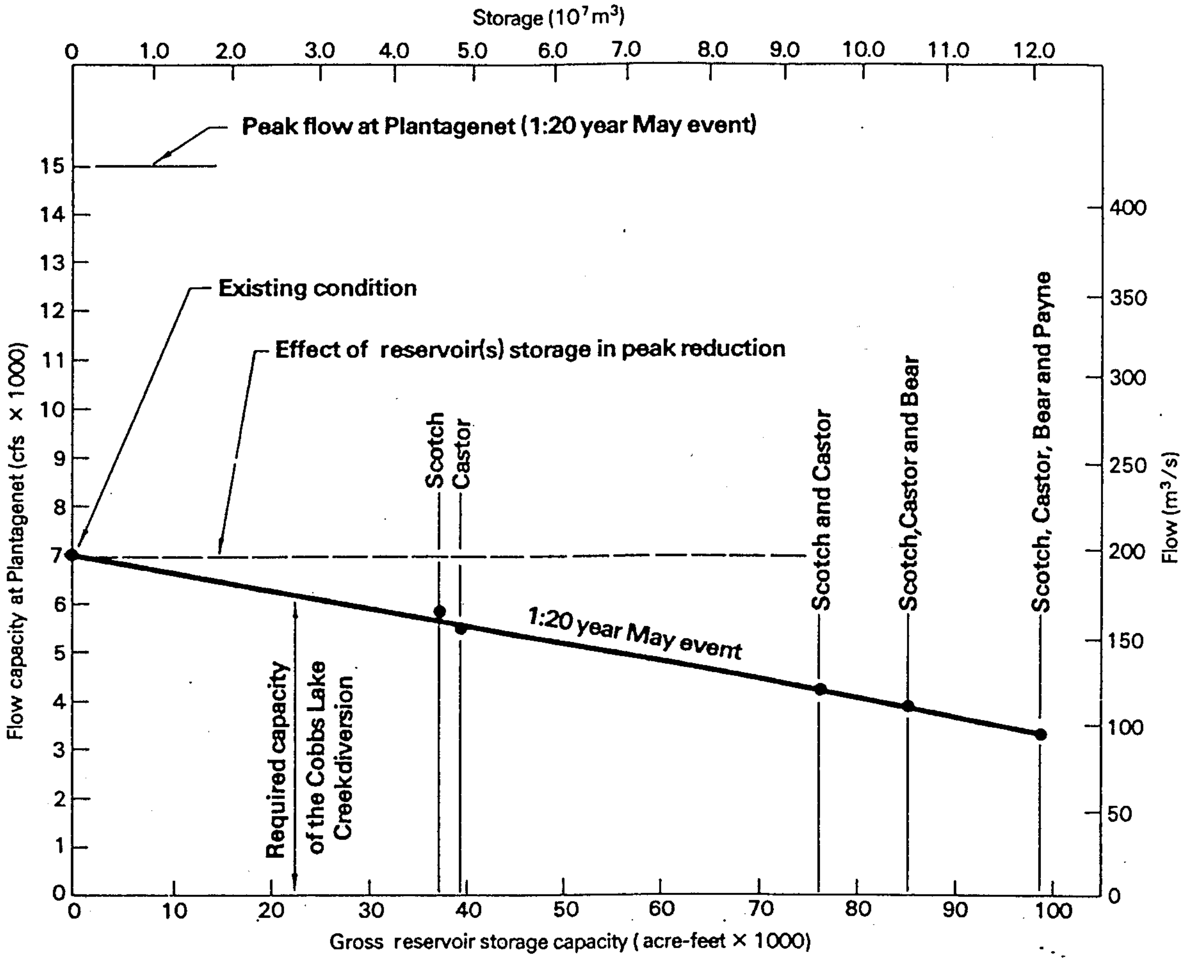
4. Bear Brook Reservoir - for flood control and low flow augmentation

Implementation of the reservoirs for flood control purposes must be viewed with caution at this time since a very preliminary economic analysis indicates that more agricultural land would be inundated at the reservoir sites than removed from the flood hazard zone at Plantagenet. Geotechnical investigations at the Bear Brook site also raise serious questions whether it is feasible to proceed with the proposed structure due to foundation constraints.

Additional reduction in flooding at Plantagenet beyond that which is achieved by the Castor, Scotch and Bear Brook Reservoirs can be realized by either the construction of the Cobb's Lake Creek Diversion or local protective measures including channelization and dyking of the South Nation River downstream of Lemieux. A preliminary investigation of the diversion confirms that this scheme is feasible however capital costs largely preclude further consideration. It is therefore apparent that reduction of flooding along the South Nation River downstream of Lemieux may be best carried out by local protective measures.

Figure 3-17

Reservoir(s) and Diversion Capacities Required to Reduce Flows in the Plantagenet Area to Non-Damage Levels 226.5 m3/s (8000 cfs)



Further investigation of local protective measures is presented in subsequent studies(8)(9)(10). Briefly, a review of channelization or dyking along the main channel and dyking of tributary waterways between Bear Brook and Plantagenet indicated the latter alternative to be the most attractive. During the summer growing season (May to October), flooding of agricultural lands is caused for flows up to a 15 year magnitude by flow reversal in drainage ditches and minor tributaries which backs up water into low lying areas. Dykes were recommended along tributaries at four locations to prevent this occurrence:

- Crystal Spring Creek
- Ditch upstream of the outlet of Springbrook Creek on the south bank
- Ditch between Cobbs Lake Creek and Bear Brook on the west side
- Dickinson Creek

CHAPTER 4

DELINEATION OF SECONDARY FLOOD PLAIN AREAS

CHAPTER 4

DELINEATION OF SECONDARY FLOOD PLAIN AREAS

4.0 DELINEATION OF SECONDARY FLOOD PLAIN AREAS

4.1 General

Due to the relatively flat topography and limited channel capacity throughout the South Nation River basin, extensive flooding has been reported annually in many parts of the watershed, particularly in the spring. The Authority has initiated flood plain mapping projects in areas where flood occurrences resulted in significant damages to property and crops. These studies identified the extent of flooding that would occur in these areas during flood events of various recurrence intervals. The objective of the flood plain delineation component is to provide an estimate of flood plain widths in those areas not previously mapped and to determine the need for additional mapping.

In accordance with the Terms of Reference, this activity does not meet Ministry of Natural Resources flood plain mapping criteria. Rather, it is intended to provide an estimate of the aerial extent of flooding in the secondary flood areas for input to a preliminary estimate of flood damages. The entire watershed was reviewed to categorize each reach according to flood hazard and to identify areas where most detailed flood plain studies might be undertaken.

4.2 Flood Hazard Categories

Four flood hazard categories were identified and coded on a 1:250 000 scale map as reference. These categories were classified according to the following definitions:

Category I - areas adjacent to the river which are steeply sloped so that floods would be confined to a limited area and/or the land use is such that if a flood were to occur, no major flood damages would be anticipated (e.g. forest areas).

Category II - areas where the extent of the flood plain can be easily identified by the topography of the land (e.g. flood plain with clearly defined valley walls) and/or locations where the land use is such that flood damages would be relatively small if inundation were to occur (e.g. agricultural lands).

Category III - includes areas where the flood plain cannot be easily identified based on topographic features and/or there a is risk of large damages in the event of a flood (e.g. town sites).

Category IV - those areas where the flood plain and damage centres have previously been identified and defined with flood plain mapping programs.

4.3 Method

4.3.1 Aerial Photograph Interpretation

A set of 1:20 000 scale aerial photographs which were taken in the spring of 1978 was used for preliminary screening and classification of the four flood hazard categories as described above. These photos showed extensive flooding over much of the basin and give a good indication of flood-prone areas. The return period of the 1978 spring flood varied from 1:2 years in the upper basin to 1:20 years in the lower parts of the basin.

The screening procedure was carried out in the following manner and sequence:

a) The complete South Nation River watershed was carefully examined reach by reach, including all tributaries and local drains using the aerial photos.

b) A preliminary estimate of the four flood hazard categories were coded on a reference map.

c) A high-power stereo-viewer was used to re-examine the aerial photographs. Attention was focused on Categories II and III which were defined in (b) above as well as on areas in which the correct classification was unclear from the preliminary examination of the photographs.

d) Potential flood prone areas were identified on the basis of the flooding and topographic features visible on the photos. An attempt was also made to identify man-made features such as high embankments with small culverts which might cause inundation of large areas.

e) Where inspection of the photographs was insufficient to clearly define flood plain extent, representative cross-sections were obtained by field survey and a simple hydraulic analysis was carried out using estimated flows.

f) Tributaries which need not be analyzed, such as small drains, were eliminated from further consideration. The categorization of flood hazard areas which had previously been established was reviewed and updated.

g) Some of the areas identified as Category II and III were investigated in more detail and the areal extent of flooding was estimated.

4.3.2 Field Survey

Cross-sections representing tributaries in Categories II and III were selected for detailed survey. The field work was done in co-ordination with the hydrology portion of the overall study. Furthermore, approximate stream slopes and appropriate roughness coefficients were also established in this process.

4.3.3 Flow Estimates

For the purposes of this analysis the 10 yr and 100 yr return frequency floods were selected for agricultural areas and town sites respectively. The flows were initially determined by interpolation or extrapolation from the Water Survey of Canada recording gauges using a single area weighting approach as follows:

$$Q_s = Q_g x\ A_s / A_g$$

where:

Q_s = peak flow rate at the section

Q_g = peak flow rate at the gauge for a specified recurrence interval as computed in the hydrology section in the report (Chapter 2)

A_s = drainage area at the section

A_g = drainage area at the gauge

This formula has been proven applicable to the South Nation basin as documented in a report by others (1).

The flow-frequency analysis, from Chapter 2 was used to determine the 10 and 100 yr flows. Because of the extensive overbank storage that occurs in the major flood areas, peak flow measurements downstream of these areas show little increase from the 10 yr to the 100 yr flow frequencies. Extrapolations from these gauges inherently include this storage effect resulting in a possible under-estimation of peak flows in reaches upstream of the major storage sites. However, most of these upstream areas have a relatively small flood damage potential due to the smaller drainage and the generally well-defined stream valleys in upstream areas.

The flow estimates used for this analysis were reviewed by the HSP-F modelling completed later in the study. (see Chapter 5).

4.3.4 Hydraulic Analysis

The depth of flooding as a function of flow rate was calculated for each surveyed cross-section by assuming normal flow depth in the stream channel and no backwater effects. This data was then used to estimate the width of the inundated area and to refine estimates of flood plain boundaries.

4.4 Discussion of Results

The results of evaluating all river reaches according to the classification discussed in Section 4.2 are shown on Figure 4.1. Also identified on the Figure are the sites for which it was felt that a more detailed evaluation of a flood damage potential is warranted. Table 4.1 gives the estimated area of flooding for each of these sites. Each site is shown in detail in Figures 4.2 to 4.14 and discussed briefly below.

Site No. 1

A tributary to the South Indian Creek, this area is noted for its limited channel capacity through the Town of Limoges. The area inundated by the 1:100 year flood has been estimated to be 120 ha. However, significant damages are not anticipated since no structures are endangered in Limoges; land use on the flood plain is currently of low value. In order to determine the flood level at Limoges more accurately, backwater effects from the main South Indian Creek must be evaluated.

Site No. 2

This site extends along a stretch of the Castor River in the vicinity of Kenmore. The area upstream of this point is known to have extensive flooding. However, through the town the area affected is rather small and no structural damages are anticipated. Additional cross-sections through the town would be beneficial in confirming this conclusion.

Site No. 3

This area is situated at the Town of Spencerville in the upstream portion of the South Nation watershed. This is an area of poor drainage containing a number of swamps which significantly reduce peak flows. The river through the Town of Spencerville does not have sufficient capacity to pass a 1:100 year flood due to the low bank elevation on the east side of the channel. However, should a flood of such magnitude occur, it appears that no dwelling units and only a small portion of the agricultural land would be affected. Additional stream cross-sections through the town and more detailed analysis are required to verify this conclusion. Possible backwater effects caused by the numerous road crossings in this area should also be investigated.

Site No. 4

This site is located on the stream reach which contains the Town of Embrun on the main Castor River. The present study shows that approximately 30 m of flood width would exist on the north side of the channel in the event of a 1:10 year return frequency flood. Even though flooding might be localized, the affected area is prime agricultural land which might warrant investigation of flood protection measures.

Site No. 5

The affected area in this reach of the Payne River would be minimal in the event of a 10 yr flood. Although the flood potential might be higher due to hydraulic constrictions caused by bridge crossings and the meandering channel, further work in this area would be a low priority.

Site No. 6

Only a small area of about 23 ha in this section of west Branch of the Scotch River near St. Elmo is expected to be affected by the 10 yr flood.

Site No. 7

Situated at the upstream end of the South branch of the South Nation River, this site would be affected only moderately by the 10 yr flood. About 11 ha would be inundated.

Sites No. 8 and 9

These two sites on the North Branch (near Van Camp) and the Main Branch (near Hyndman) of the South Nation River have an estimated flooded area of 25 ha and 15 ha respectively for the 10 yr flood.

Sites 10, 11, 12

These sites are noted for the close proximity of the rivers to several of the larger towns in the watershed (i.e. Crysler, Embrun, Russell, Chesterville). While hydraulic analysis in this study reveals that flood levels would probably be confined within the channel, backwater effects, and other factors such as ice jams may cause higher flood levels under some conditions. However, since these town sites are not historically flood prone, further studies do not seem to be warranted at this time.

Site 13

A report(1) dated January 1981 attributed the periodic flooding of the county road and septic tile beds near the Village of Hammond to undersized culverts with shallow inverts, vegetation growth and an inadequate cross-section. The report recommends the deepening and widening of 2500 m (8200 ft) of drain and the lowering and enlarging of several culverts.

The flooding in Hammond is primarily caused by shallow and undersized stream crossings. Since this type of problem cannot be identified by the screening procedures used in this study, there may be many similar local occurrences. However, outside of the Hammond area, no other reports of flooding of this nature were found. This appears to indicate that there are few significant problems of this nature in the watershed.

4.5 Conclusions

A few locations in addition to the main flood areas have been identified on major waterways within the South Nation basin where overtopping of channel banks will occur. Widths of floodwater boundaries are generally narrow even at the 1:100 year recurrence interval, and costly flood damages are not anticipated. This appears to agree with local experience at these locations.

Due to the limited extent of the estimated flood areas, and the small scale mapping which is available at these locations the Conservation Authority decided that a plot of 100 yr flood lines is not warranted. Based on the approximate methods used in the screening analysis, no additional flood line mapping work on major waterways is recommended at this time. One exception was noted at Crysler where spring ice jams aggravate high flow conditions and may cause flooding within the urban area. Most other flooding that occurs outside of the four major flood-prone areas is very local and often due to man-made constrictions or blocked culverts. These are best dealt with on a case-by-case basis as they arise.

TABLE 4.1

Estimated Extent of Flooded Areas

Category	Site No.[1]	Flowrate (m³/s) 100 yr	10 yr	Extent of Flooding Length (m)	Max. Width (m)	Area (ha)
Town Sites	1	10	–	8262	149	119
	2	95	–	8003	55	29
	3	112	–	2412	264	58
Agricultural Sites	4	–	303	7750	83	45
	5	–	23	7119	30	9
	6	–	28	8262	46	23
	7	–	12	6616	36	11
	8	–	41	11433	45	25
	9	–	111	5716	61	15
Town Sites for further investigation	10	407	–	–	–	–
	11	211	–	–	–	–
	12	354	–	–	–	–

Previously Identified Major Flood Areas[2] :	Flooded Area (ha) Average Summer	Average Annual
Bear Brook at Carlsbad Springs	114	446
South Castor River at Vernon	85	362
South Nation River at Chesterville	289	2127
South Nation River at Plantagenet	312	3698

1 See Figure 4.1
2 1981 Existing Channelization at Chesterville to Station 10+000

CHAPTER 4

DELINEATION OF SECONDARY FLOOD PLAIN AREAS

4.0 DELINEATION OF SECONDARY FLOOD PLAIN AREAS

4.1 General

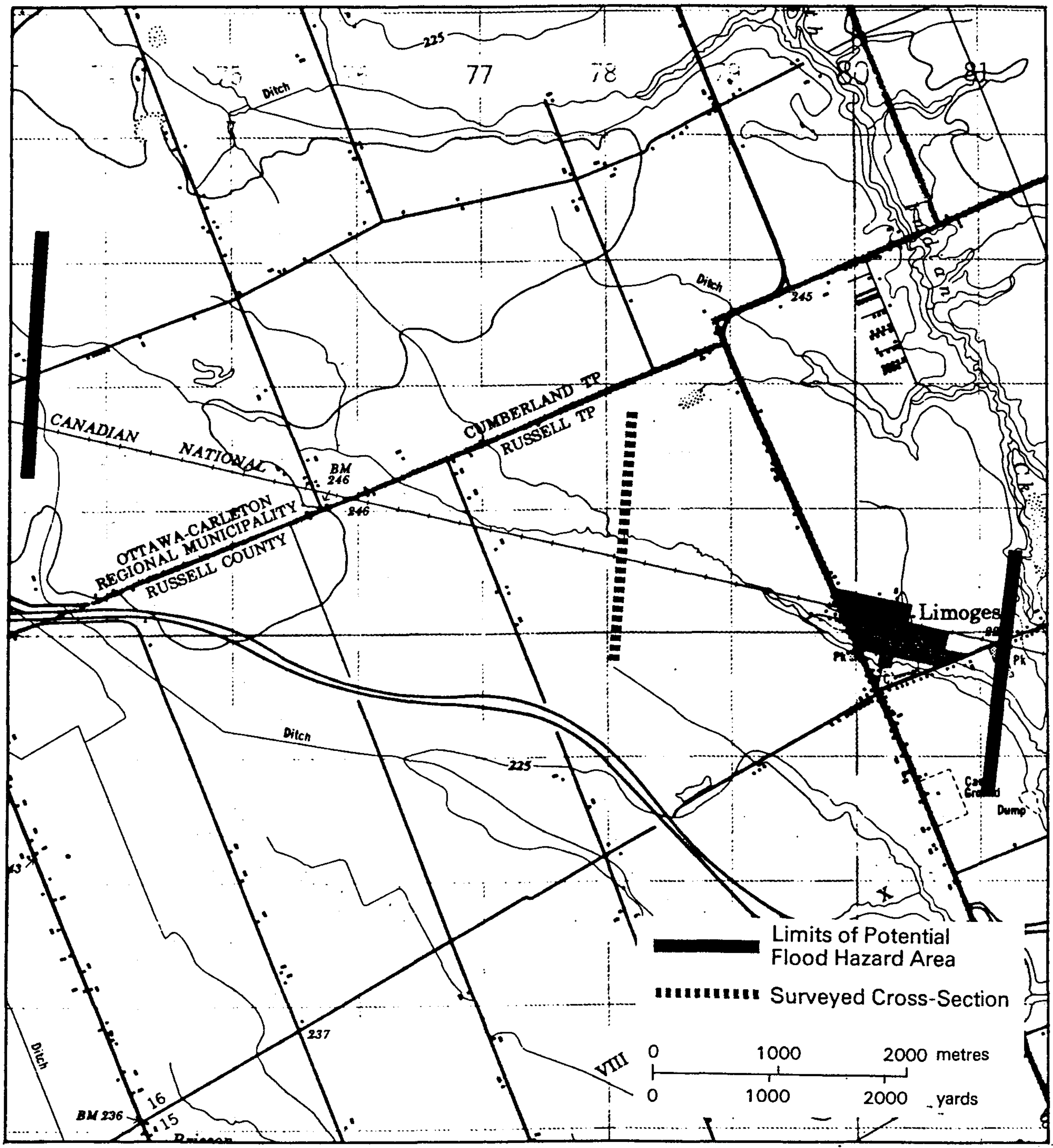
Due to the relatively flat topography and limited channel capacity throughout the South Nation River basin, extensive flooding has been reported annually in many parts of the watershed, particularly in the spring. The Authority has initiated flood plain mapping projects in areas where flood occurrences resulted in significant damages to property and crops. These studies identified the extent of flooding that would occur in these areas during flood events of various recurrence intervals. The objective of the flood plain delineation component is to provide an estimate of flood plain widths in those areas not previously mapped and to determine the need for additional mapping.

In accordance with the Terms of Reference, this activity does not meet Ministry of Natural Resources flood plain mapping criteria. Rather, it is intended to provide an estimate of the aerial extent of flooding in the secondary flood areas for input to a preliminary estimate of flood damages. The entire watershed was reviewed to categorize each reach according to flood hazard and to identify areas where most detailed flood plain studies might be undertaken.

4.2 Flood Hazard Categories

Four flood hazard categories were identified and coded on a 1:250 000 scale map as reference. These categories were classified according to the following definitions:

Flood Plain Location Plan: Village of Limoges, Site No. 1



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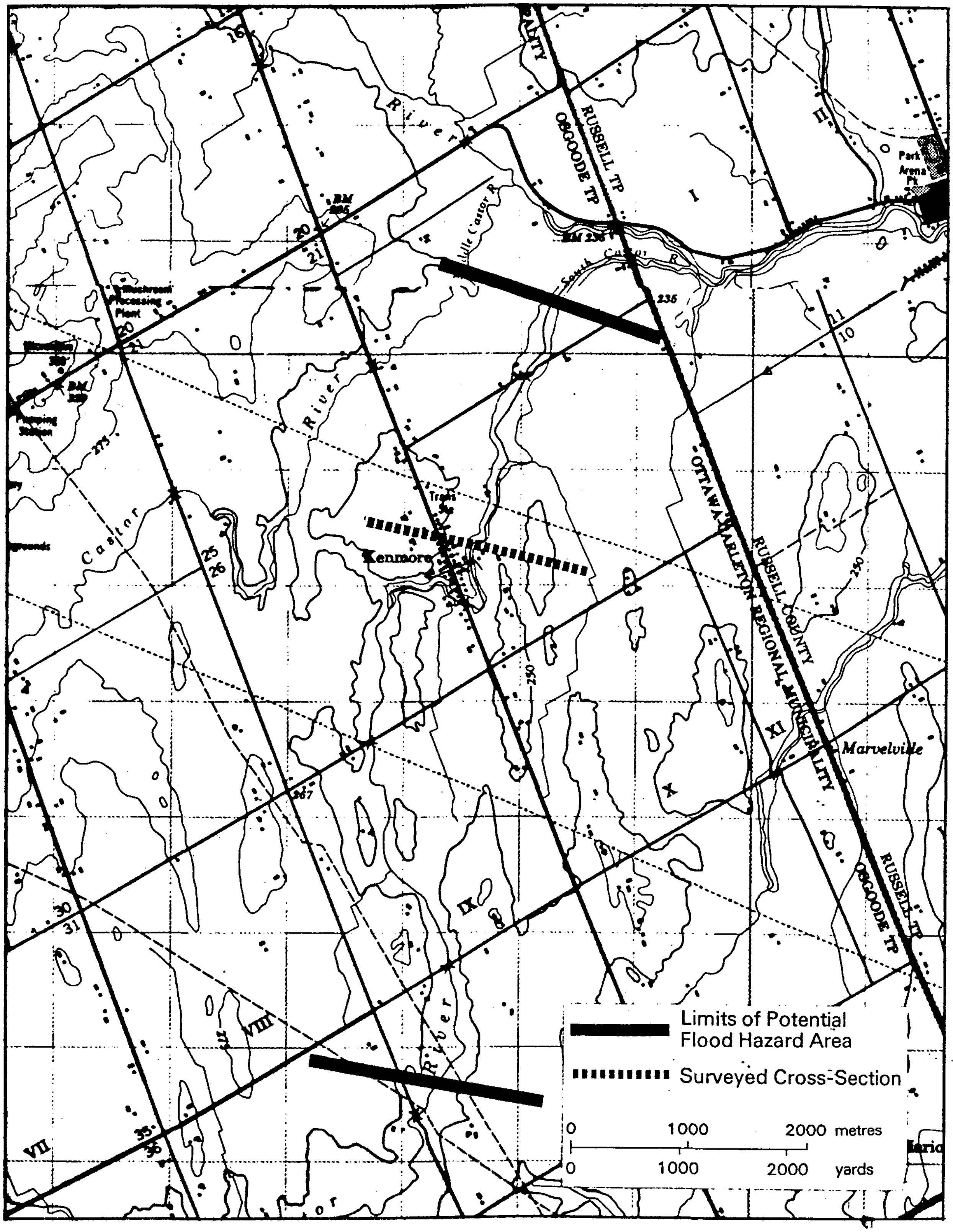
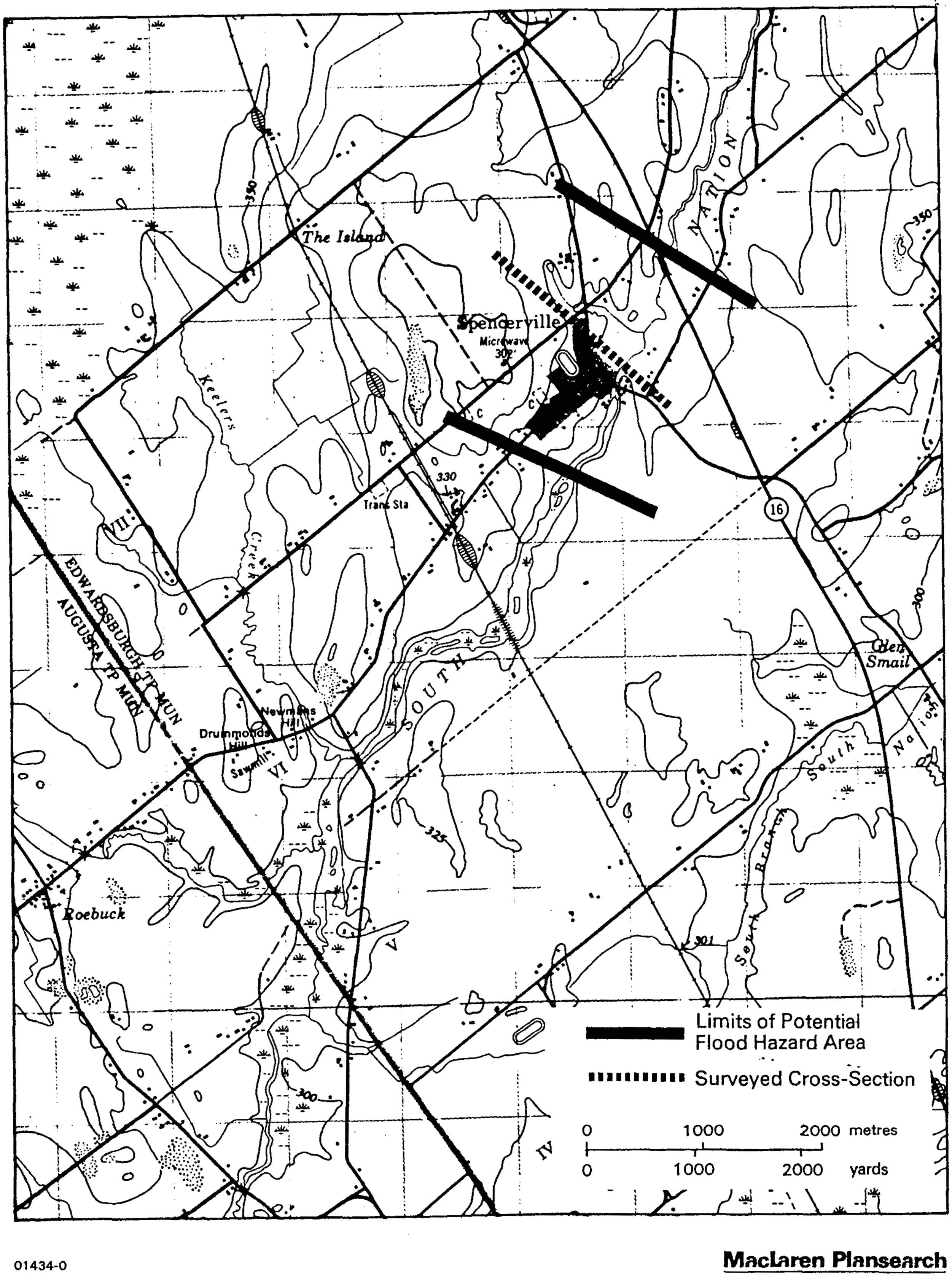
MacLaren Plansearch

Flood Plain Location Plan: Village of Kenmore, Site No. 2

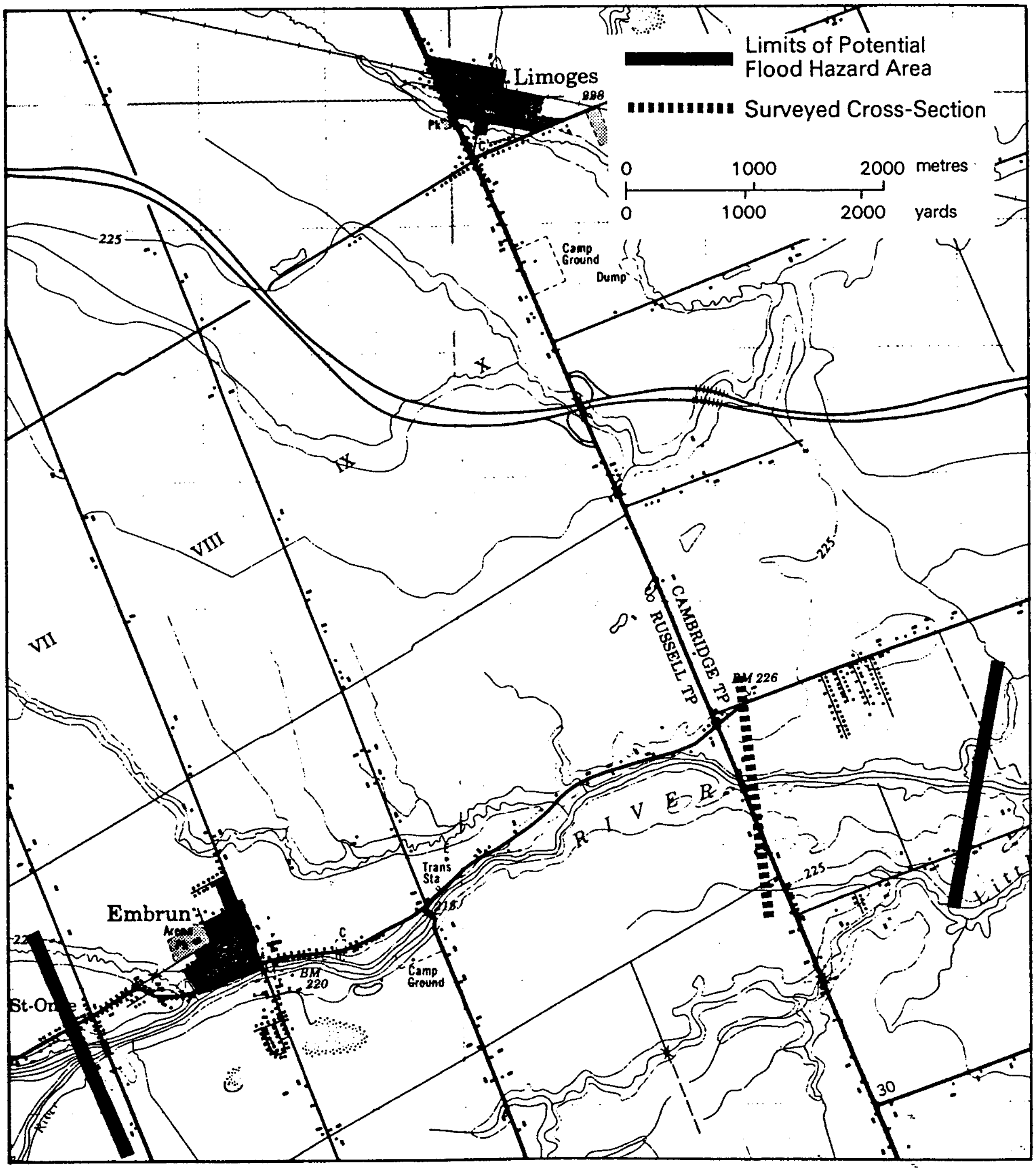


MacLaren Plansearch

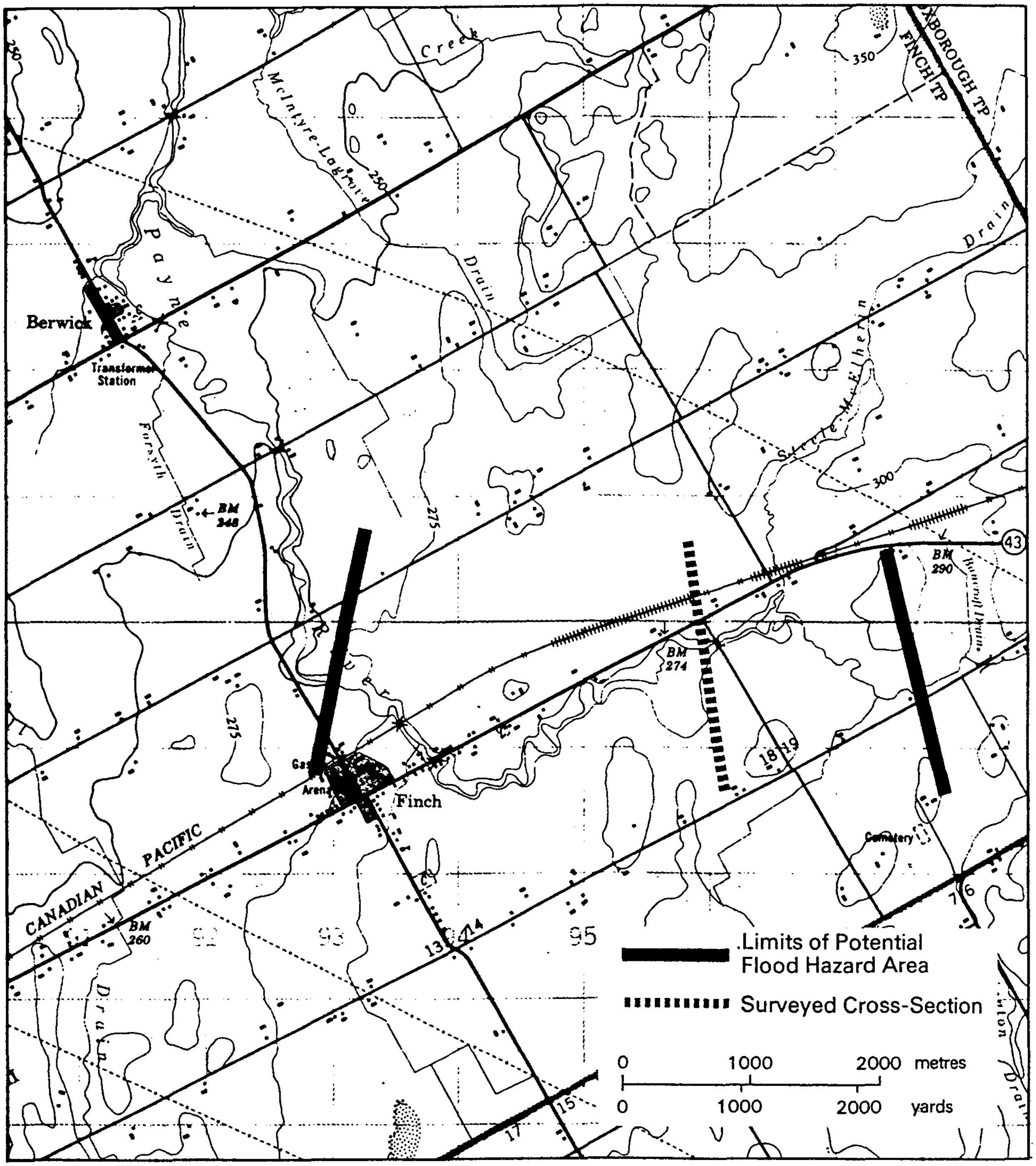
Flood Plain Location Plan: Town of Spencerville, Site No. 3



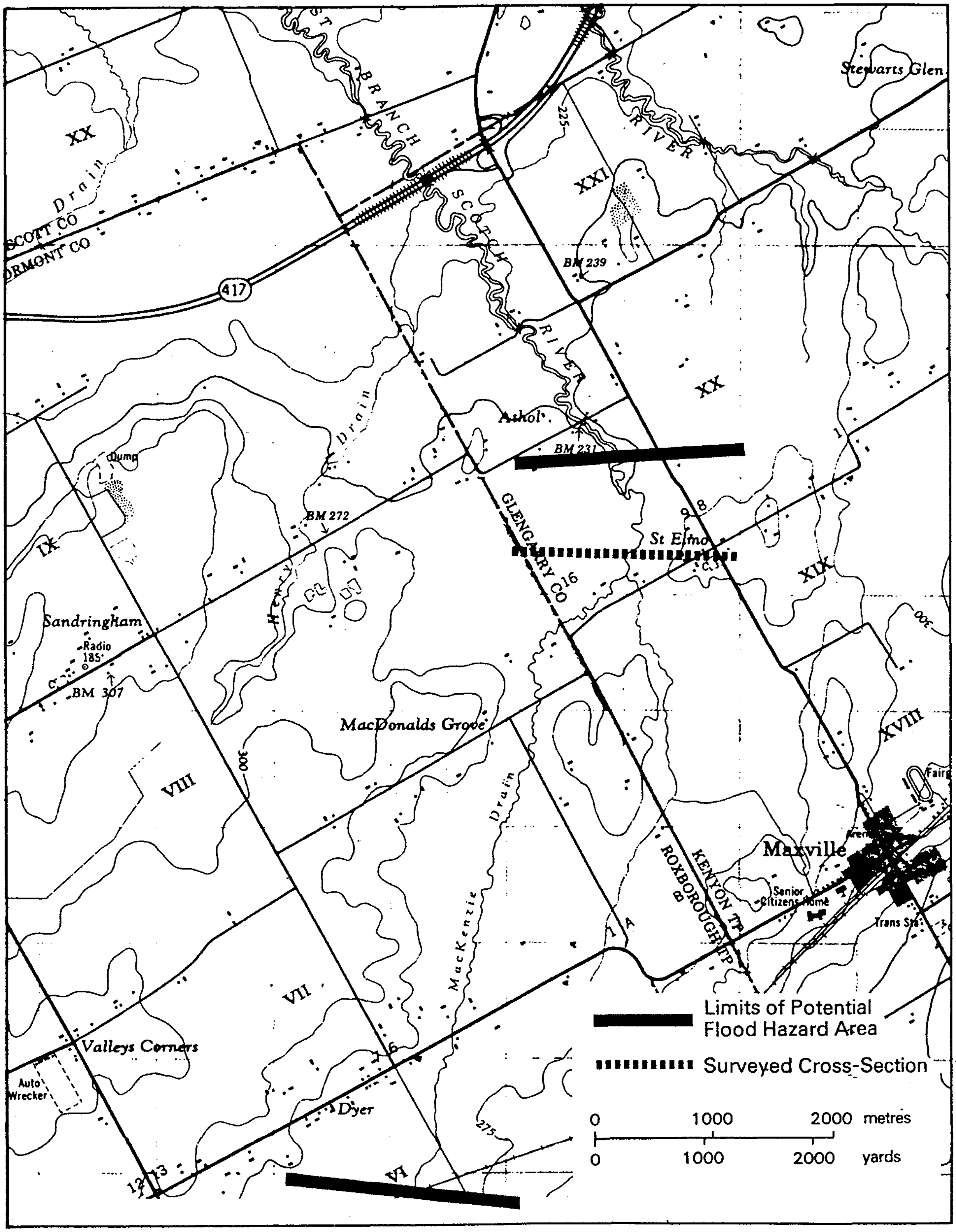
Flood Plain Location Plan: Town of Embrun, Site No. 4



Flood Plain Location Plan: Payne River, Site No. 5



Flood Plain Location Plan: Scotch River near St. Elmo, Site No. 6



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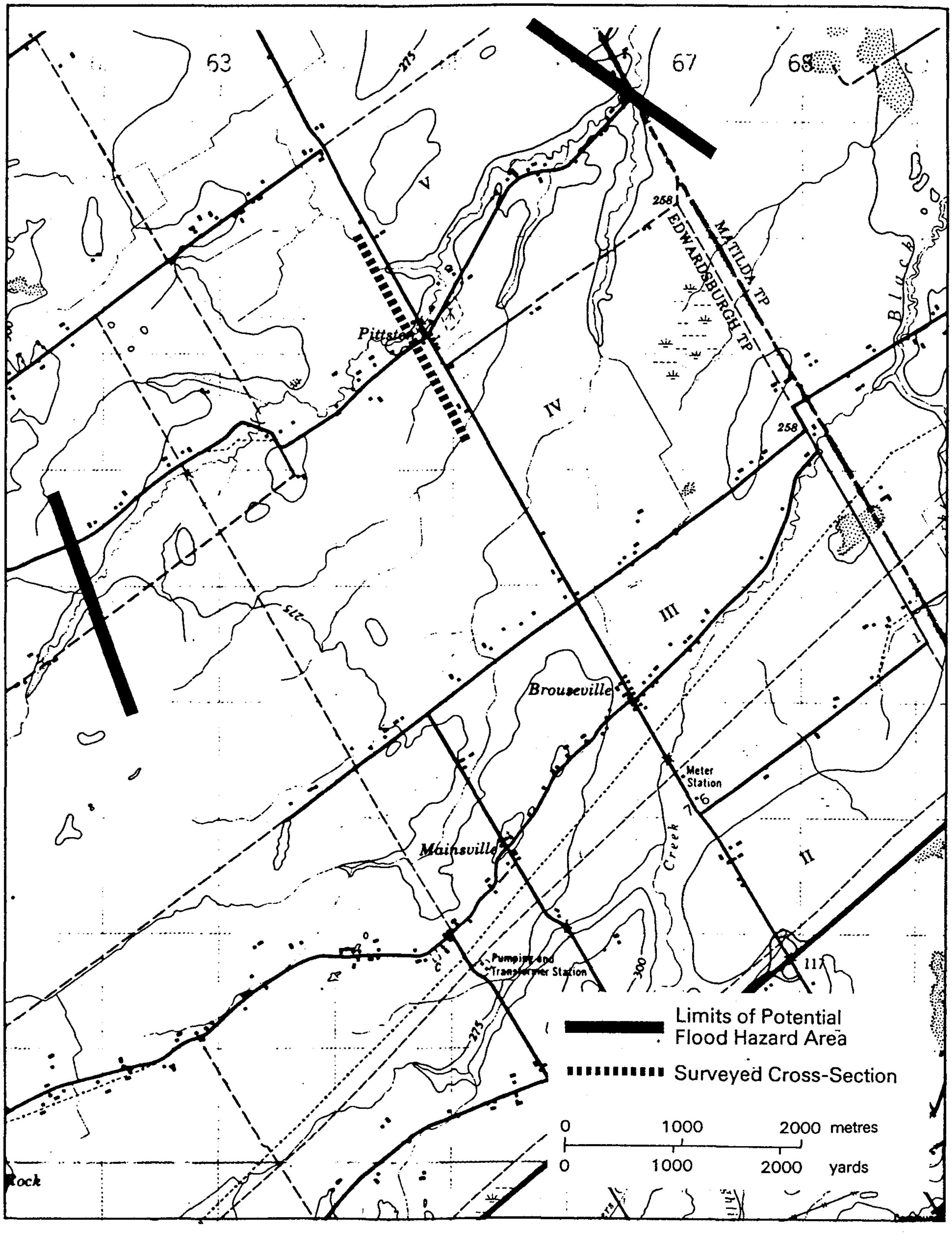
Flood Plain Location Plan: South Branch of South Nation River, Site No. 7



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Flood Plain Location Plan: North Branch of South Nation River near Van Camp, Site No. 8

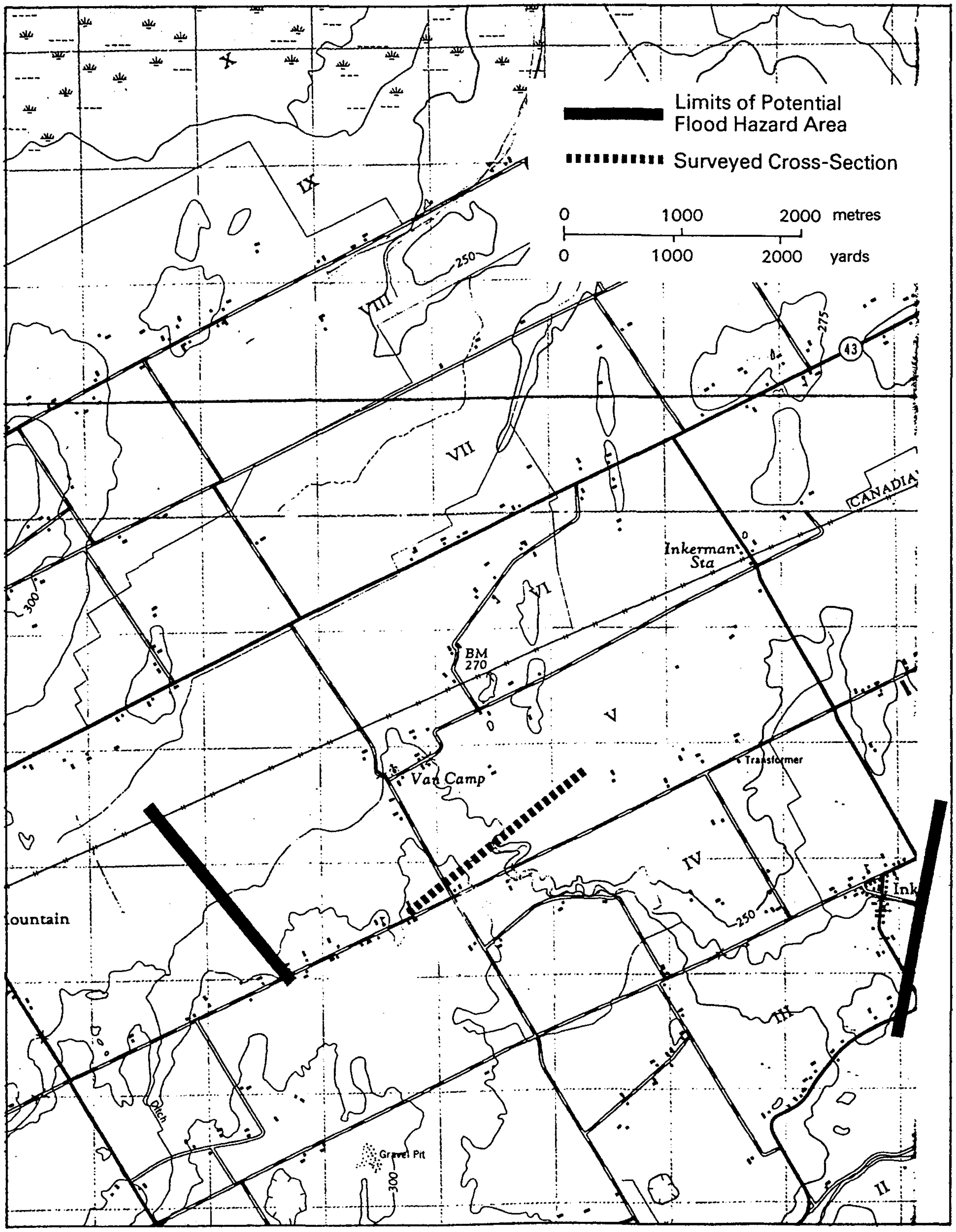
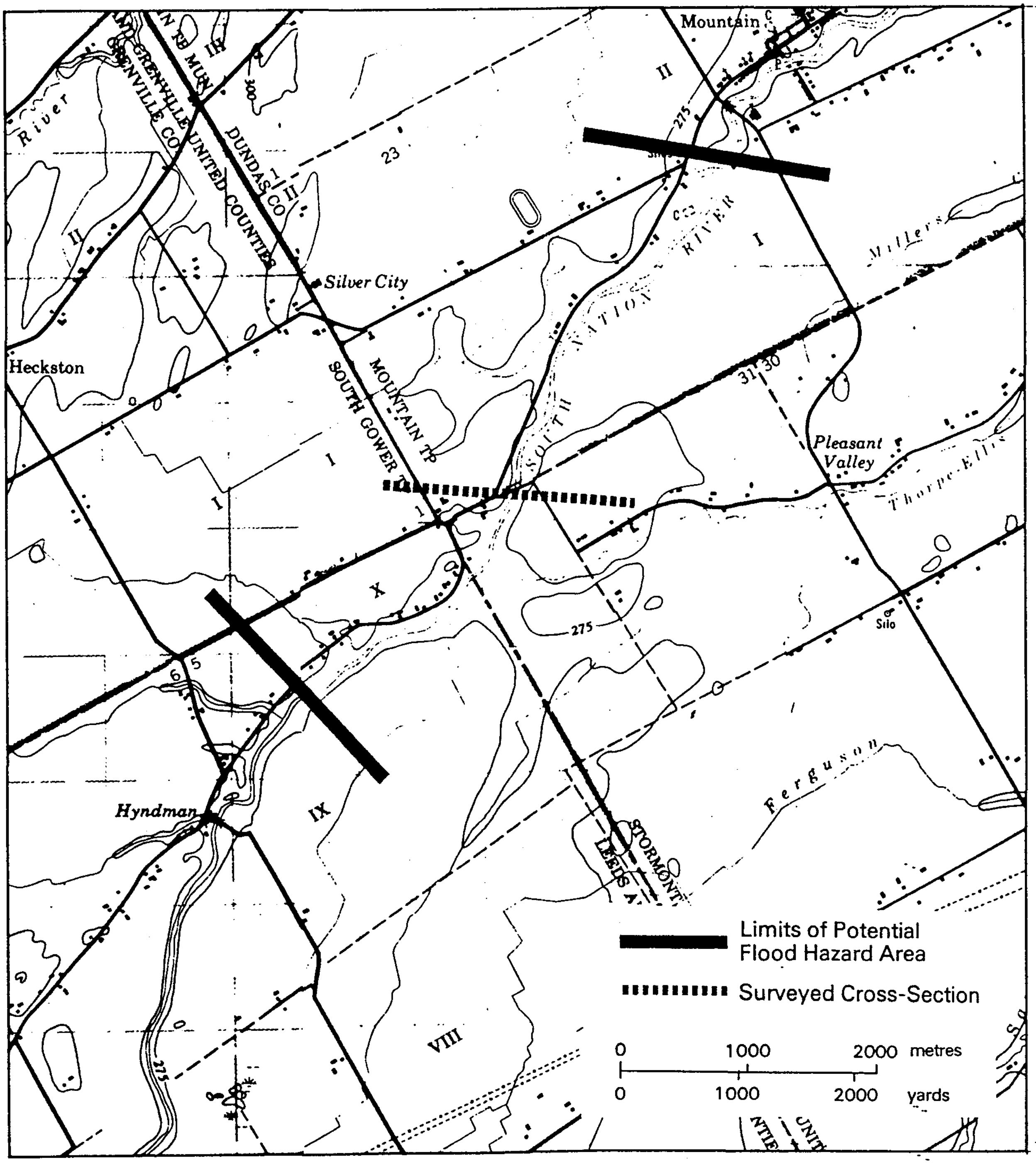


Figure 4-10

Flood Plain Location Plan: Main Branch of South Nation River near Hyndman, Site No. 9



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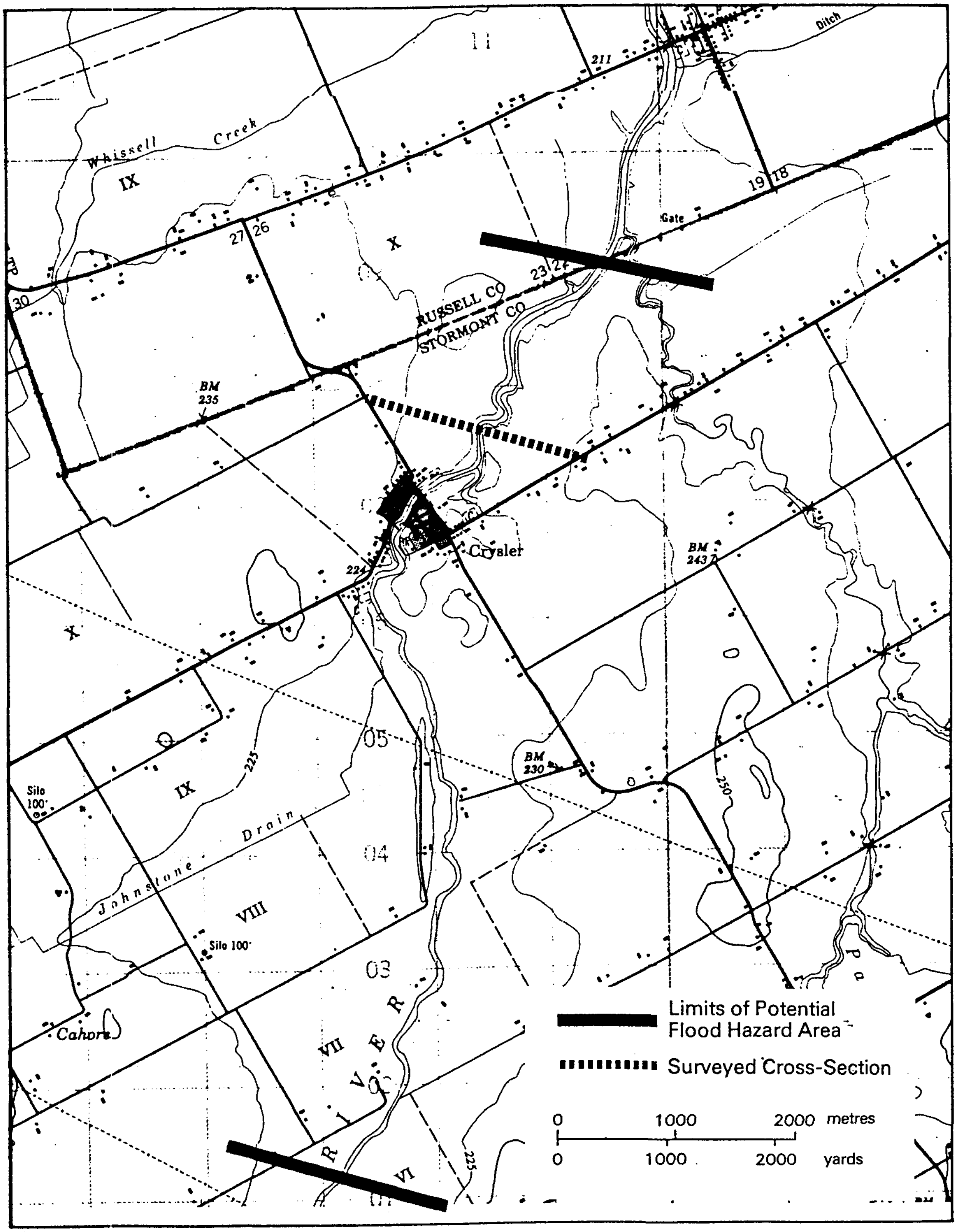
Flood Plain Location Plan: Town of Chrysler, Site No. 10



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Flood Plain Location Plan: Town of Embrun-Russel, Site No. 11

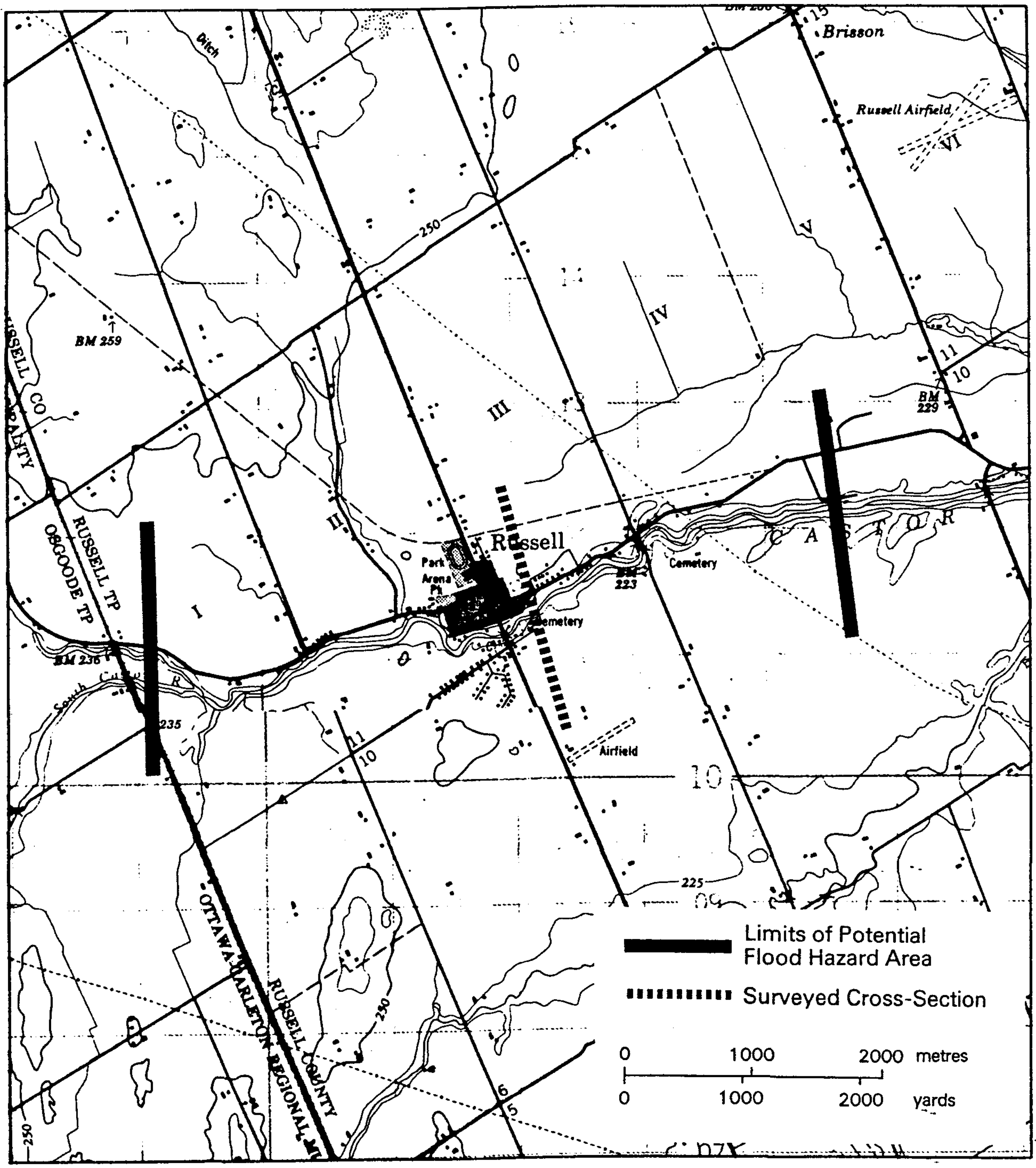
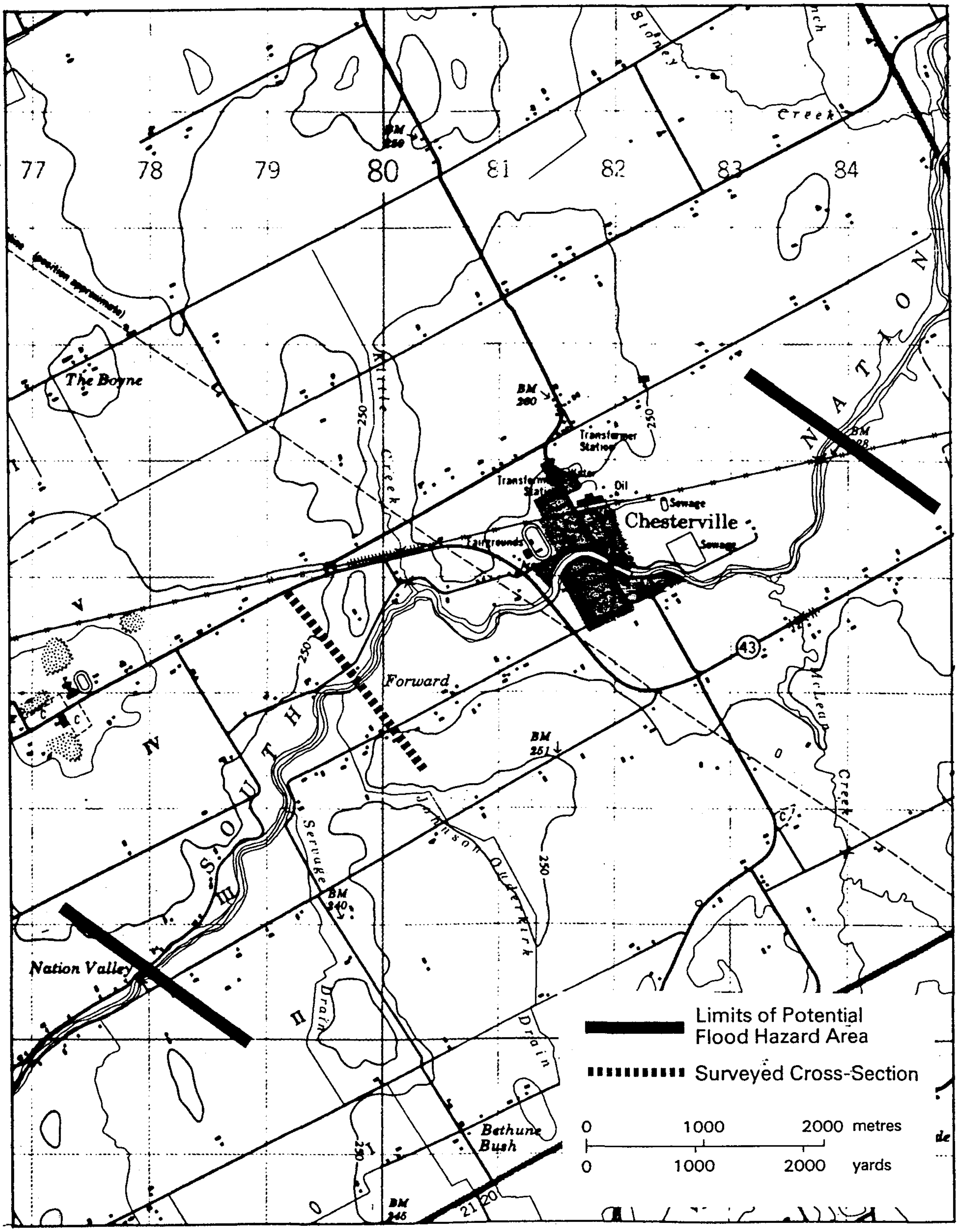


Figure 4-13

Flood Plain Location Plan: Town of Chesterville, Site No. 12



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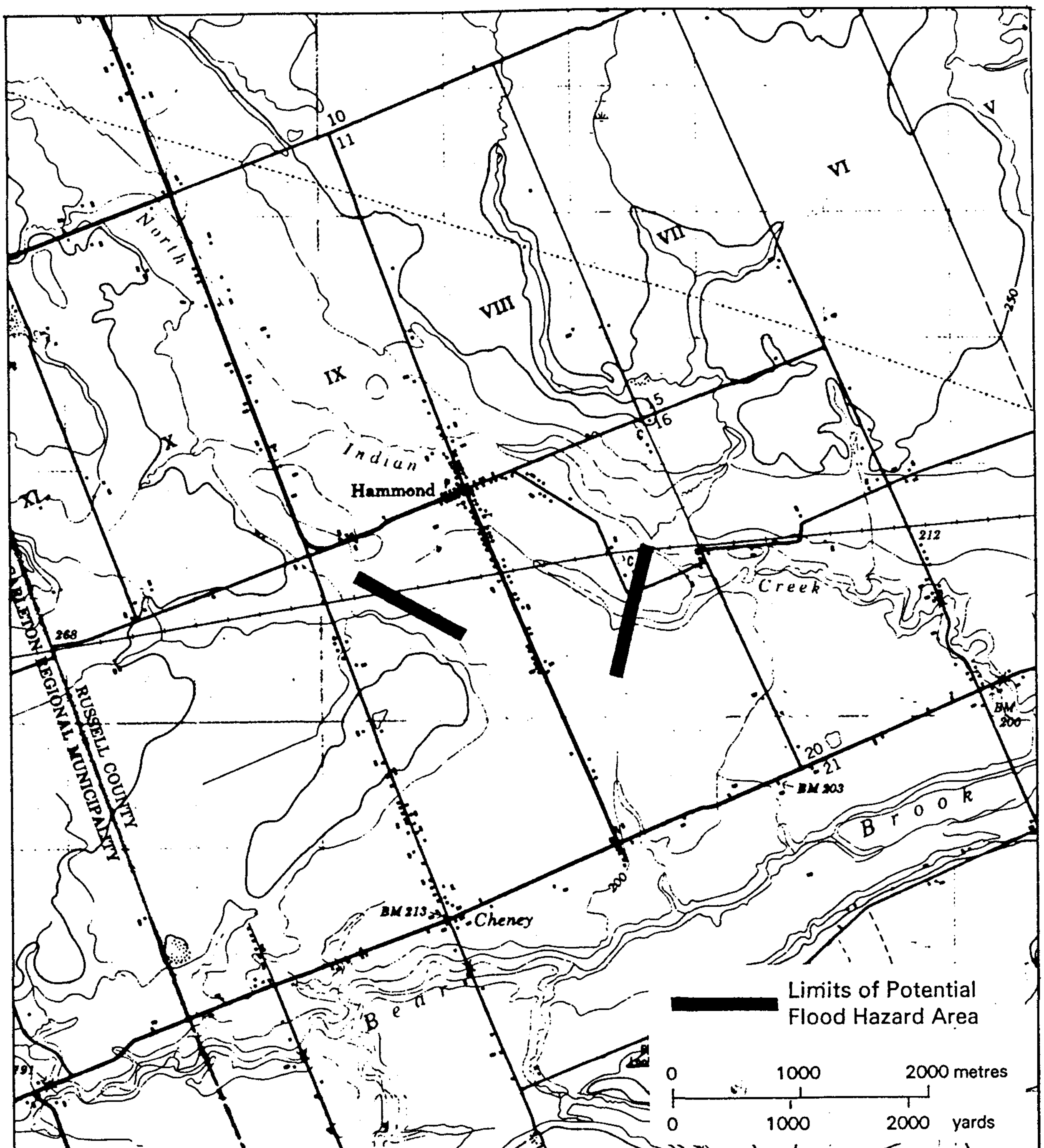
Flood Plain Location Plan: Village of Hammond, Site No. 13



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CHAPTER 5

HYDROLOGIC MODELLING OF THE SOUTH NATION BASIN

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HYDROLOGIC MODELLING OF THE SOUTH NATION BASIN

5.0 HYDROLOGIC MODELLING OF THE SOUTH NATION BASIN

5.1 General

The "Hydrological Simulation Program - Fortran" (HSP-F)(1) was selected for modelling the water resources of the South Nation River basin. The comprehensive simulation capabilities of the program, its operation in a continuous simulation mode and its deterministic representation of the hydrologic cycle and water quality processes were deciding factors in this choice. The model of the South Nation River Basin was used to:

- Extend available records of streamflow at gauged locations

- Develop streamflow records at ungauged locations of interest

- Examine the impact of the various structural water management options on the basin hydrology and water quality

- Examine the impact of various land use scenarios including land drainage on the basin hydrology and water quality.

The results of the latter investigations and all water quality aspects are discussed in subsequent report sections. In this section the implementation of HSP-F on the South Nation River basin is presented including:

- A brief description of hydrologic components of the program in order to highlight the important parameters and data needs.

- The preparation of the data base and set up of the model for the South Nation River basin.

- The objectives and limitations of the calibration and validation process applied to the model.

- The methodology and results of the calibration and validation of the model.

- The results of the long term simulations for base conditions in the watershed.

5.2 Model Description

The HSP-F model is a conceptual deterministic mathematical model since it describes the main parts of the hydrologic cycle by a system of mathematical equations. The components which are relevant to the hydrology of the South Nation River basin are:

- The snowmelt process

- The generation of runoff from pervious land surfaces

- The routing of flows through stream channels, lakes or artificially created storage reservoirs.

The following sections briefly describe the concepts used in HSP-F to model the above, the important parameters and the data needs of each component. Full details of the program and its use are given in the comprehensive Users Manual (1).

5.2.1 Snow Accumulation and Melt

In many watersheds in Canada most annual peak flows occur during the spring months as a result of snowmelt or combined snowmelt and rainfall events. An accurate representation of this process is therefore essential. The HSP-F model utilizes the full energy balance equations of the melt process as originally developed by the U.S. Corps of Engineers(2). Components of the melt process based on convection, condensation, radiation and ground heat are specifically modelled. The accumulation of the snowpack depends on whether precipitation is in the form or rain or snow as determined by a threshold temperature. Adjustments are made to allow for changing density and depth of the pack and to account for evaporation. A record of the liquid water content and heat storage of the snowpack is also maintained.

A total of about twelve parameters are involved in the snowmelt/accumulation process. The most important of these (in approximate order of sensitivity) are:

- The gauge correction factor which allows for undercatch of snowfall, SNOWCF

- The threshold temperature which distinguishes between snowfall and rainfall, TSNOW

- The percent of the basin which is forested, SHADE

- The convection melt factor, CCFACT.

The data requirments of the snowmelt modelling process are quite extensive. Time series of precipitation, air temperature, solar radiation, dewpoint temperature and wind speed are necessary. Although some of these measurements are not available at many locations, they can be transferred from relatively distant locations without undue loss of accuracy. The preparation of the data base and sources of the less common meteorological data for the South Nation River is described in Section 5.3.

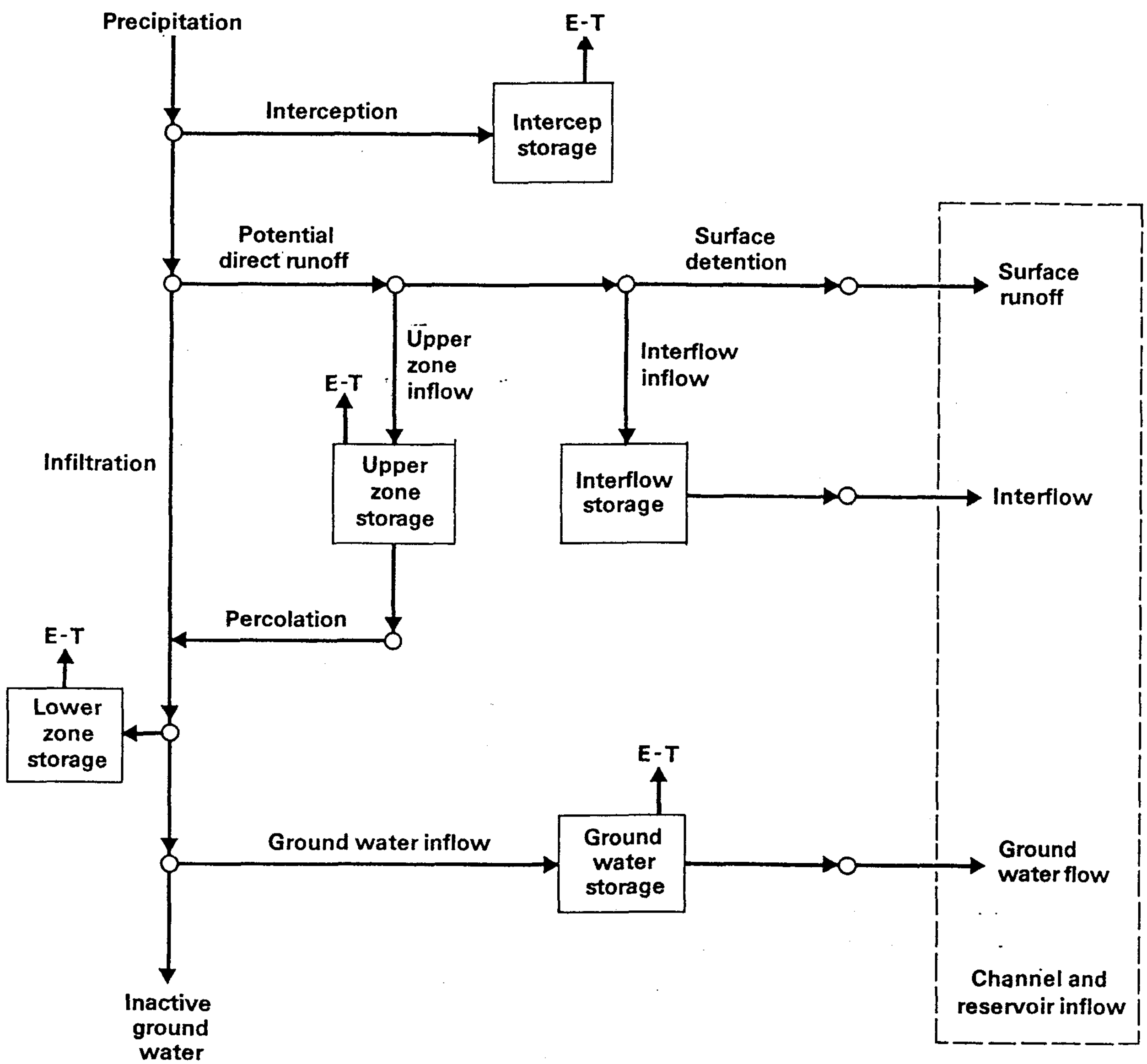
5.2.2 Runoff from Pervious Areas

As illustrated in Figure 5.1, the HSP-F model treats the various parts of the hydrologic cycle as a set of storages connected by a number of transfer processes. The storages modelled are:

- Interception storage by vegetation, leaves, stems and branches

- Interflow storage which controls the amount of shallow subsurface flow which may reappear relatively quickly during a storm event

Generalized Flow Chart for HSP-F Pervious Land Segment



- Upper zone storage which represents depression storage and storage in the surface layers of highly permeable soils

- Lower zone storage which represents soil moisture storage from just below the surface to the capillary fringe above the water table

- Groundwater storage both active which contributes to baseflow and deep seepage which is lost from the watershed by regional groundwater transfer

The processes which connect these storages and determine the amount of streamflow at any time are:

- Infiltration of incoming precipitation or snowmelt to interflow, upper and lower zone storages. The equations used are based on the work of Philip (3). Infiltration varies both with the initial moisture and spatially across the subwatershed

- Interflow or lateral flow which is particularly important if impermeable layers restrict the downward percolation of moisture

- Surface runoff which is based upon the Chezy-Manning equation and the amount of moisture available in surface detention storage

- Groundwater outflow which is dependent of the amount of groundwater storage and a recession coefficient

- Evapotranspiration which is based on an input series of potential evaporation and the current state of soil moisture. The evapotranspiration demand draws on the different storages in turn until it is satisfied. The input series can be based on either adjusted measurements of pan evaporation or derived from meteorological measurements by any of several well known techniques.

Dependent upon the exact options selected for simulating the above processes about 20 parameters are used in the HSP-F model to describe pervious area runoff. The most important of these are:

- The infiltration rate parameter, INFILT

- The interflow infiltration rate, INTFW

- The lower zone nominal moisture storage capacity, LZSN

- The upper zone nominal moisture storage capacity, UZSN

- The ground water recession rate, AGWRC

- The interflow recession rate, IRC

- The lower zone evapotranspiration parameter, LZETP.

The data needs of the pervious area runoff component of HSP-F are time series of precipitation plus any snowmelt computed as previously described and evaporation. Also required are certain parameters such as drainage area, overland slope and Manning's roughness coefficient which describe the physical characteristics of the watershed.

5.2.3 Channel and Reservoir Routing

The same component of the HSPF model represents both fully mixed reservoirs and free flowing channel reaches. The routing of flow through these elements is based on the equation of continuity and as such is of the "hydrologic routing" or "kinematic wave" type. A choice of techniques is available depending whether the outflow is a function of time, volume or both. No parameters as such are required for the routing but the extent of routing is sensitive to both the length and slope of the reach. Data input requirements vary with the option chosen but generally include stage-discharge, stage-storage and stage-surface area relationships for the reach. Input also includes time series of all inflows to the reach, precipitation onto the reach (or reservoir) and evaporation from the reach.

5.3 Data Base and Model Preparation

5.3.1 Data Requirements and Availability

Data requirements for the HSP-F model were described in general previous sections. In this section the exact requirements for the South Nation River basin will be compared to the data available within the region.

In order to obtain the accuracy required to generate reliable flood frequency curves an hourly time step was selected for the HSP-F simulations. Representative input data series were therefore required on an hourly basis for:

- precipitation
- temperature
- wind speed
- radiation
- dew point temperature
- lake evaporation

Available meteorological data in the region of the South Nation River basin is detailed in Table 5.1. Figure 5.2 shows the locations of these stations. The longest series of hourly data is available from stations in Ottawa and covers a period of approximately 30 yr. Evaporation data was the limiting factor with a record from 1957 to 1979 (22 yr). The period 1 October 1957 to 30 September 1979 was therefore selected as the standard base period for long term simulations. All data series were therefore extended or infilled as necessary to correspond to this time period using the techniques decscribed below.

5.3.2 Meteorological Data Base Preparation

The primary driving force of the hydrologic simulations is the input precipitation series. The greatest effort was

TABLE 5.1

Details of the Meteorological Data Used in the HSP-F Data Base

Station Name	Station Number	Daily Precip	Hourly Precip	Temp	Dew Pt. Temp	Wind Speed	Radiation	Evaporation
				Period of Record				
Brockville[1]	6100969	1871	–	–	–	–	–	–
Brockville PCC[1]	6100971	1965	1965	–	–	–	–	–
Chesterville	6101500	1965	–	–	–	–	–	–
Cornwall[1]	6101874	1965	–	–	–	–	–	–
Cornwall Ont H	6101901	1954	1960	–	–	–	–	–
Cumberland	6101935	1973	–	–	–	–	–	–
Kemptville	6104025	1928	1969	–	–	–	–	–
Metcalfe Osgoode	6105066	1968	–	–	–	–	–	–
Morrisburg	6105460	1913	–	–	–	–	–	–
North Augusta	6105679	1973	–	–	–	–	–	–
Ottawa Int.l A	6106000	1938	1967	1953	1953	1953	–	–
Russell	6107247	1954	–	–	–	–	–	–
St. Elmo	6107310	1966	–	–	–	–	–	–
South Mountain	6107955	1960	–	–	–	–	–	–
Spencerville	61017971	1953	–	–	–	–	–	–
Ottawa NRC	6106090	–	–	–	–	–	1957	–
Ottawa Exp. Farm	6105976	–	1960	–	–	–	–	1957

1) These stations not used as base stations in daily data base.

therefore expended in developing an accurate and areally representative set of hourly precipitation inputs. As Table 5.1 shows, a total of 15 stations record precipitation in the region of the study basin. Four of these stations record on an hourly basis. Having discarded three stations because of their proximity to other stations, a total of 12 hourly records 22 yr long were developed. These were then applied to individual subareas of the watershed using appropriate Thiessen polygon weights. The following procedures were used in developing the twelve series of hourly precipitation:

1) The records at the eight daily stations were extended to the standard 22 yr period and any missing data was infilled by pro-rating the data of the nearest station with recorded data by the ratio of their mean annual precipitations. This factor varied between 0.88 and 1.13. Table 5.2 provides details of the records and prorating factors used at each station. Double mass plotting of this information indicated no discernible trends or inconsistencies in this infilled data.

2) During the winter from approximately the end of November to mid April, hourly recording stations do not measure frozen precipitation or snowfall on an hourly basis. The Ottawa Airport station provides six-hour totals. Winter hourly precipitation at the Ottawa station was therefore obtained by dividing the six-hour total into six equal amounts. This distribution was then used to distribute the daily winter totals at all the remaining eleven gauges. Since the precipitation during this period is mostly frozen the uniform intensity given by this assumed distribution is not critical.

TABLE 5.2

Details of Data Infilling and Record Extension for the Precipitation Data Base

Station Name	Station Used for Infilling	Station Used For Extending Record	Daily Adjustment Factor	Station Used for Hourly Distribution
Chesterville	Morrisburg	Morrisburg (1958-64)	0.90	Kemptville
Cornwall, Ont. H	Cornwall	Not required	0.88	Brockville
Cumberland	Ottawa Intl.	Ottawa Intl. (1958-72)	0.98	Ottawa Intl.
Kemptville	Complete	Not required	-	Ottawa Intl.
Metcalfe	Ottawa Intl.	Ottawa Intl. (1958-67)	0.97	Ottawa Intl.
Morrisburg	Cornwall/ Cornwall Ont. H	Not required	0.88	Cornwall Ont.H
North Augusta	Brockville/ Brockville PCC	Brockville/ Brockville PCC (1958-72)	1.07	Brockville
Ottawa Intl.	complete	Not required	-	Ottawa CDA
Russell	Ottawa Intl.	Not required	0.98	Ottawa Intl.
St. Elmo	Cornwall Ont.H	Cornwall Ont. H (1958-65)	1.01	Cornwall Ont.H
South Mountain	Kemptville	Kemptville (1958-59)	0.99	Kemptville
Spencerville	N. Augusta	Not required	0.85	Brockville

3) For the summer period the daily totals at the eight daily gauges were distributed according to the hourly distribution at the nearest hourly recording gauge. Table 5.2 indicates which gauge was used at each station. For the years 1957 to 1959 no hourly precipitation data was available and therefore the hourly pattern at each station was obtained in the same manner as for the winter period.

During the study, considerable discussion arose concerning the movement of weather fronts and especially summer storms over the basin in a west to east direction. Although this pattern is generally acknowledged, no synoptic studies have been carried out for Eastern Ontario by the Atmospheric Environment Service. Calibration of the HSP-F model and subsequent runoff simulation for the 22 year period was based on temporal rainfall statistics at five hourly recording gauges located in close proximity to the basin. While this procedure reflected rainfall characteristics, further refinement of the rainfall variability encountered during summer thunderstorms may be possible in the future by means of storm tracking with weather radar located at McGill University and Carp.

The secondary input data required for operation of HSP-F were all obtained from records available in Ottawa. The variables wind speed, radiation, dewpoint temperature and evaporation are not available elsewhere within a reasonable distance of the basin. All variables were available on an hourly basis except for evaporation. This was only available as a daily measurement with a uniform distribution being applied to obtain hourly amounts. Although this is not entirely accurate on an hour by hour basis the absolute values of evaporation are very small in the order of 0.2 mm/h and the daily water balance will be accurate.

Temperature measurements are available at locations other than Ottawa. An analysis of this information indicated a slight trend towards higher temperatures at the southern end of the basin. For example, the average mean daily temperature in April is about 0.5°C higher in Brockville and Cornwall than in Ottawa. However, due to the secondary importance of the temperature in the HSP-F simulation it was decided to use the Ottawa temperature sequence throughout the basin with a correction factor applied to the southern parts of the basin during model calibration.

5.3.3 Hydrometric Data Base

The locations of the 15 existing hydrometric stations in the South Nation River basin are shown in Figure 5.3. The watershed drainage area, type and period of record are summarized in Table 5.3. The accuracy and general reliability of these measurements was discussed in detail with officials of the Water Survey of Canada and is summarized in Section 5.4.1.

The hydrometric information was extensively analyzed for consistency, trend and persistence. In addition, flood frequency analyses and flow duration analyses were carried out. For the purposes of the HSP-F model calibration/validation process the data was used in raw form for comparison of observed and simulated flows. As such no data infilling or extension was necessary. Some minor consumptive uses of water by municipalities and industries within the watershed

TABLE 5.3

Details of Available Hydrometric Data in the South Nation River Basin

Station Name	Station Number	Drainage Area, km^2 (mi^2)	Record Length N, for Continuous Data	Record Length, N, For Seasonal or Peak Flow Data
South Nation River Near Plantagenet Springs	02LB005	3810 (1470)	1916-33, 49-79 N = 49	1916-43, 45, 47-79 N = 62
Castor River Russell	02LB006	433 (167)	1968-79 N = 12	1948-79 N = 32
South Nation River at Spencerville	02LB007	246 (95)	1950-79 N = 30	1948-79 N = 32
Bear Brook near Bourget	02LB008	440 (170)	1977-79 N = 3	1949-53, 55-69, 76-7 N = 24
South Nation River at Chesterville	02LB009	1050 (404)	1972-74 N = 3	1950-52, 55-79 N = 28
(East Branch) Scotch River near St. Isidore de Prescott	02LB012	76.7 (29.6)	1970-78 N = 9	1970-79 N = 10
South Nation River at Casselman	02LB013	2410 (929)	1976-79 N = 4	1976-79 N = 4
South Nation River at Lemieux	02LB015			
Little Castor River near Embrun	02LB016	76.1 (29.4)	1978-79 N = 2	1978-79 N = 2
North Branch South Nation River near Heckston	02LB017	62.9 (26.7)	1978-79 N = 2	1978-79 N = 2

TABLE 5.3 (cont'd)

Details of Available Hydrometric Data in the South Nation River Basin

Station Name	Station Number	Drainage Area, km^2 (mi^2)	Record Length N, for Continuous Data	Record Length, N, For Seasonal or Peak Flow Data
West Branch Scotch River near St. Isidore de Prescott	02LB018	99.5 (258)	1979 N = 1	1979 N = 1
South Indian Creek near Limoges	02LB019	72.3 (27.9)	1979 N = 1	1979 N = 1
South Castor River at Kenmore	02LB020	189 (73.0)	1979 N = 1	1979 N = 1
East Castor River near Russell	02LB021	145 (56.0)	1979 N = 1	1979 N = 2
Payne River near Berwick	02LB0221	152 (58.5)	1977-78 N = 2	1977-79 N = 3
Bear Brook atq Carlsbad Spring	02LB101	65.0 (25.1)	1976-77 N = 2	1976-78 N = 3

N.B. Discharge Data were obtained from the Inland Waters Directorate of the Water Resources Branch, Water Survey of Canada at Ottawa, Ontario.

were noted in other sections of the study and are presented in Tables 8.6 and 9.1. However, no adjustment was made to the flow data to account for these since they were relatively small.

5.3.4 Model Set-Up and Parameter Initialization

For the purposes of the hydrologic modelling of the South Nation River basin the watershed was divided into 15 segments corresponding to the 15 points at which historical streamflow records were available. Watershed parameters such as maximum soil moisture storages, infiltration and groundwater recession rates are taken as constant over each land segment. Since these factors must be derived by calibration on the basis of recorded flows, the breakdown of the watershed into land segments matching gauged subareas is the most appropriate approach.

Initial attempts to model the basin in segments of homogeneous land use proved unsuccessful since establishing model parameters for diverse land use above a single gauge point became a matter of conjecture. It is acknowledged that several subareas including areas 5 and 8, are non-homogeneous and that the model parameters reflect the composite effect of land use and physiographic features. In order to specifically model the impacts of individual land uses, a data collection program would be required to monitor flows from these areas. This would serve as a basis for calibration of the model and eliminate arbitrary assumptions regarding parameter values.

Since simulated flows were desired at numerous points within the watershed, each of these pervious land segments (PERLND's) was further partitioned by the use of channel routing reaches (RCHRES's). Figure 5.3 shows the subwatershed boundaries corresponding to the pervious land segments and the thirty-seven points at which flows were generated.

The physical parameters of the subwatersheds are indicated in Table 5.4. These were derived in the following manner:

- Drainage area was measured by planimeter from 1:50 000 topographic maps.

- Overland slope was measured from a 1:50 000 topographic map at the nodes of a 5 km grid. These were than averaged over each land segment.

- The percentage of each land segment under the land uses forest and bush; swamp and wetland and agriculture were derived from the Agricultural Component Background Study provided by the South Nation River Conservation Authority.

- Soils data although not directly utilized in deriving model parameters was obtained from Ontario Soil Survey maps of those counties within the basin (4, 5, 6, 7, 8, 9).

The reach slopes and lengths for the channel routing components are also indicated in Table 5.4. This information was derived from the 1:50 000 topographic maps. Stage-storage,

TABLE 5.4

Physical Parameters of the Sub-areas Used in the HSP-F Model of the South Nation River

Pervious Land Segment No.	Land Segment Name	Drainage Area km² (mi²)	Land Use Type % Forest[1]	% Swamp	% Agriculture	Surface Slope	Routing Reach Details No.	Length km	(mi)	Slope
5	Plantagenet	854.6 (330.2)	33.7	4.2	62.1	0.0140	15	14.9	(9.2)	0.0001
							20	10.9	(6.7)	0.0001
							205	10.5	(6.5)	0.0013
							25	23.2	(14.3)	0.0006
							105	19.6	(12.1)	0.0008
							5[2]	10.0	(6.2)	0.0005
							10[2]	4.4	(2.7)	0.0001
6	Russell	286.0 (98.9)	35.1	0.1	64.8	0.0052	315	2.6	(1.6)	0.0001
							320	16.0	(9.9)	0.0012
							325	20.1	(12.4)	0.0014
7	Spencerville	238.0 (92.0)	58.2	5.6	36.2	0.0090	85	3.6	(2.2)	0.0000
							90	17.7	(10.9)	0.0014
8	Bourget	373.9 (144.5)	39.9	0.3	59.8	0.0075	210	8.4	(5.2)	0.0005
							215	18.1	(11.2)	0.0005
9	Chesterville	(684.5) 264.5	33.5	3.1	63.4	0.0033	60	20.3	(12.5)	0.0007
							505	8.6	(5.3)	0.0004
							605	15.1	(9.3)	0.0007
							75	26.4	(16.3)	0.0007
							750	10.0	(6.2)	0.0009
							705	30.1	(18.6)	0.0008
12	Prescott (E.S.R.)	72.5 (28.0)	40.8	0.8	58.4	0.0102	120	18.6	(11.5)	0.0019

TABLE 5.4 (cont'd)

Physical Parameters of the Sub-areas Used in the HSP-F Model of the South Nation River

Pervious Land Segment No.	Land Segment Name	Drainage Area km[2] (mi[2])	Land Use Type			Surface Slope	Routing Reach Details			
			% Forest[1]	% Swamp	% Agriculture		No.	Length km	Length (mi)	Slope
13	Casselman	508.0 (196.3)	26.6	0.2	73.2	0.0035	305	21.5	(13.3)	0.0008
							350	8.1	(5.0)	0.0004
							45	26.4	(16.3)	0.0004
							405	6.5	(4.0)	0.0016
16	Ebrum	79.9 (30.9)	14.5	0.1	85.4	0.0035	355	15.1	(9.3)	0.0012
17	Heckston	79.8 (30.8)	59.4	4.9	35.7	0.0035	610	5.3	(3.3)	0.0013
18	Prescott (W.S.R.)	94.0 (36.3)	36.3	1.6	62.1	0.0140	155	3.2	(2.0)	0.0022
							160	14.1	(8.7)	0.0024
19	Limoges	91.3 (35.3)	32.7	0.1	67.2	0.0075	250	12.6	(7.8)	0.0004
20	Kenmore	179 (69.3)	28.7	4.1	67.2	0.0052	330	28.2	(17.4)	0.0004
21	Russell (E.C.R.)	143.7 (55.5	14.7	3.8	81.5	0.0035	348	27.7	(17.1)	0.0004

TABLE 5.4 (cont'd)

Physical Parameters of the Sub-areas Used in the HSP-F Model of the South Nation River

Pervious Land Segment No.	Land Segment Name	Drainage Area km[2] (mi[2])	Land Use Type			Surface Slope	Routing Reach Details			
			% Forest[1]	% Swamp	% Agriculture		No.	Length km	Length (mi)	Slope
22	Berwick	147.6 (57.0)	33.9	1.5	64.6	0.0035	410	6.5	(4.0)	0.0022
							415	12.6	(7.8)	0.0011
23	Carlshad	55.7 (21.5)	43.9	0.0	56.1	0.0075	220	11.0	(6.8)	0.0008

1 'Forest' includes bush and overgrown idle land.
2 Below gauge point.

stage-discharge and stage-water surface area relationships were derived from two sources:

- Field surveyed cross-sections obtained at 27 locations throughout the watershed. These were also used in the flood prone area identification part of the study.

- HEC-2 backwater model data and flood plain mapping at Plantagenet, Chesterville, Bear Brook and Vernon.

The actual curves stored as F-tables in HSP-F were derived using the program XSECT developed by Hydrocomp Inc.

Table 5.4 indicates that one group of the HSP-F model parameters including drainage area, overland slope and percent forest cover can be directly initialized from physical measurements. The remaining parameters however are calibration values and must be initialized by alternative methods. Some of these parameters including the fraction of the basin shaded, SHADE; Manning's roughness for the surface routing component, NSUR; the interception storage, INTCEP; and the lower zone evaporation parameter, LZETP are closely related to land use and can be expected to change as land use varies. Consequently, the values of these parameters were derived from simple relationships relating to the percent of the area covered by forest and agriculture. These relationships were determined on the basis of coarse preliminary model runs and values available in the literature. For example, interception storage values of 2.5 mm and 5.0 mm (0.1 and 0.2 in) were indicated in the literature (10, 11) for grassland and heavy forest cover respectively. Hence the relationship:

INTCEP = 0.01 (0.2 F + 0.1 A)
where F is the percent forest cover
and A is the percent agriculture in the basin was used to determine this parameter.

Non-agricultural land uses such as wetlands and idle lands are assigned interception values similar to forest cover.

The relationships:

NSUR = 0.01 (0.4 F + 0.2A)
SHADE = 0.01 (F + 0.3 A)
LZETP = 0.01 (F + 0.3 A)

were used to derive values of Manning's roughness coefficient for surface routing, the shade parameter and the lower zone evapotranspiration parameter respectively.

The remaining model parameters were initialized on the basis of discussions with the HSP-F model's original author, Dr. N. Crawford. A range of typical parameter values, as shown in Table 5.5, was provided based on Dr. Crawford's experience in applying the model in many different types of watershed throughout the United States.

5.4 Model Calibration and Validation

5.4.1 Objectives of the Calibration/Validation Process

The term "calibration" refers to the adjustment of a model's parameters in order to match the model's simulated value of some variable to that actually observed. In general the

TABLE 5.5

Typical Range of Values for HSP-F Parameters[1]

Type of Parameters	Name of Parameter	Typical Range
Snowmelt	SNOWCF	1.1 - 1.2
	TSNOW	28 - 33
	CCFACT	0.0 - 1.0
	COVIND	1.0 - 2.0
	MWATER	0.03 - 0.05
	MGMELT	0. - 0.01
Pervious Area Runoff	INFILT	0.01 - 0.02
	INTFW	1.5
	LZSN	7.0 - 9.0
	UZSN	0.12 LZSN - 0.15 LZSN
	AGWRC	0.9 - 0.995
	IRC	0.5
	LZETP	0.3 - 0.4
	LSUR	250 - 500
	CEPSC	0.06 - 0.08
	KVARY	0.

For PETMAX, PETMIN, INFEXP, INFILD, DEEPER, BASETP, AGWETP use default values.

(1) As provided by Dr. N. Crawford, the model's original author in Imperial Units.

simulated streamflow for a watershed is the variable of interest. Since most models, including HSP-F, contain parameters which cannot be directly measured from available information the objective of calibration is to obtain values of these parameters such that the model will accurately reproduce the hydrologic response of the watershed.

Validation refers to the checking of the model's performance using an independent set of data from that used for calibration. In general this set of data will be from the same flow gauge but from a different time period. This process ensures an objective assessment of the model's response. It is particularly valuable if the validation period contains hydrologic events of a type not found during the calibration period. If this period is reproduced accurately then greater confidence is gained in the model's ability to reproduce unusual or extreme hydrologic conditions outside the calibration range.

Although the calibration/validation process is extremely important, there are limitations which must be recognized in determining the level of effort assigned to this task. The main limitations are imposed by the accuracy of the available data. It is well known, for example, that measured streamflows have an accuracy of order of 10 percent during open water and lower accuracy during ice periods. In addition many stage-discharge curves at Water Survey of Canada gauges are based upon low to mid-range flows using extrapolation for high flows. Hence the accuracy of peak flow measurements will be lower than during normal periods. Discussions were held with officials of Water Survey of Canada during the early part of this study with respect to accuracy of the data available (see Table 5.3). The limitations of the information is indicated in Table 5.6.

The model input data, particularly precipitation, is similarly susceptible to error. Hence, during the calibration/validation process it is generally best to reproduce the long-term hydrologic properties such as seasonal runoff volumes, rates of accession and recession of the hydrographs, flow-duration properties and flood-frequency responses. Although the reproduction of individual events should be within the range of accuracy of the data, large discrepancies in some cases will not necessarily invalidate the entire calibration/validation.

5.4.2 Calibration/Validation of the HSP-F Model of the South Nation River Basin

As previously mentioned the HSP-F model was set up using 15 pervious land segments corresponding to Water Survey of Canada gauge points. Calibration was therefore possible to some extent at each of these points. The five year period 1 October 1974 to 30 September 1979 was used for calibration at the six gauges noted on Table 5.3 with records available for this duration. At the remaining gauges, the available period of record up to 30 September 1979 was used. Validation was possible at four points. For two of these at Plantagenet and Spencerville the validation period covered the remainder of the 22 yr period (1957 to 1979) for which the data base had been created. For the Russell and Prescott

TABLE 5.6

Reliability of Hydrometric Data in the South Nation River Basin

Station Name	Station Number	Comments on Reliability as Provided By Water Survey of Canada
South Nation River Near Plantagenet Springs	02LB005	Overall accuracy good; v. unreliable in summers of 1973 and 1974 due to construction in vicinity
Castor River Russell	02LB006	Occasional ice jam problems, low flows affected by weed growth and moving bed at control
South Nation River at Spencerville	02LB007	Low flow measurements unstable at this location
Bear Brook near Bourget	02LB008	Backwater problems due to ice
South Nation River at Chesterville	02LB009	Seasonal (March to May) operation only
(East Branch) Scotch River near St. Isidore de Prescott	02LB012	Rating curve problems particularly due to ice have caused some unreliable flows
South Nation River at Casselman	02LB013	Leaky weir prevents accurate low flow measurement Control moves during high flows
South Nation River at Lemieux	02LB015	Water level only, operates seasonally (March to May)
Little Castor River near Embrun	02LB016	Good accuracy at this station
North Branch South Nation River near Heckston	02LB0171	Reliable results to date but based on very short short record

TABLE 5.6 (cont'd)

Reliability of Hydrometric Data in the South Nation River Basin

Station Name	Station Number	Comments on Reliability as Provided By Water Survey of Canada
West Branch Scotch River near St. Isidore de Prescott	02LB018	New station, i.e. few measurements for rating curve, some ice jam problems
South Indian Creek near Limoges	02LB019	Low flow control is unstable, use of measurements not recommended during these periods
South Castor River at Kenmore	02LB020	Some problems with low flow measurements but generally good
East Castor River near Russell	02LB021	Only one high water discharge measurement for rating curve, low water problems with instrument
Payne River near Berwick	02LB022	Recently taken over by WSC, previous flows unreliable, problems measuring low flows
Bear Brook at Carlsbad Spring	02LB101	-

gauges the validation period was 1968 to 1974 and 1970 to 1974 respectively.

During all computer runs the simulation was started approximately 12 months ahead of the period of interest to allow the model to "warm up" thus removing the effect of any assumed initial conditions. The runs commenced in the fall before any snowpack had formed to avoid assumptions with regard to the initial areal distribution of the snowpack.

In general the calibration process made extensive use of both summaries of simulated and observed flows and graphical comparisons of flows produced on a Calcomp plotter. The method adopted in calibrating the model was:

- Adjustment of the annual runoff volumes by changing the evaporation and snowcatch factors, LZETP and SNOWCF, and the lower zone storage and infiltration parameters, LZSN and INFILT. The gauge correction factor (SNOWCF) was used to adjust recorded precipitation volumes in the winter to account for the poor catch efficiency of precipitation gauges. This is a function of both wind speed and degree of shielding. The factor was set by comparing the observed volume of runoff to the recorded volume of precipitation for the winter months of the calibration. The volume of runoff was 1.25 times the volume of precipitation for this period and the SNOWCF was set therefore to 1.25. This is representative of average wind conditions of 8 to 16 km/h.

- Adjustment of the baseflow component during low flow periods by variation of the groundwater parameters, particularly AGWREC. This was initially estimated from baseflow records but adjusted as necessary during calibration to match observed flows.

- Adjustment of the interflow component during the recession of major events using the interflow parameters IRC and INTFW and the convection melt factor (CCFACT) for snowmelt events. This parameter (CCFACT) is used to fit the theoretical snowmelt equations to field conditions in the modelled watershed. It affects the timing and magnitude of the peak flows due to snowmelt. It was set by adjusting the simulated snowmelt peaks to match the shape and timing of the observed snowmelt peaks.

- Adjustment of the surface runoff component to match peak flows. For small summer rainfalls the upper zone storage, UZSN, was used to control the volume of runoff.

To some extent the process is iterative since the parameters are not independent and a change in one parameter may require subsequent adjustment of a previously tuned parameter. Emphasis in the calibration procedure was on those parameters indicated as having the greatest sensitivity as discussed in sections 5.2.1 and 5.2.2.

The validation procedure consisted of running the calibrated model for the independent period of data without changing the model parameters. Comparisons of the simulated and observed responses were then carried out. The results of the validation runs were satisfactory and required no further model adjustments.

5.4.3 Results of the Calibration/Validation

An initial overview of the model calibration is provided in Table 5.7. The observed and simulated runoff volumes at the 15 calibration points over the five year calibration period or over the gauge period of record are presented. For those stations with 3 or more years of record the observed and simulated runoff volumes agree within ±10%. The agreement is particularly good (∓5%) at the four stations with 10 or more years of record.

A more detailed comparison of the observed and simulated hydrologic responses is indicated in Figures 5.4 to 5.20. Individual events were considered during the calibration and most events compare favourably. However, the primary calibration criteria was an accurate simulation of flows for long periods of record. In order to compare well on a statistical basis it was necessary to adjust the model's parameters in an "average" manner such that some events were slightly over-estimated while others were under-estimated. The following points are worth noting with respect to the simulations:

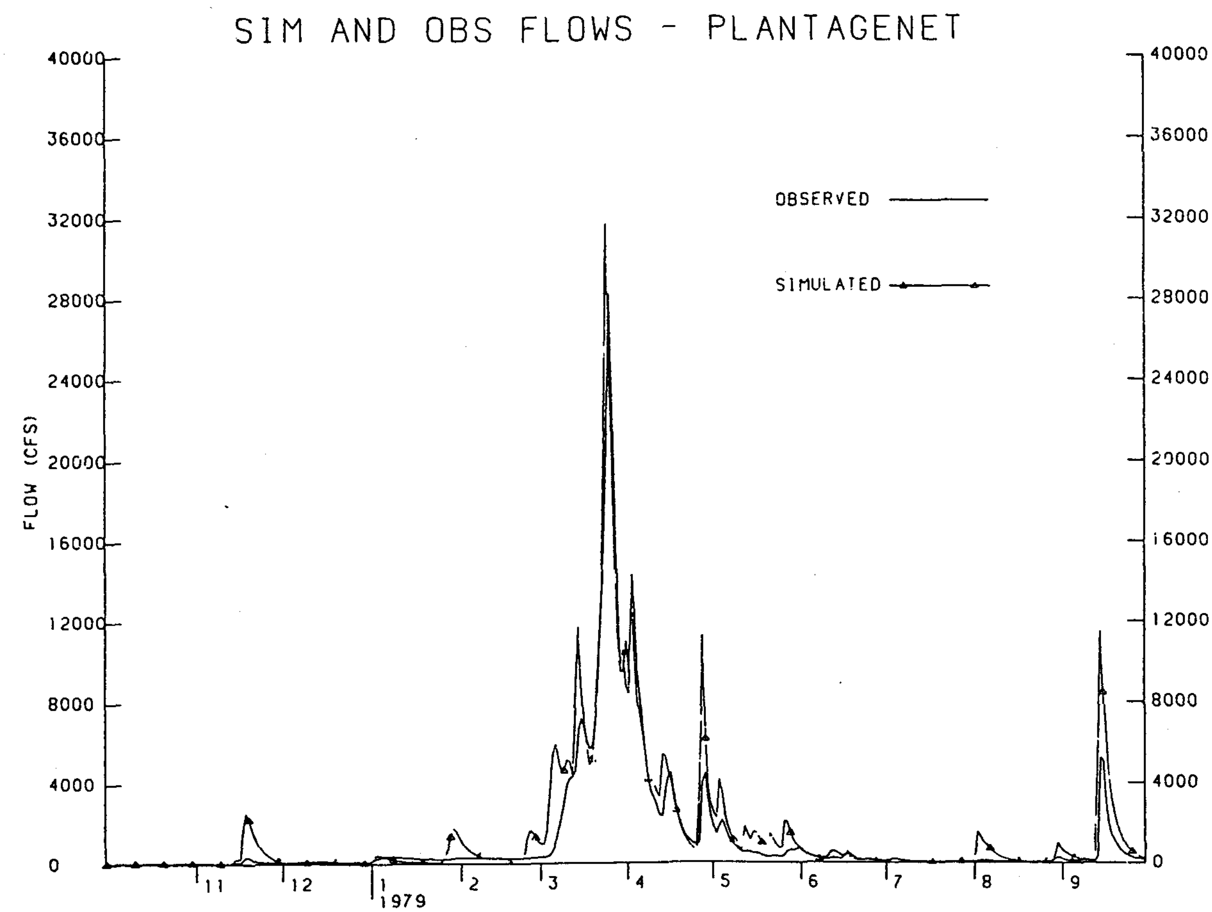
1) Figure 5.4 shows a graphical comparison of daily observed and simulated flows at the Plantagenet gauge for the year 1979. Both the observed annual peak flow of 801 m^3/s (28 287 cfs) and the average flow for this year 36 m^3/s (1271 cfs) were close to the mean (735 m^3/s and 41 m^3/s respectively) for the period of record. The simulation corresponds well with the observed flows with the simulated annual peak of 900 m^3/s (31 811 cfs) being about 12% higher than the observed peak. The simulated peak occurs on 25 March; one day before the observed

TABLE 5.7

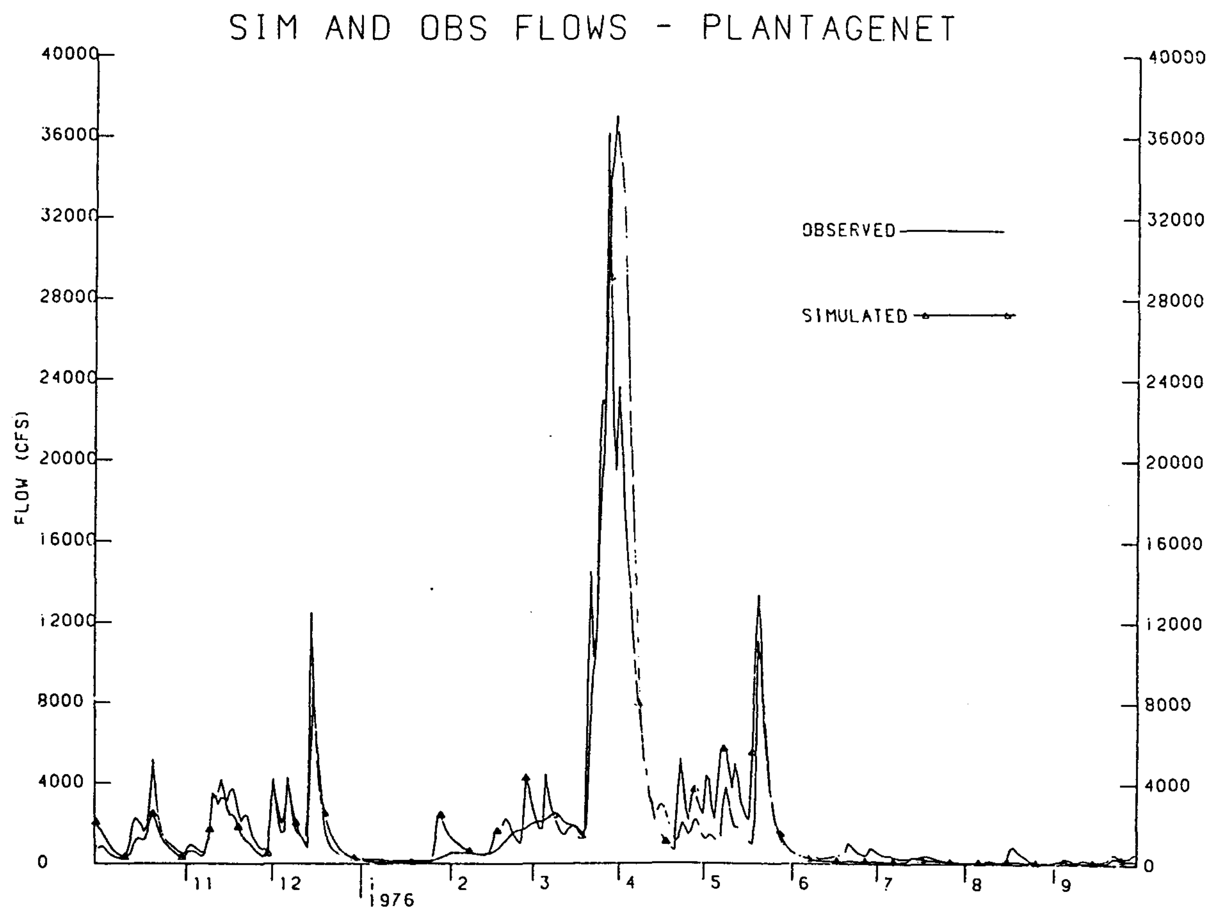
Comparison of Observed and Simulated Annual Runoff Volumes
(Based on the October to September Water Year)

Name	Station Number	Number of Years Comparison	Annual Runoff Volume Observed m^3/s	(cfs)	Simulated m^3/s	(cfs)	Difference %
South Nation River near Plantagenet Springs	02LB005	22	41.2	(1456)	43.3	(1530)	+5
Castor River at Russell	02LB006	12	5.81	(205.2)	5.82	(205.5)	<1
South Nation River at Spencerville	02LB007	22	2.8	(99.9)	2.7	(96.7)	-3
Bear Brook near Bourget	02LB008	3	6.3	(221)	6.6	(233)	+5
South Nation River at Chesterville	02LB009	2	18.8	(664)	15.8	(558)	-16
(East Branch) Scotch River near St. Isidore de Prescott	02LB012	10	1.1	(37.3)	1.0	(35.7)	-4
South Nation River at Casselman	02LB013	4	29.8	(1051)	32.9	(1161)	+10
Little Castor River near Embrun	02LB016	2	1.1	(39.1)	1.2	(44.1)	+13
North Branch South Nation River near Heckston	02LB017	2	1.0	(34.2)	1.2	(40.9)	+19
Water Branch Scotch River near St. Isidore de Prescott	02LB018	<1	1.6	(54.8)	1.9	(66.7)	-
South Nation Creek near Limoges	02LB019	<1	0.8	(26.8)	1.4	(50.1)	-
South Castor River at Kenmore	02LB020	<1	1.5	(52.3)	2.2	(77.8)	-
East Castor River near Russell	02LB021	<1	1.3	(44.5)	2.0	(71.3)	-
Payne River near Berwick	02LB022	3	2.1	(72.4)	1.9	(65.8)	-9
Bear Brook at Carlsbad Springs	02LB101	3	1.2	(43.6)	1.0	(35.6)	-18

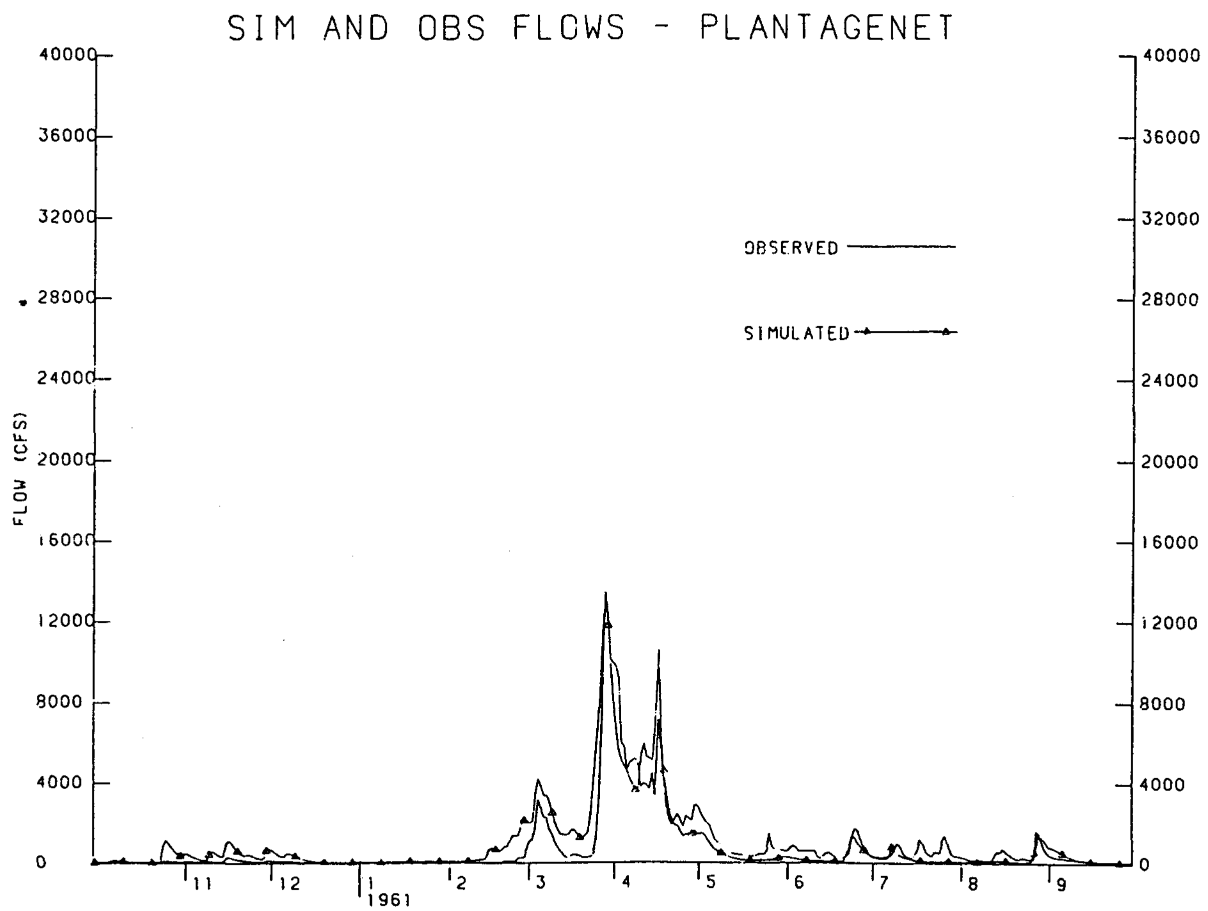
Observed and Simulated Daily Flows at Plantagenet for 1979 Water Year



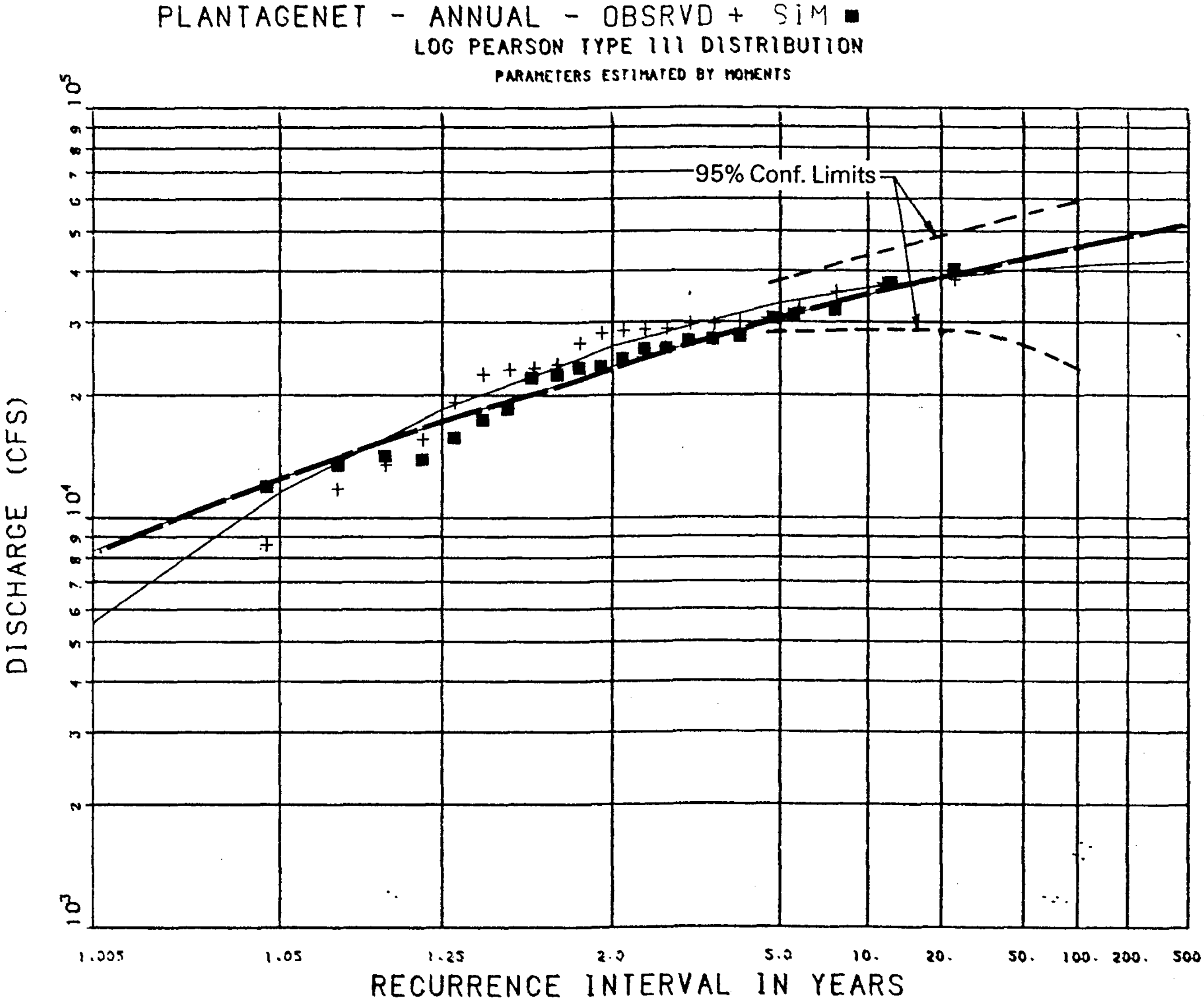
Observed and Simulated Daily Flows at Plantagenet for 1976 Water Year



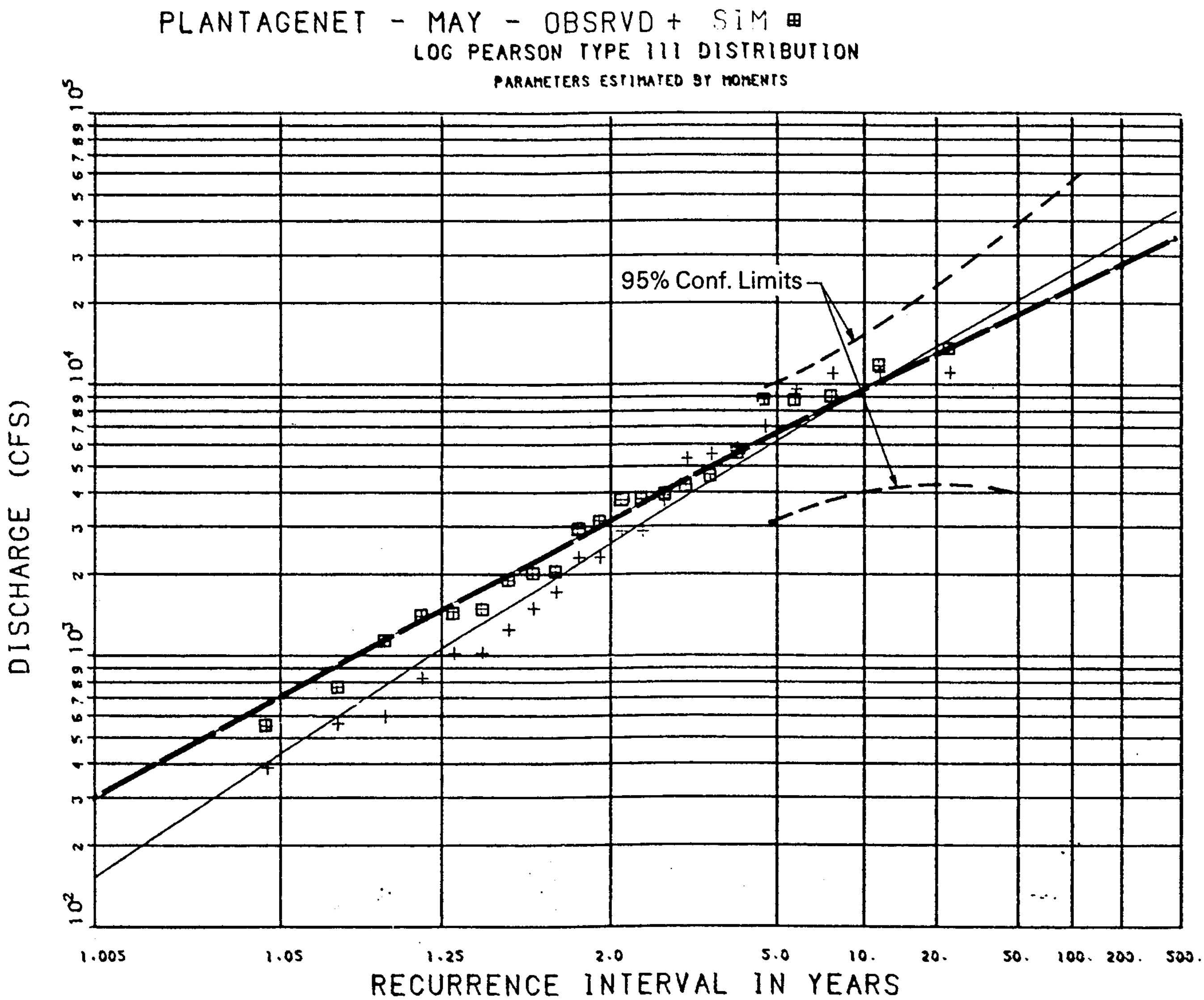
Observed and Simulated Daily Flows at Plantagenet for 1961 Water Year



Comparison of Annual Peak Flow Frequency Curves for Observed and Simulated Flows at Plantaganet, 1958–1979



Comparison of May Peak Flow Frequency Curves for Observed and Simulated Flows at Plantaganet, 1958–1979



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Comparison of Summer Peak Flow Frequency Curves for Observed and Simulated Flows at Plantaganet, 1958–1979

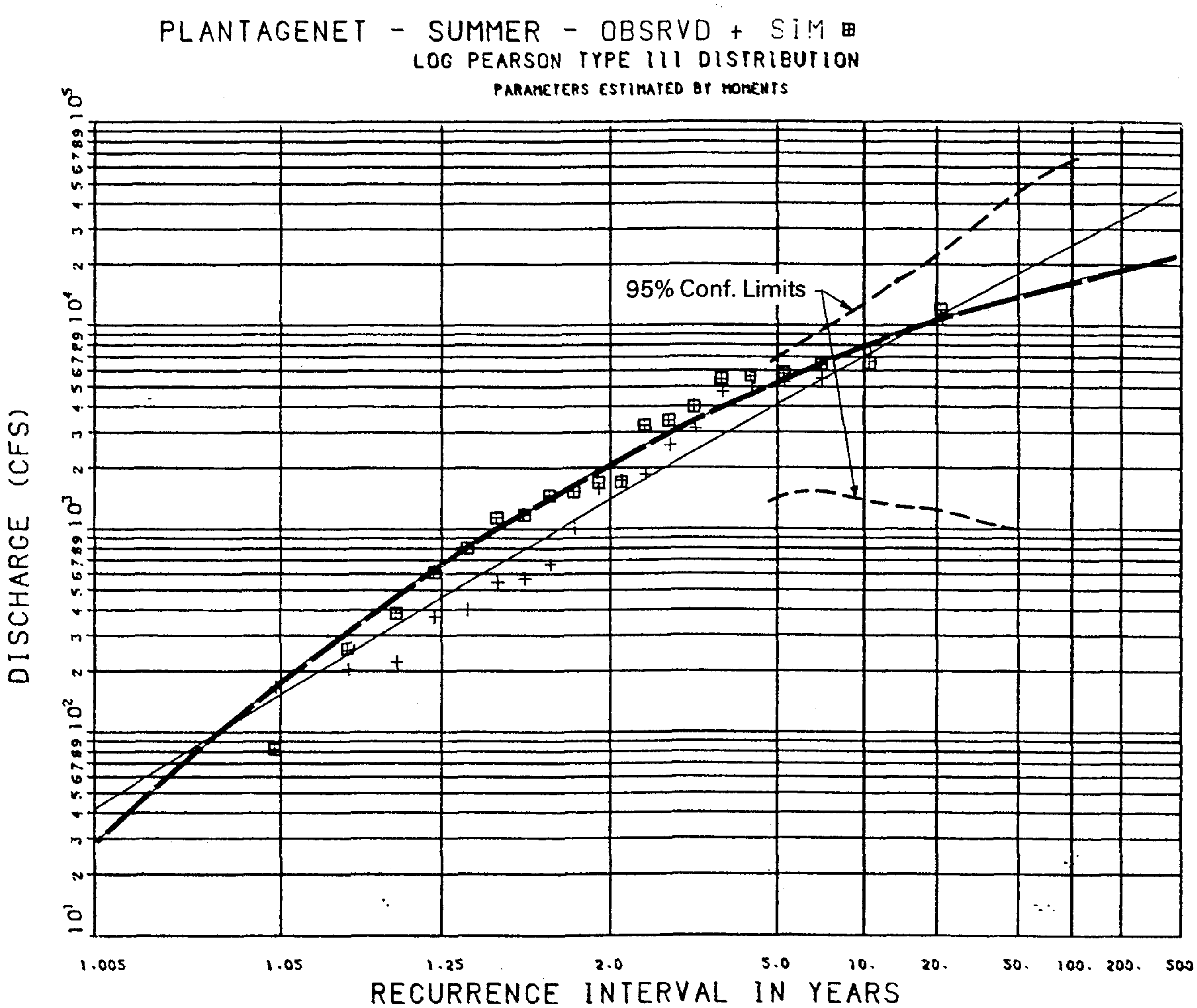


Figure 5-10

Comparison of Annual Peak Flow Frequency Curves for Observed and Simulated Flow Using a 2 Hour Time Step at Plantaganet, 1958–1979

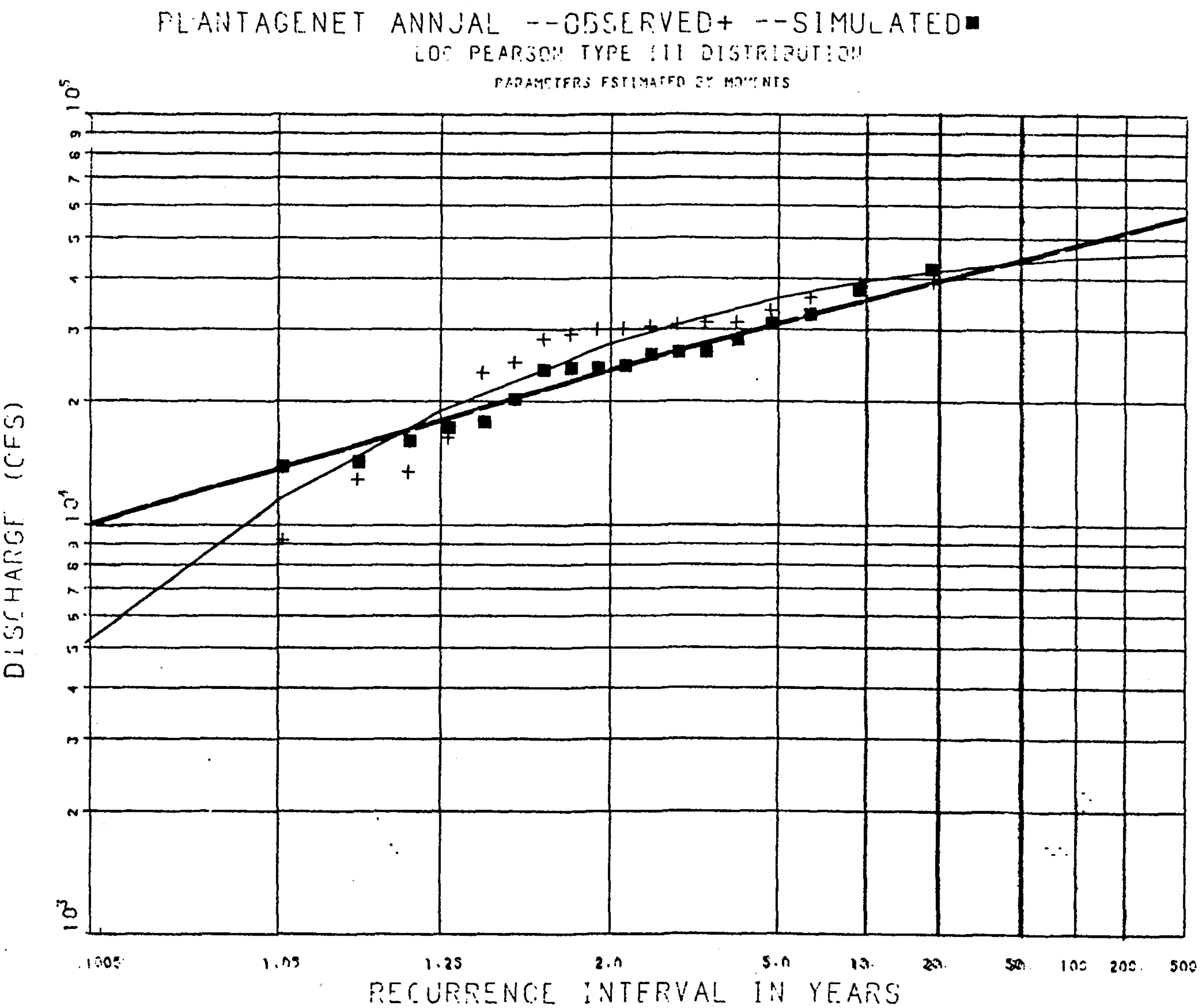


Figure 5-11

Flow Duration Curves for Observed and Simulated Flows at Plantagenet, 1958-1979

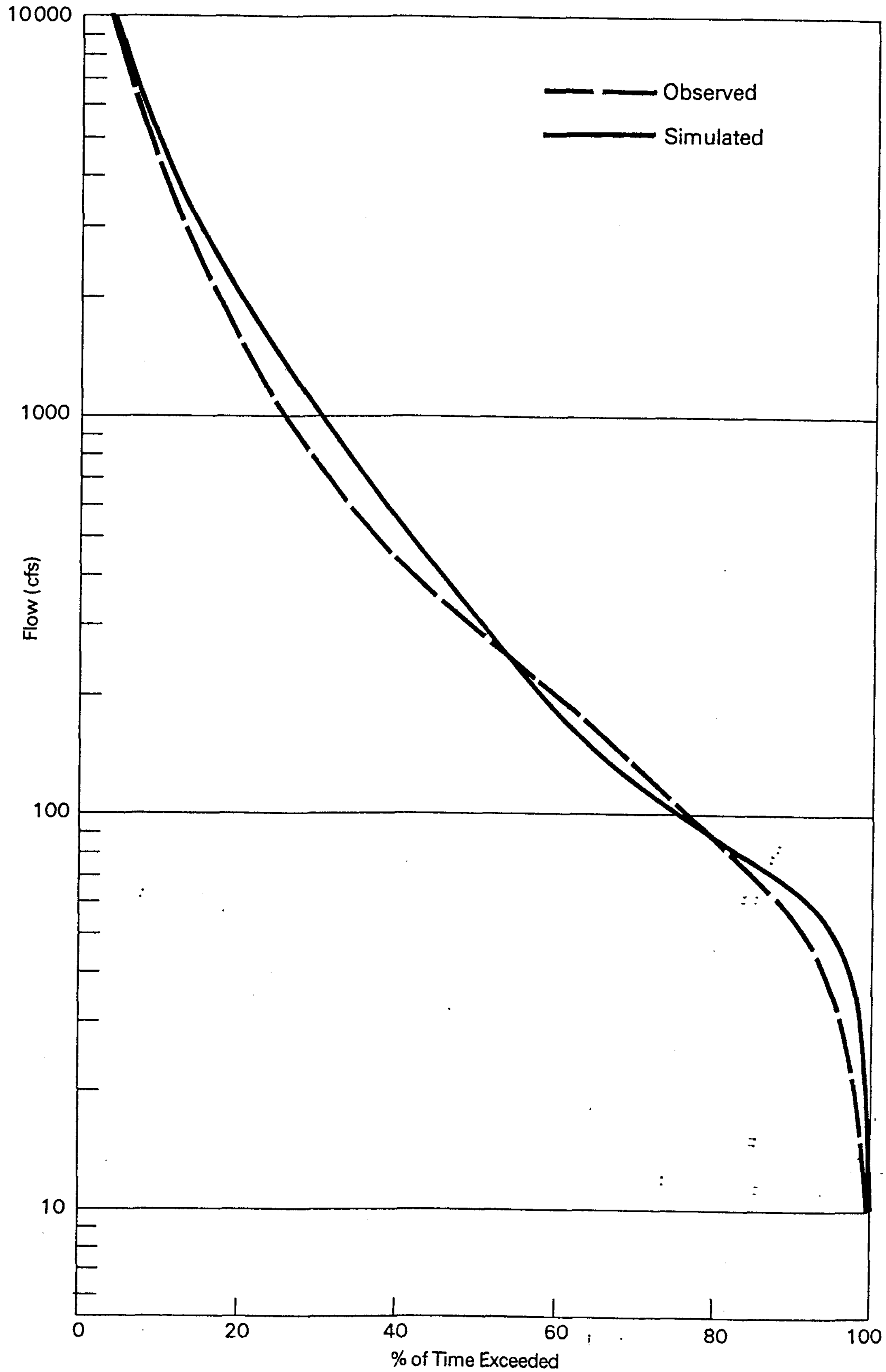


Figure 5-12

Comparison of Observed and Simulated Flows for Low Flow Period, July to November 1964

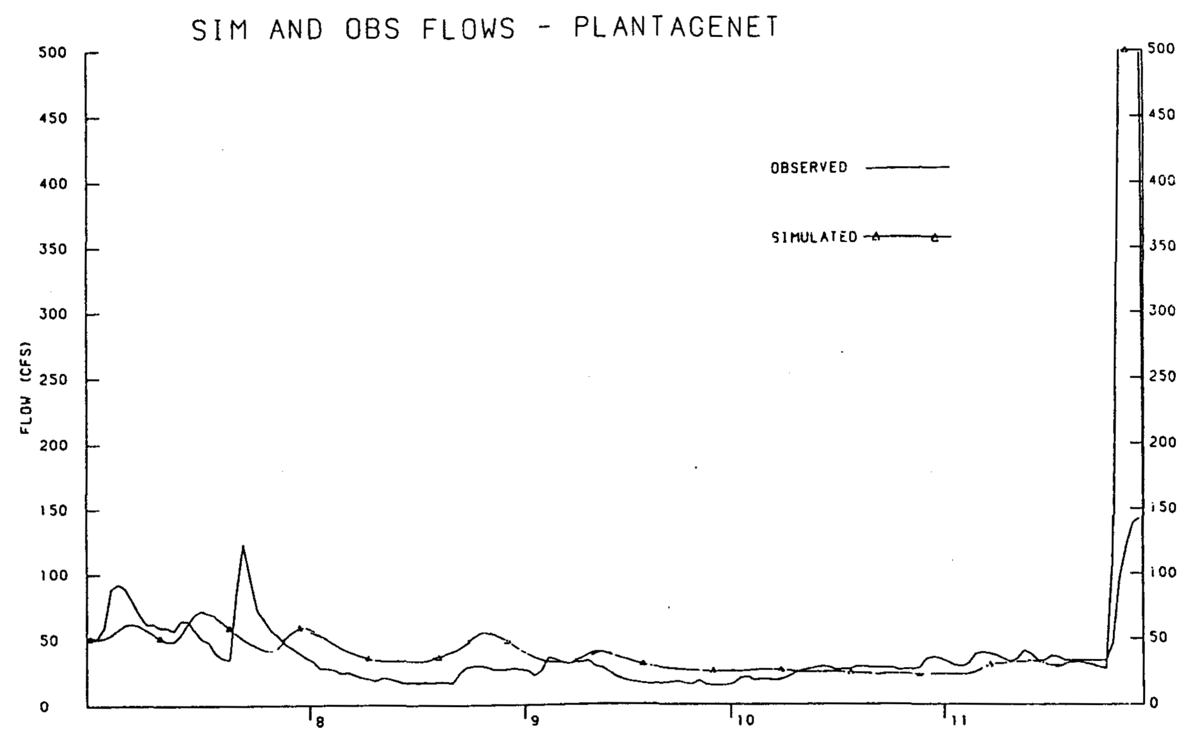
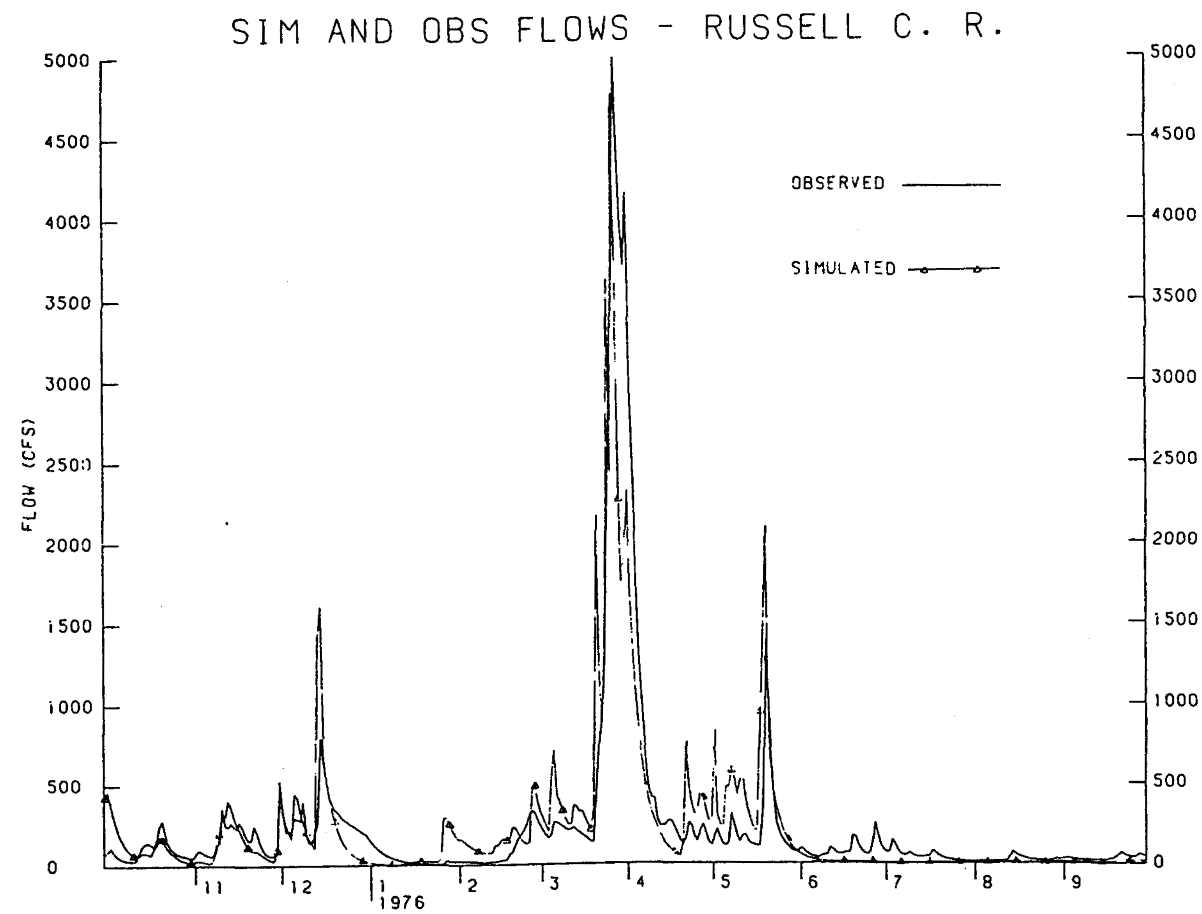
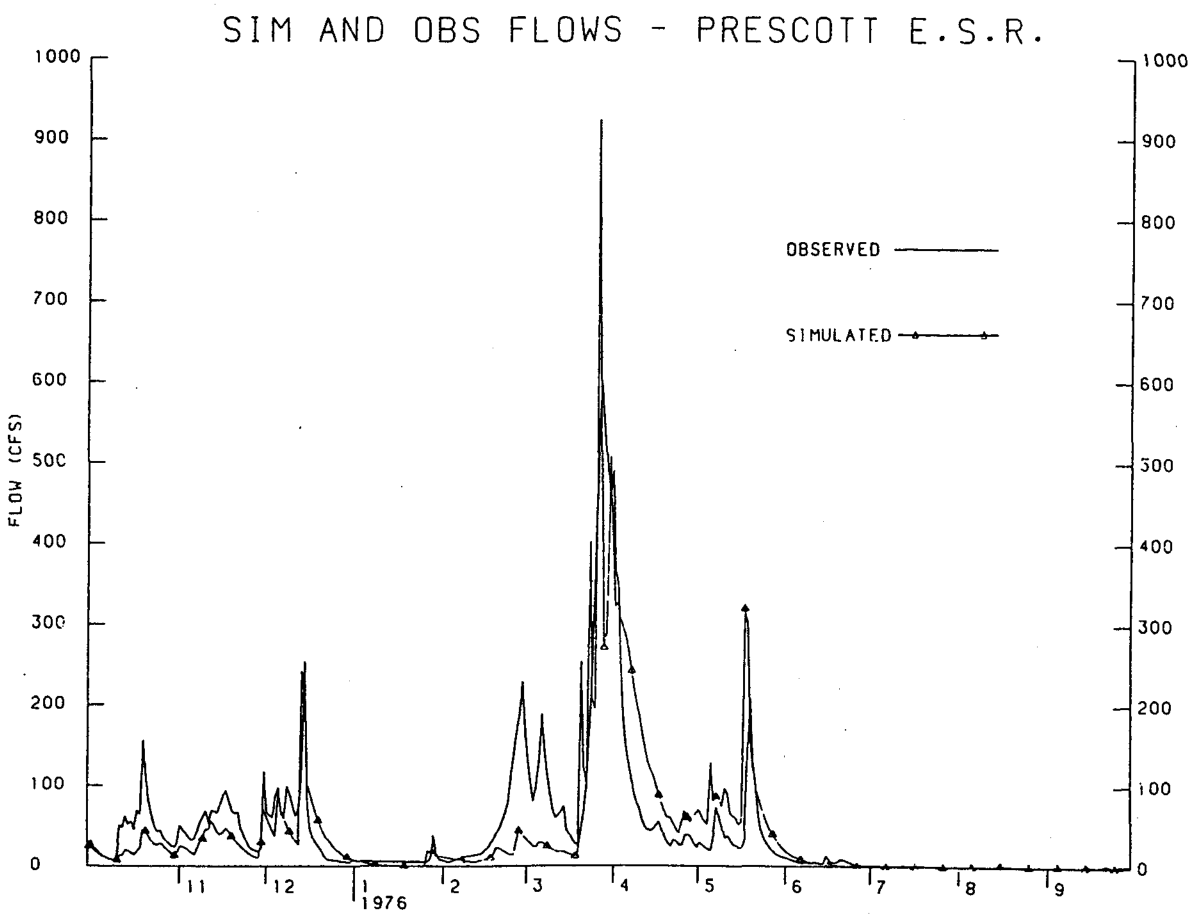


Figure 5-13

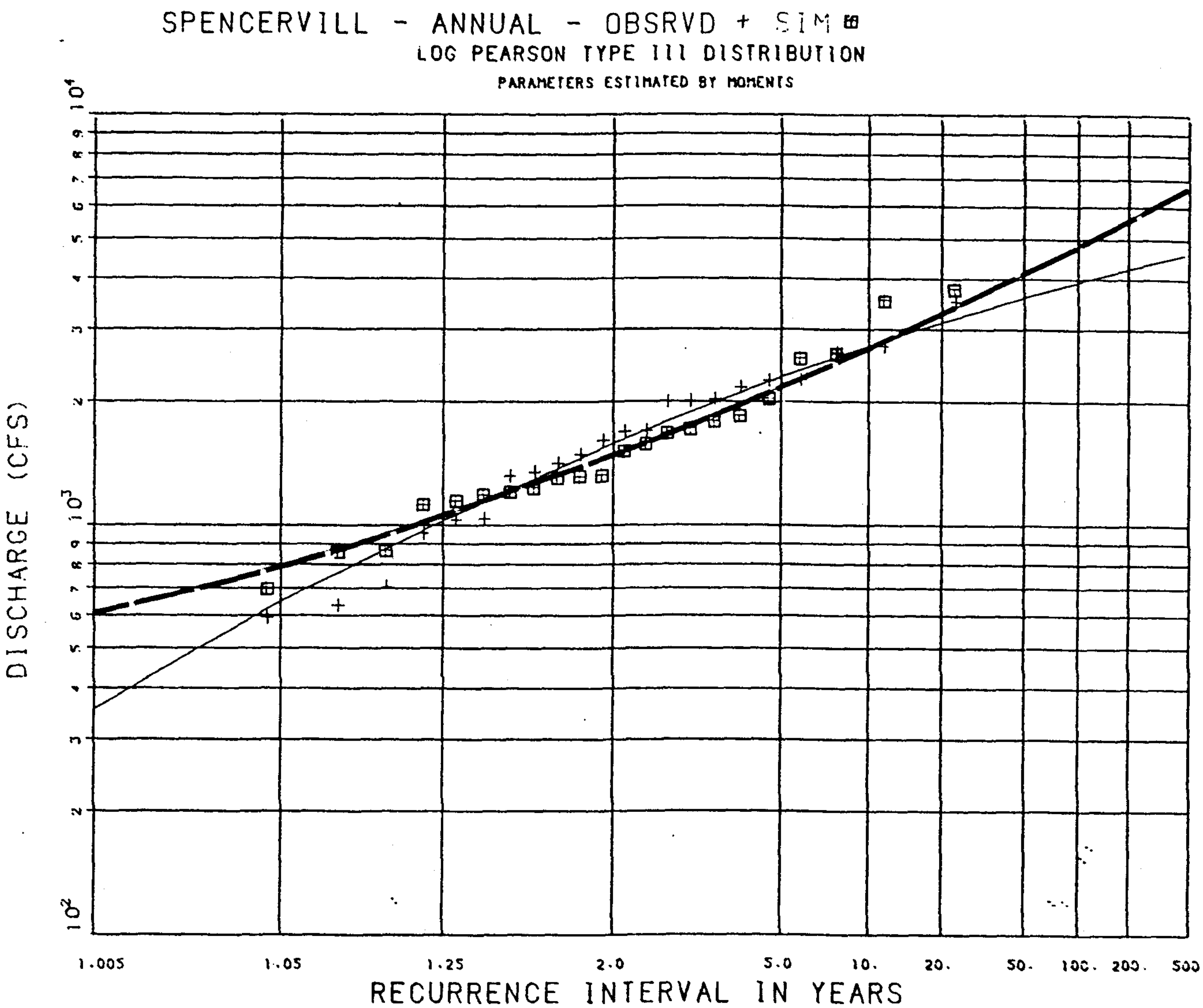
Observed and Simulated Daily Flows at Russell, Castor River for Water Year 1976



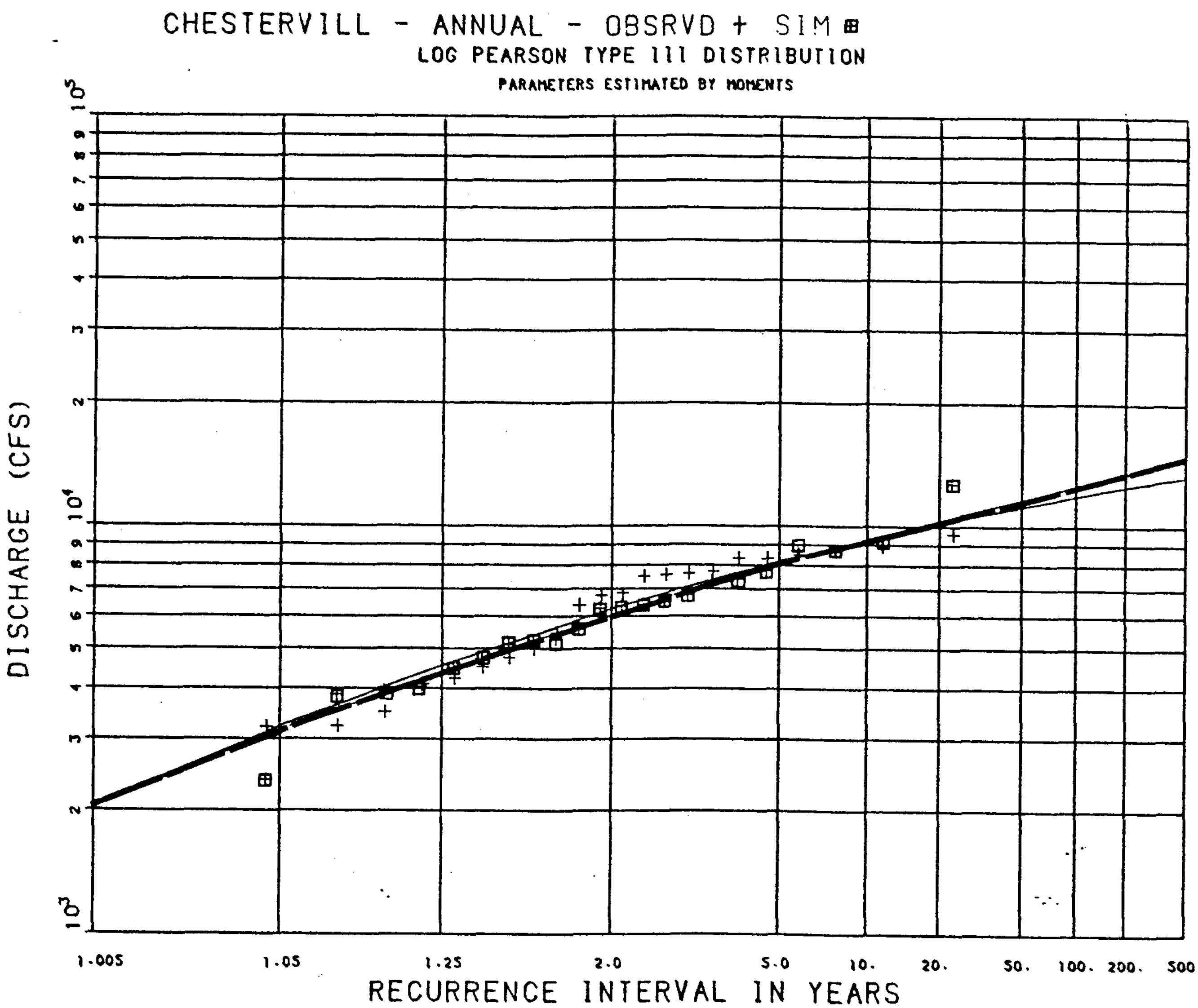
Observed and Simulated Daily Flows at Prescott E. Branch, Scotch River for Water Year 1976



Comparison of Annual Peak Flow Frequency Curves for Observed and Simulated Flows at Spencerville, 1958–1979



Comparison of Annual Peak Flow Frequency Curves for Observed and Simulated Flows at Chesterville, 1958–1979



Comparison of Annual Peak Flow Frequency Curves for Observed and Simulated Flows at Russel, Castor River 1969-1979

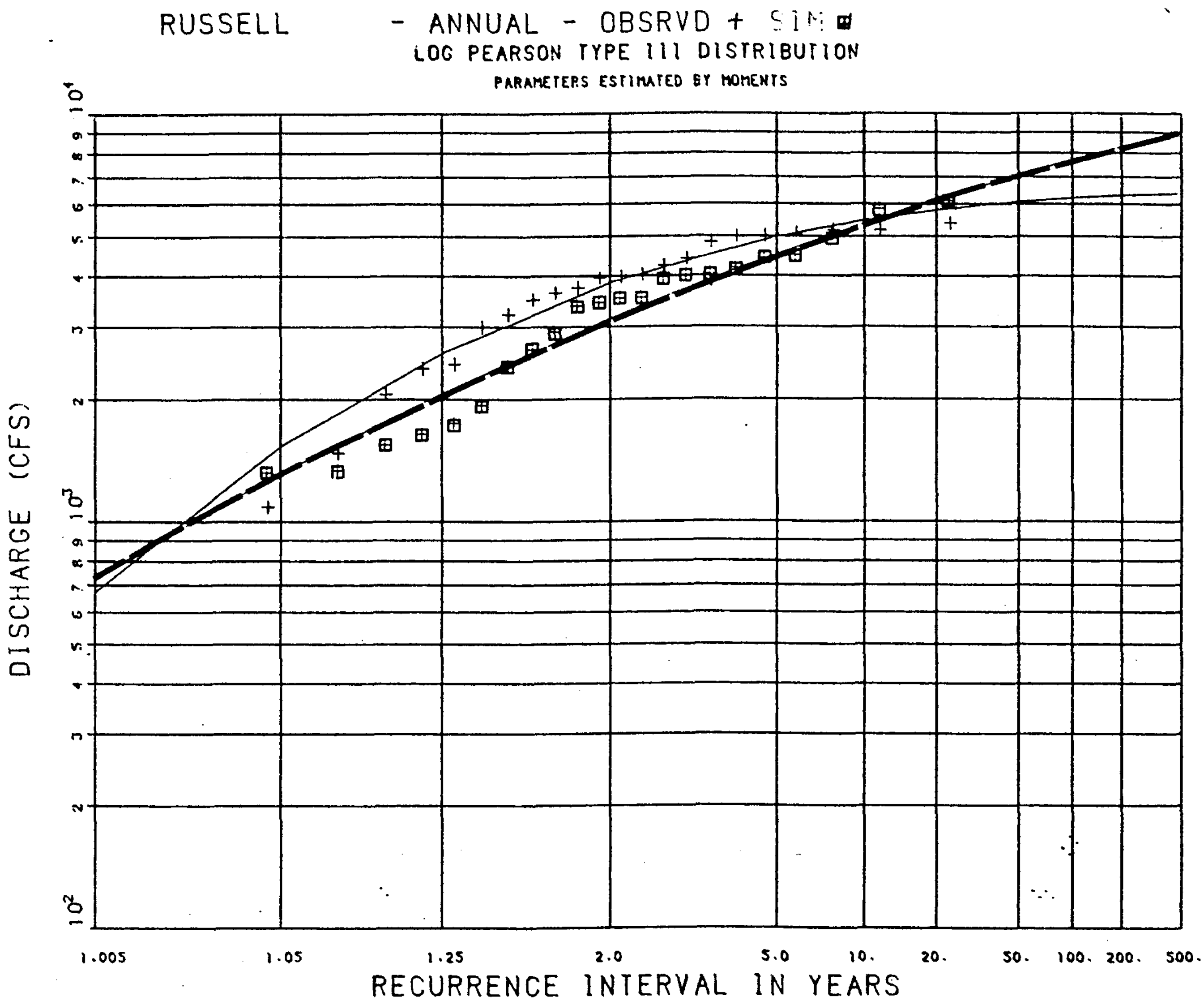


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Figure 5-18

Flow Duration Curves for Observed and Simulated Flows at Spencerville, 1969-1979

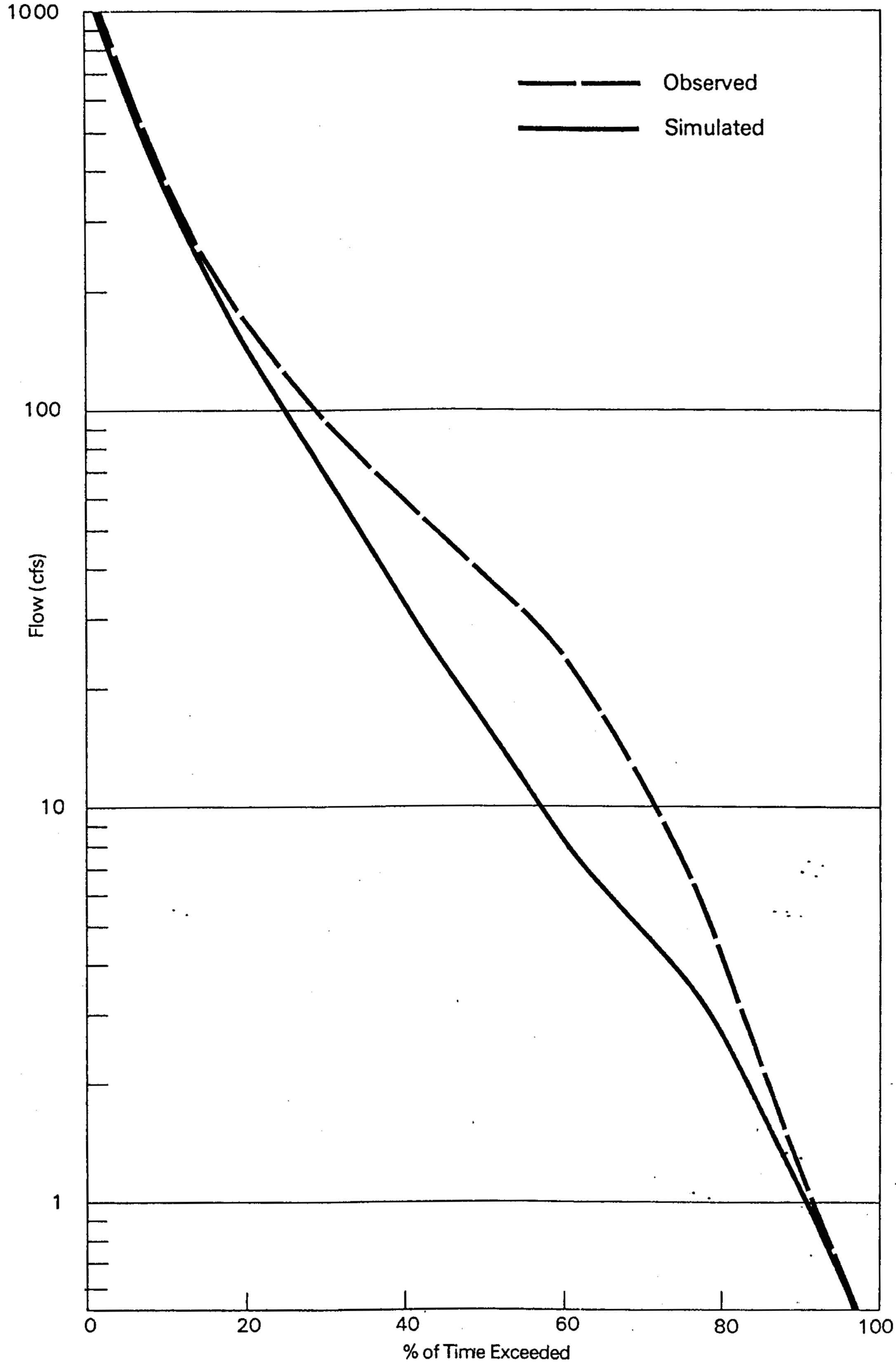


Figure 5-19

Flow Duration Curves for Observed and Simulated Flows at Russell, 1969-1979

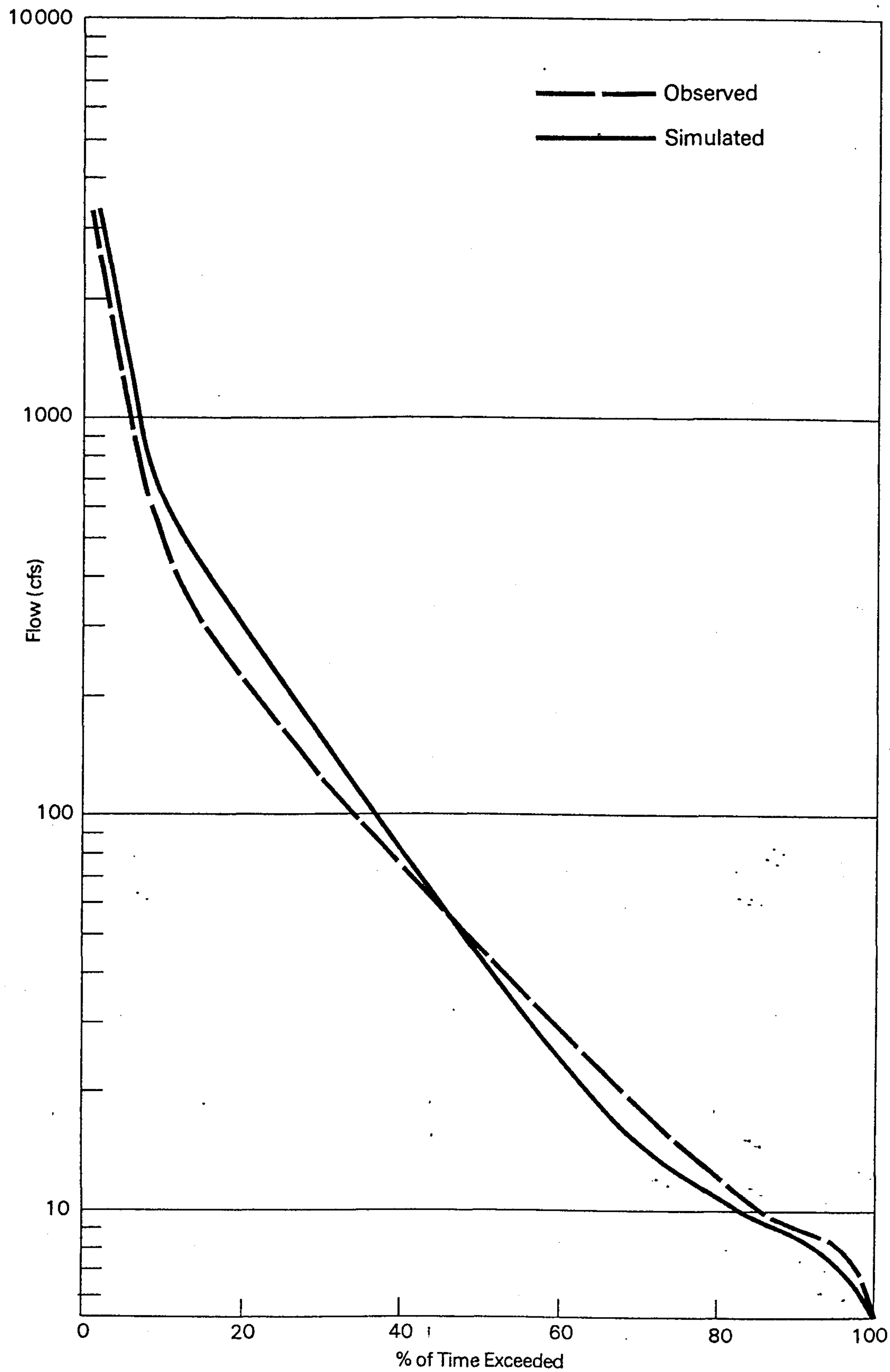
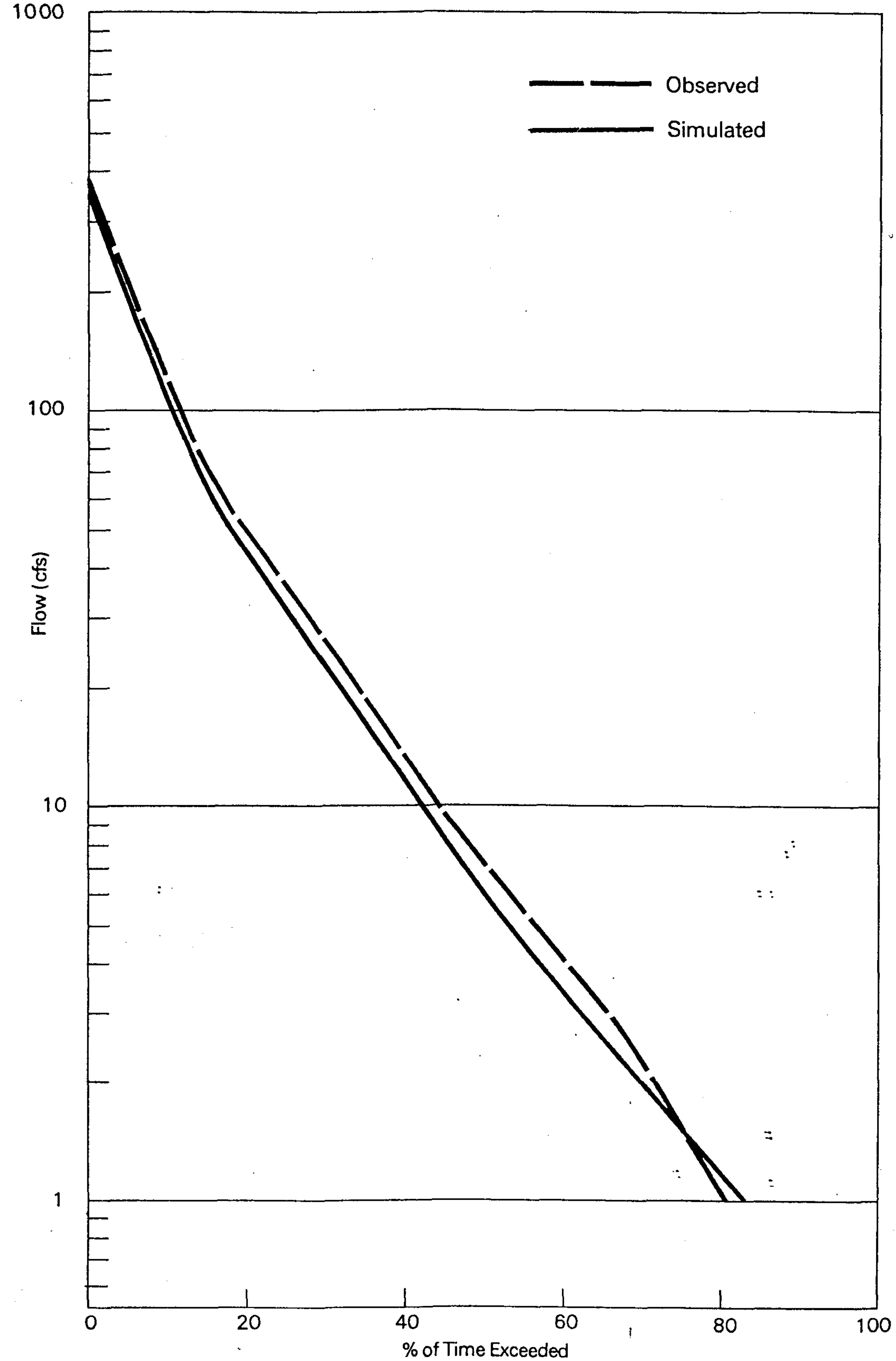


Figure 5-20

Flow Duration Curves for Observed and Simulated Flows at Prescott, 1970-1978



peak. Secondary peaks occurring in April and September are also relatively well matched (385 m^3/s and 327 m^3/s simulated as opposed to 407 m^3/s and 149 m^3/s observed). On a month-by-month basis the correlation between observed and simulated flows is good with a coefficient of determination of 0.98. This indicates a good representation of the seasonal variation of runoff. Also worth noting is the good correspondence in the shape of the hydrographs.

2) Figure 5.5 shows a comparison between observed and simulated daily flows at Plantagenet for a 'wet' year. During the year 1976 the mean annual recorded flow was 63.2 m^3/s (2233 cfs) about 49% higher than the average for the period of record. Similarly the peak annual flow of 1050 m^3/s (37 081 cfs) was 43% higher than the mean annual flood and was the fourth highest on record. As indicated in Figure 5.5, the simulated flows correspond well with the observed flows with the simulated annual peak of 1026 m^3/s (36 221 cfs) being about 2% low. Over the complete year the mean flow was 62.6 m^3/s (2212 cfs), about 1% low. There was a slight discrepancy in timing of the peak annual flow with the simulated flow occurring about 3 days early.

3) Figure 5.6 shows a comparison between observed and simulated daily flows at Plantagenet for a 'dry' year. During 1961 the mean annual flow recorded was 22.9 m^3/s (810 cfs) which is about 44% below the mean for the period of record. The peak annual flow was 382 m^3/s (13 489 cfs) about 48% below the mean annual flood and the fifth lowest annual peak recorded in the 49 years of

record. The modelled flows also indicated an unusually 'dry' year with a mean annual flow of 26.5 m^3/s, about 14% above the observed value. The peak flow simulated was 378 m^3/s (13 372 cfs) about 1% low. The simulated peak also occurred on the same day, 29 March, as the observed peak. Of particular interest is the fact that the year 1961 is part of the validation period rather than the calibration period for the model. The calibration period was in fact close to normal for the period of record: an average flow of 43.0 m^3/s as opposed to 42.3 m^3/s for the entire record. It is therefore encouraging that the model can reproduce the characteristics of a 'dry' year using parameters derived in a period of average flow. The correspondence between observed and simulated flows for other validation years is also good as indicated by the computer plots which have been retained by the Conservation Authority.

4) The previous discussion has indicated the model's performance during specific years. In a broader sense, a comparison of flood frequency curves and flow duration curves derived from the modelled and observed flows demonstrates the ability of the model to reproduce the statistical characteristics of the watershed response. Figures 5.7, 5.8 and 5.9 present the results of frequency analyses of peak annual flows, peak flows in May and peak flows during the summer (June to September) for Plantagenet. In each case the correspondence between the curves based on the observed and simulated flows is very good since the slope and position of the curves are very similar. As an example, for the peak annual flows the difference in the mean annual flood is 10% while

at the 20 year return period which is approximately the length of the flow series analyzed the difference is less than 1%.

For more extreme flood events, estimates of flood peaks based on a frequency analysis of simulated and observed flows over a 20 year period will diverge as noted in Table 5.8. It is emphasized that during the 1958-1979 observation period which was used for comparison purposes, events greater than a 25 year magnitude have not been recorded. Therefore, both simulated and observed estimates of 50 year and 100 year events are an extrapolation based on smaller floods.

Nevertheless, at Plantagenet, the simulated 100 year annual peak is 10% higher than the value computed from observations while the 50 year and 100 year summer peaks are 24% and 35% lower, respectively. The simulated 100 year annual peak on the Castor River at Russell is similarly 19% higher than computed from flow records. However, agreement at Chesterville is closer with the 100 year simulated flows being 5% higher than the value from observed events. Within the upper portions of the watershed at Spencerville, the annual and summer 100 year events are 18% and 24% higher for simulated values.

5) The above frequency curves are based on a comparison of simulated and observed mean daily flows. Figure 5.10 shows a comparison of flow frequency curves at Plantagenet based upon a shorter time step of 2 hours. The correspondence is good over the range of flows shown.

TABLE 5.8

Comparison of Observed and Simulated Return Period Flows at Calibration/Validation Points

Location	Season	Flows at Specified Period m^3/s (cfs) 2 yr	5 yr	10 yr	20 yr	50 yr	100 yr
Plantagenet							
Simulated (1958-79)	Annual[1]	675 (23200)	864 (30500)	983 (34700)	1087 (38400)	1212 (42800)	1297 (45800)
	May[2]	89 (3150)	185 (6530)	268 (94900)	365 (12900)	510 (18000)	623 (22000)
	Summer[3]	59 (2100)	115 (5260)	222 (7830)	297 (10500)	394 (13900)	467(16500)
Observed (1958-79)	Annual	745 (26300)	946 (33400)	1031 (36400)	1087 (38400)	1138 (40200)	1164 (41100)
	May	76 (2670)	176 (6230)	274 (9680)	394 (13900)	583 (20600)	754 (26700)
	Summer	40 (1410)	117 (4120)	202 (7120)	314 (11100)	515 (18200)	711 (25100)
Observed (1916-79)	Annual	745 (26300)	940 (33200)	1028 (36300)	1087 (38400)	1141 (40300)	1172 (41400)
	May	85 (3010)	198 (6990)	306 (10800)	436 (15400)	651 (23000)	847 (29900)
	Summer	99 (3500)	229 (8100)	334 (11800)	447 (15800)	597 (21100)	714 (25200)
Spencerville							
Simulated (1958-79)	Annual	42 (1470)	61 (2160)	76 (2690)	92 (3260)	116 (4090)	136 (4800)
	May	7 (260)	16 (560)	24 (848)	34 (1200)	51 (1800)	67 (2360)
	Summer	1 (43)	4 (144)	8 (275)	13 (474)	25 (886)	38 (1350)
Observed (1958-79)	Annual	45 (1590)	65 (2300)	76 (2740)	89 (3130)	102 (3600)	111 (3930)
	May	5 (182)	10 (335)	14 (479)	19 (657)	27 (962)	36 (1260)
	Summer	5 (110)	8 (265)	11 (405)	16 (565)	23 (808)	29 (1010)

1 Based on Calendar year
2 Month of May only
3 June to September

TABLE 5.8 (Cont'd)

Comparison of Observed and Simulated Return Period Flows at Calibration Validation Points

Location	Season	Flows at Specified Period m^3/s (cfs) 2 yr		5 yr		10 yr		20 yr		50 yr		100 yr	
Spencerville													
Observed (1948-79)	Annual	657	(1650)	67	(2360)	79	(2790)	90	(3180)	103	(3630)	112	(3940)
	May	6	(204)	11	(371)	15	(516)	19	(686)	27	(955)	34	(1200)
	Summer	5	(190)	12	(420)	17	(610)	23	(815)	31	(1100)	38	(1340)
Chesterville													
Simulated (1958-79)	Annual[1]	170	(6020)	228	(8040)	262	(9250)	292	(10300)	328	(11600)	354	(12500)
Observed (1958-79)	Annual	177	(6260)	232	(8200)	263	(9280)	289	(10200)	317	(11200)	337	(11900)
Observed (1950-79)	Annual	180	(6350)	234	(8280)	262	(9240)	282	(9970)	303	(10700)	317	(11200)
Russell													
Simulated (1958-79)	Annual[2]	89	(3130)	128	(4510)	152	(5360)	173	(6120)	199	(7020)	217	(7660)
Observed (1958-79)	Annual	106	(3750)	141	(4990)	155	(5480)	164	(5800)	172	(6080)	176	(6210)
Observed (1948-79)	Annual	113	(4000)	149	(5250)	165	(5810)	176	(6220)	187	(6600)	179	(6310)

1 The gauge at Chesterville is seasonal, March-May; annual peak assumed to occur in this period
2 The gauge at Russell operated seasonally until 1970 therefore Summer and May results not directly comparable

It is notable that there is very little difference between these flows and those based on the mean daily flow analysis.

6) The flow duration curve indicates the response of the watershed over a broader range of flows than the peak flow frequency analysis. Figure 5.11 shows the similarity of the curves derived from the observed and modelled flows at Plantagenet. A further verification of the model's performance in the mid to low range of flows is presented in Figure 5.12. This illustrates the observed and simulated flows for July to November 1964 at an enlarged scale. The general pattern of flows is similar although the minimum flow is slightly overestimated by the model in this year.

7) The previous discussions have indicated the model's performance over a wide range of conditions at the single location of Plantagenet. The drainage area at that point is 3810 km^2 (1470 mi^2). Table 5.7 indicates that on an annual basis the model performs well at locations with drainage areas one or two orders of magnitude smaller. In particular the Castor River at Russell and the Scotch River (East Branch) at St. Isidore de Prescott have drainage areas of 433 km^2 (167 mi^2) and 76.7 km^2 (29.6 mi^2) respectively. Based upon 12 and 10 yr of record, the simulated mean annual flows at these locations agree with the observed values within 1 and 4% respectively.

8) Figures 5.13 and 5.14 present comparisons of observed and modelled daily flows on the Castor River at Russell

and the Scotch River (East Branch) at St. Isidore de Prescott for the year 1976. The mean flow for 1976 was above normal by about 18% and 19% respectively at these two locations. The agreement between the observed and simulated average flows is excellent with 6.0 m^3/s observed versus 6.9 m^3/s simulated at Russell and 1.25 m^3/s observed versus 1.22 m^3/s simulated at Prescott. The recorded annual peak flow at Russell was 142 m^3/s (5014 cfs) compared to a simulated peak of 135.3 m^3/s (4778 cfs) occurring one day earlier than observed. At Prescott the observed peak was 17.1 m^3/s (604 cfs) whereas the simulated peak was somewhat overestimated at 26.2 m^3/s (925 cfs). Secondary peaks in December and May were both well matched. Flows during the low flow months correspond reasonably well, although there is some tendency to overestimate the minimum flow. At Prescott the observed mean flow from June to September was 0.06 m^3/s (2.0 cfs) compared to a simulated value of 0.07 m^3/s (2.4 cfs). However, the observed minimum daily flow was 0.002 m^3/s (0.07 cfs) whereas the simulated value was 0.02 m^3/s (0.7 cfs). The correspondence in time was however, very good with both the observed and simulated minima occurring in the first few days of August.

9) Figures 5.15, 5.16 and 5.17 present frequency analyses of observed and simulated annual peak flows at Spencerville, Chesterville and Russell. The close correspondence between the curves indicates good model performance in reproducing the statistical characteristics of the flood frequency regime for a wide range of watershed sizes (1050 km^2 to 246 km^2).

10) Figures 5.18, 5.19 and 5.20 present flow duration curves at Spencerville, Russell and Prescott. The correspondence between observed and simulated results is closest at Prescott (area 76.7 km^2) but not as adequate at Spencerville. Although the high flow frequency and low flow frequencies seem to be well represented the mid-range flows are relatively poorly matched at Spencerville. At Russell the general shape of the curves is very similar.

11) As a final overview of the performance of the model in simulating the frequency response of the watershed, Table 5.8 presents comparisons between the observed and simulated flows for three seasons at the four calibration/validation locations. The simulated flows are based on the period 1958 to 1979. The observed flows based on both the 1958 to 1979 period and the entire record where this is longer are presented.

It is noted that:

i) At Plantagenet, near the basin outlet, the comparison between observed and simulated mean daily frequency curves is good with a close correspondence in peak estimates up to the 20 year magnitude for both the Summer and Annual period. For more extreme events in which flood magnitudes are extrapolated from the 22 year period, simulatd 100 year annual flood peaks are 10 percent higher than estimates based on records while summer values are 35 percent lower.

ii) Within the upper basin, 100 year annual peak flow values based on simulations are 19 percent higher than estimates based on flow records at Russell while at Chesterville and Spencerville they are 5 percent and 18 percent higher, respectively. Simulation values over the summer period at Spencerville are 24 percent lower at the 100 year return period.

12) Recorded snow-course data throughout the basin was used as a check on the temporal distribution of water equivalent and the date of the disappearance of the snowpack in the spring during the calibration of the model. However, agreement was not particularly good and more emphasis was placed on a comparison of recorded and simulated flows.

13) As previously indicated, the HSP-F model accurately simulates the hydrologic response of the South Nation River basin for a wide range of meteorological and seasonal conditions and over a wide variation of drainage areas. There are however some limitations and inaccuracies which should be noted:

i) in some years snowmelt occurs during the early winter which is not observed in reality. This leads to an underestimate of the peak snowmelt later in the spring since the snow water equivalent is too low. One possible source of this error is an overestimate of ground melt which is set as a constant value in the model. In actual conditions when the snowpack is shallow the ground below it may freeze and the ground melt may be reduced to zero. Another possible source of this error may be the use of a fixed threshold temperature to differentiate between frozen and unfrozen the precipitation. In some cases precipitation which should actually have been added to the snowpack will be identified as rainfall and may become runoff.

ii) some summer events are not closely simulated because the input precipitation is not truly representative of basin conditions. This results from both the method used to prepare the standard data base, and from the non-uniformity of summer precipitation with respect to area.

iii) some minor inaccuracies may have been introduced due to transfers of water within the basin. These include withdrawals from the river and from groundwater for municipal and industrial water supply and their eventual discharge as sewage. The sewage discharges are generally seasonal. They are held in lagoons and discharged during the spring freshet. Details of these activities are provied in sections 8 and 9, and Tables 8.6 and 9.1. Another possible transfer which was ignored in the HSP-F modelling was the regional movement of groundwater from one sub-basin to another. In some areas such as sub-basins 7 and 17 the subarea boundary crosses a wetland area. At these locations the subsurface flow may not necessarily correspond to the surface topography. However, hydrogeological investigations based on existing data were not able to establish conclusively the presence of regional groundwater movements.

iv) in the calibration period, 1974 to 1979, tile drainage in the South Nation River basin covered between 10 and 12% of the watershed area. The calibration parameters reflect the effects of this level of drainage. This built-in factor must be accounted for in adjusting the model to reflect an increase in tile drainage.

5.4.4 Discussion of Final Model Parameters

Table 5.9 lists the final values of some of the important model parameters discussed in sections 5.2.1 and 5.2.2. The following points are noted:

1) The relationships developed to estimate values of INTCEP, NSUR, SHADE and LZETP appear to give reasonable values of these parameters and allow for an adequate calibration of the model using reasonable values of the other parameters. These relationships therefore provide a rational basis for adjusting these four parameters to account for land use changes.

2) Many of the parameters, including LSUR, the length of overland flow path, AGWRC, the groundwater recession constant, and the snow parameters, TSNOW, SNOWEVAP and MAXWAT are either constant or vary very little from subarea to subarea. This is consistent with sensitivity runs made to examine the effect of aereal discretization on the performance of the model. With only one pervious

TABLE 5.9

Final Parameter Values for Pervious Land Segments[1]
(see Figure 5.3 to identify segments)

Land Segment Number	Parameters Which Vary By Sub Area								
	SHADE	CCFACT	INFILT	INTFW[2]	LSZN	USZN	IRC[1]	LZETP	NSUR
5	0.57	0.5	0.0035	10.0	4.0	0.45	0.76	0.57	0.276
6	0.55	0.5	0.0015	9.5	9.0	0.8	0.81	0.55	0.270
7	0.75	0.7	0.0012	12.0	13.0	1.5	0.88	0.75	0.328
8	0.58	0.5	0.0018	9.0	5.0	0.6	0.76	0.58	0.280
9	0.56	0.5	0.0009	10.0	13.0	1.8	0.76	0.56	0.273
12	0.59	0.6	0.0010	13.0	13.0	1.0	0.89	0.56	0.283
13	0.49	0.5	0.0009	10.0	13.0	1.8	0.76	0.49	0.254
16	0.40	0.5	0.0009	10.0	13.0	1.8	0.76	0.40	0.229
17	0.75	0.5	0.0009	10.0	13.0	1.8	0.76	0.75	0.329
18	0.57	0.5	0.0035	10.0	4.0	0.45	0.76	0.57	0.276
19	0.53	0.5	0.0018	9.0	5.0	0.6	0.76	0.53	0.266
20	0.53	0.5	0.0015	9.5	9.0	0.8	0.81	0.53	0.266
21	0.43	0.5	0.0009	10.0	13.0	1.8	0.76	0.43	0.237
22	0.55	0.5	0.0009	10.0	13.0	1.8	0.76	0.55	0.271
23	0.61	0.5	0.0018	9.0	5.0	0.6	0.76	0.61	0.288

Constant Parameters: SNOW CF = 1.25 in
TSNOW = 35°F
AGRWC = 0.998
LSVR = 300 ft

1 The HSP-F model was in Imperial Units and therefore parameters are given in this system

2 Varies by season, figure given is spring value

land segment, including a constant set of parameters and hence a constant unit rate of runoff across the entire catchment, the model still provided a good prediction of flows at the outlet and intermediate locations within the watershed.

3) The parameter LSUR, the length of overland flow, was set at a constant value of 91 m (300 ft) thoughout the entire watershed. This is representative of the distance which flow has to travel to reach a first-order stream.

4) The parameter NSUR varies slightly from sub-area to subarea reflecting land uses. The values range from 0.229 to 0.329. While these may appear high compared to normal Manning's n values for channel flow it must be borne in mind that they represent the passage of very low rates of flow through the micro-topopgraphy of the overland flow plain. They values are entirely consistent with values used in other models including the Stormwater Management Model(12), which use a kinematic wave representation of overland flow.

5) A number of parameters such as LZSN and INFILT vary over a wide range from subarea to subarea. For example, the lower zone storage, LZSN, varies from 102 mm (4 in) to 330 mm (13 in). This reflects variations in sub-watershed characteristics but cannot be directly attributed to the variation in one particular aspect of the subarea. There does appear to be a relatively constant relationship between UZSN and LZSN.

6) The parameters INTFW, the interflow infiltration rate, and IRC, the interflow recession rate, vary with season. The former are approximately 30 to 50 percent higher during the months February to April than during the rest of the year. The latter are decreased by about 10 percent during the same months.

7) The parameter CCFACT, the convection melt coefficient, varies slightly between subareas and accounts to some extent for the variation in temperatures from the north to south of the basin.

5.5 Base Condition Model Runs

5.5.1 General

The HSP-F model of the South Nation River basin was used to generate a daily streamflow record for the 22 yr period 1957 to 1979 inclusive at the thirty seven points indicated in Table 5.4. This data base was stored on magnetic computer tape for future use. This data base was subjected to the following analyses:

1) High flow frequency curves were generated for two seasons, annual and growing season, May to October, and flows for six specific return periods were tabulated at five specified locations in the watershed. The return periods considered were 2, 5, 10, 20 and 50 and 100 yr. The Log-Pearson type III statistical distribution was fitted to the computed flows. This is consistent with the distribution used in analysis of the measured flow records. The five locations were Plantagenet, Bear

Brook, Vernon, Chesterville and Spencerville. The frequency curves provided a basis for evaluating the impacts of tile drainage and the effects of six water management schemes.

2) The same analyses were carried out at the outlet of five major municipal drains. The specified locations were the Payne Creek, the Van Camp, the Ferguson, the Mullen (Gannon) and the South Castor drains. The latter is concident with the Vernon flood prone area.

3) Low flow frequency analyses were carried out at six locations within the watershed for critical low flow periods. A seven-day low flow period was utilized. The locations were selected by comparing water supply requirements at communities within the basin with estimated groundwater availability. At those locations with a predicted shortfall, surface water can often be used to meet the demand. A low flow frequency curve was developed at these locations to review this option.

5.5.2 High Flow Frequency Analysis - Flood Prone Areas

Figures 5.21 to 5.30 present the results of high flow frequency analyses at the flood prone areas of Plantagenet, Bear Brook, Vernon and Chesterville for the annual and growing seasons. Frequency curves for Spencerville are also shown. Table 5.10 presents a numerical tabulation of flows at these locations for the 2, 5, 10, 20, 50 and 100 yr return periods.

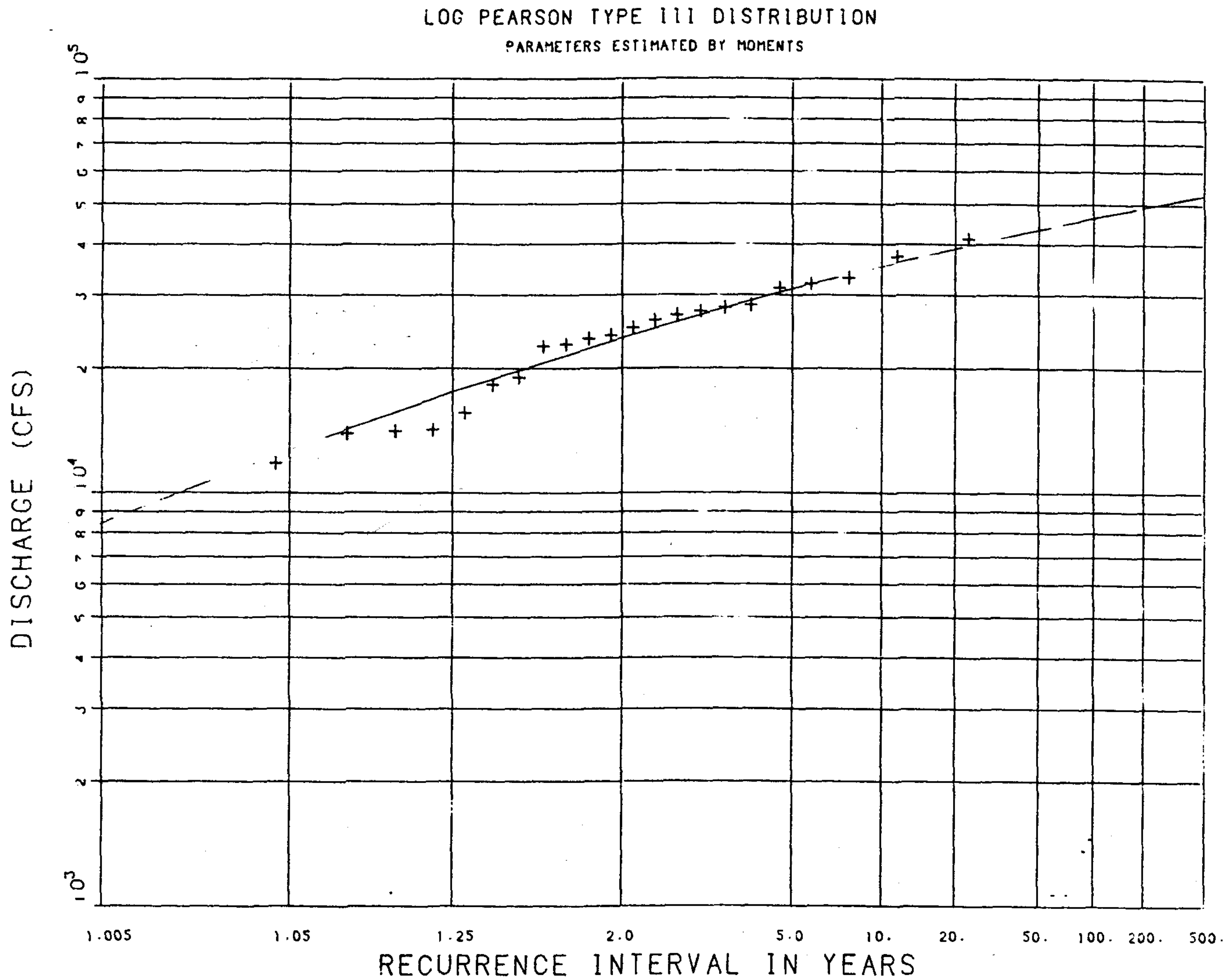
TABLE 5.10

Flows for the 2, 5, 10, 20, 50 and 100 Year Return Periods at Five Specified Flood Areas

Location	Season	Flows at Specified Period m^3/s (cfs)					
		2 yr	5 yr	10 yr	20 yr	50 yr	100 yr
Plantagenet	Annual[1]	589. (20800)	762. (26900)	850. (30000)	918. (34900)	989. (34900)	1030. (36400)
	Growing[2] Season	122. (4300)	234. (8260)	312. (11000)	386. (13600)	478. (16900)	544. (19200)
Bear Brook	Annual	70. (2470)	91. (3200)	104. (3660)	116. (40800)	131. (4620)	142. (5020)
	Growing Season	12. (434)	24. (853)	31. (1110)	38. (1340)	45. (1580)	49. (1730)
Vernon	Annual	34. (1190)	45. (1500)	51. (1800)	56. (1970)	61. (2160)	64. (2270)
	Growing Season	7. (243)	17. (598)	26. (910)	36. (1270)	51. (1810)	64. (2270)
Chesterville	Annual	203. (7180)	263. (9270)	292. (10300)	314. (11100)	340. (12000)	354. (12500)
	Growing Season	30. (1060)	69. (2420)	104. (3660)	144. (5090)	207. (7320)	263. (9270)
Spencerville	Annual	42. (1470)	61. (2160)	76. (2690)	92. (3260)	116. (4100)	136. (4800)
	Growing Season	8.4 (297)	17. (613)	25. (892)	34. (1210)	48. (1700)	61. (2140)

1 Annual refers to the calendar year
2 Growing season refers to May to October

Annual Peak Flow Frequency Curve at Plantagenet



Growing Season (May to October) Peak Flow Frequency Curve at Plantagenet

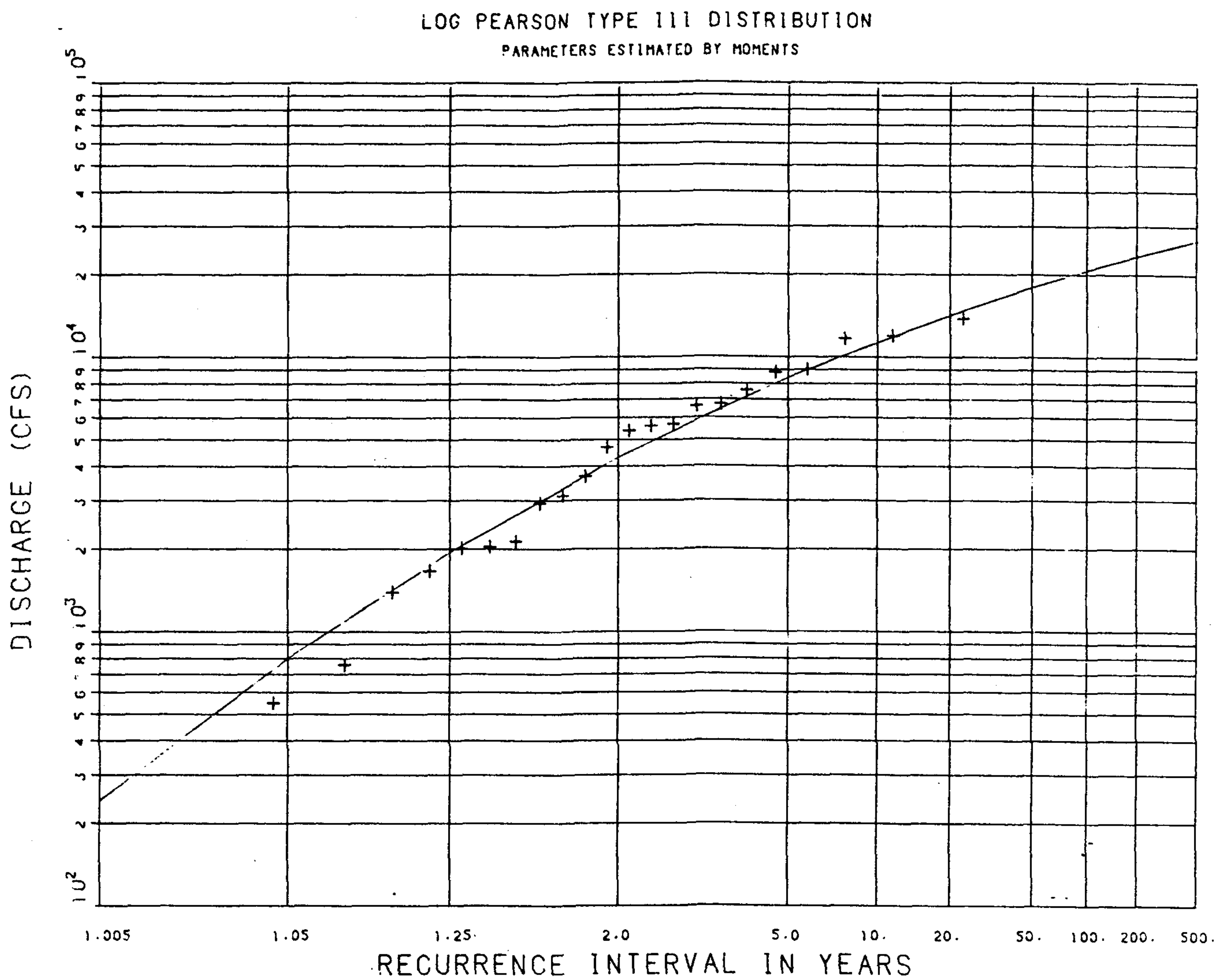
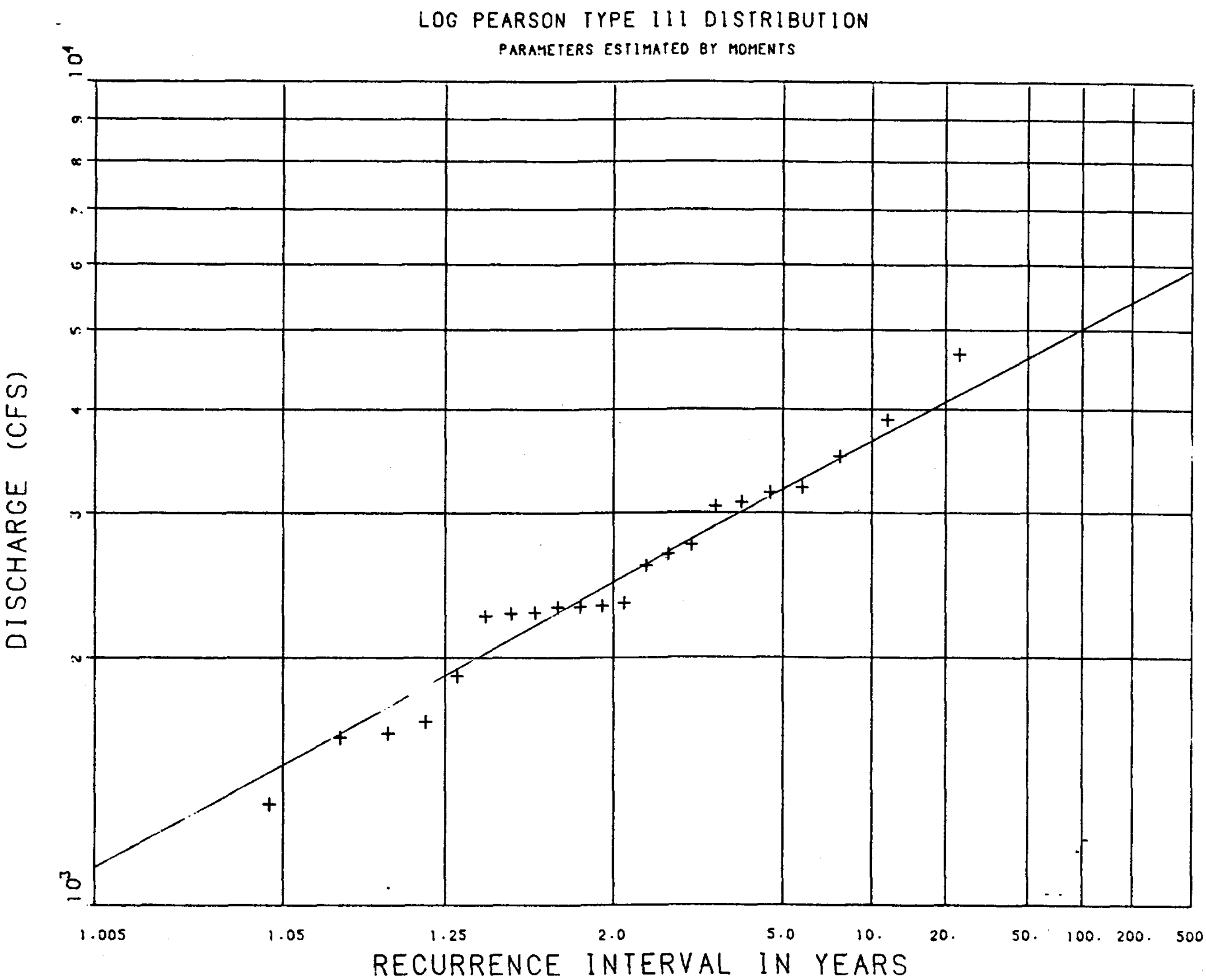
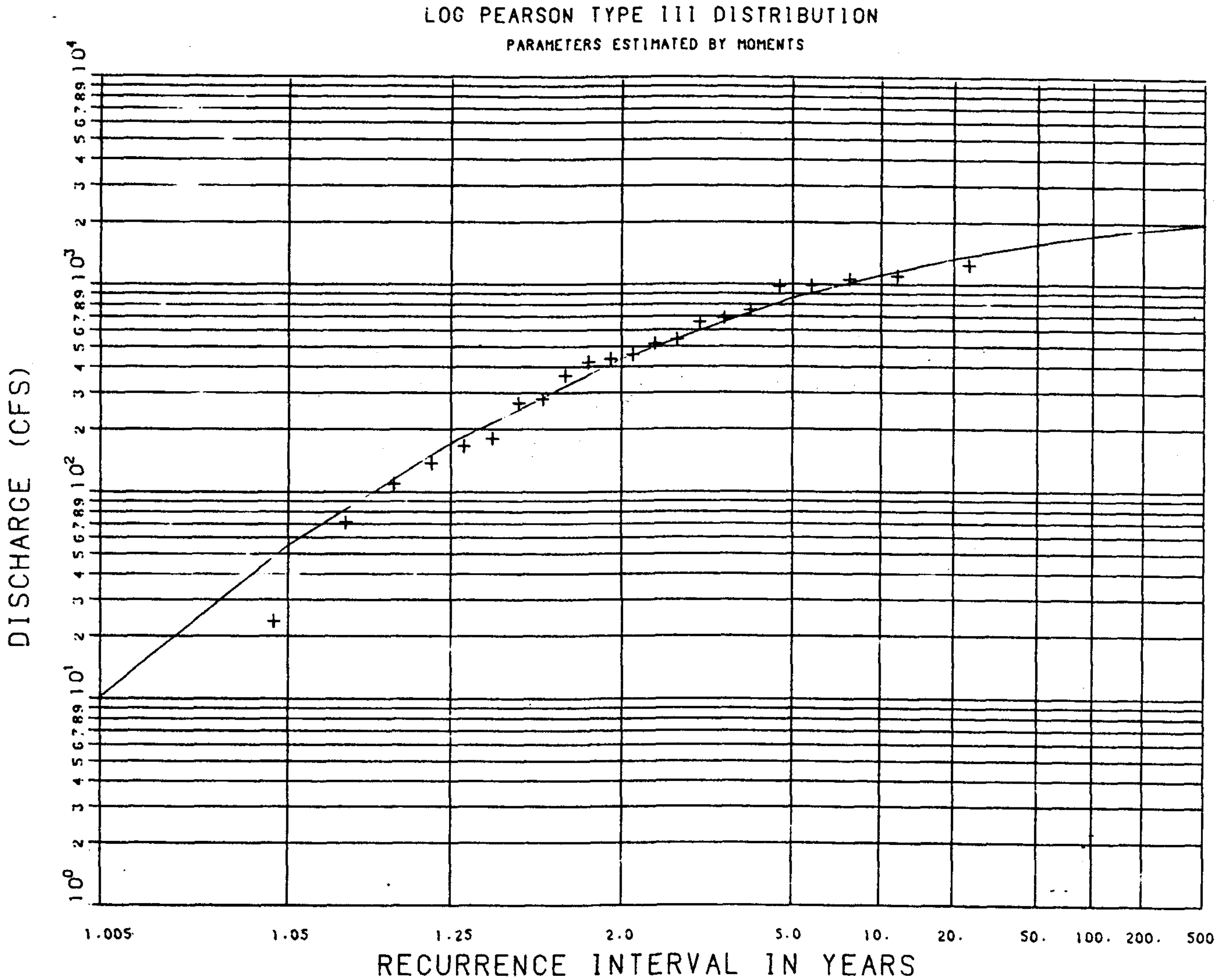


Figure 5-23

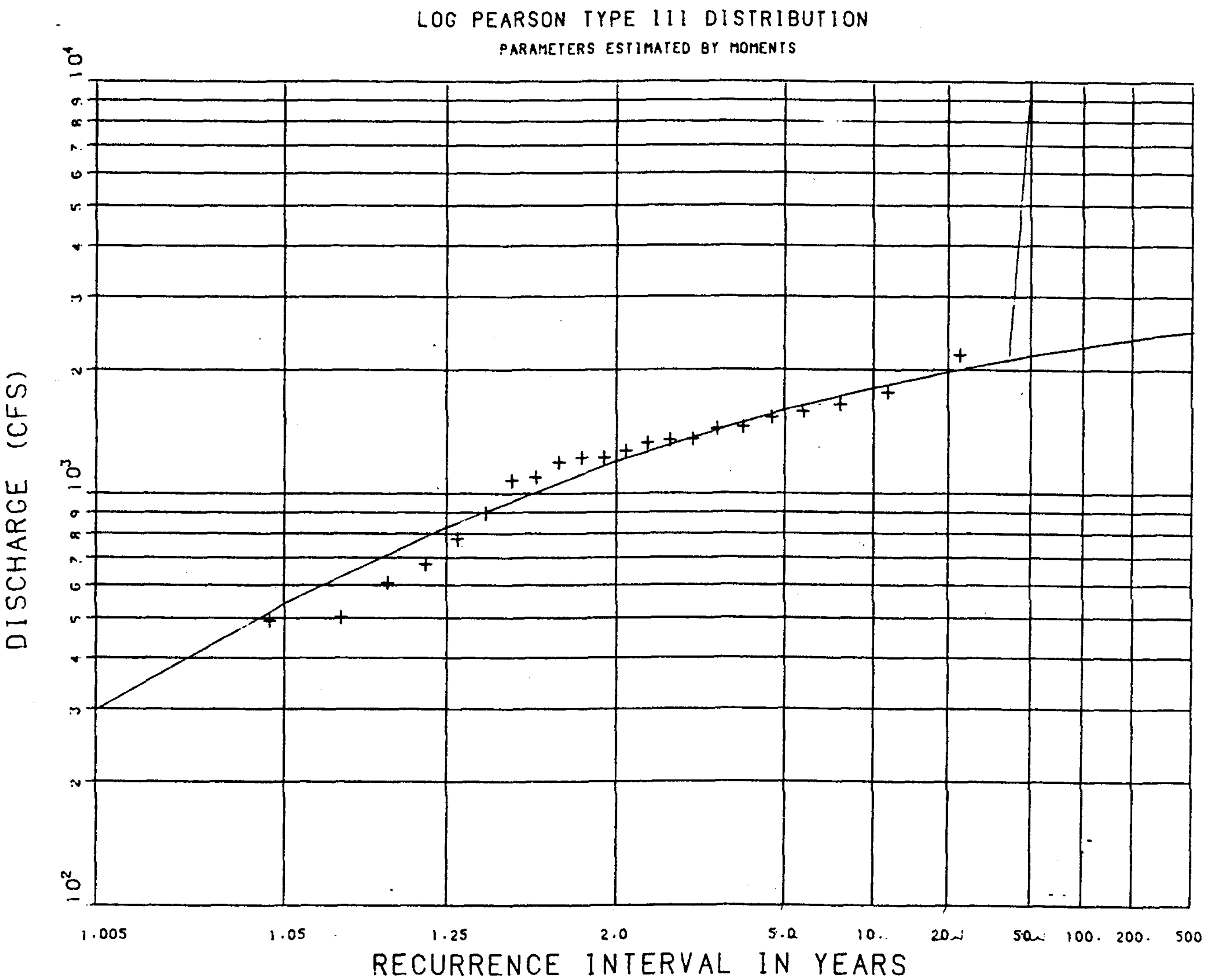
Annual Peak Flow Frequency Curve at Bear Brook



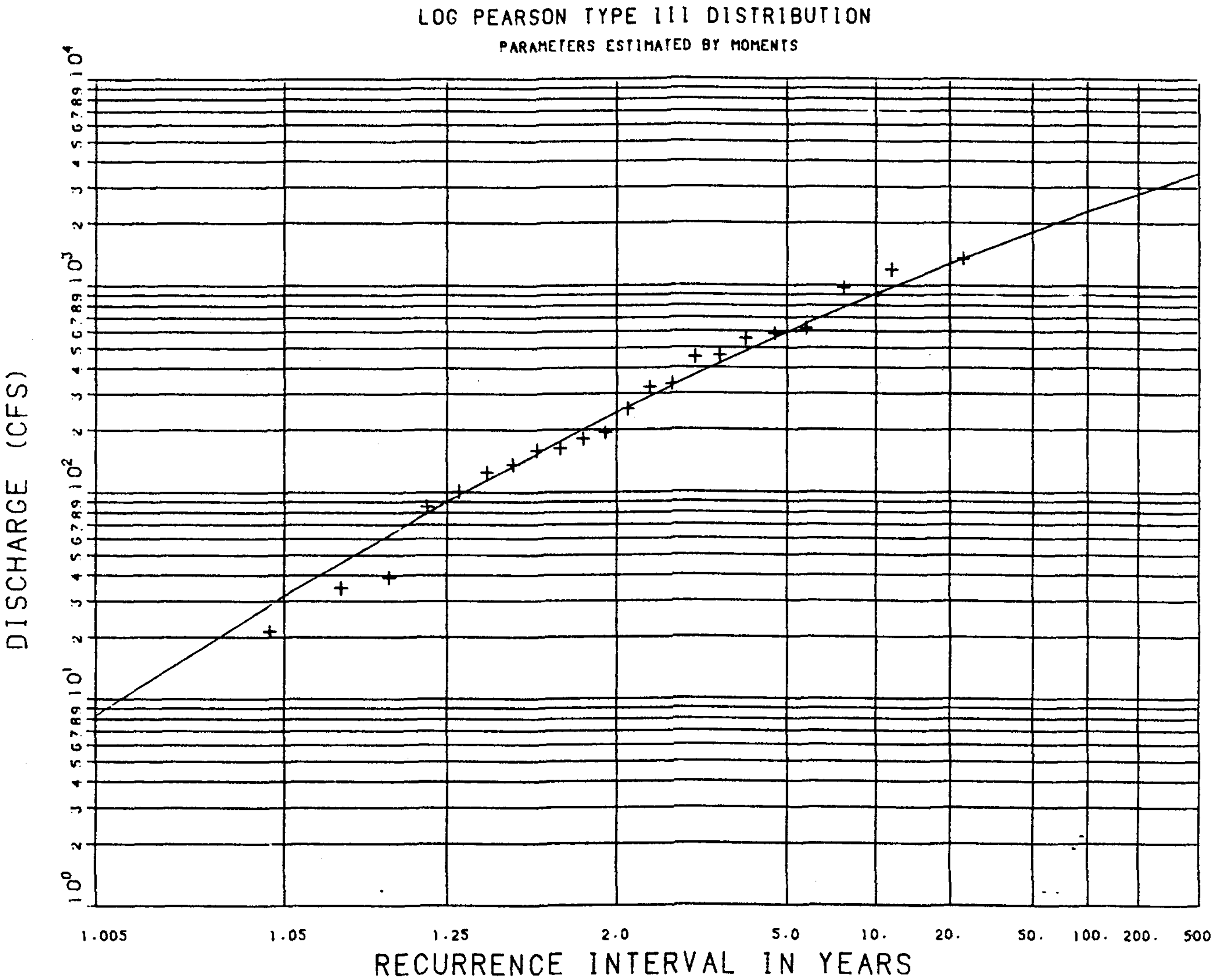
Growing Season (May to October)Peak Flow Freqency Curve at Bear Brook



Annual Peak Flow Frequency Curve at Vernon



Growing Season (May to October) Peak Flow Frequency Curve at Vernon



Annual Peak Flow Frequency Curve at Chesterville

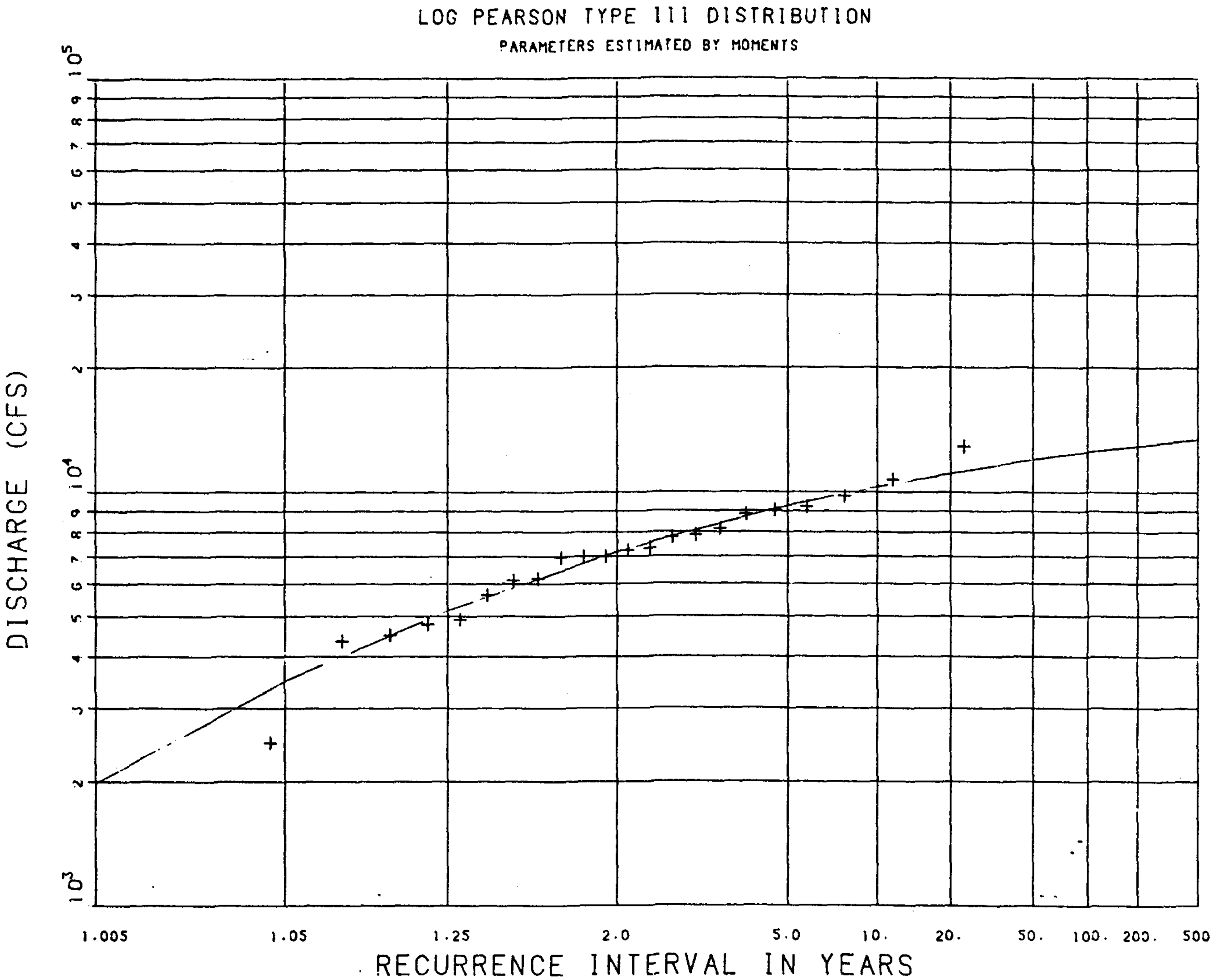


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Figure 5-28

Growing Season (May to October) Peak Flow Frequency Curve at Chesterville

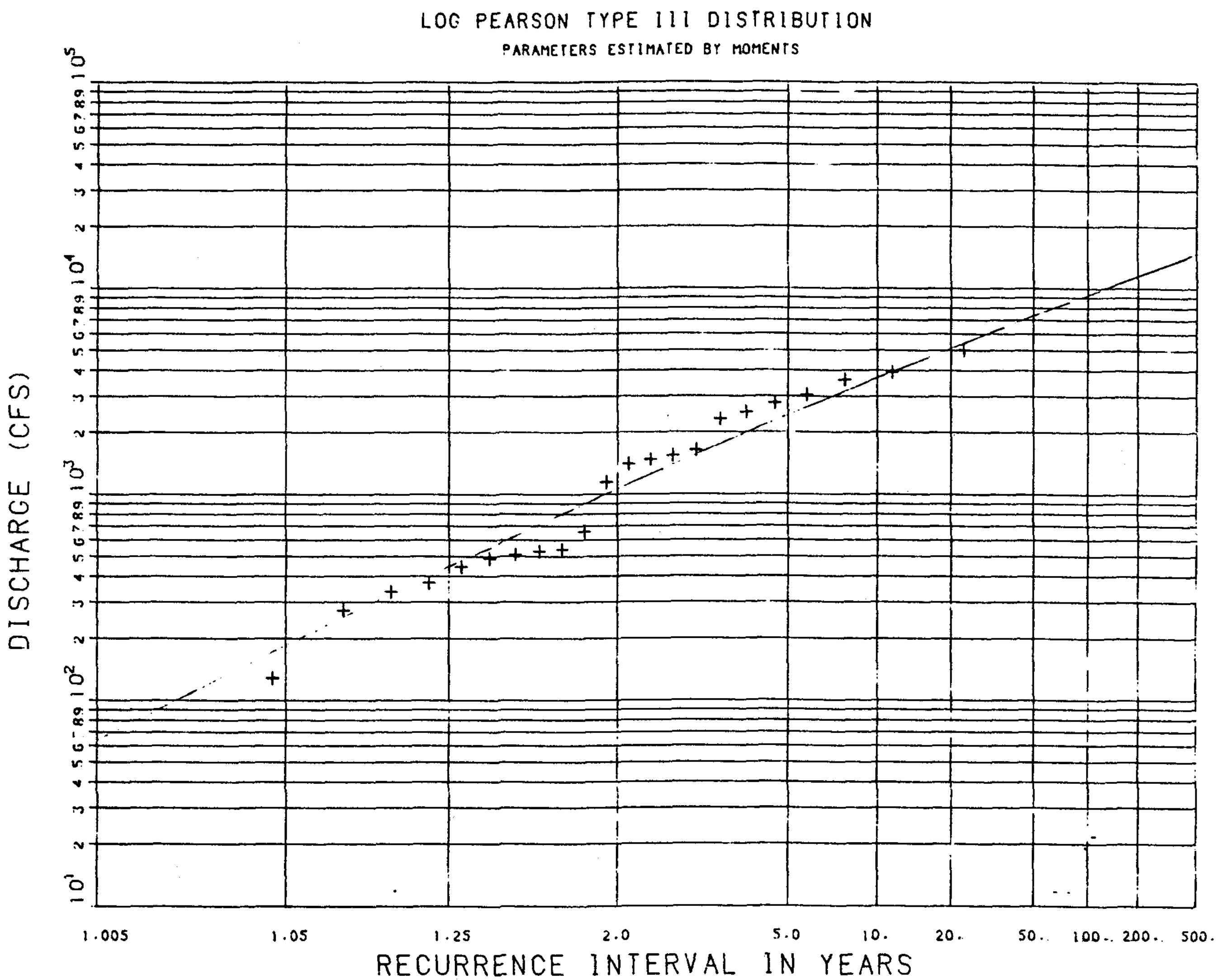


Figure 5-29

Annual Peak Flow Frequency Curve at Spencerville

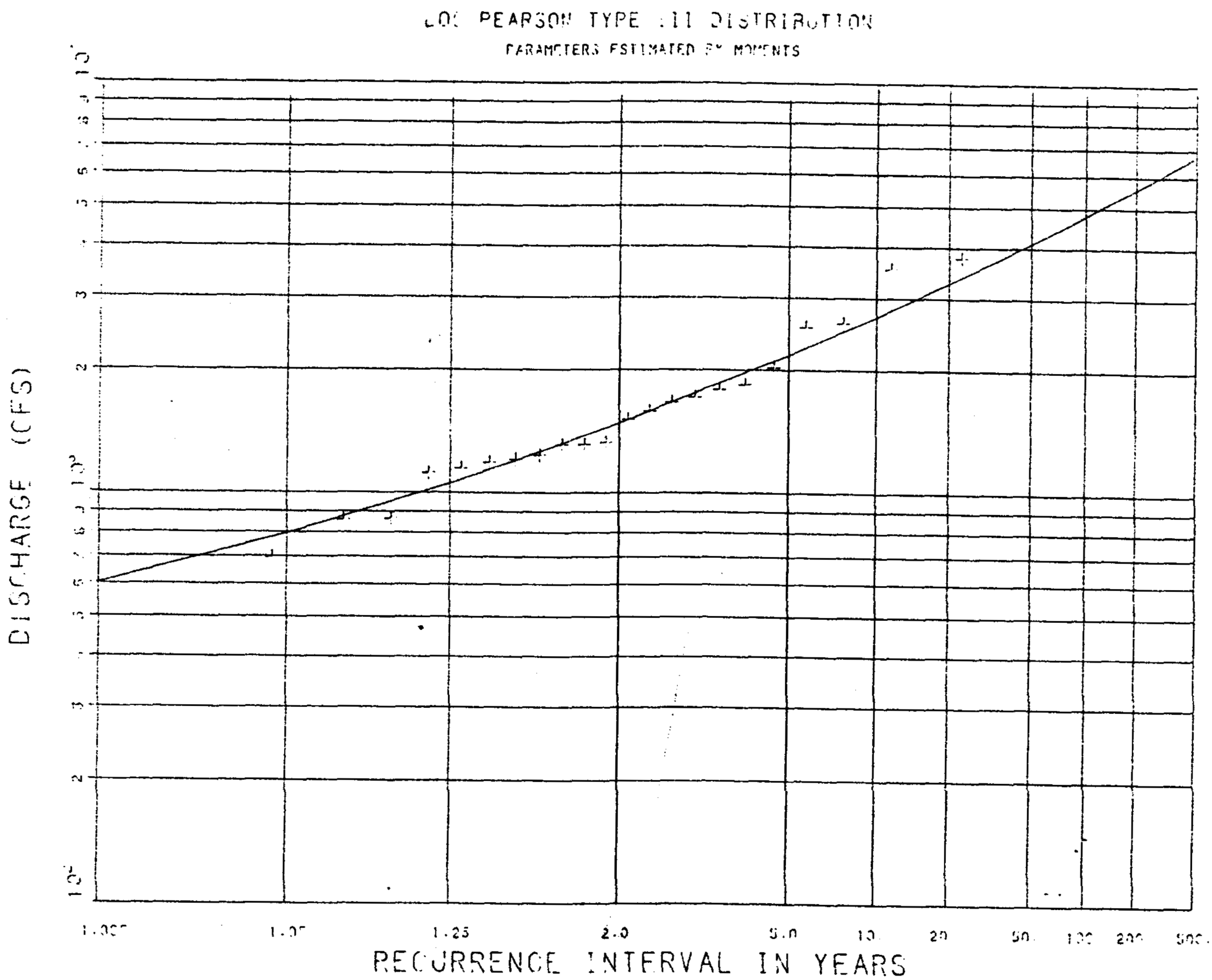
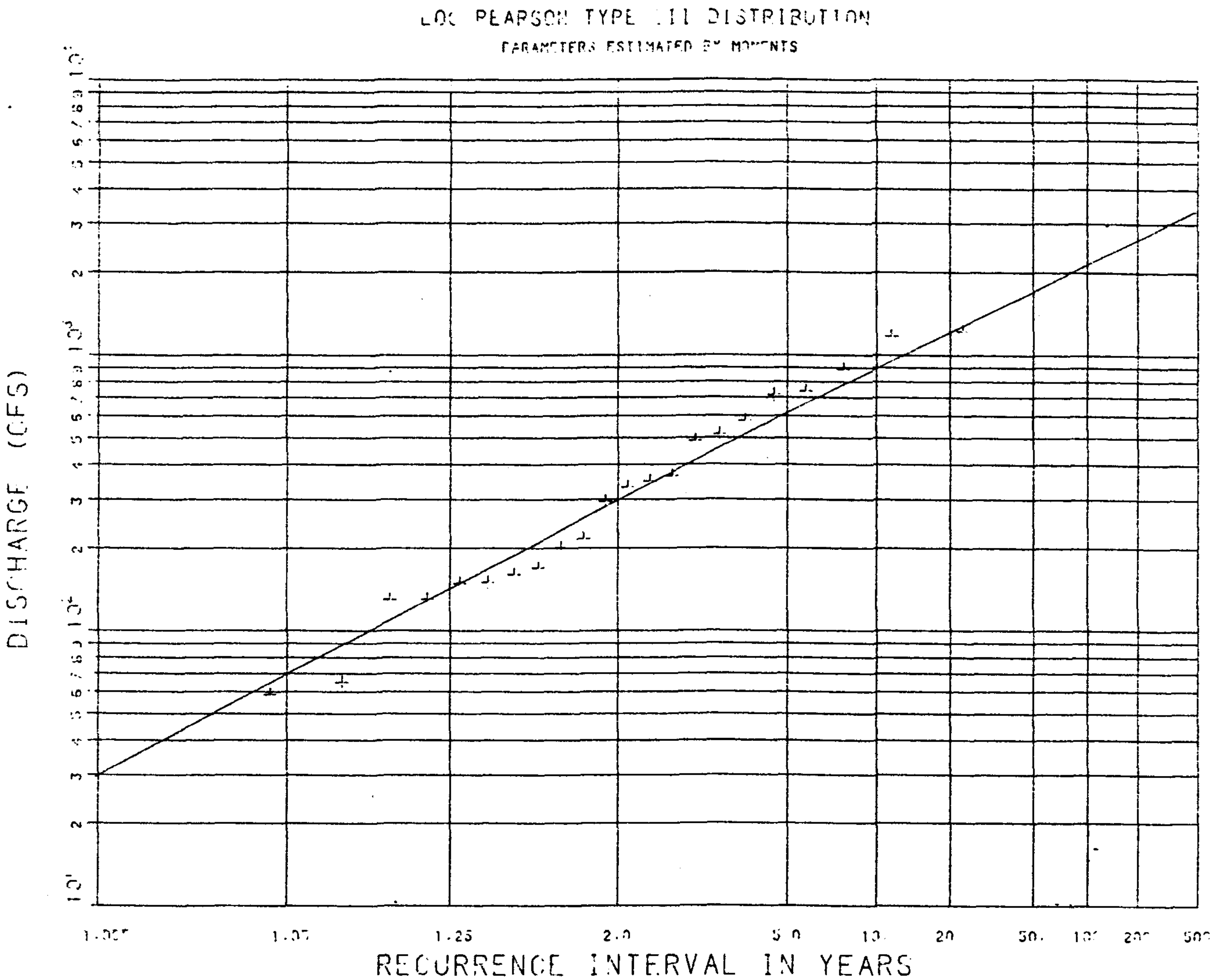


Figure 5-30

Growing Season (May to October) Peak Flow Frequency Curve at Spencerville



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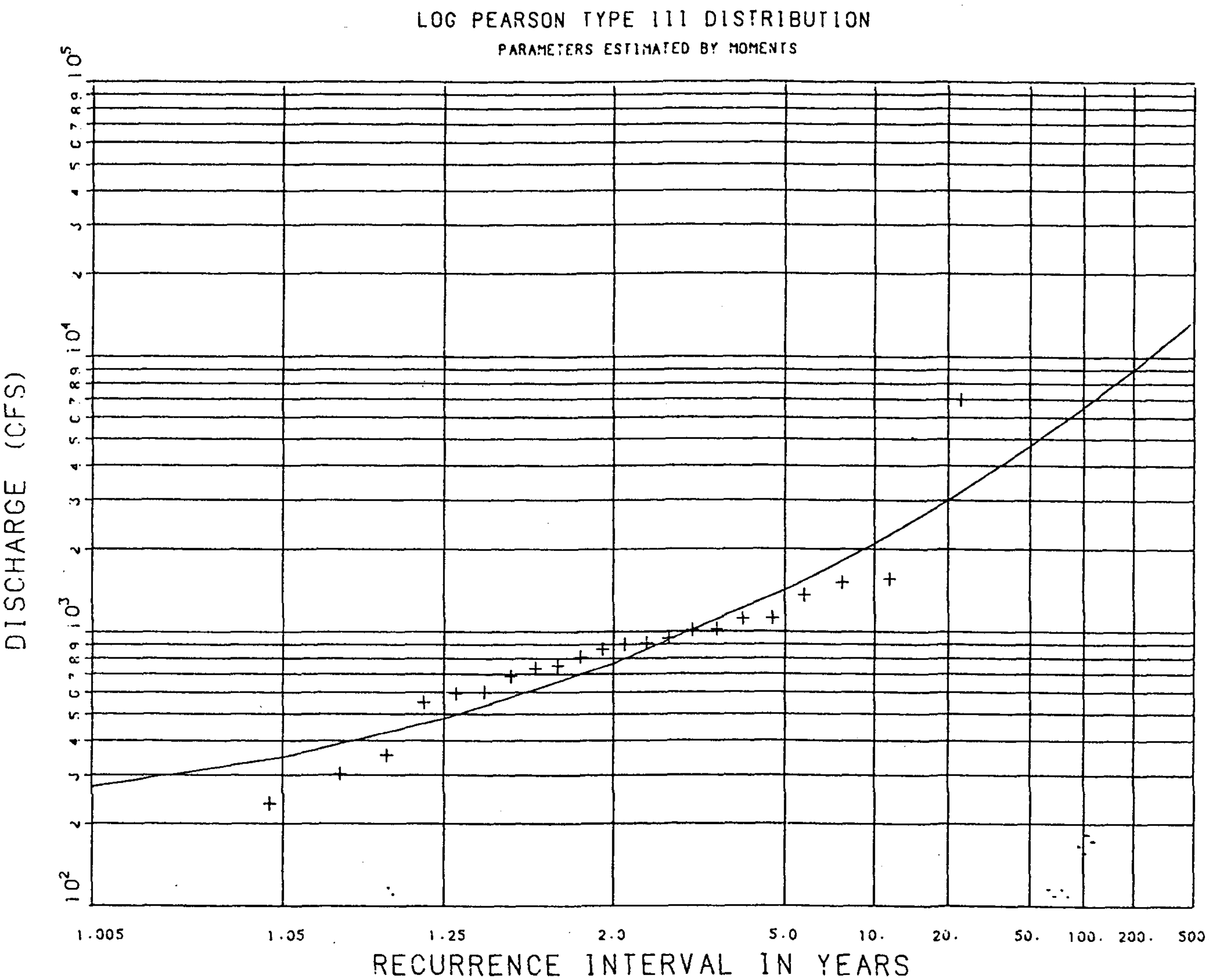
5.5.3 High Flow Frequency Analysis - Outlet of Municipal Drains

Figures 5.31 to 5.42 present the results of high flow frequency analyses at outlets of the four agricultural outlet drains known as the Payne Creek, the Van Camp, the Ferguson and the Mullen (Gannon) drains. The South Castor drain is coincident with the Vernon flood prone area shown on Figures 5.25 to 5.26. The flows for the 2, 5 10, 20, 50 and 100 yr return periods are presented in Table 5.11.

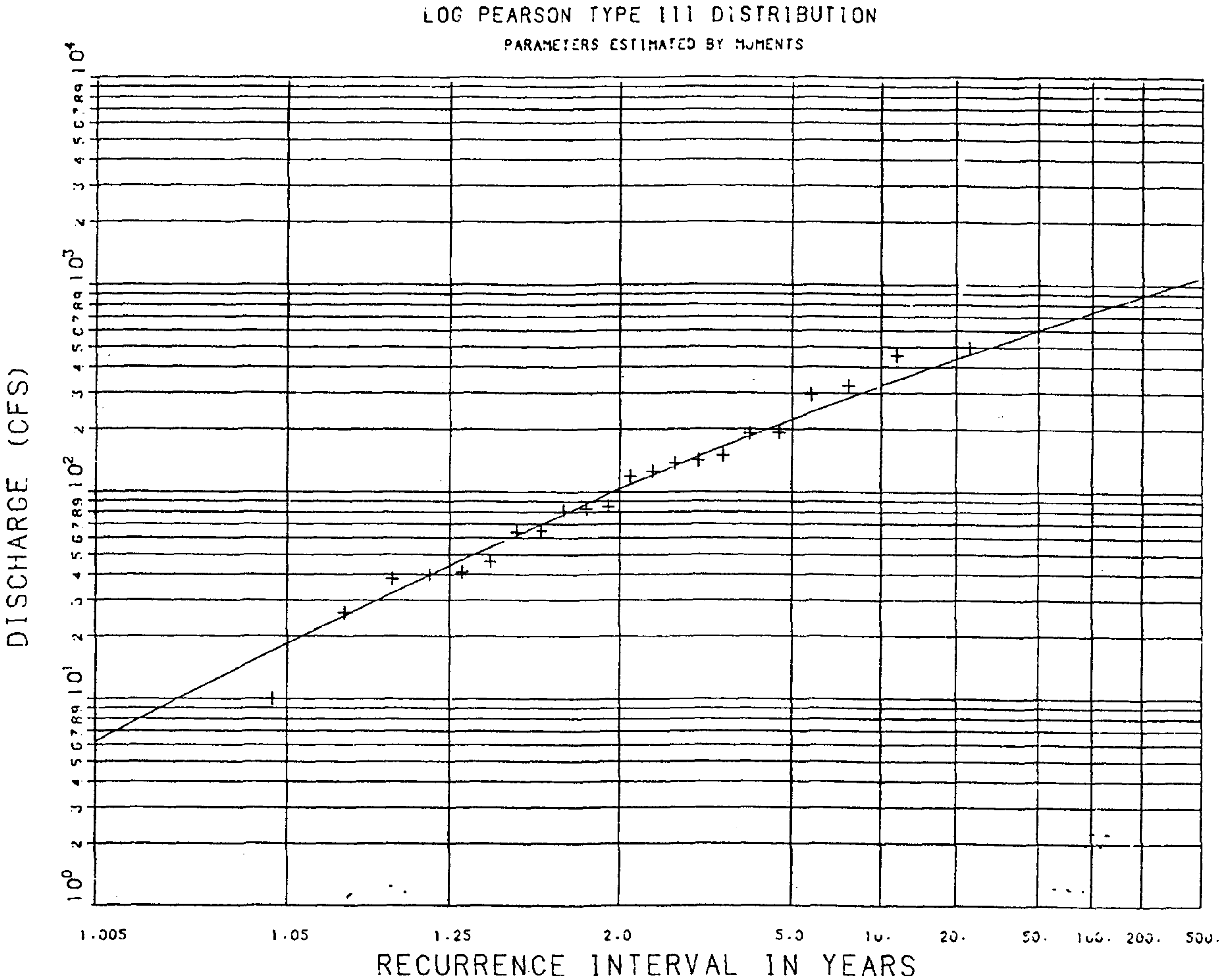
5.5.4 Low Flow Frequency Analysis - Potential Water Supply Points

Figures 5.43 to 5.48 present the low frequency analyses for 7 day periods at Chesterville, St. Isidore de Prescott, Bourget, Embrun, Casselman and Plantagenet. Table 5.12 presents a numerical tabulation of the average seven day minimum flows at these locations for the 2, 5, 10, 20, 50 and 100 yr return period.

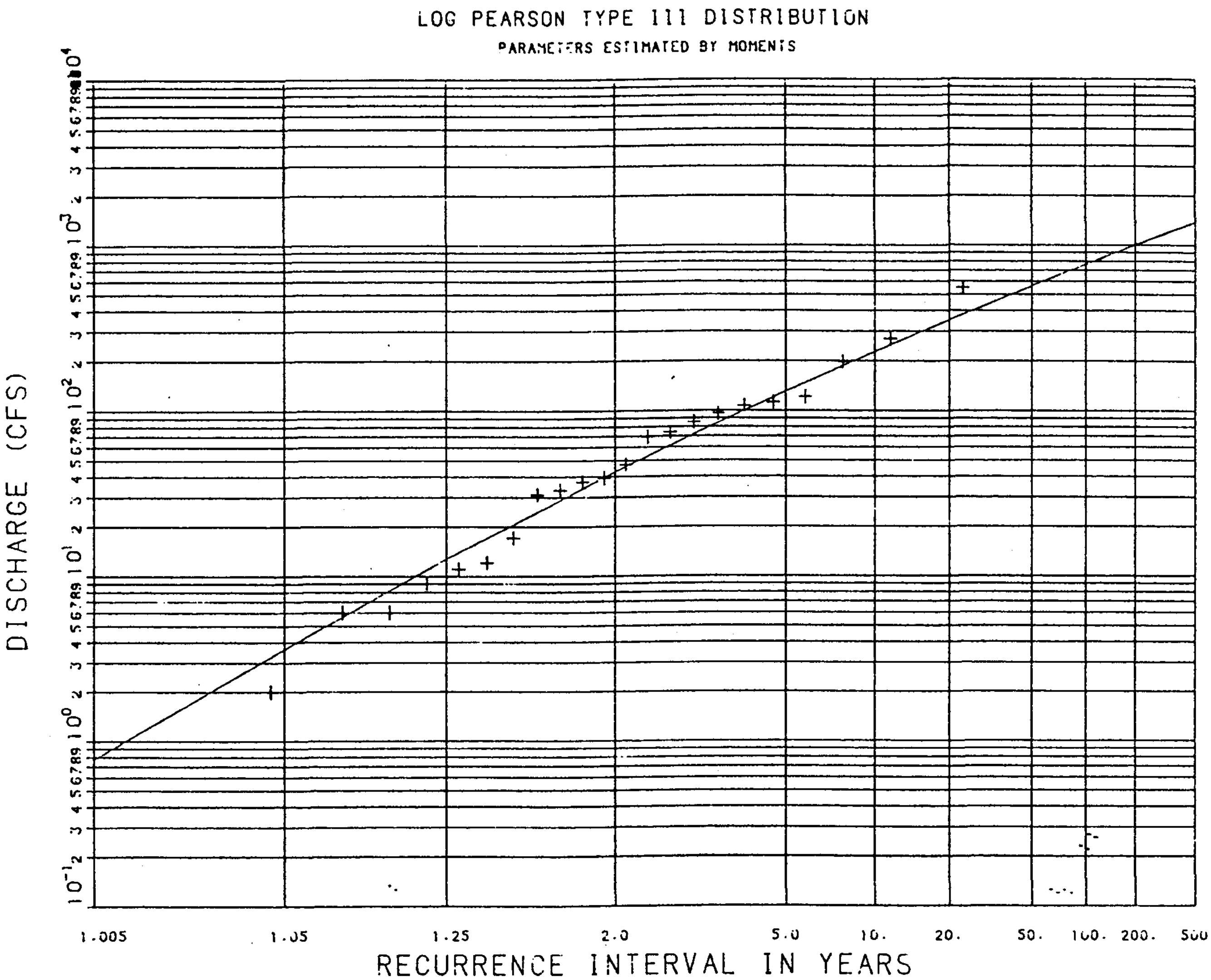
Annual Peak Flow Frequency Curve at Payne Creek Drain



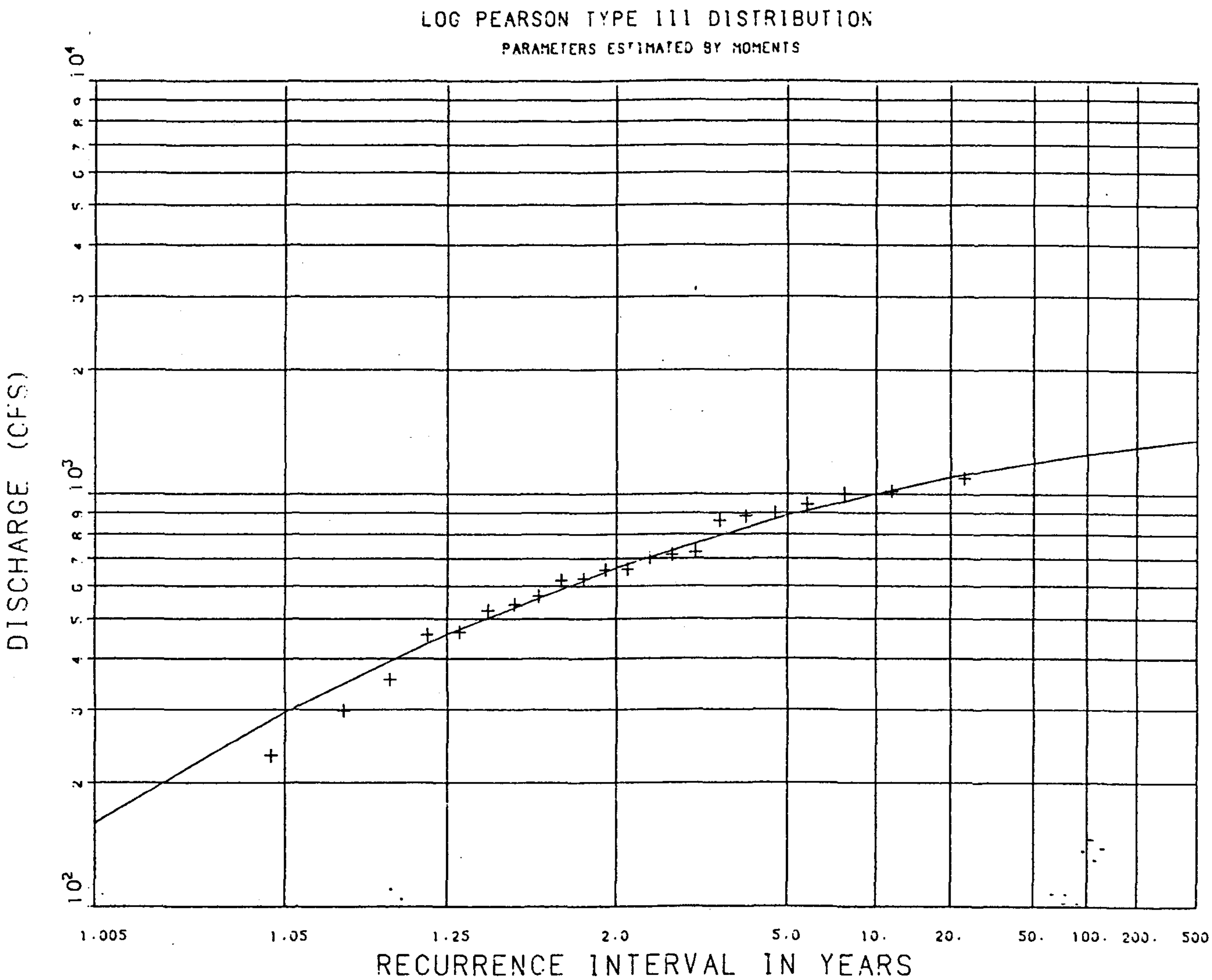
May Peak Flow Frequency Curve at Payne Creek Drain



Summer (June to September) Peak Flow Frequency Curve at Payne Creek Drain



Annual Peak Flow Frequency Curve at Van Camp Drain



May Peak Flow Frequency Curve at Van Camp Drain

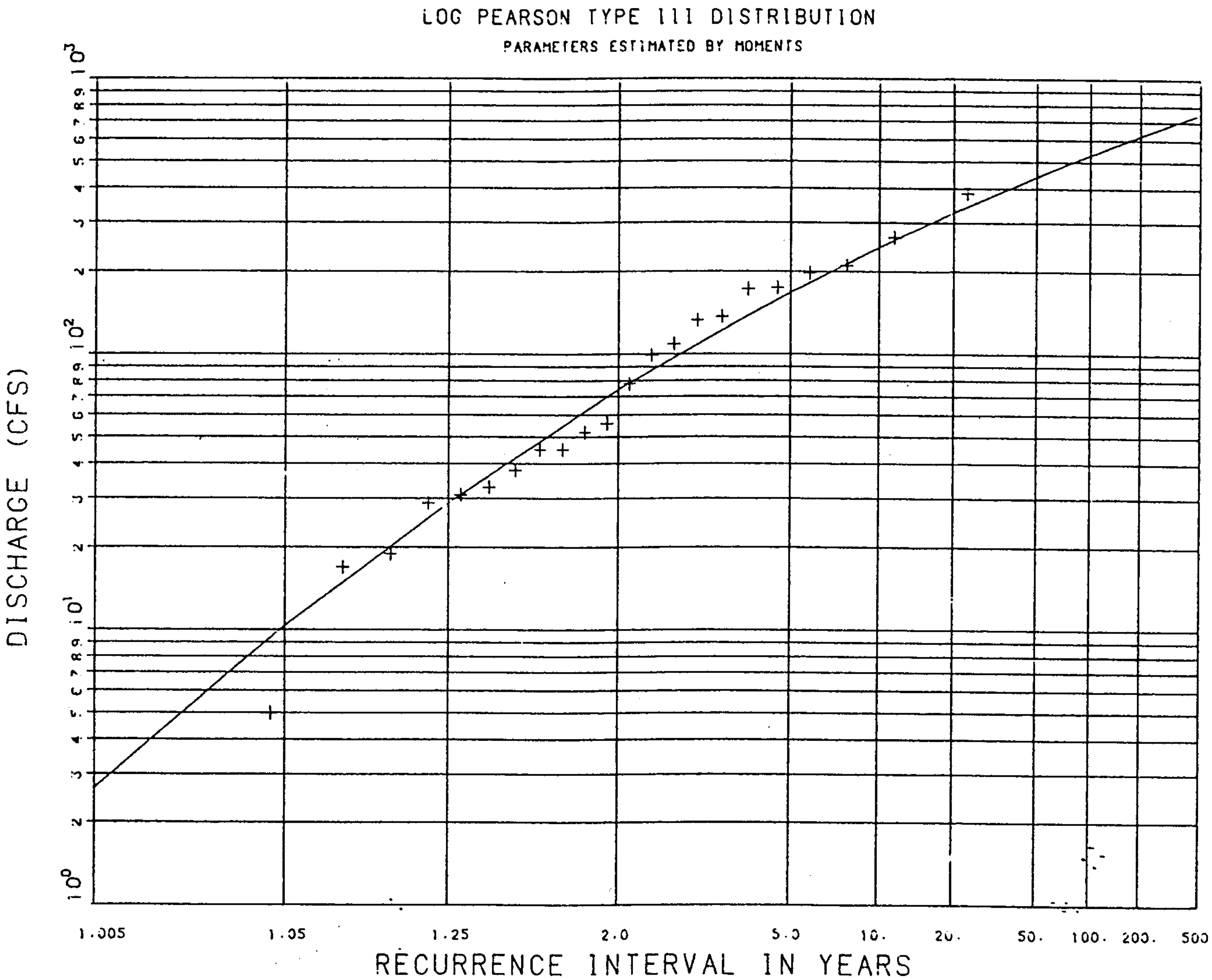


Figure 5-36

Summer (June to September) Peak Flow Frequency Curve at Van Camp Drain

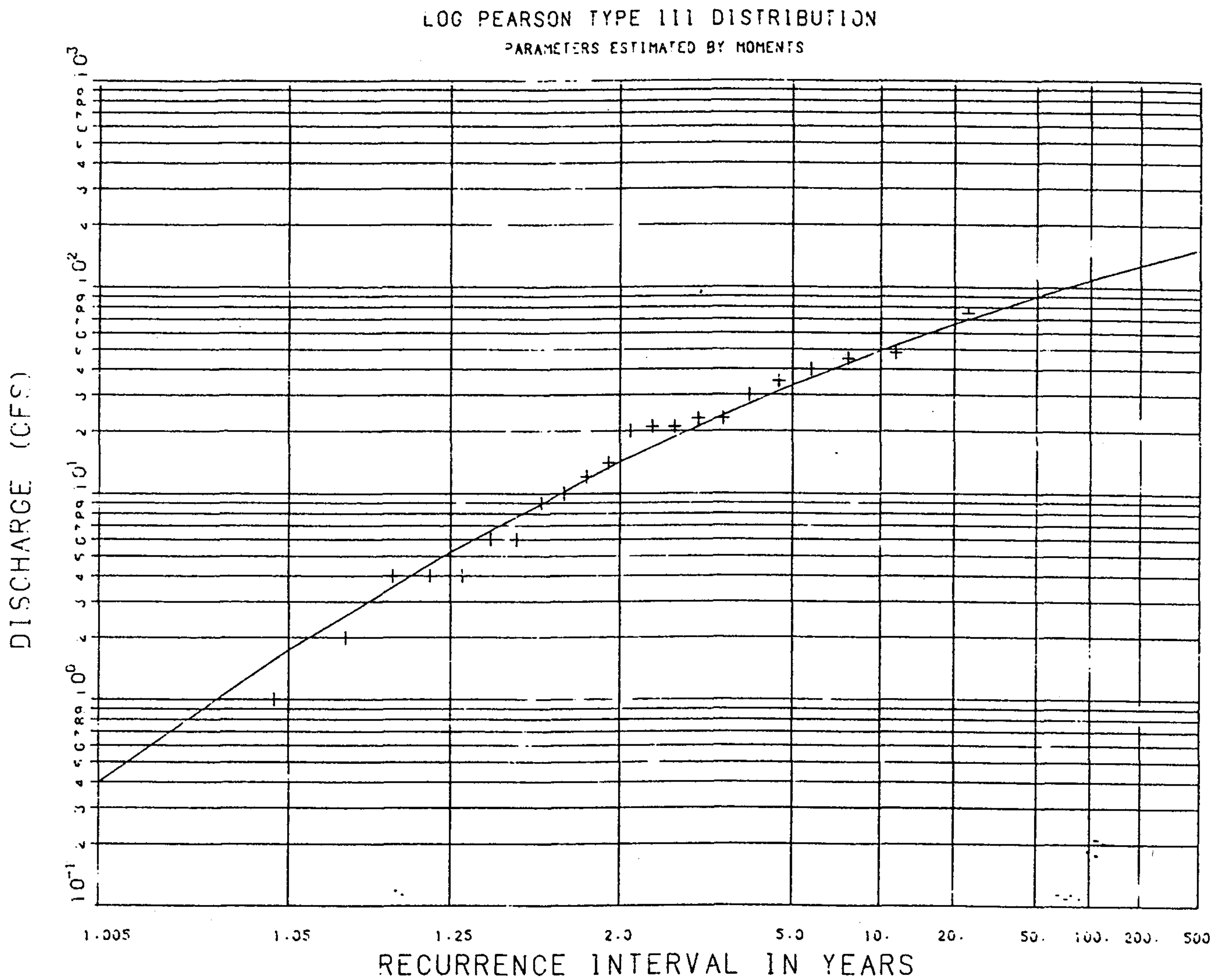


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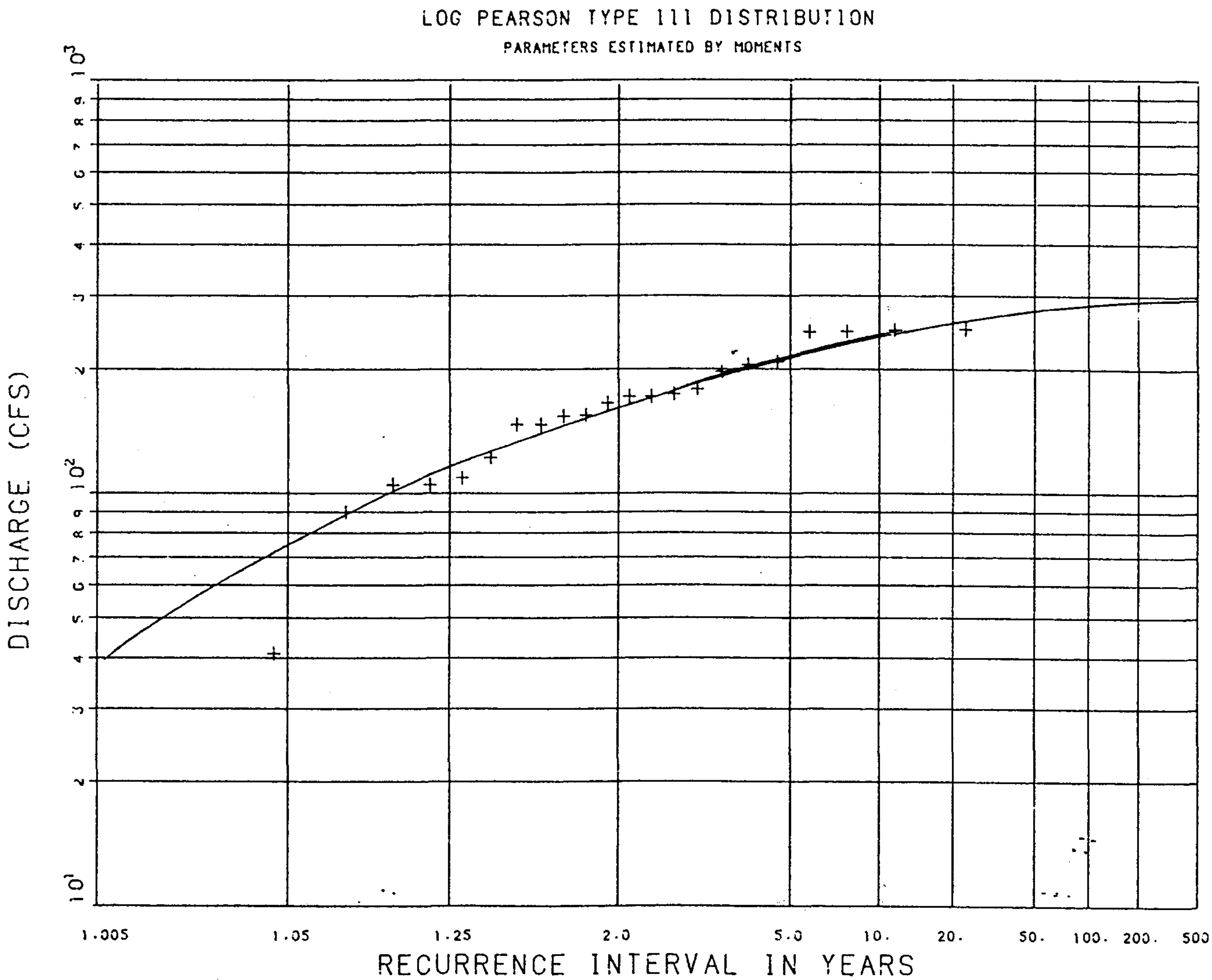
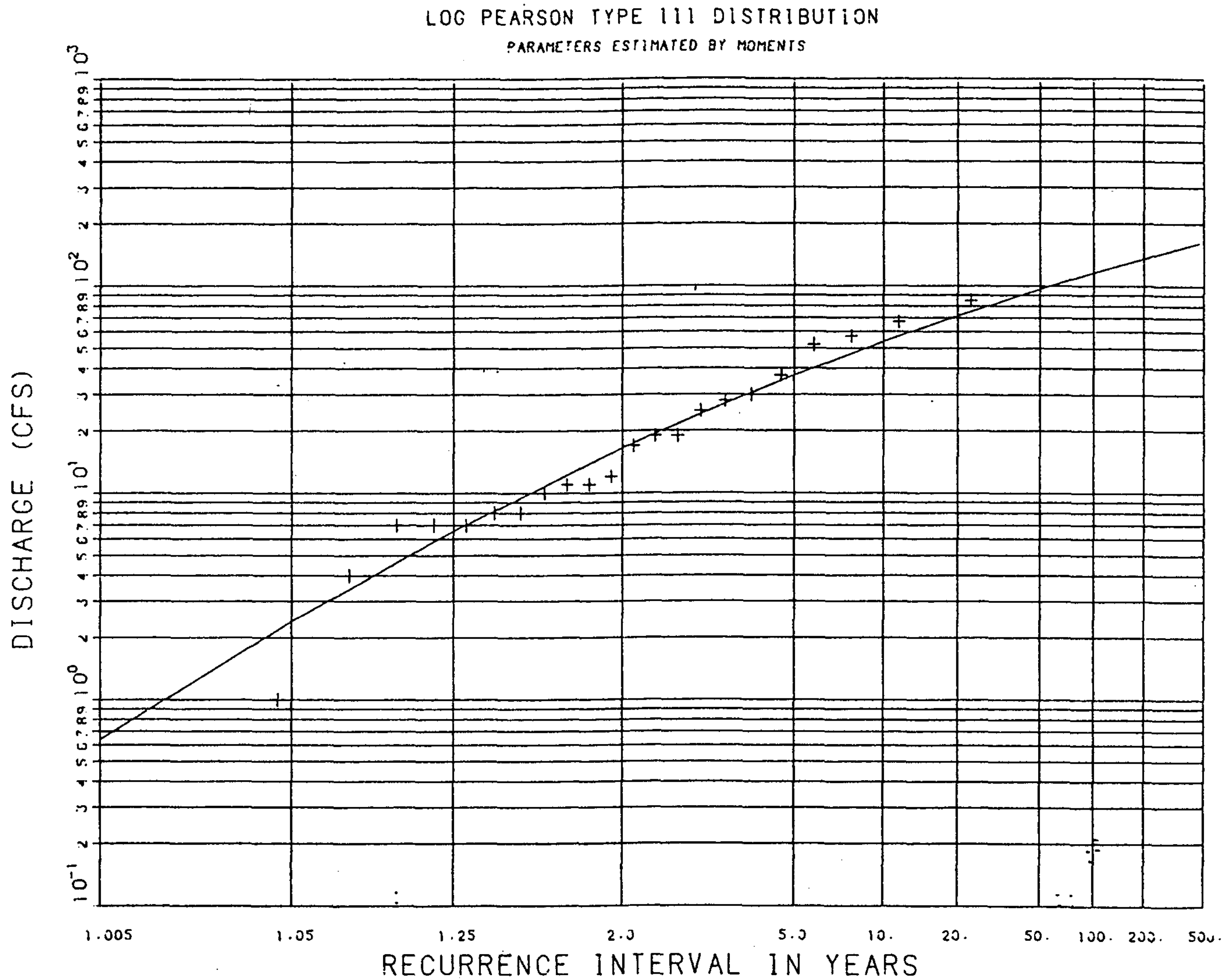
Figure 5-37

Annual Peak Flow Frequency Curve at Ferguson Drain



May Peak Flow Frequency Curve at Ferguson Drain



Summer (June to September) Peak Flow Frequency Curve at Ferguson Drain

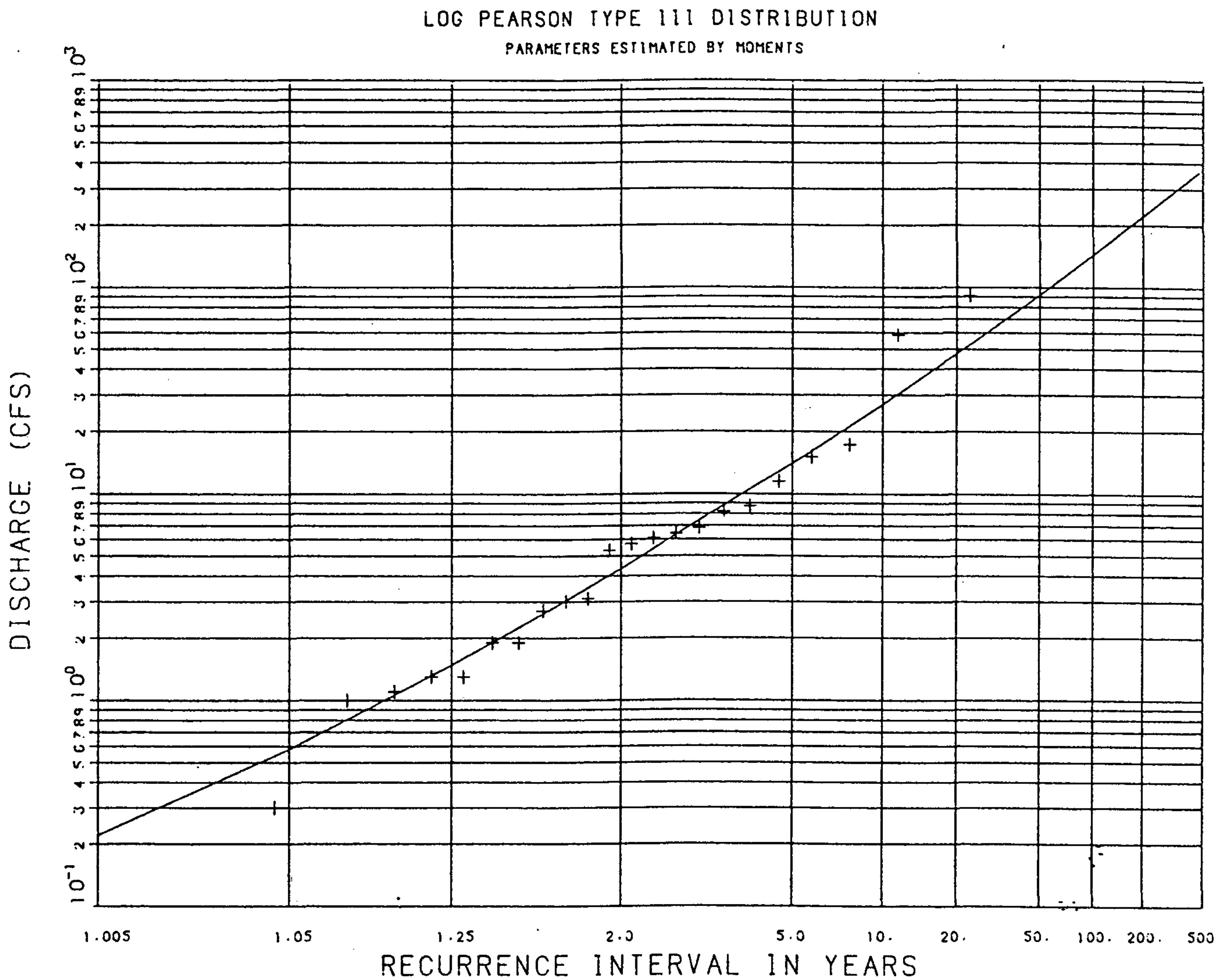
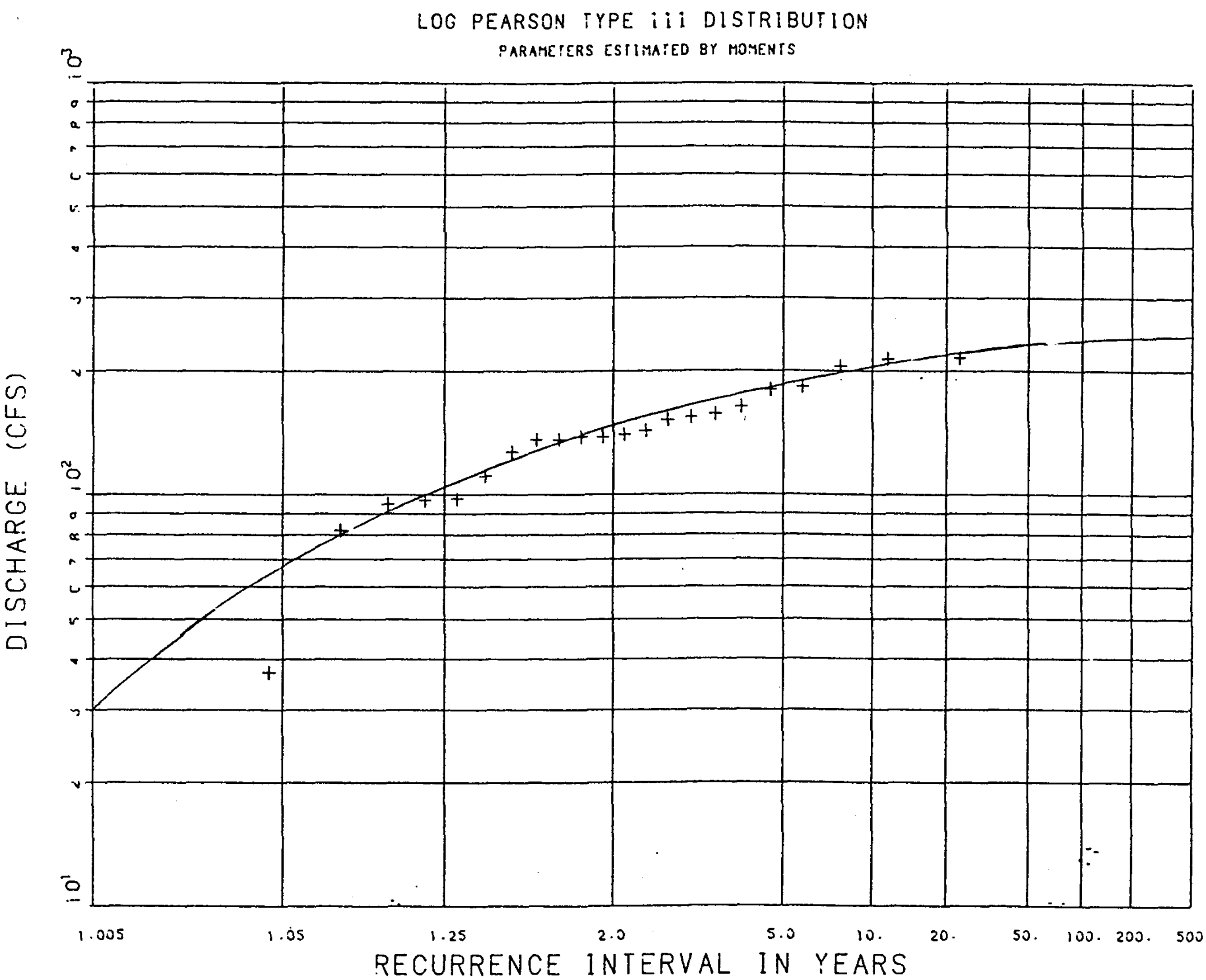
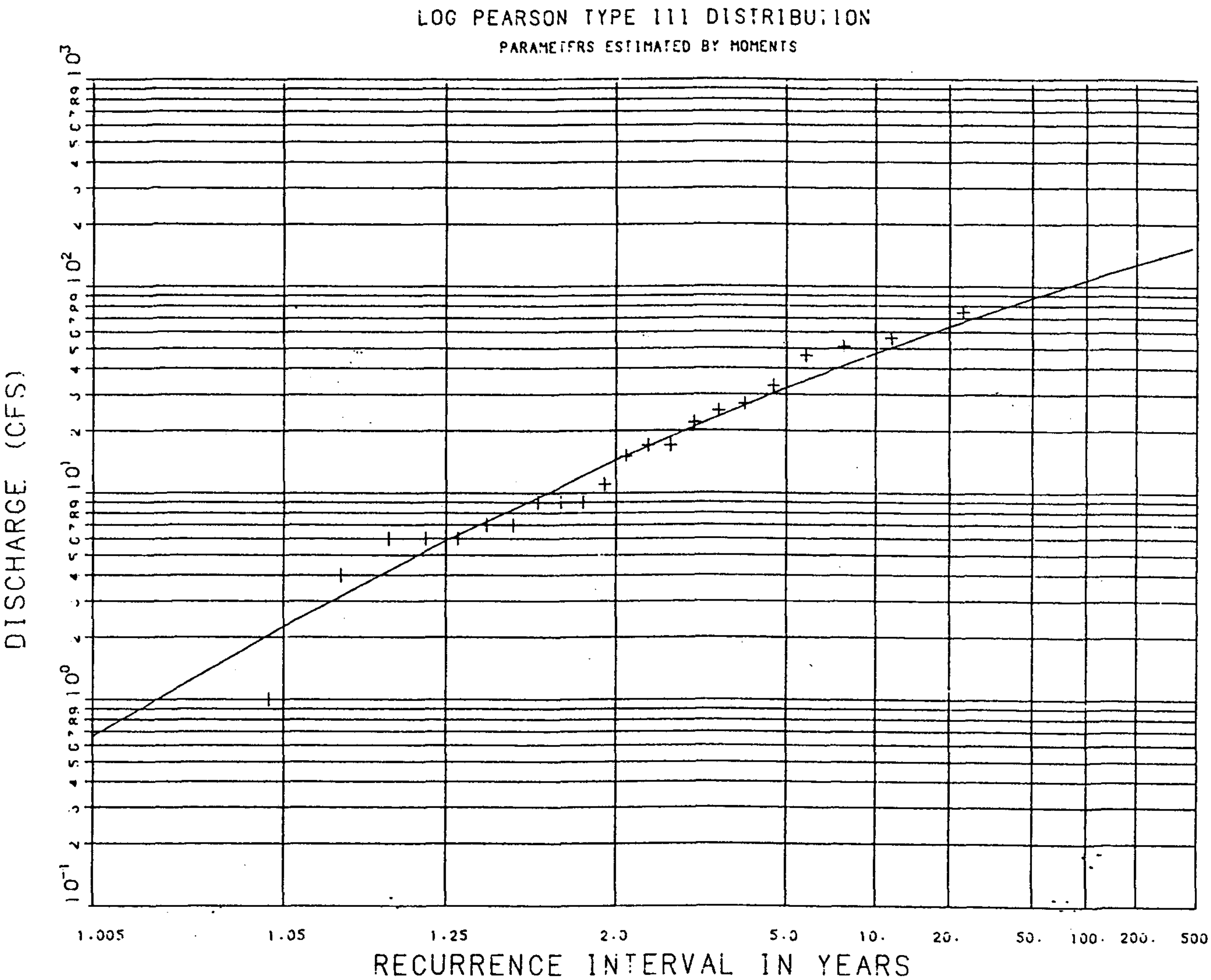


Figure 5-40

Annual Peak Flow Frequency Curve at Mullen (Gannon) Drain



May Peak Flow Frequency Curve at Mullen (Gannon) Drain



Summer (June to September) Peak Flow Frequency Curve at Mullen (Gannon) Drain

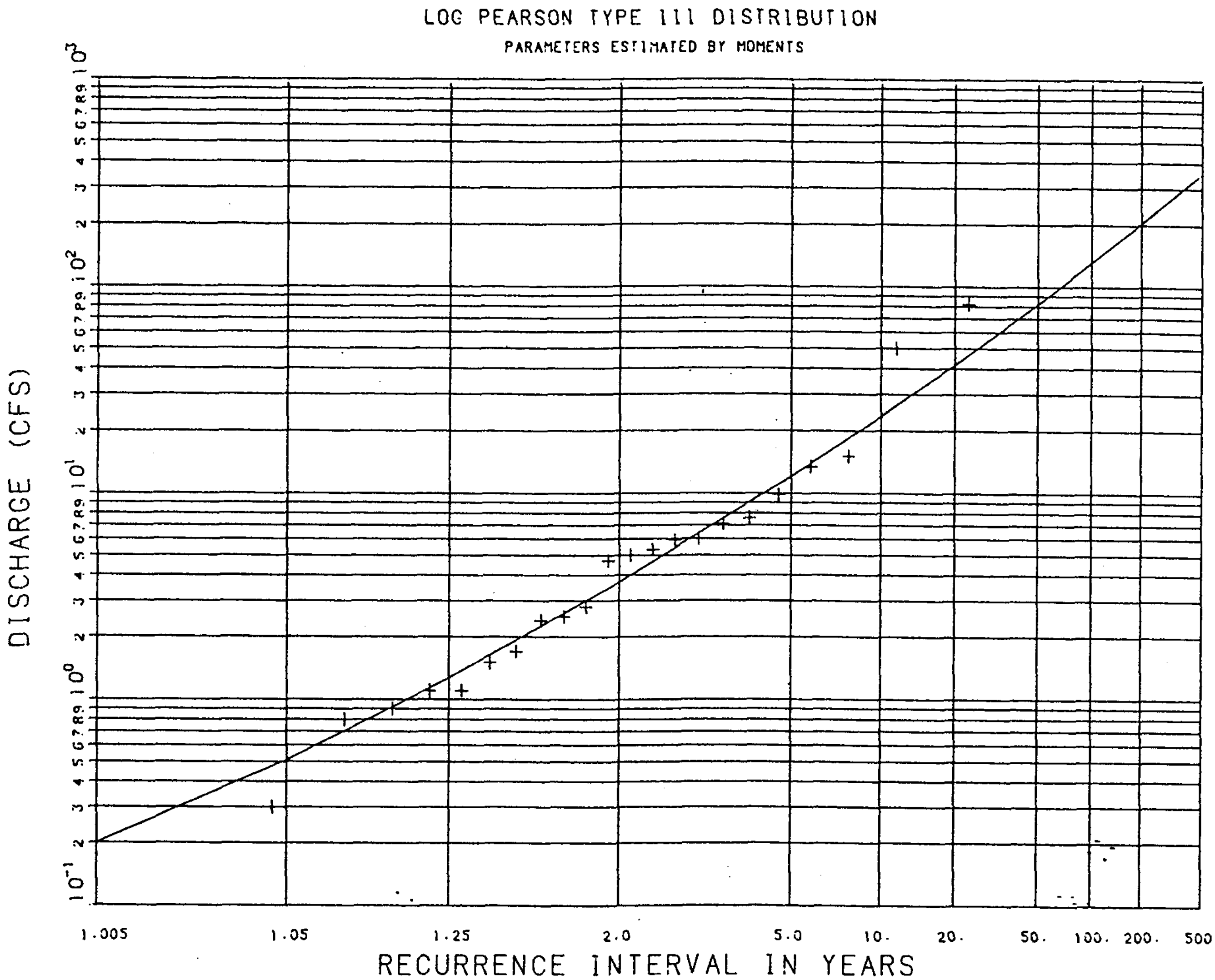
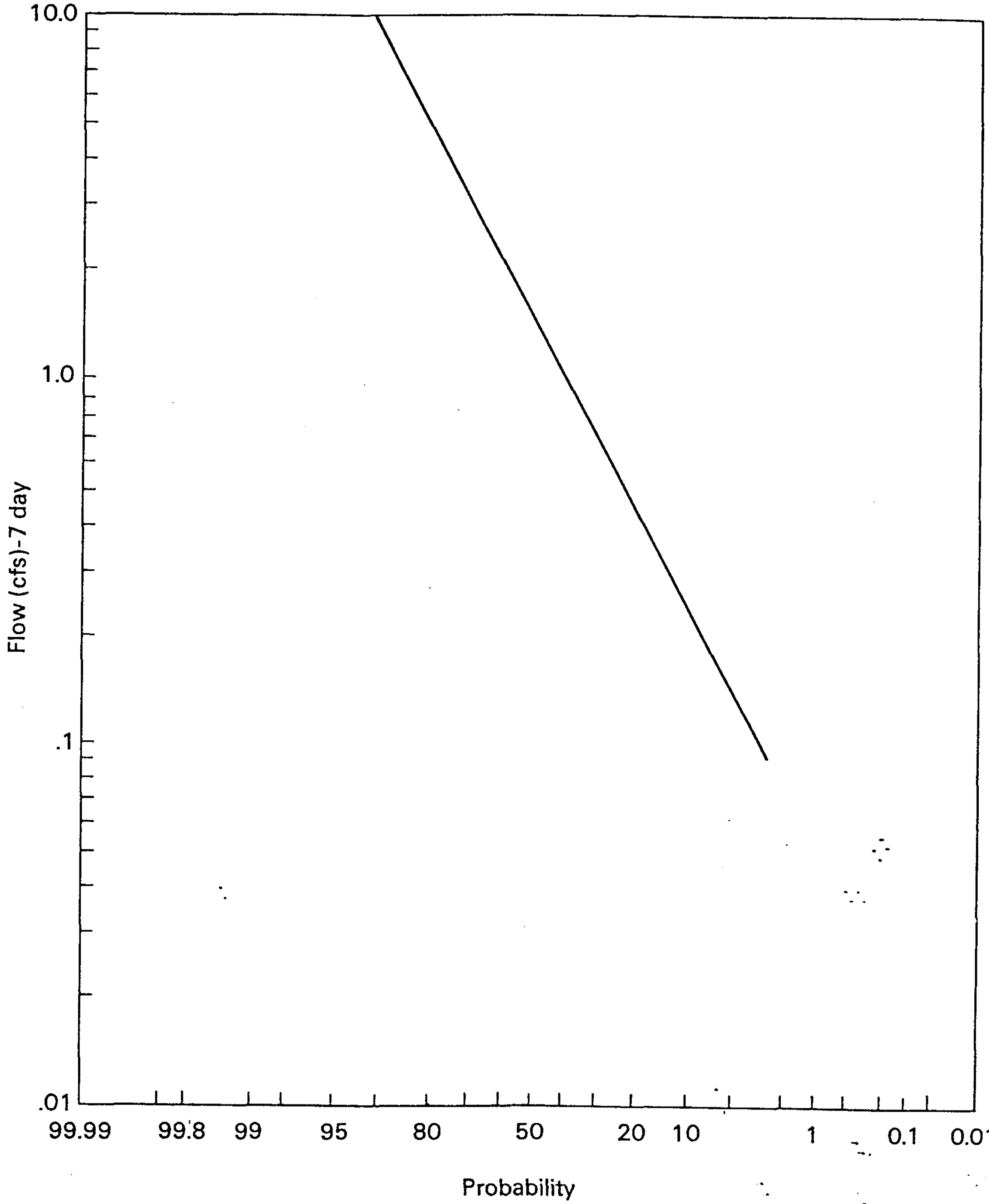


TABLE 5.11

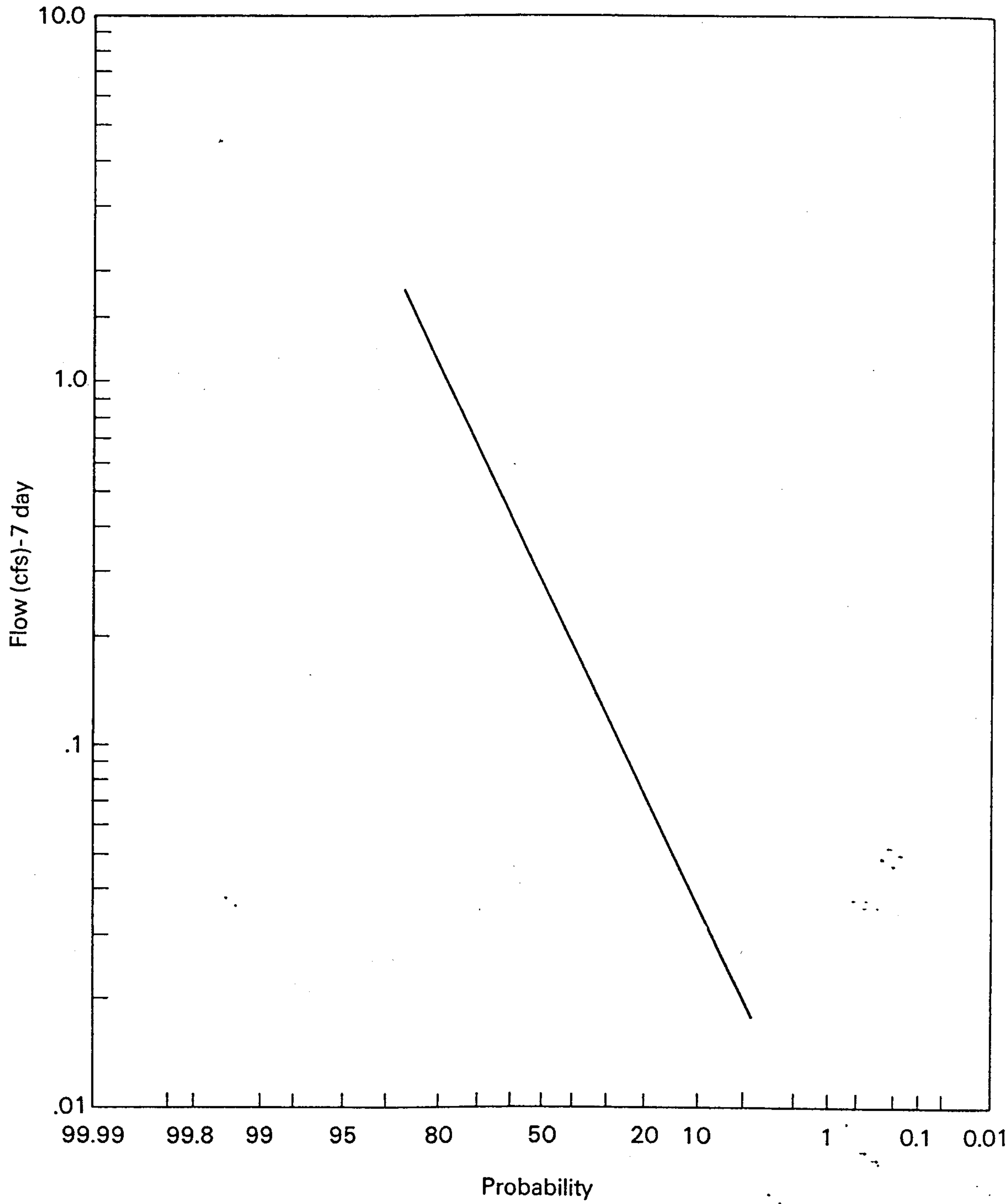
Flows for the 2, 5, 10, 20, 50 and 100 Year Return Periods at Four Specified Drains

Location	Season	Flows at Specified Period m^3/s (cfs)											
		2 yr		5 yr		10 yr		20 yr		50 yr		100 yr	
Payne Creek Drain	Spring	22	(766)	40	(1420)	59	(2100)	85	(3010)	134	(4730)	185	(6550)
	May	3	(103)	6	(222)	9	(324)	12	(436)	17	(601)	21	(738)
	Summer	1	(43)	4	(131)	6	(227)	10	(352)	16	(564)	22	(764)
Van Camp Drain	Spring	19	(666)	25	(888)	28	(1000)	31	(1100)	34	(1190)	35	(1250)
	May	2	(74)	5	(168)	7	(345)	9	(327)	12	(441)	15	(531)
	Summer	0.4	(14)	1	(33)	1	(49)	2	(66)	3	(90)	3	(109)
Ferguson Drain	Spring	5	(160)	6	(220)	7	(240)	7	(250)	8	(270)	8	(290)
	May	0.5	(17)	1	(37)	2	(54)	2	(72)	3	(96)	3	(116)
	Summer	0.1	(4)	0.4	(14)	0.8	(27)	1	(64)	3	(91)	4	(144)
Mullen (Gannon) Drain	Spring	4	(150)	5	(190)	6	(210)	6	(220)	7	(230)	7	(235)
	May	0.4	(14)	0.9	(32)	1	(64)	2	(47)	2	(88)	3	(107)
	Summer	0.1	(4)	0.3	(12)	0.7	(24)	1	(42)	2	(82)	4	(132)

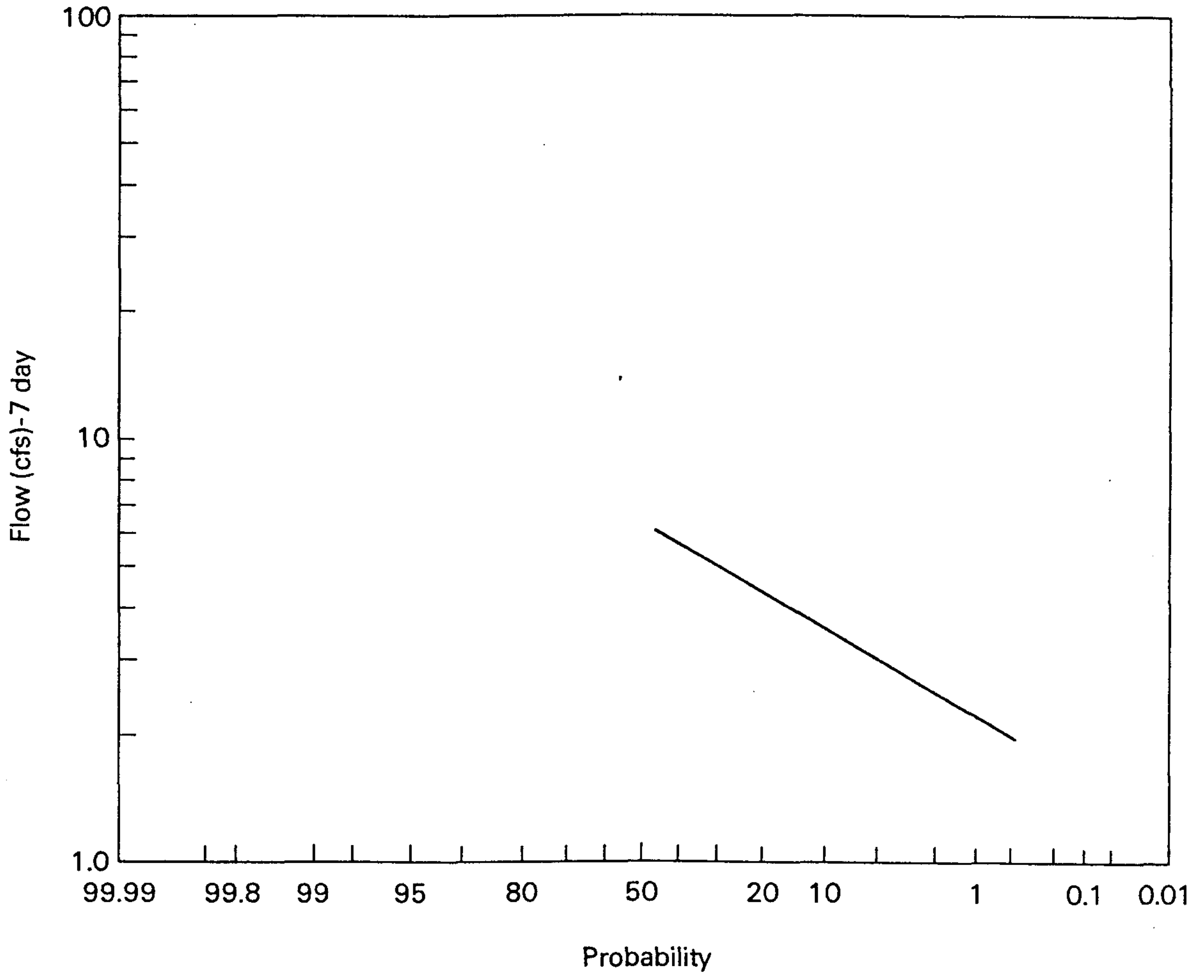
Seven Day Minimum Flow Frequency Curve at Chesterville



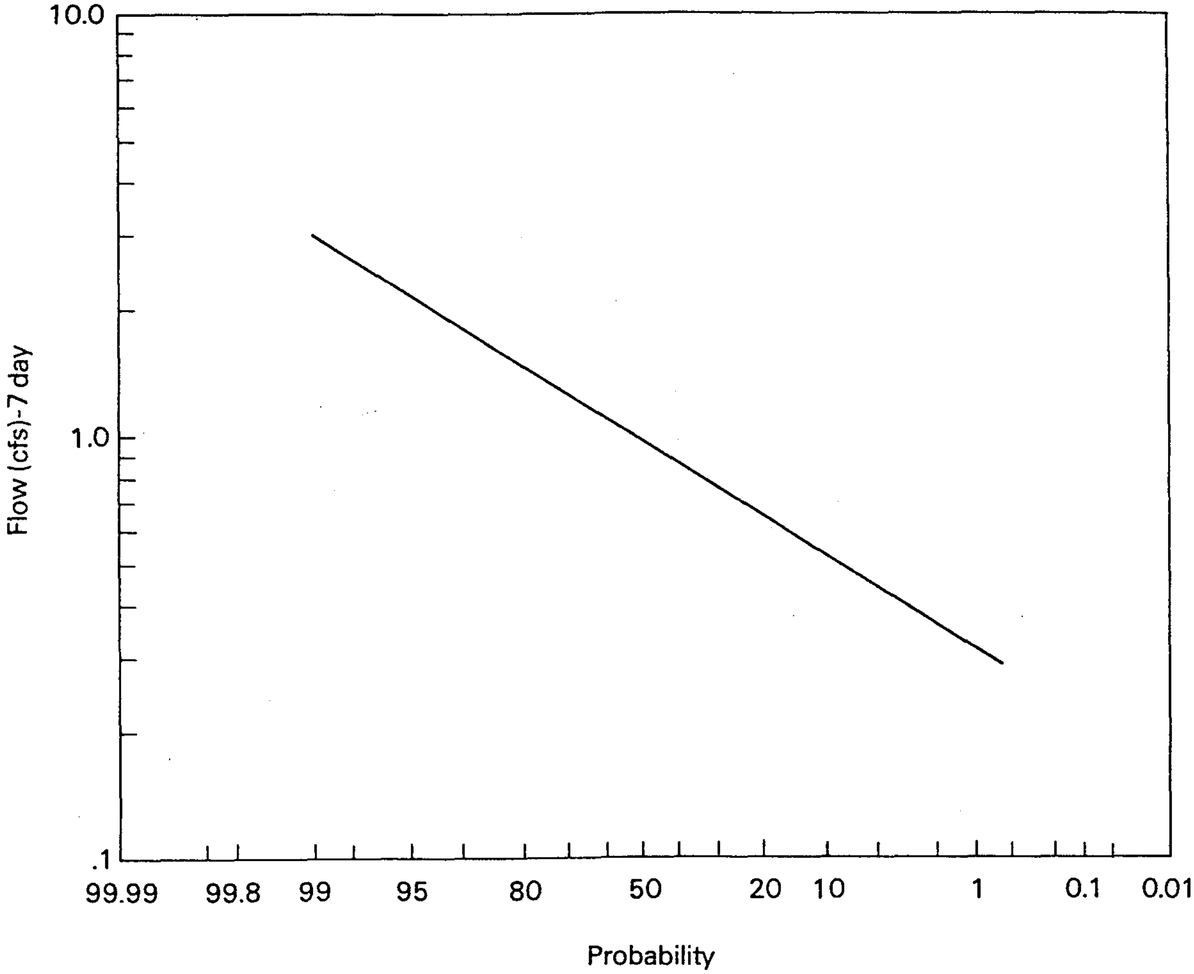
Seven Day Minimum Flow Frequency Curve at St. Isidore de Prescott



Seven Day Minimum Flow Frequency Curve at Bourget



Seven Day Minimum Flow Frequency Curve at Embrun



Seven Day Minimum Flow Frequency Curve at Casselman

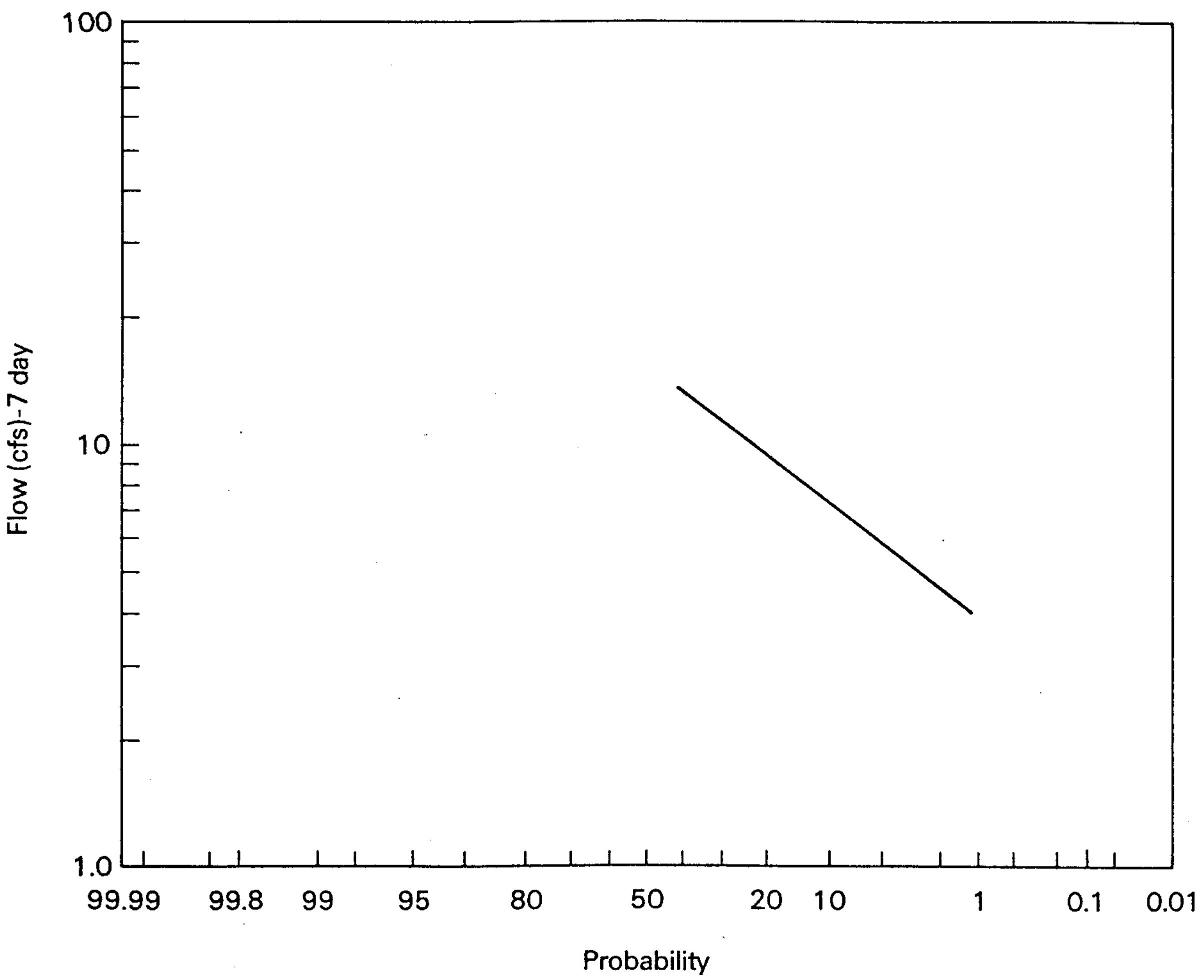


Figure 5-48

Seven Day Minimum Flow Frequency Curve at Plantagenet

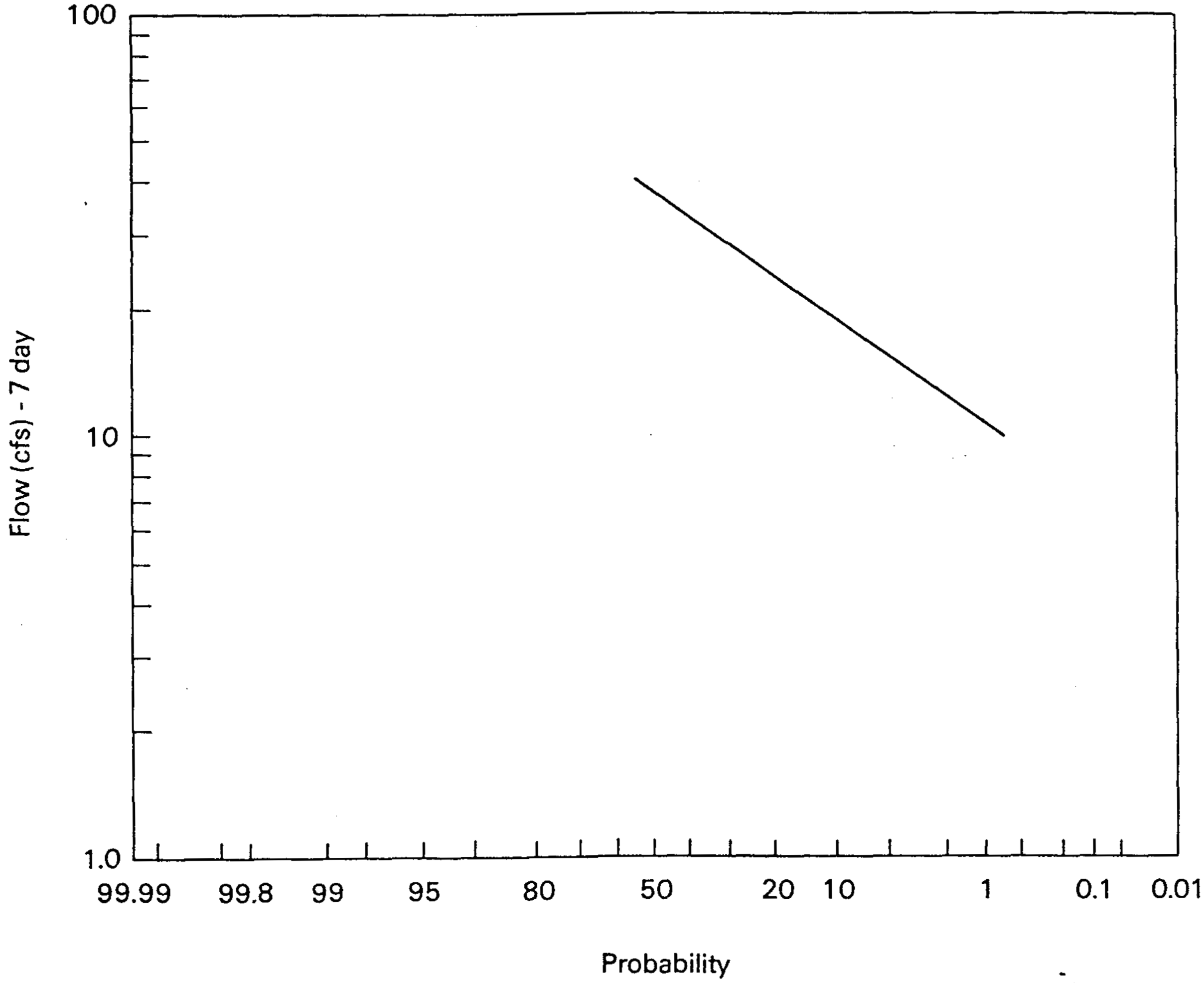


TABLE 5.12

Average Seven Day Minimum Flows For 2, 5, 10, 20, 50 and 100 Year Return Periods at Selected Sites

Location	Flows at Specified Period m^3/s (cfs)					
	2 yr	5 yr	10 yr	20 yr	50 yr	100 yr
Chesterville	0.052 (1.82)	0.018 (0.64)	0.010 (0.37)	0.007 (0.23)	0.004 (0.14)	0.003 (0.10)
St. Isidore	0.009 (0.33)	0.003 (0.10)	0.002 (0.056)	0.001 (0.034)	0.0005 (0.019)	0.0004 (0.013)
Bourget	0.210 (7.41)	0.173 (6.12)	0.157 (5.54)	0.144 (5.10)	0.132 (4.65)	0.124 (4.37)
Embrum	0.033 (1.15)	0.026 (0.93)	0.023 (0.83)	0.021 (0.75)	0.019 (0.68)	0.018 (0.63)
Casselman	0.521 (18.40)	0.377 (13.30)	0.317 (11.20)	0.275 (9.71)	0.235 (8.29)	0.211 (7.46)
Plantagenet	1.422 (50.20)	1.065 (37.60)	0.915 (32.30)	0.807 (28.50)	0.702 (24.80)	0.640 (22.60)

CHPATER 6

IMPACTS OF AGRICULTURAL DRAINAGE PRACTICES

CHAPTER 6

IMPACTS OF AGRICULTURAL DRAINAGE PRACTICES

6.0 IMPACTS OF AGRICULTURAL DRAINAGE PRACTICES

6.1 Introduction

Agricultural land drainage is undertaken to improve the soil environment for better crop production and to lengthen the effective growing season through improved field machine trafficability. In the South Nation watershed, drainage improvements have been taking place for many years and most watercourses have already been converted to improved municipal drains. Recently, there is an increasing trend in the basin to install subsurface drainage systems, commonly called 'tile drainage', to improve land and crop productivity. Many of the municipal drains will require deepening and enlarging to provide adequate outlets. This trend is a concern to many residents in the watershed who feel that further drainage improvements may aggravate the extensive flooding that already occurs in several locations.

It is generally true that improving stream channels by straightening, widening or deepening will induce a more rapid response to runoff events. This often results in higher peak flows and shorter peak flow durations. However, in a large watershed with many tributaries, the net effect on the peak flows in the main channel may be much less significant due to routing effects and the time-offset of peak flows arriving from tributaries. The installation of subsurface drainage further alters the runoff process. Tile drainage accelerates the water table drawdown in the first metre of the soil which theoretically could produce higher rates of flow from the soil during runoff events. On the other hand, this improved soil drainage will create a drier antecedent condition, higher infiltration and more soil storage which will tend to reduce surface runoff rates from most runoff events.

The objective of this component of the water resources study is to investigate the effects of agricultural drainage improvements and determine their impact on the basin.

6.2 Method Overview

It is not practical to evaluate watershed-scale effects with a very detailed model. On a large scale, local effects cannot be simulated explicitly and it is necessary to determine average parameters characterizing local conditions such as field tiles and drain improvements for relatively large subcatchments. The approach used in this study was to use detailed models of local conditions to supplement the watershed model. The detailed models were calibrated to field data and then used to simulate representative drainage areas similar in size to the watershed model subcatchments for various drainage conditions. The watershed model parameters were then adjusted on the basis of these results to simulate the effects of local drainage improvements on the entire South Nation watershed.

A model which can accurately simulate drainage conditions both with and without field tiles was not available during the study. Instead two models were used, the DRAINMOD model developed at the University of North Carolina for tiled-drained areas and the HSP-F model for untiled conditions. The DRAINMOD model is a continuous simulation model formulated to simulate tile drainage conditions explicitly. A detailed description of DRAINMOD may be found in Appendix F. The model is capable of considering detailed soil moisture characteristics and water table elevations. The HSP-F model was selected for untiled conditions to provide continuity with the watershed modelling. All outlet drain and stream channel routing was done with the HSP-F model routing routines.

A schematic overview of the method used to evaluate the impacts of drainage improvements is shown in Figure 6.1.

6.3 Test Area Monitoring Data

The Conservation Authority established flow monitoring stations on six outlet drains and two tile drain outlets late in 1980 and continued the monitoring during 1981. The sites were representative of the general conditions in the watershed, covering a variety of soil types and various degrees of tile drainage. Characteristics are summarized in Table 6.1.

Several rain gauges were added to the network during the last week of May 1981 and rating curves for the outlet drains were established during the spring runoff period.

A number of runoff events were collected in 1981 from each of the test watersheds. However, the rating curves which were developed for the drains in the spring became increasingly inaccurate as vegetation grew over the spring and summer period. The rating curve at one location was partially recalibrated in September and found to estimate about 25% lower flows than the spring curve for similar water levels. The other five test areas were not recalibrated. On the basis of field observations and the one recalibration, it was assumed that the rating curves for the other areas had changed by a similar amount.

The use of test area data for calibration purposes is further hampered by the location of rainfall gauges. Most recorded runoff events occurred before the end of May when site rain gauges were installed. Rainfall for events preceding this date was recorded at gauges located as much as 20 km away from test catchments which greatly reduces the reliability of the measurements.

6.3.1 Analysis of Flow Data

The events for which data was collected in 1981 are listed in Table 6.2. Due to the late start-up date of the monitoring program in 1980, little useful data was collected from this period.

As a preliminary verification of the data, approximate ratios of runoff volume over rainfall volume were computed for each event from the tabulated rainfall data recorded at the nearest gauge and from the plotted runoff hydrographs. Many of these ratios were found to be greater than 1 which clearly illustrates the problems with the rainfall and rating curves discussed previously. All events with unrealistic runoff ratios were not considered further. As a further concession to the possible inaccuracies of the rating curves due to vegetation growth, most events subsequent to the first week in June were also deleted.

The data remaining after this initial screening was analyzed graphically as shown in Figures 6.2 through 6.4. Figure 6.2 presents a plot of runoff/rainfall ratios versus the percent of the test area with tile drainage, Figure 6.3 shows unit runoff volume versus tile drainage; and Figure 6.4 shows unit runoff peak versus tile drainage. The first two plots indicate a trend towards higher runoff volumes during the storm event and the following few days with increased tile drainage. It is suggested that this effect may be due to the release of additional volumes of subsurface water by tile drains. A long-term analysis of the volumetric relationship between tiled and untiled conditions was not possible with the data available. Peak runoff rates do not seem to be affected by the degree of tile drainage for these events. Given the uncertainty in the recorded data and the small number of events from the more densely tiled catchments, these results cannot be considered conclusive.

6.4 Modifications to DRAINMOD

In order to apply the DRAINMOD model during this study, several modifications to the program were required with respect to the time interval, evapotranspiration, winter/spring runoff and overland flow routing. Only the first two items required changes to the program code. In the first case, an option for an hourly output file was incorporated since all subsequent calculations were based on hourly time steps. Secondly, the DRAINMOD evapotranspiration calculations based on the Thornthwaite Method were superceded by monthly average values based on recorded pan evaporation data. These monthly

Figure 6-1

Method Schematic for Evaluating Impacts of Drainage Improvements

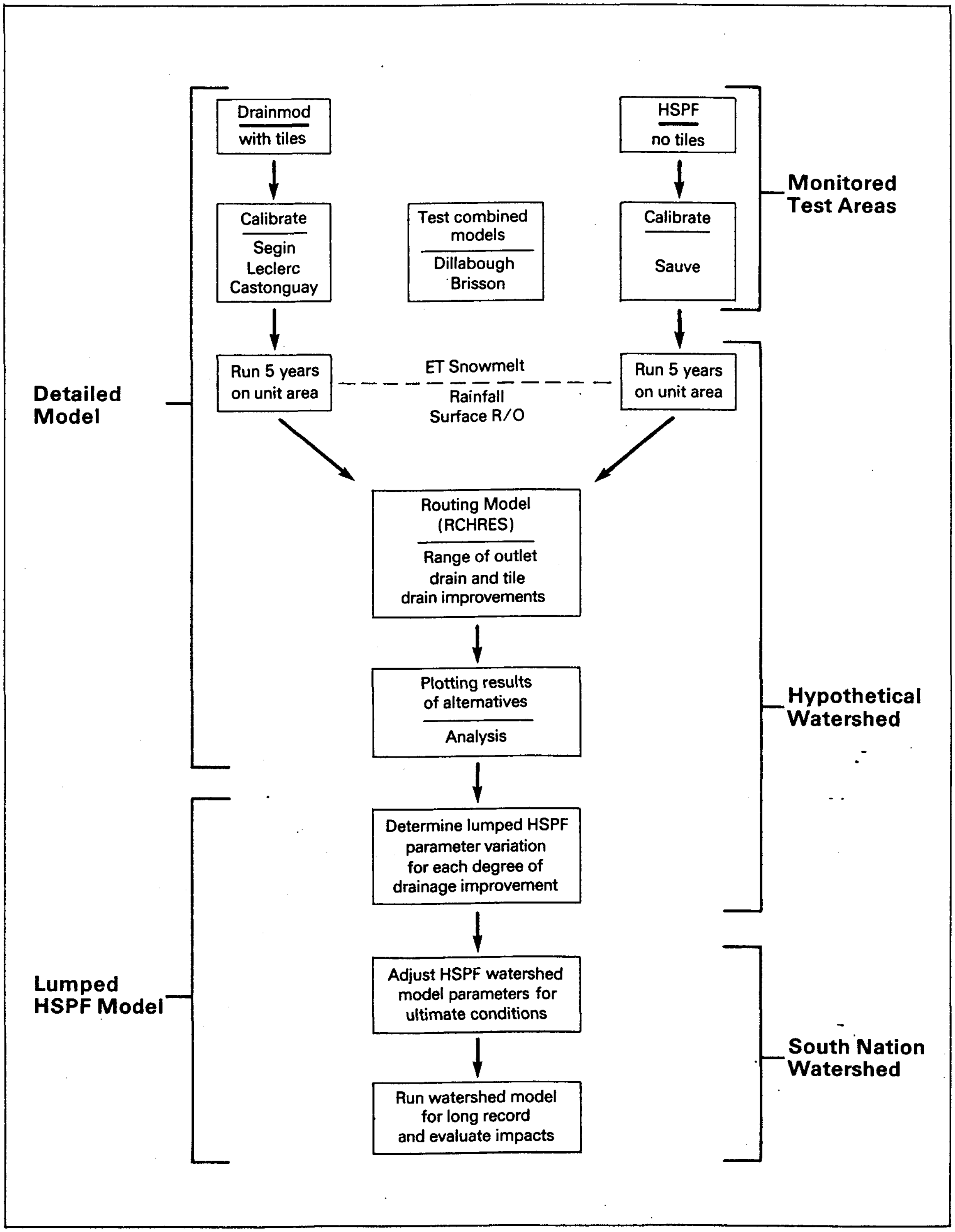


TABLE 6.1

Agricultural Drain Test Catchments

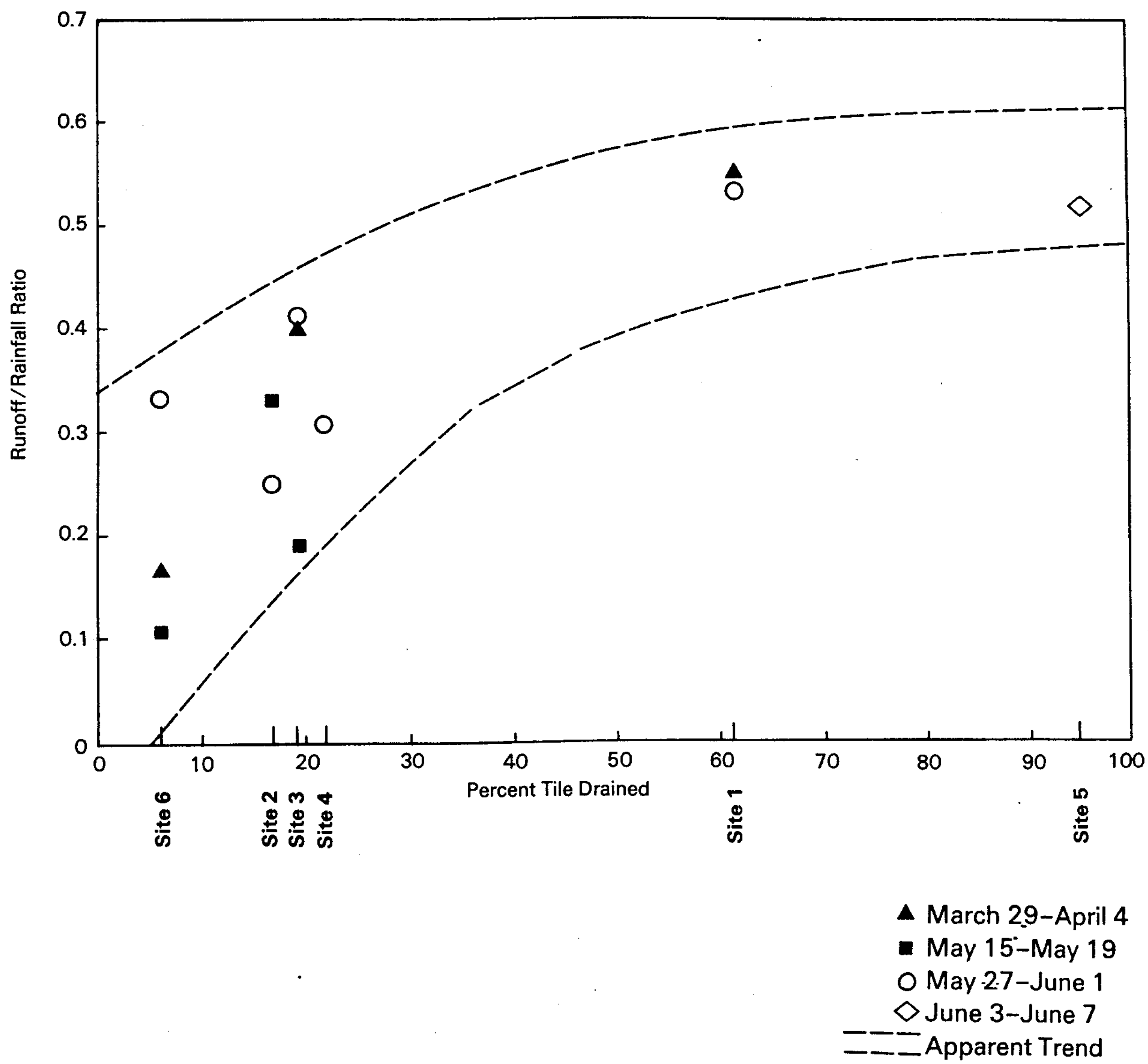
Description	Area (ha)	% Tile Drained	Monitoring Site
1. Dillabough	745	61	Outlet drain
2. Ouderkirk	240	17	Outlet drain
3 Brisson	898	19	Outlet drain
4. Small Creek	137	22	Outlet drain
5. Castonguay	156	95	Outlet drain
6. Sauvé	231	6	Outlet drain
7. Leclerc (tiles)	13.8	100	Tile drain
8. Seguin (tiles)	7.5	100	Tile drain

TABLE 6.2

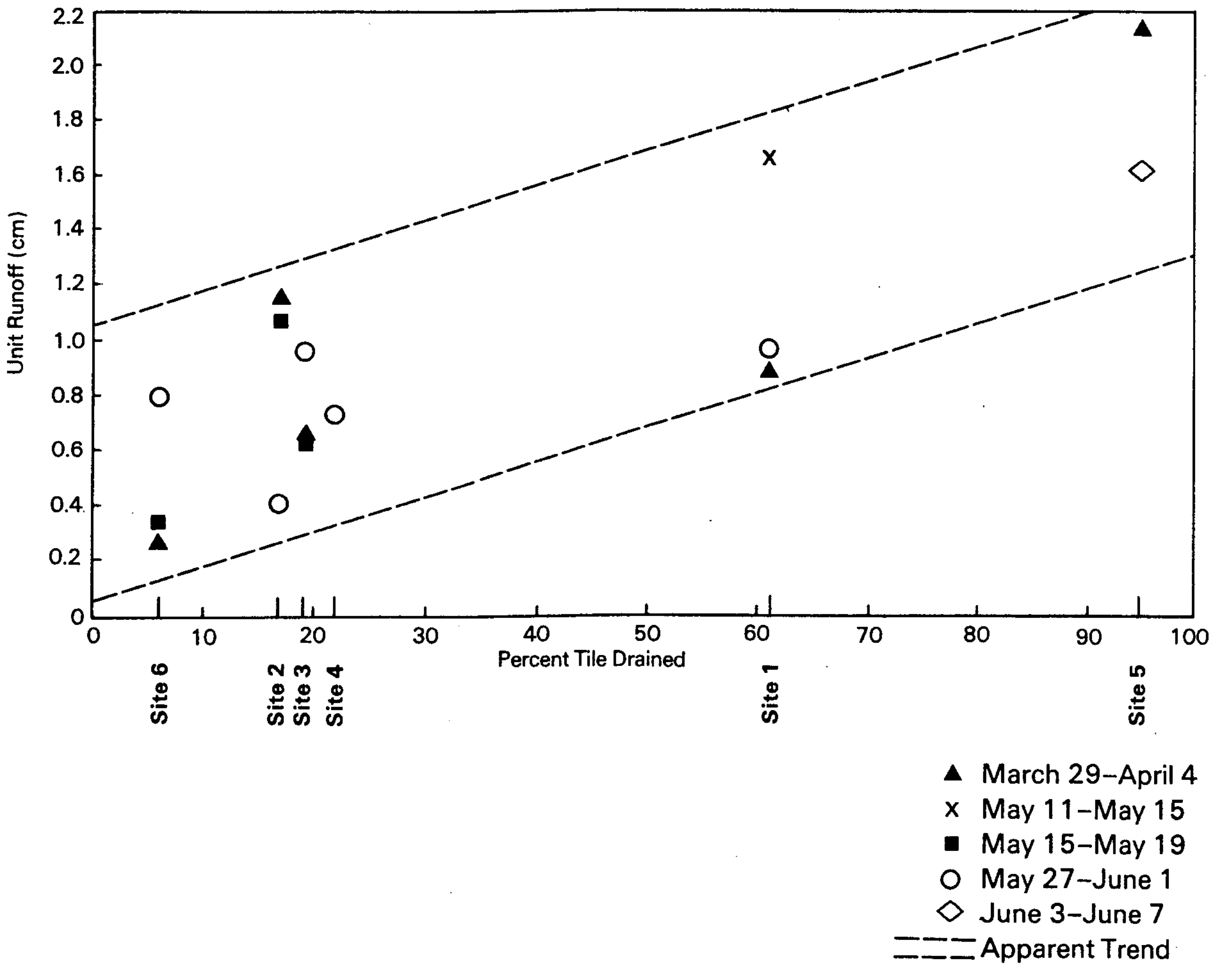
Recorded Runoff Events

Event Period	Dillabough	Ouderkirk	Brisson	Small Creek	Castonguay	Sauvé
Mar. 29 - Apr.4						
Rain (cm)	1.63	1.63	1.63	1.63	1.63	1.63
Runoff/Rain	0.55	0.71	0.40	4.18	1.32	0.17
May 11 - 15						
Rain (cm)	3.84	3.84	3.84	3.84	-	3.84
Runoff/Rain	0.44	2.05	0.06	1.61	-	0.11
May 15 - 19						
Rain (cm)	3.23	3.23	3.23	3.23	-	3.23
Runoff/Rain	0.89	0.33	0.19	1.16	-	0.11
May 27 - June 1						
Rain (cm)	1.85	1.65	2.39	2.39	-	2.41
Runoff/Rain	0.53	0.25	0.41	0.31	-	0.33
June 3 - 7						
Rain (cm)	-	-	-	5.28	3.10	-
Runoff/Rain	-	-	-	1.09	0.52	
June 16 -22						
Rain (cm)	0.56	-	-	-	-	-
Runoff/Rain	3.48	-	-	-	-	-
June 22 - 25						
Rain (cm)	-	2.34	-	5.08	-	-
Runoff/Rain	-	2.27	-	1.79	-	-
June 22 - 27						
Rain (cm)	5.54	-	-	-	-	-
Runoff/Rain	1.02	-	-	-	-	-
June 25 - 29						
Rain (cm)	-	1.02	-	-	-	-
Runoff/Rain	-	2.49	-	-	-	-

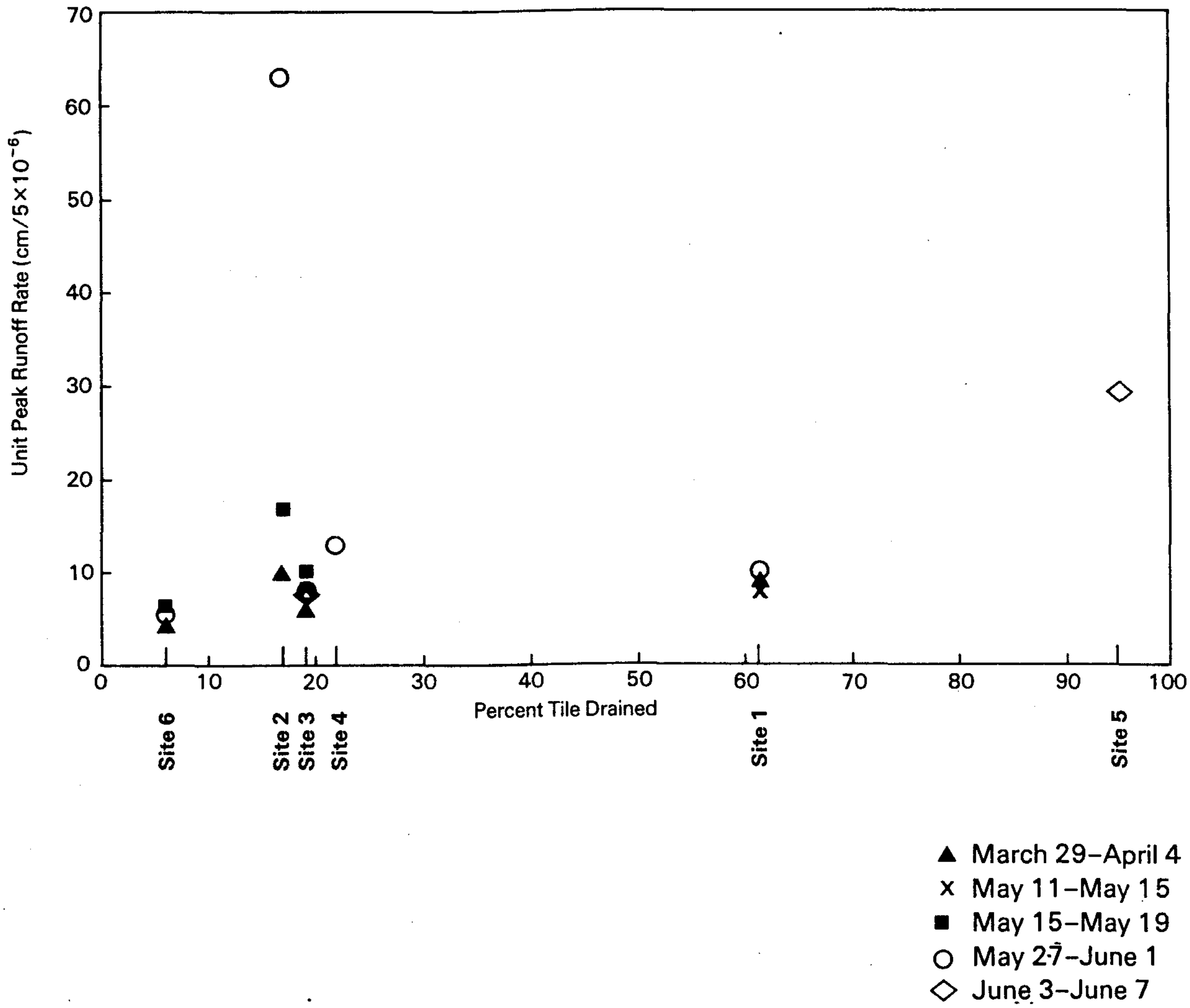
Test Area Data Analysis
Runoff / Rainfall Ratio vs Percent Tile Drainage



Test Area Data Analysis
Unit Runoff vs Percent Tile Drainage



Test Area Data Analysis
Unit Peak Runoff vs Percent Tile Drainage



values were obtained from the HSP-F simulation for the same period and they formed the basis of the DRAINMOD model input. This ensured that both models were working with the same evapotranspiration data base.

The HSP-F model was also used indirectly to enable the DRAINMOD model to be run continuously over a number of years through winter periods. The computed "moisture supply rate" from the HSP-F simulation, consisting of the total precipitation and snowmelt moisture available on the land surface before any storage, infiltration or runoff processes occur, was extracted and converted to the DRAINMOD input format in place of the usual rainfall input. The foregoing changes resulted in both models utilizing exactly the same meteorological input. No attempt was made to modify DRAINMOD for frozen soil conditions since the effect of this condition is not presently known.

Lastly, a post-processor was written to transform the hourly output files from DRAINMOD to HSP-F compatible format for input to the RCHRES routing program. As part of the transformation process, the surface runoff component of the DRAINMOD output was modified by an overland flow routing program. The routing program was also extracted from the HSP-F model. The routed surface runoff was then added to the computed tile flow to obtain the total outflow for the tile-drained area.

6.5 Model Calibration

Four of the test areas were selected to represent a range of tile drainage density. These were the 156 ha Castonguay site with 95% tile drainage, the 231 ha Sauvé site with 6%, the 745 ha Dillabough site with 61% and the 898 ha Brisson site with 23% tile drainage by area. Further details are provided on Table 6.1. The extent and location of tile drainage in each site was determined by field inspections and interviews with property owners. The HSP-F model was applied to the Sauvé test data, which was considered to be an area without tile drainage and the DRAINMOD model was applied to the Castonguay test data which was considered to represent complete tile drainage. The DRAINMOD model was also tested on the field tile monitoring sites.

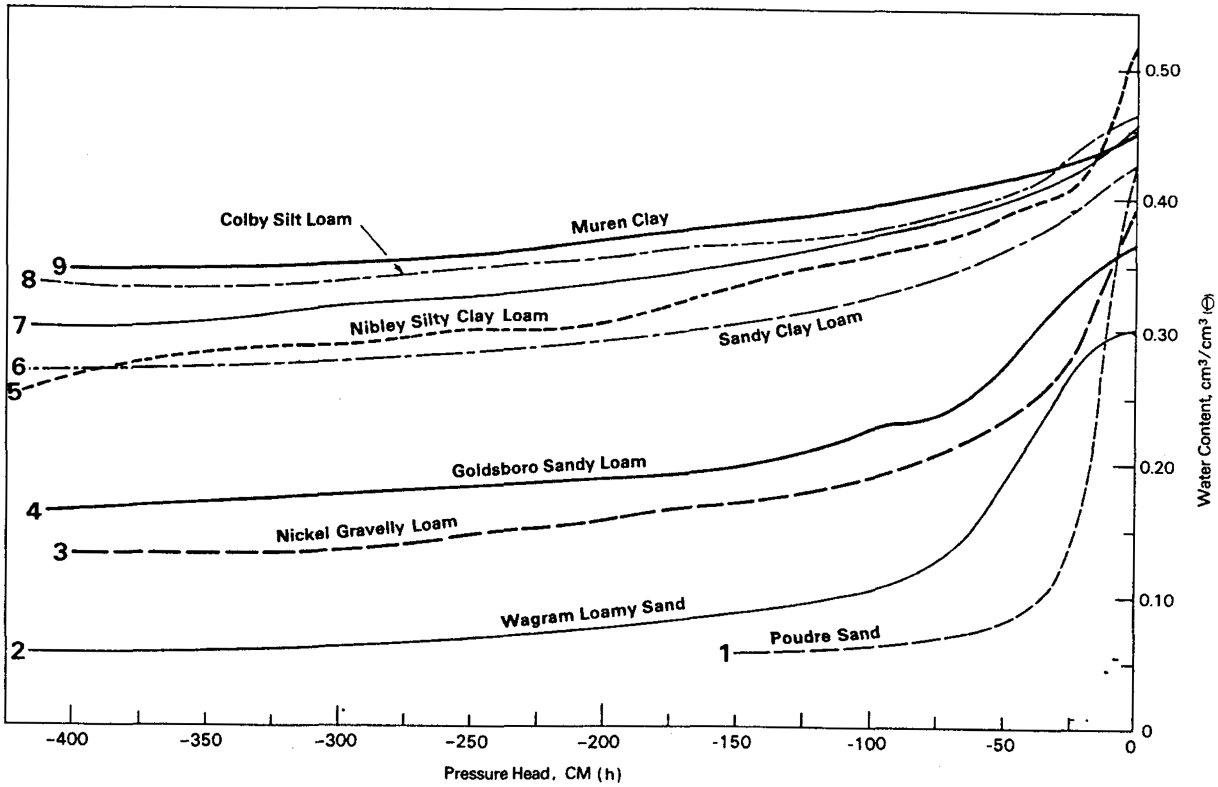
6.5.1 Calibration of DRAINMOD

The initial selection of the soil moisture characteristic was based on representative curves given in the program documentation for various soil textures and the soil description for each site.

Some minor adjustments were made to these curves in the calibration process. One other parameter found to be significant in the calibration is the lateral hydraulic conductivity (K). Some measurements of this parameter were conducted in the field as part of the overall study but there was a large variability in the results and few measurements were actually made within the boundaries of the test catchments. As a result, K values were derived primarily from the calibration process. The Green-Ampt infiltration parameters were also derived from the literature values and the calibrated hydraulic conductivity. The soil water characteristic curves used in the study are shown in Figure 6.5.

Soil Water Characteristics Curves

Test Area	Characteristic Curve Used
Castonguay	9
Dillabough	8
Sauvé	7
Brisson	4



(after Skaggs (1))

The calibration results are plotted against recorded data for the Castonguay site in Figure 6.6. The recorded event at the end of March 1981 should be discounted as the runoff/rainfall ratio for this event was greater than 1. The other event in June 1981 shows very good agreement between the model and measurements when the problems with the rating curve are taken into consideration. No flow data were recorded during dry weather periods.

Figures 6.7 and 6.8 show the plots of the calibration results on the Seguin and Leclerc tile flow monitoring sites. Both plots show good agreement between the observed and computed runoff, particularly for the June 5, 1981 event for which site rainfall data was available. The Seguin data also exhibit the effects of tile drain capacity restrictions on both recorded events. The observed maximum value was 0.005 m^3/s (0.6 cm/day) from the 7.5 ha site and this value was used as the maximum tile flow capacity for all subsequent analyses in the study.

These results confirmed that the DRAINMOD model was adequately reproducing the division of runoff between tile flow and other runoff and that it could be used to simulate the completely tiled condition.

6.5.2 Calibration of HSP-F

As an initial step the parameter set from the HSP-F calibration of the watershed model was selected for the Sauvé test area. It was found that relatively large changes in other parameters relating to infiltration and interflow were necessary to reduce the simulated peak flows to the approximate recorded values. Figure 6.9 shows the results of this calibration process.

There is some doubt about the validity of the foregoing calibration and the calibrated HSP-F parameter set for the Sauvé data was not used in subsequent analyses. First, the HSP-F model generally requires several years of data for a good calibration. Secondly, the large disparity between recorded and simulated flows points toward some inaccuracies in the estimated rainfall on the test catchment since precipitation was measured many miles from the site. This observation is supported by the fact that for the May 1981 event the recorded flow values show a higher first peak and a lower second peak while the simulated values show an exactly opposite trend. Finally, a dramatic change in HSP-F parameters to provide a better estimate of the Sauvé flow record was found to result in significant discrepancies between the HSP-F and DRAINMOD models for spring runoff conditions.

The HSP-F and DRAINMOD models were subsequently investigated for spring conditions to ensure that they were representing this phenomena correctly. During the spring period snowmelt together with rainfall will saturate soils to the ground surface. Under these conditions antecedent soil storage is reduced to a minimum and surface runoff rates are similar for both natural and tile drained catchments.

Initially, it was found that the HSP-F model using the Sauvé calibration parameters for an untiled area gave much less surface runoff than the DRAINMOD model for a similar tiled area. In view of the more successful calibration of the DRAINMOD model including the subsurface drainage component, the HSP-F parameters were modified to give a more consistent comparison with the DRAINMOD model for spring runoff conditions.

Figure 6.10 shows a comparison of the two models for spring condition after adjusting the HSP-F parameters. Changes were made to the HSP-F infiltration (INFILT) and interflow (INTFW) parameters to create more surface runoff and a peakier response while the upper zone storage parameter (UZS) was left at the Sauvé calibration value. This HSP-F parameter set was still within the range used in the watershed model calibration, although tending towards extreme values. These values are consistent with the expectation that a smaller area with a tight clay soil as represented by the test catchment would produce a quicker, peakier response than larger subcatchments of more open soil found in many parts of the watershed. This parameter set was used in all subsequent simulations on the hypothetical test area.

6.5.3 Testing on Partially Tiled Areas

The drainage models were applied to the Brisson and Dillabough test data to verify their applicability to partially tiled areas. For these test sites, the appropriate calibrated model was applied to the tiled and untiled portion of the catchment. The subarea flows were then combined in the HSP-F routing model (RCHRES) to obtain flows for comparison with the test data.

Figures 6.11 and 6.12 show the simulation results. While both of these areas exhibit problems with the recorded data, the results of the Dillabough area (61% tile drained) do show that the shape of the simulated hydrograph matches the recorded hydrograph shape very well. The results of the Brisson area (19% tile drained) are not as good.

6.5.4 Conclusions on Calibration

Due to the limitations of the data, a true model calibration and verification procedure was not possible. The models were adjusted to fit the recorded data as well as possible and in most cases a reasonably good correlation between the shape and timing of the flow record and the simulated flow series was obtained. Because more data was available for intensively tiled areas, the results with the DRAINMOD model were generally better than those for the HSP-F model on a single naturally drained test site.

The lack of good calibration of the models must be borne in mind when evaluating the results of the study. However, it is felt on the basis of the test area computations and previous model applications that they are reliable simulators of agricultural drainage processes. Model simulations, therefore, will adequately reflect flow modifications resulting from drainage improvements on a watershed scale.

6.6 Effects of Outlet Drain Improvements

During the study the impacts of outlet drain improvements were evaluated on a watershed scale by first applying the HSP-F routing model to a typical sub-watershed. Drainage courses were modelled within this catchment in sufficient detail to reflect the hydraulic changes of drainage improvements. This procedure defined the local flow impacts. In order to extrapolate these effects to the entire basin the hydraulic routing characteristics in the calibrated watershed model were adjusted for each stream reach as required to reflect the appropriate degree of drainage improvement within the tributary sub-catchment.

6.6.1 Method of Outlet Drain Analysis

In order to ensure that conditions before and after drainage improvement were truly represented in the HSP-F watershed model, it was necessary to determine with some degree of accuracy the existing condition of the outlet drains in each sub-watershed. There are five conditions to be considered:

1. Natural, unimproved streams that may be deepened, straightened and widened.

2. Drains that have been improved in the past but require deepening to permit tile drainage.

3. Improved drains that have to be deepened to permit tile connections and enlarged for increased capacity (major outlet works).

4. Improved drains that need maintenance to restore the original design capacity.

5. Improved drainage channels which are currently adequate.

It was determined by the Conservation Authority and OMAF field staff that few natural unimproved watercourses remained in the South Nation River basin and that most improvements would consist of upgrading existing municipal drains with tributary areas of about 3.25 km^2 or less - the type 2 drain improvements described above. A smaller number of drains with tributary areas greater than 3.25 km^2 (Type 3) may also be improved. These data are given in Table 6.3. It was assumed that drain maintenance carried out on a cyclic basis would be a constant factor over the entire watershed.

For purposes of modelling local drainage impacts, a typical watershed was selected with a 90 km^2 drainage area and eighteen equally sized sub-catchments. This breakdown was chosen according to the spacing of outlet drains and the nature of future drain improvements.

The typical watershed was also arranged in two shapes, one rectangular and the other square as shown in Figure 6.13. Representative drain cross-sections for existing conditions were obtained from the Authority based on field data from engineering reports. In addition, a number of reports for the larger drain improvements were reviewed to obtain estimates of typical existing cross sections for Type 3 drains. The area of a number of unimproved cross sections from the reports was plotted against tributary drainage area and compared to literature values as shown in Figure 6.14. Since the South Nation values compare favourably with the published data, these relationships were used as shown to interpolate appropriate Type 3 drain cross sections for the hypothetical test areas.

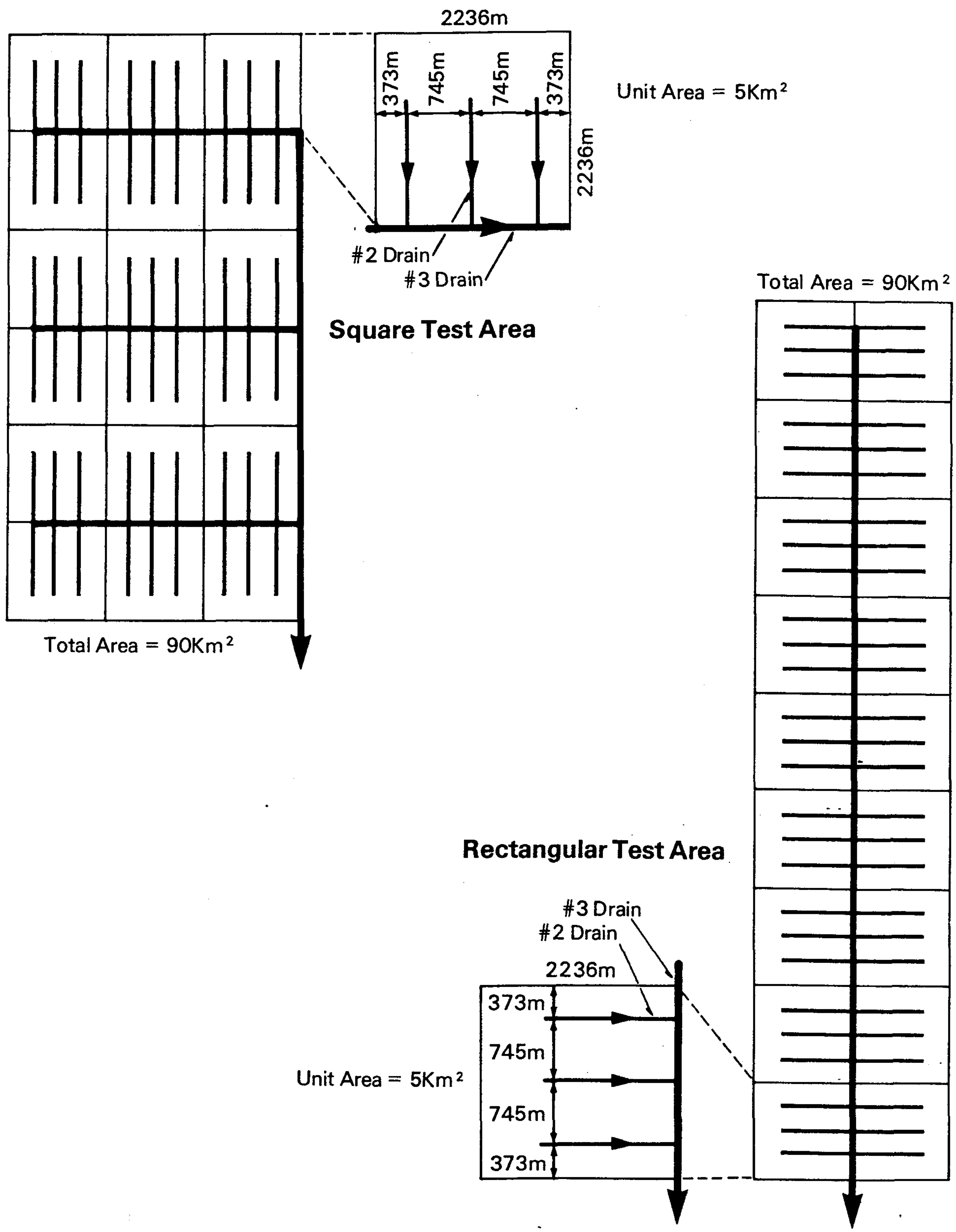
TABLE 6.3

Potential Extent of Future Drain Improvements

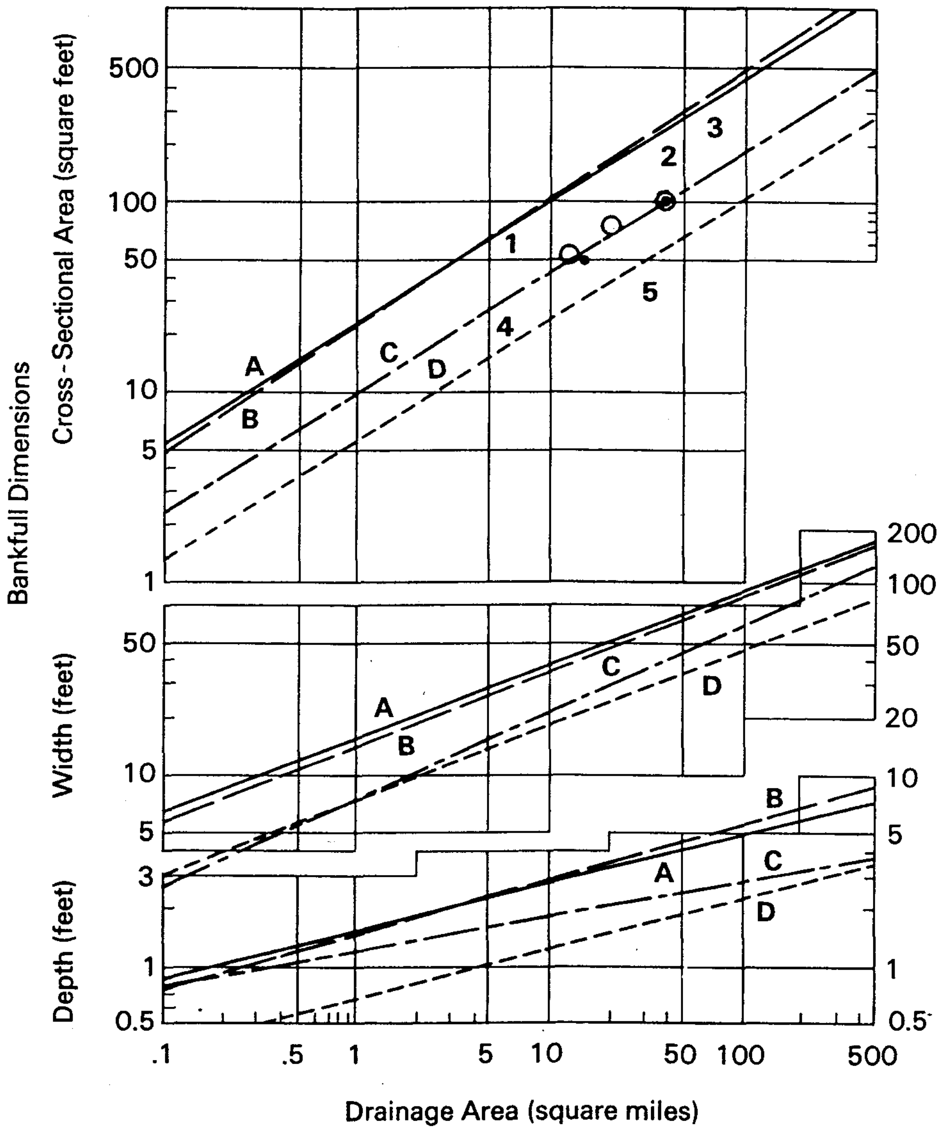
Township	% of Township Area Adequately Served	% of Township Area To Become Drained	Type of Drains Required
Augusta	5	25	#2 75%; #3 25%
Edwardsburg	20	30	#2 100%;
South Gower	35	60	#2 100%;
Oxford	0	15	#2 50%; #3 50%
Matilda	50	95	#2 50%; #3 50%
Winchester	75	85	#2 100%;
Williamsburg	75	85	#2 100%;
Mountain	40	75	#2 75%; #3 25%
Finch	50	80	#2 75%; #3 35%
Osnabruck	25	35	#2 100%;
Roxborough	25	60	#2 75%; #3 25%
Kenyon	30	45	#2 100%;
Cambridge	20	45	#2 100%;
Russell	75	90	#2 100%;
North Plantagenet	20	30	#2 100%;
South Plantagenet	40	60	#2 100%;
Clarence	20	45	#2 100%;
Cumberland	25	50	#2 75%; #3 25%
Caledonia	30	60	#2 100%;
Alfred	20	45	#2 75%; #3 25%
Osgoode	15	30	#2 50%; #3 50%
Gloucester	15	30	#2 100%;

Figure 6-13

Test Areas



Typical Stream Cross Sections



1 Mullan Drain
2 Payne Drain
3 South Castor Drain
4 Ferguson Drain
5 Van Camp Drain
O Square Test Area
• Rectangular Test Area

A San Francisco Bay Region at 30" Annual Precipitation
B Eastern United States
C Upper Green River, Wyoming
D Upper Salmon River, Idaho (Emmett 1975)

Source- After Dunnet Leopold: Water in Environmental Planning, – Freeman & Co. 1978

The investigation of local drainage impacts initially involved an HSP-F runoff simulation for a five year period from 1972 to 1976. The resultant flows were then routed through the drainage network of open waterways with the HSP-F model to represent existing baseline conditions before further drain improvements. The degree of waterway cross-section enlargement was determined from a number of Engineers' reports for recently constructed outlet drains in the South Nation River watershed. It was determined that Type 2 improvements would increase drain cross-sections by an average of 80% and that Type 3 improvements would increase cross-sections by about 50%.

The extent of proposed drain improvements varies across the basin as shown in Table 6.3. The maximum extent of Type 2 drain improvement is 100% within a Township while the maximum Type 3 improvement is 23% in Matilda Township since 50% of the Type 3 drains will be improved in 45% of the area. These values were the maximum improvements simulated in the hypothetical area. To simulate the impacts of these drain modifications, the proposed improvements were simply incorporated into the hypothetical area model on the basis of length of the improved channel and the results compared to those for unimproved conditions. The improvements simulated were cross-section enlargement and a reduction in Manning's n from 0.030 to 0.025. Tile drainage was not included in the municipal drain improvements.

6.6.2 Impacts of Outlet Drain Improvement

The impacts of outlet drain improvement were evaluated at both the outlet of the Type 2 drains as shown on Figure 6.15 and at the outlet of the entire test area as shown on Figure

6.16 for a typical 5 yr period (1972-1976). The improvement of the Type 2 drains had a negligible impact on the peak flows. This is consistent with the assumption that Type 2 drains are usually deepened to provide outlets for tile installations and only rarely because of capacity restrictions. The minimal hydraulic effect is caused by the small reduction of channel roughness.

Figure 6.16 indicates the simulated flows at the outlet of the 90 km^2 square test area following the maximum outlet drain improvement in which 100% of Type 2 and 23% of Type 3 drains improved are improved. An increase in peak flows of only 5-7% was found. This result is not surprising since the effect of Type 2 drain improvements was found to be negligible and only 22% of the Type 3 drains was improved. The flows at the outlet from the rectangular test area exhibited a smaller increase in magnitude following similar drain improvements.

6.6.3 Conclusions Regarding Outlet Drain Improvements

An investigation of typical small drainage areas within the South Nation River basin indicates that anticipated improvements in outlet drains will not have a large effect on local peak flows. Large scale drain improvements represented by the proposed South Castor, Payne, Mullen, Van Camp and Ferguson Drains will have a more significant flow impact and are reviewed separately in Section 7.1.1.

6.7 Effects of Tile Drainage

6.7.1 Method of Tile Drainage Analysis

The effects of tile drains on the runoff characteristics of the test watershed was simulated with DRAINMOD. Various proportions of tile drainage were evaluated ranging up to 77% of the catchment area by incrementing the unit runoff simulated with DRAINMOD as opposed to the untiled area simulated by HSP-F. The unit runoff for each model was multiplied by the appropriate area for each degree of tile drainage, and then summed and routed in the RCHRES model of the hypothetical test area.

It was assumed that as tile drainage installations occur, they will be distributed uniformly over the entire test area. In order to reduce the number of alternatives to be evaluated, it was also assumed that all outlet drain improvements would take place before a significant amount of tile installation occurred. Therefore, all simulation results with tile drainage included the maximum outlet drain improvement. This procedure permitted the effects of outlet drain and tile drain improvements to be evaluated both separately and cumulatively.

With the installation of tile drainage, there is often a shift in agricultural practices to higher value crops such as corn. This results in a change in evapotranspiration conditions from grass crops or pasture. This effect was accounted for in the analysis by modifying the ET values obtained from the HSP-F model according to field measurements from previous studies. This data is shown in Table 6.4. Assuming that the HSP-F ET data represents a grass crop condition without tile drainage, and that the DRAINMOD model represents a corn crop with tiles, the ET input to DRAINMOD was obtained by multiplying the HSP-F values by the ratio of grass crop ET to corn crop ET for each month.

TABLE 6.4

Evapotranspiration Rates Used to Derive DRAINMOND Input

		Grass, Hay (no tiles) cm/day	Corn, Soy Beans (with tiles) cm/day
April	15	.10	.08
May	15	.20	.10
June	10	.36	.28
June	20	.36	.36
June	30	.36	.43
July	15	.38	.48
August	15	.36	.43
September	10	.24	.28
September	20	.24	.10
October	15	.11	.08
November	15	.05	.05

6.7.2 Impacts of Tile Drainage

The results of the simulation of tile drainage for the 5 year period from 1972 to 1976 are illustrated in Figures 6.17 and 6.18. Figure 6.17 shows the maximum impact of tile drainage plotting the maximum 2 h flow/day from both the HSP-F runoff model with no tile drainage and the DRAINMOD model with 100% tile drainage as unit area runoff before outlet drain routing.

One anticipated effect of tile drainage is the more rapid drawdown of soil moisture storage creating a larger soil storage capacity and thereby reducing peak runoff. This effect is clearly illustrated by these plots for most events. The tiled condition results in a less peaky response in general and for some events, particularly during the summer to early winter period, the increased storage capacity available in the soil eliminates the occurrence of runoff altogether. This occurrence was observed from July to December in 1973 and in 1975. In the tiled condition, much of the moisture that does not appear as high rate runoff drains at a lower rate over a longer period of time as tile flow. The sustained constant flows from the tiled condition in the spring reflects the maximum hydraulic capacity of the tiles themselves (0.6 cm/day) while the sharp bursts of runoff projecting above this are surface runoff.

When several large events occur in close sequence, Figure 6-17 indicates that the effectiveness of the tile drainage in reducing peak flows is diminished. Typically, during the first event in March when considerable soil storage is available in tiled areas, the peak runoff is substantially reduced. However, the next event a few days later actually produces a higher peak from the tiled area. This occurs as a result of the soil storage capacity being full and the subsurface drains flowing at capacity when the second event is experienced. In this situation the surface runoff peak is superimposed on the maximum tile flow from the preceding event to give somewhat higher peaks than occurred for the untiled condition. A similar situation occurs for the third and largest event in this series but in this case the increase in peak flows for the tiled condition is small.

Figure 6.18 shows a similar comparison for the tiled and untiled condition for the entire test area after routing.

6.8 LUMPED HSP-F MODEL

The large sub-catchments of the watershed model will each be affected to different degrees by future drainage improvements. To account for this effect, the extent of tile drain installations was varied within the typical test area and flows were computed with the DRAINMOD and HSP-F models for the tiled and untiled portions of the catchment. Since the impact of outlet drain improvements was small, only the maximum improvement was simulated. A lumped HSP-F model was also prepared for the test area.

The purpose of the lumped HSP-F model was to determine the appropriate changes in the lumped model parameters required to reproduce the impacts of both the outlet drain and tile drain improvements demonstrated by the detailed model simulations. The parameter set for the lumped model was then used in the HSP-F watershed model to estimate the impacts of subsurface drainage improvement within the major watercourses of South Nation watershed.

6.8.1 Method of Lumping

The lumped HSP-F model consisted of a single catchment and one routing reach. To investigate hydraulic impacts of drain improvements, both the square and rectangular test areas were used. For investigating the added effect of tile drainage, only the rectangular area was used.

6.8.2 Lumping Hydraulic Impacts

Flow simulations of the detailed area indicated that the relative increase in peak flows due to outlet drain improvement was very similar for both the square and rectangular areas. Furthermore, the impacts were not large ranging typically from 5% to 7% and seemed to result primarily from Type 3 drain improvement.

In order to reproduce these hydraulic effects, the storage/ discharge curve represented by the F-table for the lumped model reach was initially adjusted to provide a good continuous fit of the detailed model flows for the unimproved condition. Subsequently, the effect of outlet drain improvements was accounted for by changing the F-Table values until the lumped HSP-F model accurately simulated the maximum annual flows provided by the detailed model.

For the six year period simulated, the average increase in maximum annual flows for both the square and rectangular test areas was 3.5% as shown in Table 6.5. The lumped model F-table was adjusted to give the same percentage increase. In practical terms this was achieved by reducing the channel storage at given flow rates. This resulted in a good fit between the detailed model and the lumped model for the improved condition as shown in Figure 6.19.

TABLE 6.5

Increase in Maximum Annual Flow With Drain Improvement

Year	Rectangular Area	Square
1971	1.01	1.04
1972	1.00	1.06
1973	1.03	1.07
1974	1.03	1.03
1975	1.04	1.05
1976	1.03	1.03
Averge	1.02	1.04

Average value used in model = 1.035

6.8.3 Lumping Tile Drainage Impacts

The impacts of tile drainage were accounted for in the lumped model by modifying only hydrologic parameters in the PERLND segments of the HSP-F model. To ensure that the tile drainage effects were separated from the hydraulic effects of improved outlet drains, the hypothetical test area model was run for various degrees of tile drainage after replacing the detailed routing network with the single unimproved routing reach from the lumped model. The PERLND segment parameter governing interflow (INTFW) was adjusted to give good agreement between the lumped HSP-F model and the detailed model for a range of tile drainage from 0% to 75% of the drainage area. The upper limit of 75% was derived by the Authority based on land use projections and discussions with field staff.

The INTFW parameter was selected as the single parameter to represent tile drainage since it is conceptually appropriate in the context of the HSP-F model. Infiltration, storage and evapotranspiration parameters were not used since these all have interactive characteristics which could result in complex and misleading secondary effects on the water balance.

The foregoing analysis was carried out for tile drainage areas representing 0, 20, 35, 50 and 100 percent of a catchment. Figures 6.21 and 6.22 illustrate the flows from the lumped model and the detailed model simulations for two degrees of tile drainage. An interflow multiplier representing the ratio between tile drained and natural conditions was subsequently calculated for each degree of tile drainage.

Table 6.6 and Figure 6.20 show the variation of the lumped model INTFW parameter required to reproduce the detailed model results for varying degrees of tile drainage. To obtain an accurate fit, it was necessary to differentiate between spring conditions during the months of February to April and the rest of the year.

Intermediate values of the INTFW multiplier were checked during the study by further simulation of flows with the detailed drainage model and the lumped HSP-F model using the curves on Figure 6.20. A favourable comparison at the 75 percentage tile drainage level provided further support for the suggested parameter values.

6.8.4 Conclusions Regarding Model Lumping

The results of the hypothetical area analysis have shown that the combined HSP-F and DRAINMOD models can realistically reproduce the impacts of improved outlet drains and tile drain installation. It was also shown that the HSP-F model can be adjusted to reproduce these results as a lumped model. It was therefore possible to use the watershed model to determine the impacts of agricultural drainage improvements on the major intercourses of the South Nation River Basin.

6.9 Low Flow Simulation

The model simulation approach used in this study gives continuous flow results. It was possible to calibrate the HSP-F model for the South Nation River watershed over the entire flow range including low flows, however, this was not possible on the smaller agricultural test areas due to a lack of

TABLE 6.6

Variation of Lumped HSP-F INTFW Parameter With Various Percent Tile Drainage

Months	Spring (Months 2 - 4) Fitted INTFW Value[1]	Spring (Months 2 - 4) Multiplier of Base Value[2]	Summer (Months 5 - 1) Fitted INFTW Value	Summer (Months 5 - 1) Multiplier of Base Value
Base Run (0% tile drained)	9	1	7	1
20% tiled	10.8	1.2	14	2
35% tiled	12.2	1.36	21	3
50% tiled	13.5	1.5	28	4
75%	15.3	1.7	42	6
100% tiled	16.2	1.8	70	10

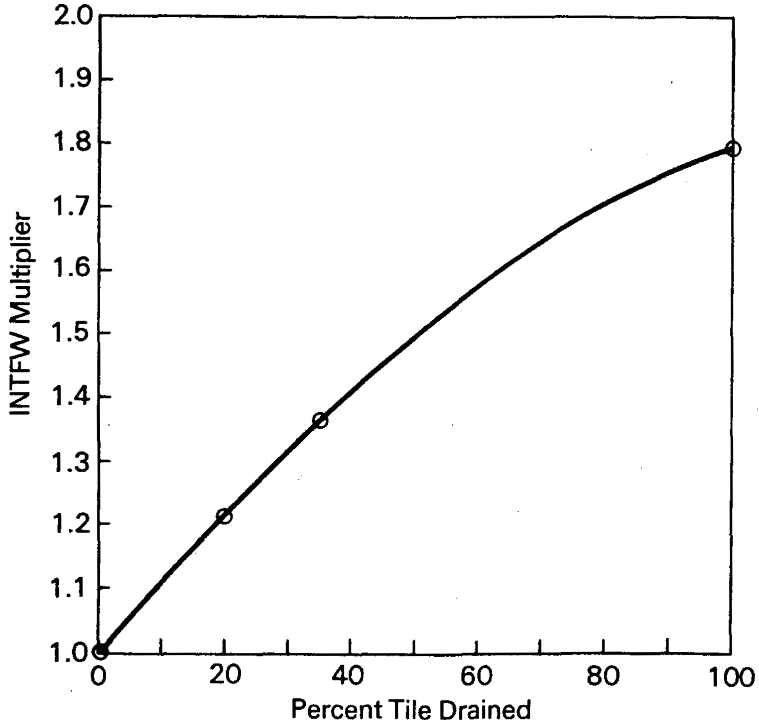
Notes:

1 Fitted value is the lumped INTFW value to give agreement with the detailed test area results.

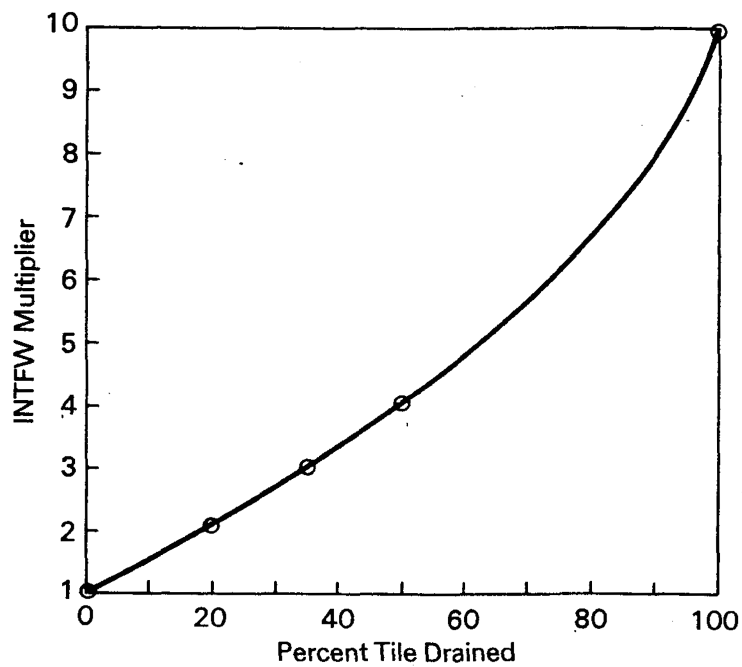
2 Base value is the initial INTFW value from watershed model calibration.

Figure 6-20

Variation in HSPF Interflow Parameter (INTFW) With Percent Tile Drainage



Spring (February-April)



Summer-Fall-Winter (January, May-December)

recorded data. Unfortunately, the detailed drainage model DRAINMOD could not provide this information since the model does not simulate baseflows when groundwater levels fall below subsurface drains. While the lumped HSP-F model can provide some insight into low flows from agricultural watersheds, conclusions regarding drainage impacts on low flows are inconclusive and must be supported by further field data.

CHAPTER 7

ANALYSIS OF FUTURE FLOOD CONTROL AND LAND USE SCENARIOS

CHAPTER 7

ANALYSIS OF FUTURE FLOOD CONTROL AND LAND USE SCENARIOS

7.0 ANALYSIS OF FUTURE FLOOD CONTROL AND LAND USE SCENARIOS

This chapter outlines the flow impacts of selected water control structures, drainage works and land use changes which were investigated during the study. Changes effected by a number of proposed municipal drain projects, the general improvements to agricultural drainage including outlet drains and the installation of subsurface drains, major riverine improvements, several proposed reservoirs and an increase in forest production are considered.

The scenarios discussed in this chapter were selected for detailed investigation after discussions with the Conservation Authority and the study advisors. The results are presented by revised flow frequency curves for the four flood prone areas at Plantagenet, Chesterville, Bear Brook and Vernon which are compared with the current flow regime at these locations. For several flood control and reservoir alternatives, an evaluation of flood area reduction was also completed.

7.1 Municipal Drain Improvement

7.1.1 Proposed Drain Improvements

The hydrologic impacts resulting from the improvement of five municipal drains were investigated as part of the overall watershed modelling study. The five proposed drains shown in Figure 7.1 are:

1) South Castor Drain
2) Payne Drain
3) Mullen Drain
4) Van Camp Drain
5) Ferguson Drain

The remaining two municipal drains, Bear Brook and Chesterville, indicated on Figure 7.1, are considered in conjunction with overall agricultural drainage improvements and discussed within report sections 7.2 and 7.3.

The five foregoing drains are existing watercourses, which provide drainage for agricultural lands acting as collectors for both surface runoff and flow from sub-surface drains. Two problems are encountered at the present time:

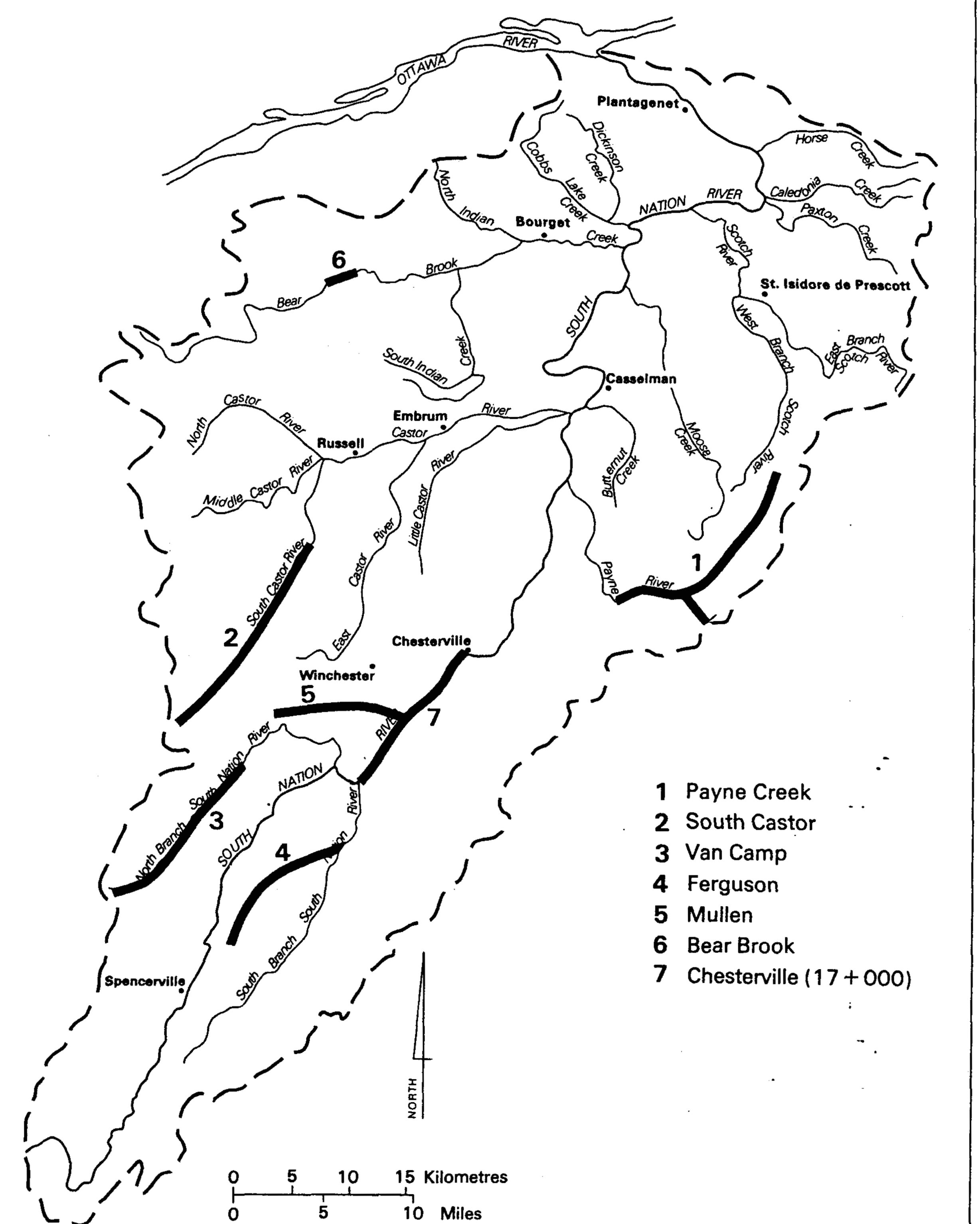
- low channel capacity resulting in frequent flooding of adjacent lands, and
- channel inverts that do not provide adequate sub-surface drain outlets.

Engineering studies(1) have been carried out for each drain which recommend improvements by widening and/or deepening the channels. Hydrological impacts of these improvements are evaluated on both the local and downstream areas of the watershed.

7.1.2 Method

The five drains were simulated in the overall HSP-F watershed model by representing the existing waterways as five of the 36 reaches which form the river routing component of the model. River routing is carried out in the HSP-F model by

Location of Proposed Municipal Drain Improvements



1 Payne Creek
2 South Castor
3 Van Camp
4 Ferguson
5 Mullen
6 Bear Brook
7 Chesterville (17 + 000)

the kinematic wave method and stage-discharge-storage relationships are based on Manning's equation for uniform flow. Runoff is computed with the watershed model first with the existing drains and subsequently with the proposed drain improvements. Any change in flows throughout the watershed as a direct result of drain improvements can therefore be assessed.

The five drains were modelled for existing waterway conditions based on cross-sections taken in the field, engineer's reports on drain improvements, a flood plain mapping study for the South Castor River(2) and topographic maps at scales of 1:50 000 and 1:25 000.

Using the calibrated HSP-F model, a computer simulation run of 23 yr from 1957 to 1979 was carried out to generate flows at the downstream limit of each drain, and at other downstream locations throughout the watershed.

To represent conditions after the proposed improvements have taken place, the drain model was revised according to the Engineer's Reports. The details of the improvements generally involve deepening, widening, and cleaning of the existing waterway. The HSP-F model was adjusted to incorporate these changes in the drains, and a second 23 year simulation was carried out for the 1957 to 1979 period. This procedure provided flows representing the effects of the improved drains for comparison with existing conditions at the downstream limit of the drains and at other stream locations in the watershed.

7.1.3 Impacts of Drain Improvements

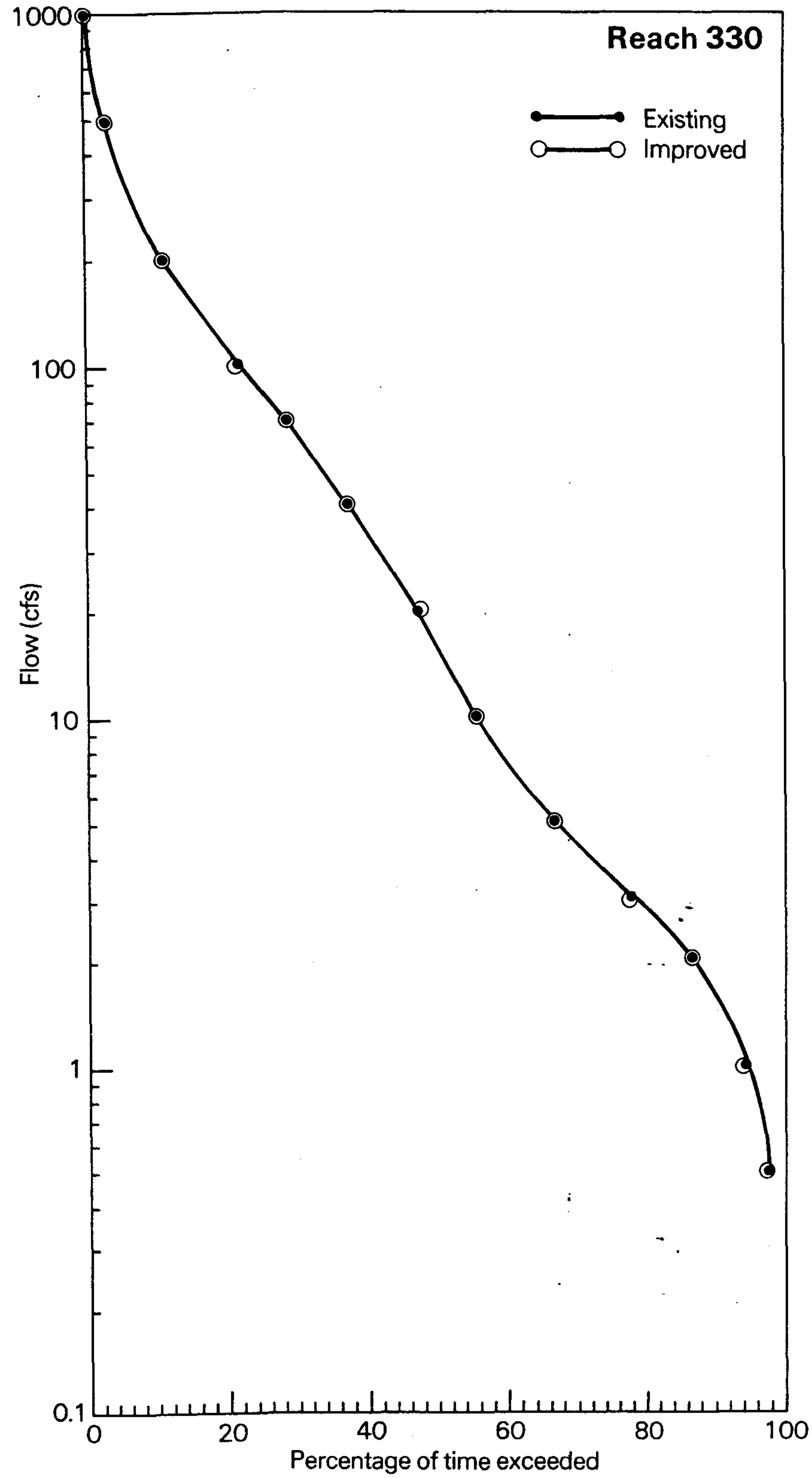
The flows estimated by the two simulations are given as flow-duration curves and flood-frequency curves for the existing and improved drain conditions. Peak flows for one specific event are also compared.

Flow-duration curves which indicate the percent of time that a particular flow is exceeded are shown for each drain in Figures 7.2 through 7.6. The curves are computed from 23 years of simulated flows representing a continuous hydrograph of two hour mean flows.

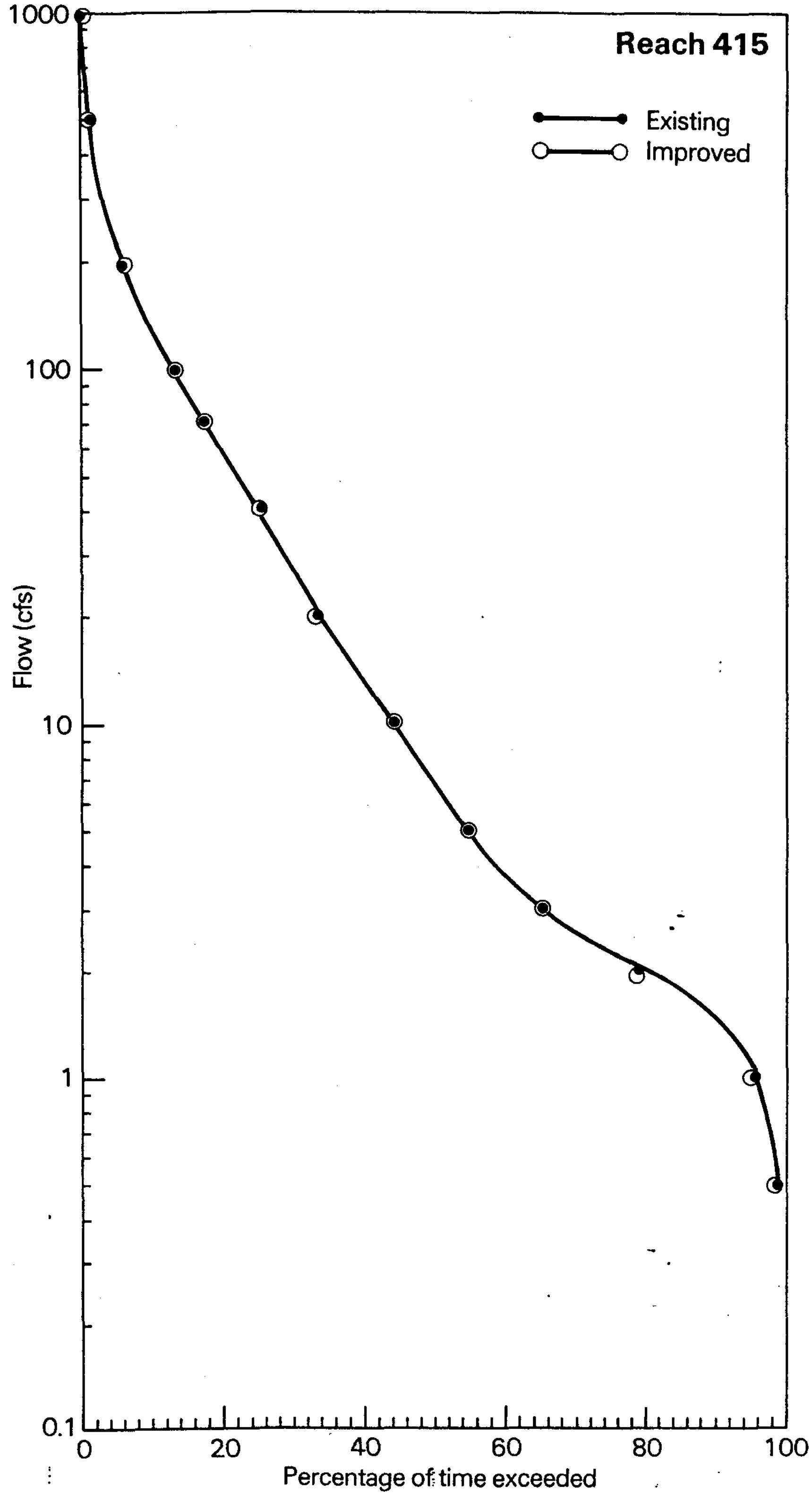
The flood-frequency curves are plotted for each of the five drains and for four other downstream reaches on Figures 7.7 to 7.15. Using these plots, the effects of the drain improvements can be traced downstream from the drains to the lower part of the basin at Plantagenet.

The flood frequency plots illustrate that after drain improvements are completed peak runoff rates at the downstream limits of the drain will be increased. Since runoff volumes tributary to the municipal drains are the same as the pre-improvement conditions, flow rates from the drains during the recession portion of an event will decrease more quickly than previously experienced. Nevertheless the flow duration curves which are identical for both the existing and improved drain conditions indicate that low flows occurring between runoff events remain unchanged. It is noted that the basin model did not account for local water tables and subsurface flows before and after municipal drain construction. A comprehensive evaluation of municipal drain effects on low flows would require further investigation of this question.

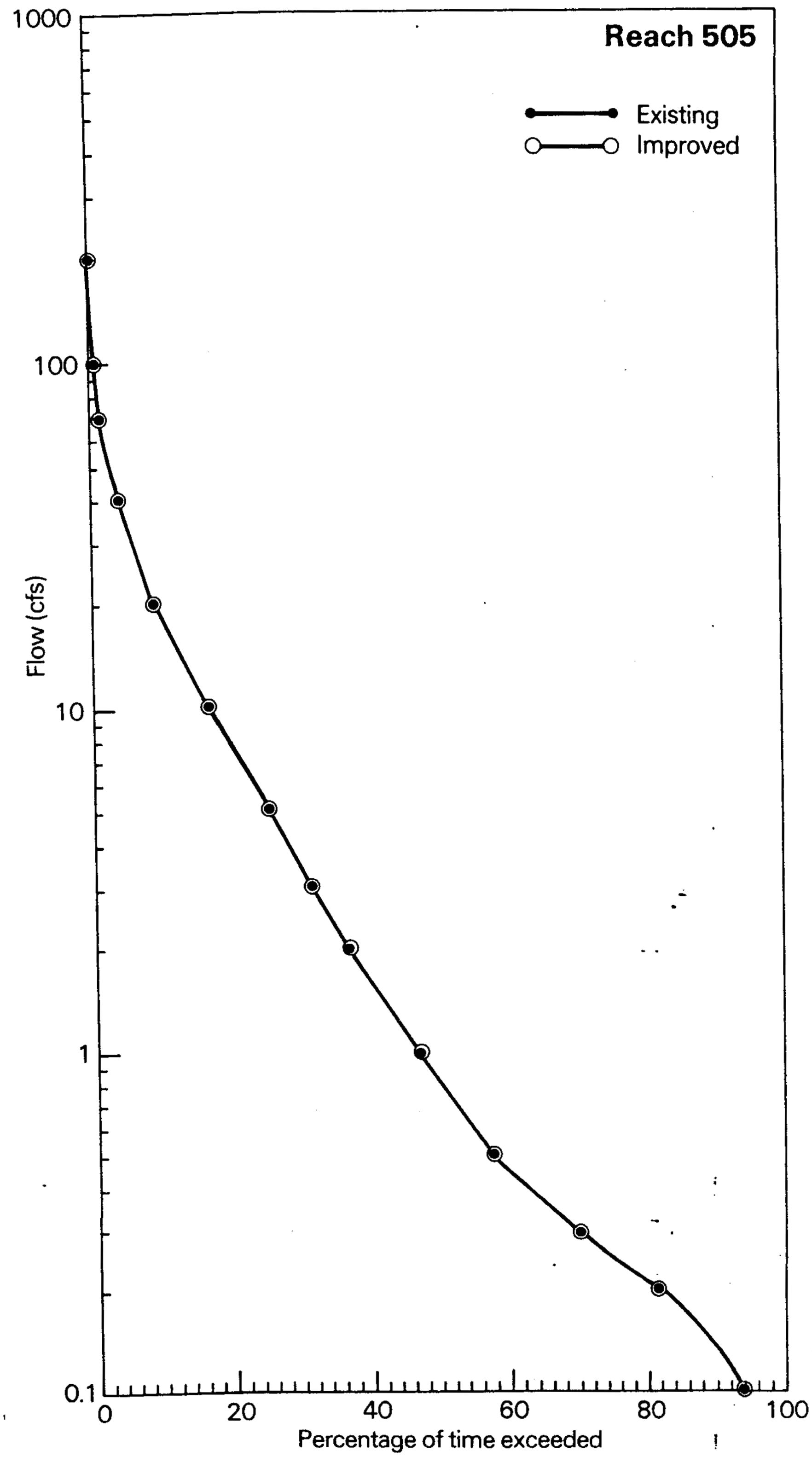
Flow Duration Curve: South Castor Drain



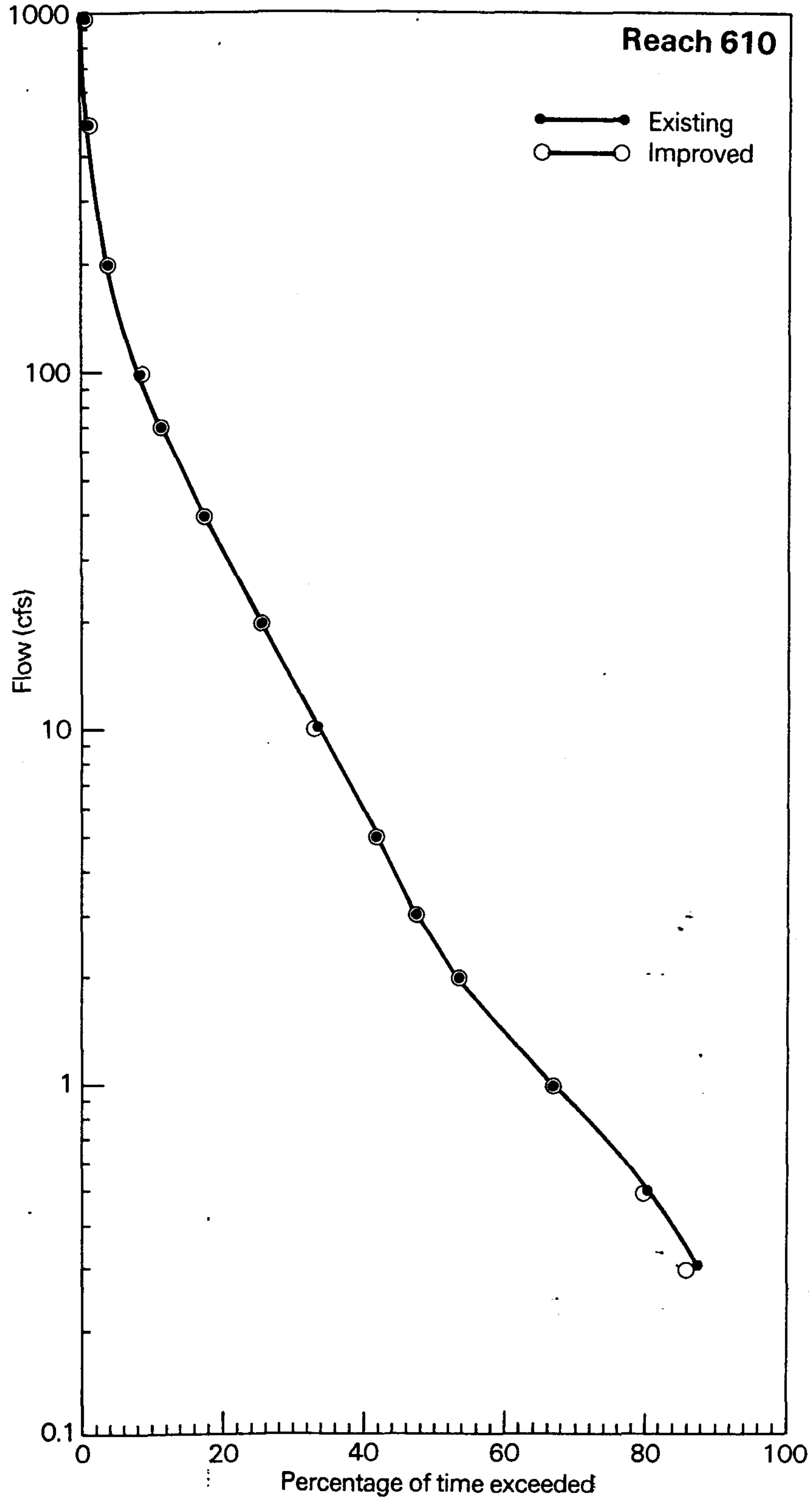
Flow Duration Curve: Payne Creek Drain



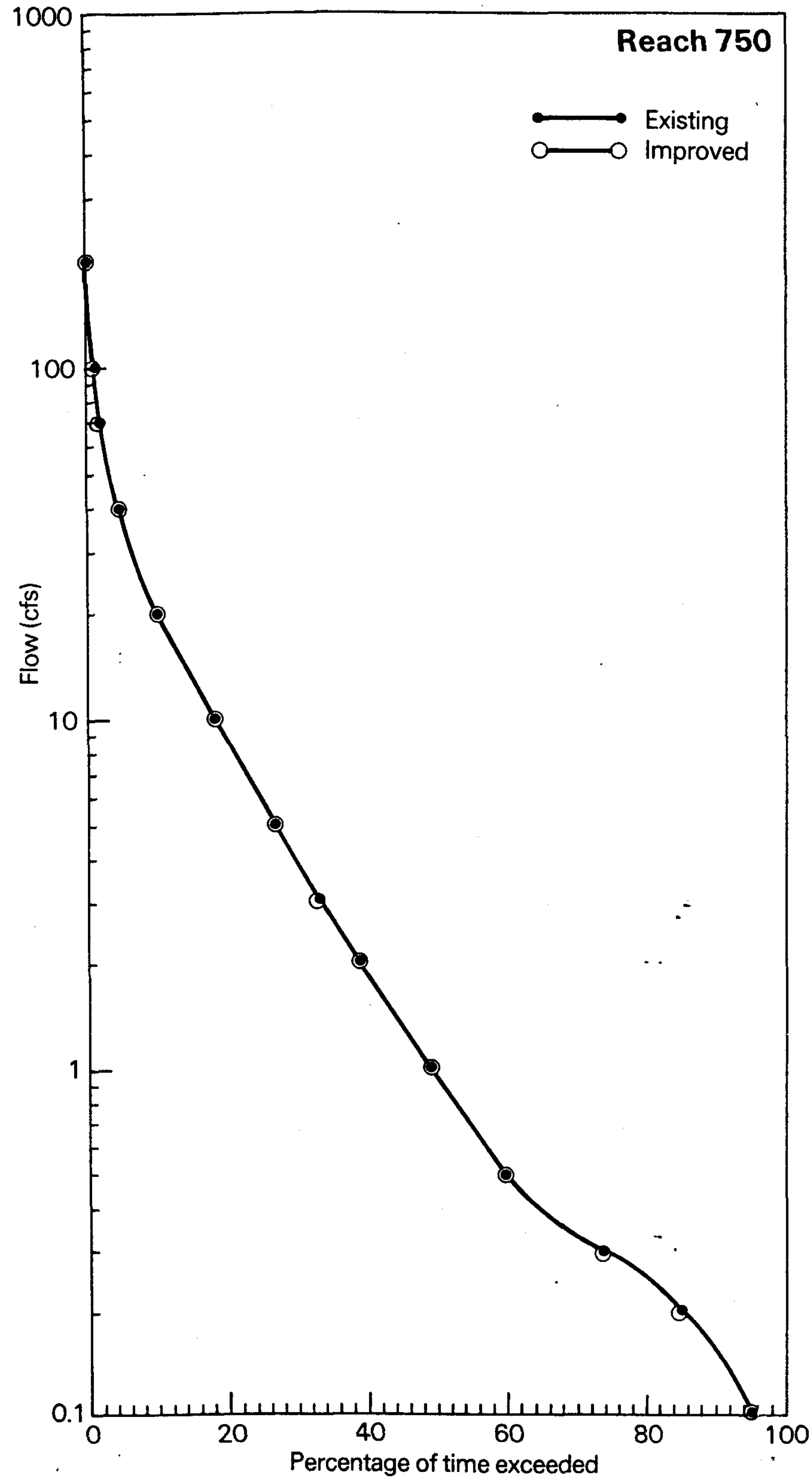
Flow Duration Curve: Mullen Drain



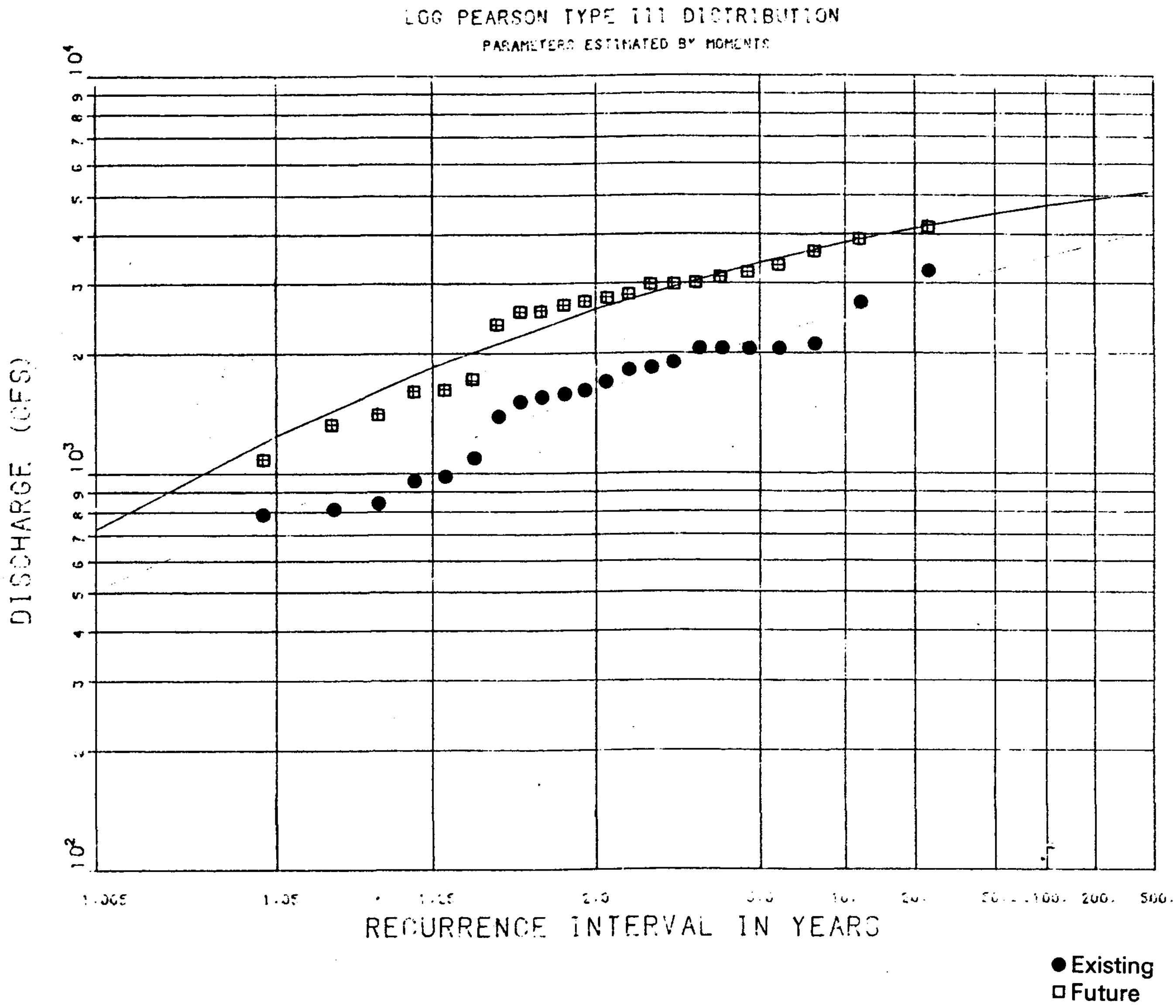
Flow Duration Curve: Van Camp Drain



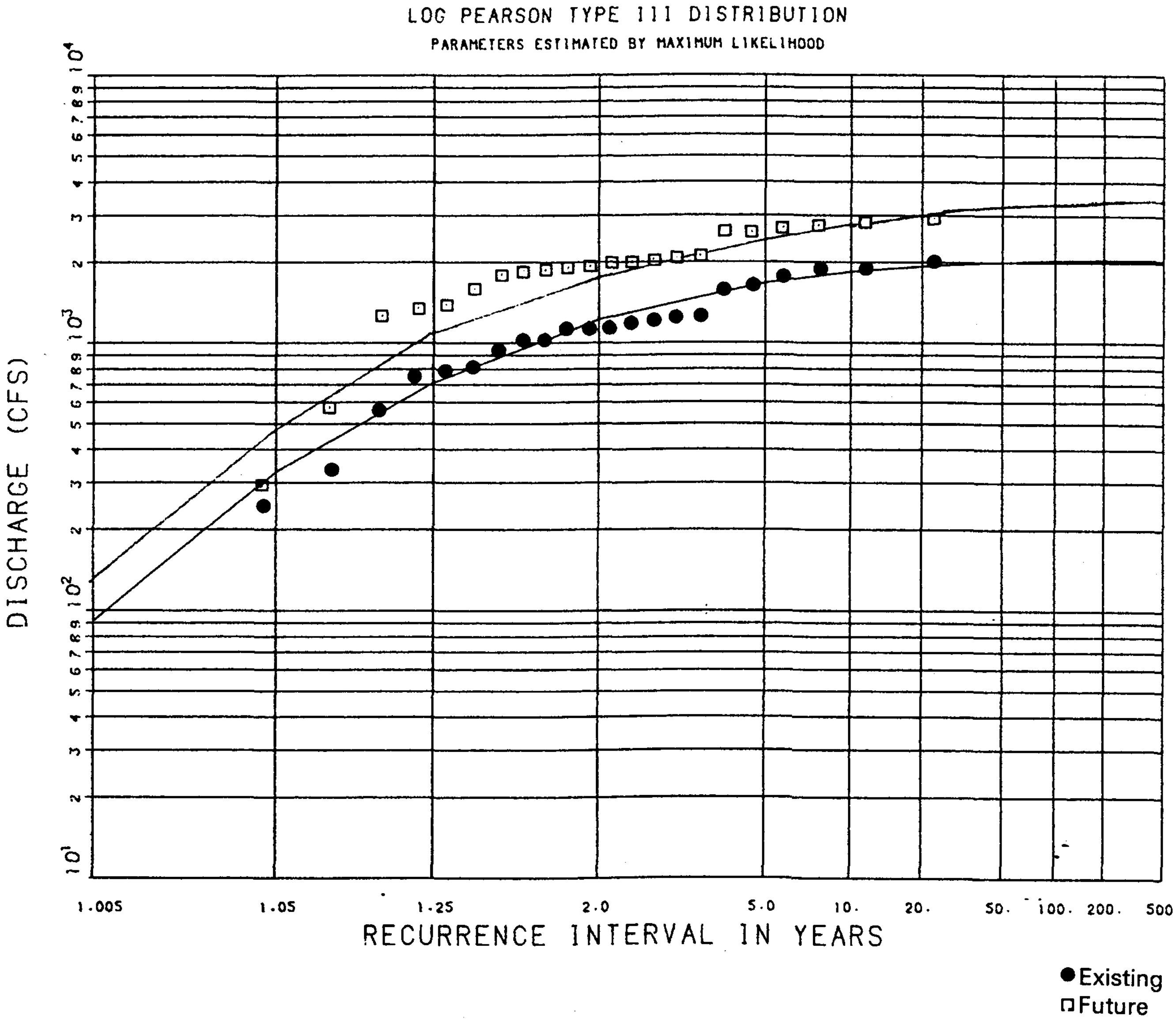
Flow Duration Curve: Ferguson Drain



Annual Flood Frequency Curve at the South Castor Drain with Municipal Drain Improvements



Annual Flood Frequency Curve at the Payne Creek Drain with Municipal Drain Improvements



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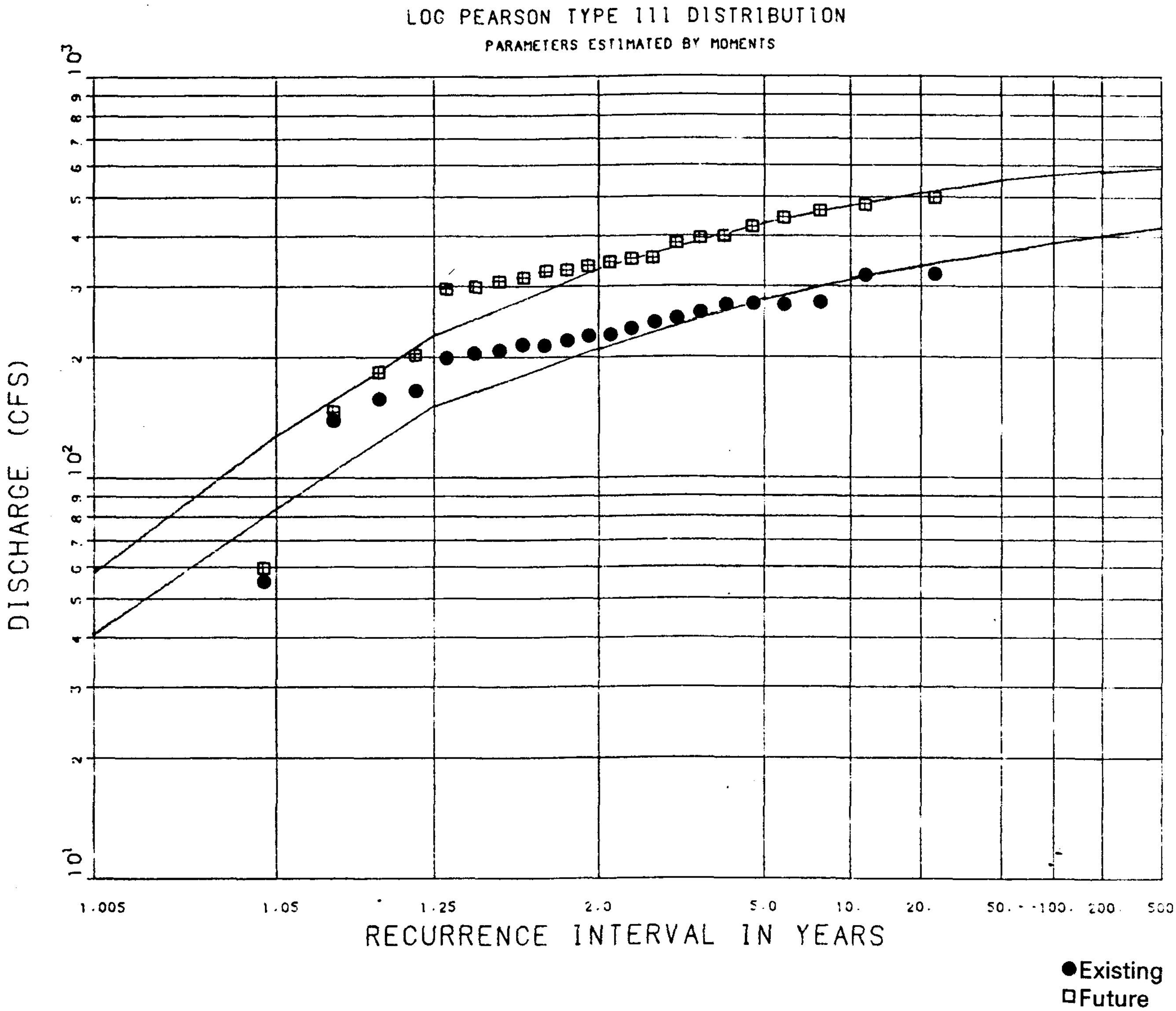
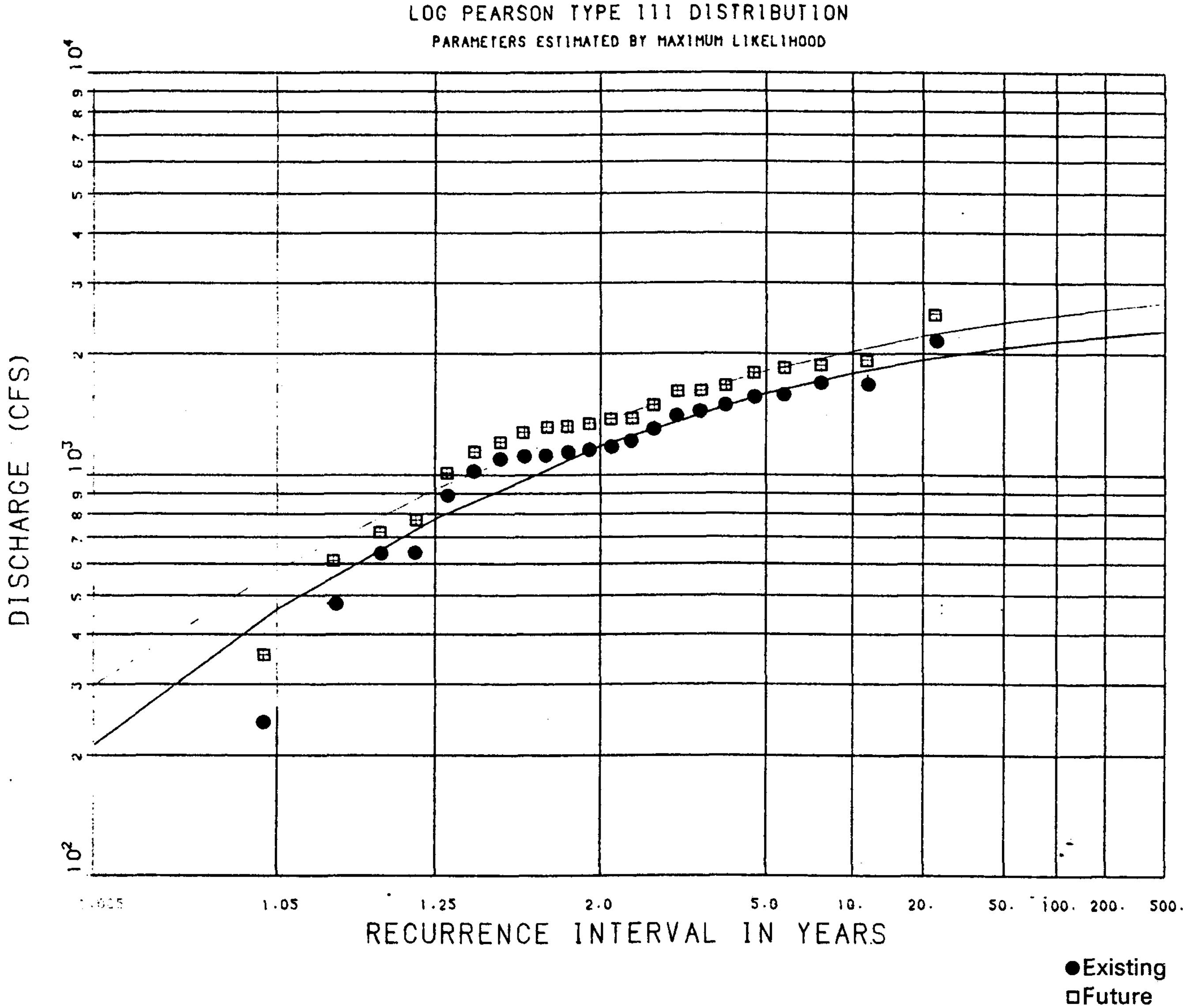
Annual Flood Frequency Curve at the Mullen Drain with Municipal Drain Improvements



Annual Flood Frequency Curve at the Van Camp Drain with Municipal Drain Improvements



Annual Flood Frequency Curve at the Ferguson Drain with Municipal Drain Improvements

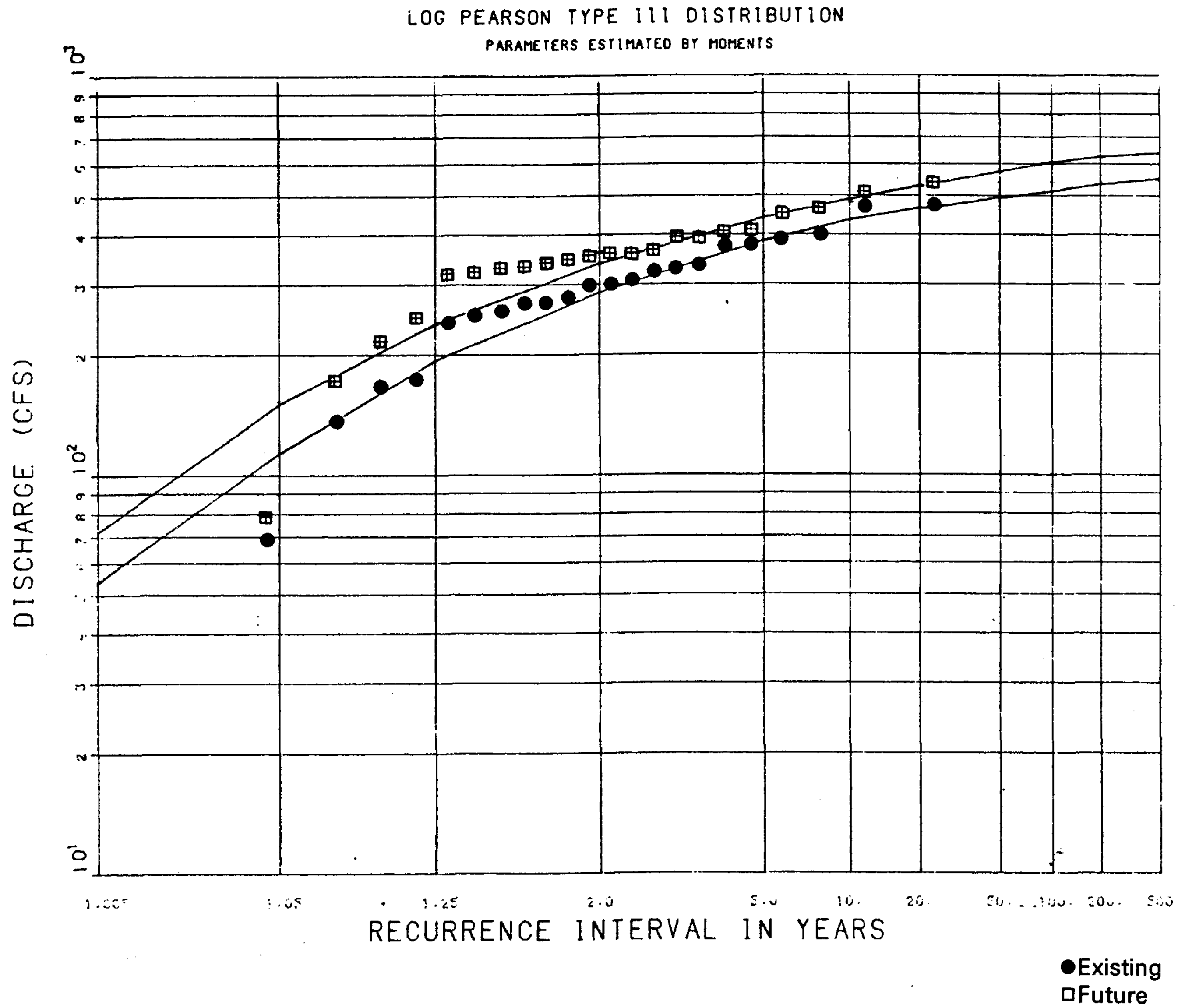
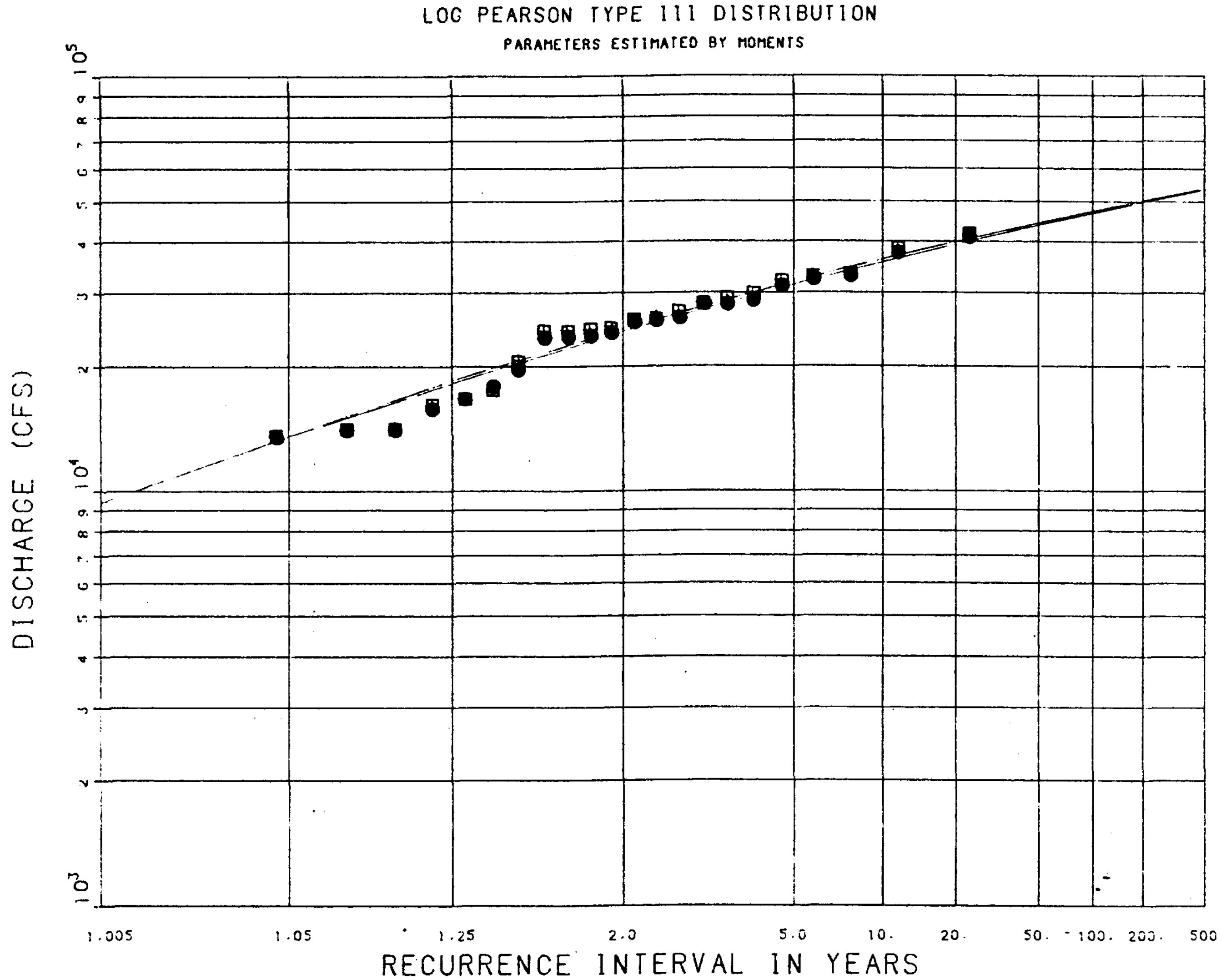


Figure 7-12

Annual Flood Frequency Curve at Plantagenet with Municipal Drain Improvements



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Annual Flood Frequency Curve at Chesterville with Municipal Drain Improvements

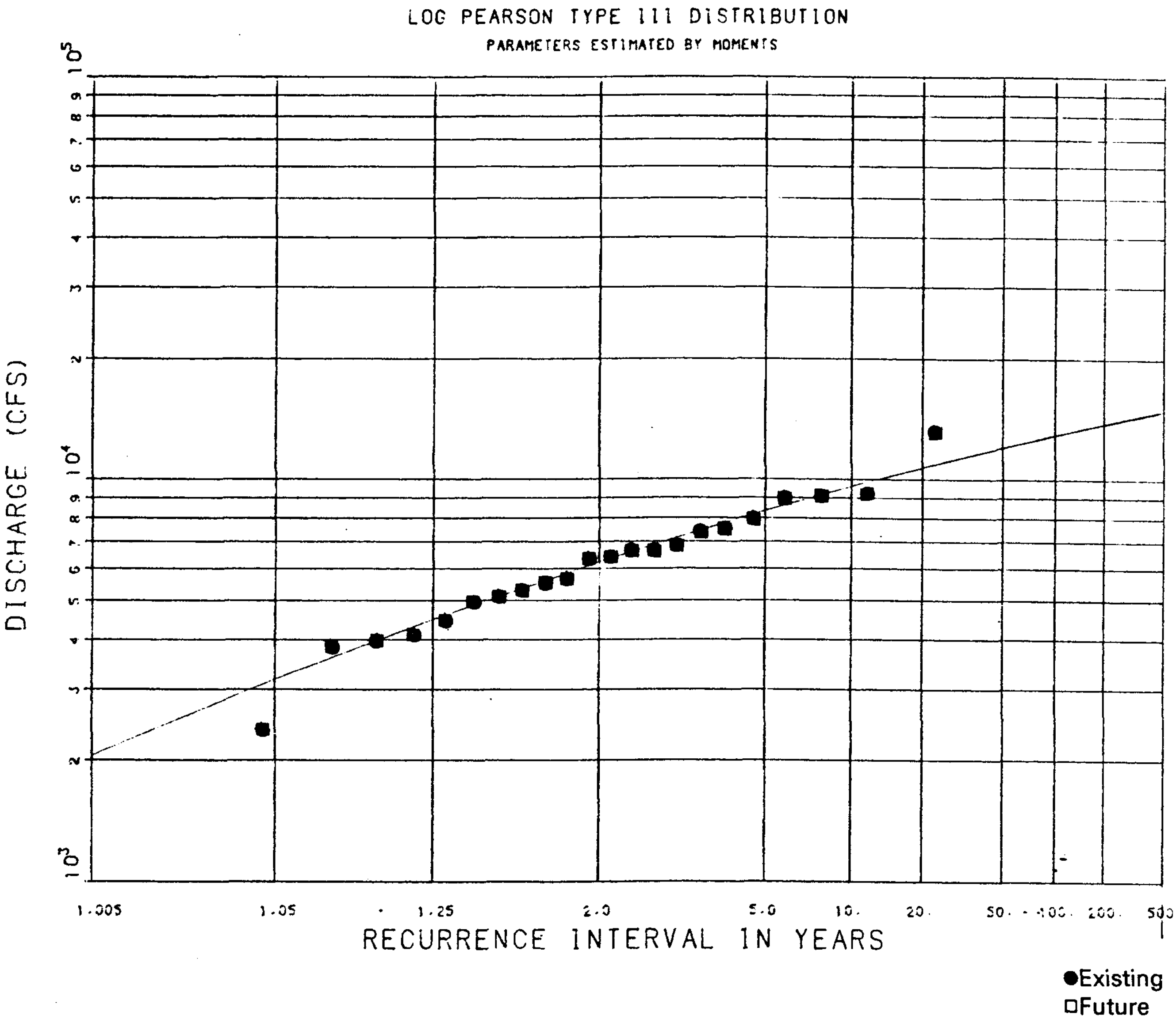
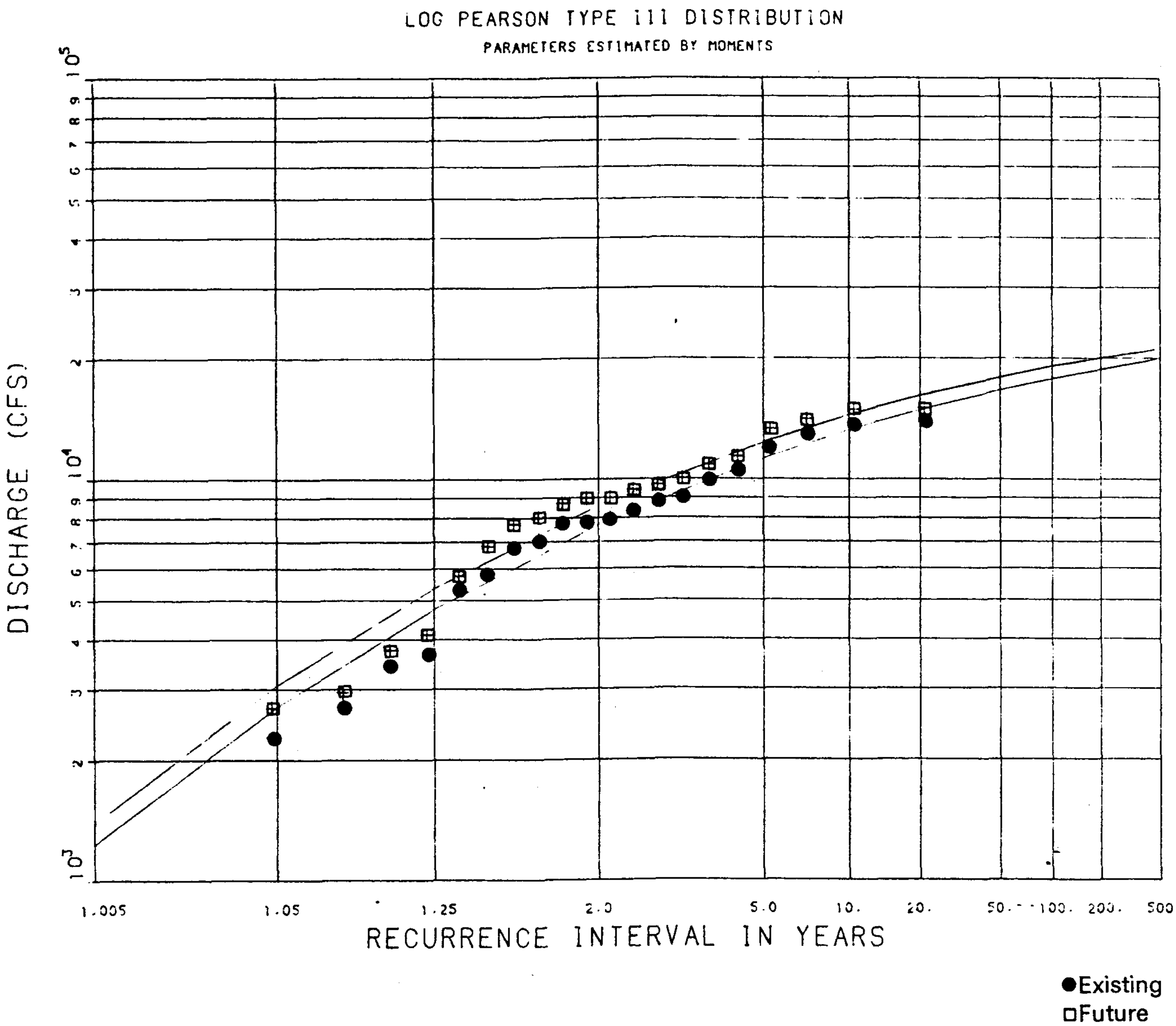
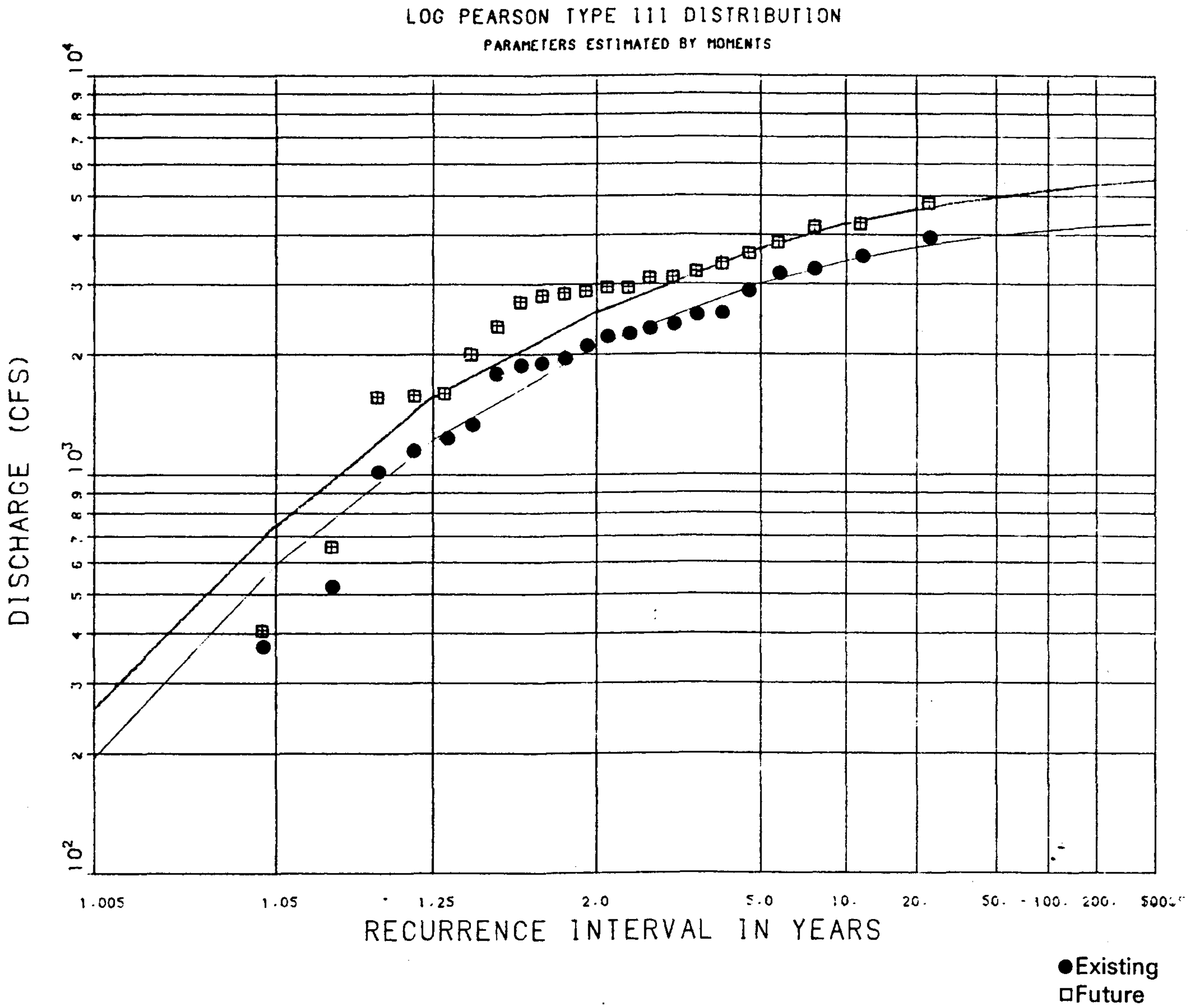


Figure 7-14

Annual Flood Frequency Curve at Mouth of Castor River with Municipal Drain Improvements



Annual Flood Frequency Curve at Mouth of Payne River with Municipal Drain Improvements



Low flow frequency curves were not computed since a further comparison of annual minimum 2 hour flows before and after the construction of the municipal drains did not indicate any change in low flows.

Table 7.1 summarizes the percentage change in peak flows caused by each drain for various return periods. Downstream reaches include effects of all upstream improvements. In order of peak flow increase, the drains rank as follows:

1) Payne Drain
2) Mullen Drain
3) South Castor Drain
4) Van Camp Drain
5) Ferguson Drain

Downstream effects of the drain improvements are noteworthy on the Payne River. The percentage increase in peak flows at the confluence with the South Nation River is reduced to one-half the magnitude at the drain outlet but remains a significant 27%.

Flow impacts on the Castor River due to the South Castor drain are less noticeable due to the relative magnitude of tributary runoff from other portions of the watershed. While peak flow increases are large locally, at the confluence with the South Nation River the percentage increase in peak flows has diminished to 9%.

Flood prone lands adjacent to the South Nation River upstream of Chesterville and Plantagenet will not be affected by the

TABLE 7.1

INCREASE IN MEAN 2-HOUR PEAK FLOWS WITH

DRAIN IMPROVEMENT

DRAIN/REACH	% INCREASE FOR RETURN PERIOD				
	5 YR	10 YR	20 YR	50 YR	100 YR
Van Camp	13	13	14	15	15
Ferguson	15	13	13	12	12
Mullen	54	52	47	45	44
Chesterville	≤1	≤1	≤1	≤1	≤1
Payne	50	54	55	55	55
Mouth of Payne R.	30	27	27	24	22
South Castor	56	51	46	39	35
Mouth of Castor R.	10	9	9	8	8
Plantagenet	2	2	2	1	1

combined flow impact of the five drains which were studied. In both cases, annual flood frequency analyses reveal that peak flows will be increased by less than 2%.

In order to further illustrate the change in flows, the recent March 1976 event was selected and the relative frequency of this occurrence was estimated for existing and improved drain conditions as shown in Table 7.2. As an example, flows of this magnitude could be expected on the average every three years after construction at the outlet of the Payne drain whereas at present the flow would have a recurrence interval of 55 yr.

7.2 Agricultural Drainage

Agricultural drainage improvements were evaluated using the lumped HSF-F model according to the procedures developed in Chapter 6. In the context of agricultural drainage improvements the future development scenario included the estimated maximum extent of subsurface drainage within existing agricultural lands and corresponding local outlet drain improvement as well as the proposed Mullen, Van Camp and Ferguson Drains and the Chesterville channelization works completed to date. Additional larger scale channel works are discussed separately in Section 7.3.

7.2.1 Subsurface Drainage Improvement

Varying degrees of subsurface drainage are installed across the watershed at the present time. The calibrated parameter set for the HSP-F model therefore includes the appropriate

TABLE 7.2

IMPACT OF DRAIN IMPROVEMENT ON MARCH 1976 FLOOD EVENT

DRAIN/REACH	FLOW EXPERIENCE IN MARCH 1976			MARCH 1976 FLOW AFTER DRAIN IMPROVEMENT	
	Peak 2-Hour FLOW m^3/s (cfs)	AVERAGE FREQUENCY OF OCCURRENCE (YEARS)		PEAK 2-HOUR FLOW m^3/s (cfs)	PERCENTAGE INCREASE
		EXISTING CONDITIONS	AFTER DRAIN IMPROVEMENT		
Van Camp	61.0 (2154)	50	12	70.8 (2500)	16
Ferguson	13.5 (477)	25	8	14.6 (514)	8
Mullen	9.1 (320)	12	2	13.6 (482)	51
Chesterville	258.7 (9135)	8	8	259.8 (9173)	0.4
Payne	57.1 (2018)	50	3	83.3 (2940)	46
Mouth of Payne River	91.2 (3219)	7	4	119.6 (4225)	31
South Castor	91.9 (3244)	40	4	119.7 (4228)	30
Mouth of Castor River	395.2 (13956)	15	8	426.3 (15053)	6
Plantagenet	1068.4 (37729)	15	15	1093.9 (38632)	2

change in parameters to simulate existing tile drainage conditions. The analysis of the hypothetical area determined relationships for HSP-F parameters for conditions ranging from no tile drainage to 100% tile drainage. Using these results, it was possible to derive the incremental parameter values within each PERLAND area in the HSP-F model which are required to reflect changes in agricultural drainage practices from the existing degree of tile drainage to the maximum anticipated tile drainage. Values of the parameters are summarized in Tables 7.3 and 7.4.

Studies by the Conservation Authority and the Ontario Ministry of Agriculture and Food have determined that the optimum degree of subsurface drainage within the South Nation River taking into account the anticipated cropping patterns will be 75% of existing agricultural lands. This value has been adopted for the investigation of agricultural impacts. Increased areas of subsurface drainage reflected in this scenario are summarized in Table 7.6.

7.2.2 Outlet Drain Improvement

The future outlet drain improvements considered included the proposed Mullen, Ferguson and Van Camp Drains as well as the currently completed portion of the Chesterville channelization to station 10+000. In addition, it was assumed that the estimated maximum extent of local outlet drain improvements as indicated in Table 6.4 would occur. In the Townships where the proposed Ferguson, Mullen and Vam Camp Drains are located, it was assumed that these drains would account for the Type 3 drain improvements required. In the HSP-F PERLAND areas containing these drains the changes to the modelled

TABLE 7.3

DERIVATION OF SPRING HSP-F

INTFW PARAMETER FOR FUTURE

TILE DRAINAGE

HSP-F PERLND NO.	EXISTING % TILE	SPRING EXISTING MULTIPLIER* (1)	FUTURE % TILE	SPRING FUTURE MULTIPLIER* (2)	SPRING NET MULTIPLIER (3)=(2)/(1)	SPRING EXISTING INTFW (4)	SPRING FUTURE INTFW (4)x(3)
5	5	1.05	45	1.46	1.39	10	13.9
6	7	1.08	43	1.44	1.33	9.5	12.7
7	2	1.02	25	1.27	1.25	12	14.9
8	7	1.08	41	1.42	1.53	9	13.8
9	10	1.11	47	1.48	1.33	10	13.3
13	8	1.09	43	1.44	1.32	13	17.2
14	12	1.13	53	1.53	1.35	10	13.5
16	16	1.17	63	1.61	1.38	10	13.8
17	1	1.00	26	1.28	1.28	10	12.8
18	7	1.08	45	1.46	1.35	10	13.5
19	9	1.10	48	1.49	1.35	9	12.2
20	10	1.11	49	1.49	1.34	9.5	12.8
21	16	1.17	60	1.58	1.35	10	13.5
22	9	1.10	47	1.48	1.35	10	13.5
23	5	1.05	26	1.28	1.22	9	11.0

* data from Figure 6.20

TABLE 7.4

DERIVATION OF HSP-F SUMMER

INTFW PARAMETER FOR FUTURE

TILE DRAINAGE

HSP-F PERLND NO.	EXISTING % TILE	SUMMER EXISTING MULTIPLIER* (1)	FUTURE % TILE	SUMMER FUTURE MULTIPLIER* (2)	SUMMER NET MULTIPLIER (3)=(2)/(1)	SUMMER EXISTING INTFW (4)	SUMMER FUTURE INTFW (4)x(3)
5	5	1.2	45	3.6	3.0	8	24
6	7	1.3	43	3.5	2.7	7.5	20
7	2	1.1	25	2.3	2.1	8	17
8	7	1.3	41	3.3	2.5	7	18
9	10	1.5	47	3.8	2.5	8	20
12	8	1.4	43	3.5	2.5	9	23
13	12	1.6	53	4.2	2.6	8	21
16	16	1.8	63	5.0	2.8	8	22
17	1	1.0	26	2.4	2.4	8	19
18	7	1.3	45	3.6	2.8	8	22
19	9	1.5	48	3.8	2.5	7	18
20	10	1.5	49	3.9	2.6	7.5	20
21	16	1.8	60	4.8	2.7	8	21
22	9	1.5	47	3.8	2.5	8	20
23	5	1.2	26	2.4	2.0	7	14

* data from Figure 6.20

drainage reaches were based on the cross-section information in the relevant Engineer's reports. In all other areas where unspecified outlet drain improvements are expected according to Table 6.4, the discharge curves for the routing reach in each affected PERLAND area was adjusted by a constant multiplier as discussed in section 6.8.2.

7.2.3 Impacts of Agricultural Drainage Improvements

The HSP-F model of existing conditions was modified to reflect the drainage improvements discussed above. The model was then run for the same 23 yr period of record from 1957 to 1979 which was previously completed for existing drainage conditions. The results are presented in Figure 7.16 through 7.23 as revised flow frequency curves for each of the major flood prone areas for both annual and growing season (May to October) peak flows.

Two of the four flood prone sites considered, Plantagenet and Chesterville, are on the main branch of the South Nation River while the Bear Brook and Vernon sites are on major tributaries as shown on Figure 7.1. In all locations, and for all frequencies and seasons, the simulation of agricultural drainage improvements resulted in significantly lower peak flows as noted in Table 7.5. With respect to annual peak flows, the Plantagenet location near the outlet of the watershed shows a tendency for larger flow reductions with lower frequency events, ranging from a reduction of 7% for a 2 yr event to 14% for a 100 year event. The Vernon and Chesterville locations with much smaller tributary areas displayed the opposite tendency while the Bear Brook site gave a nearly constant 12 to 13% reduction at all frequencies.

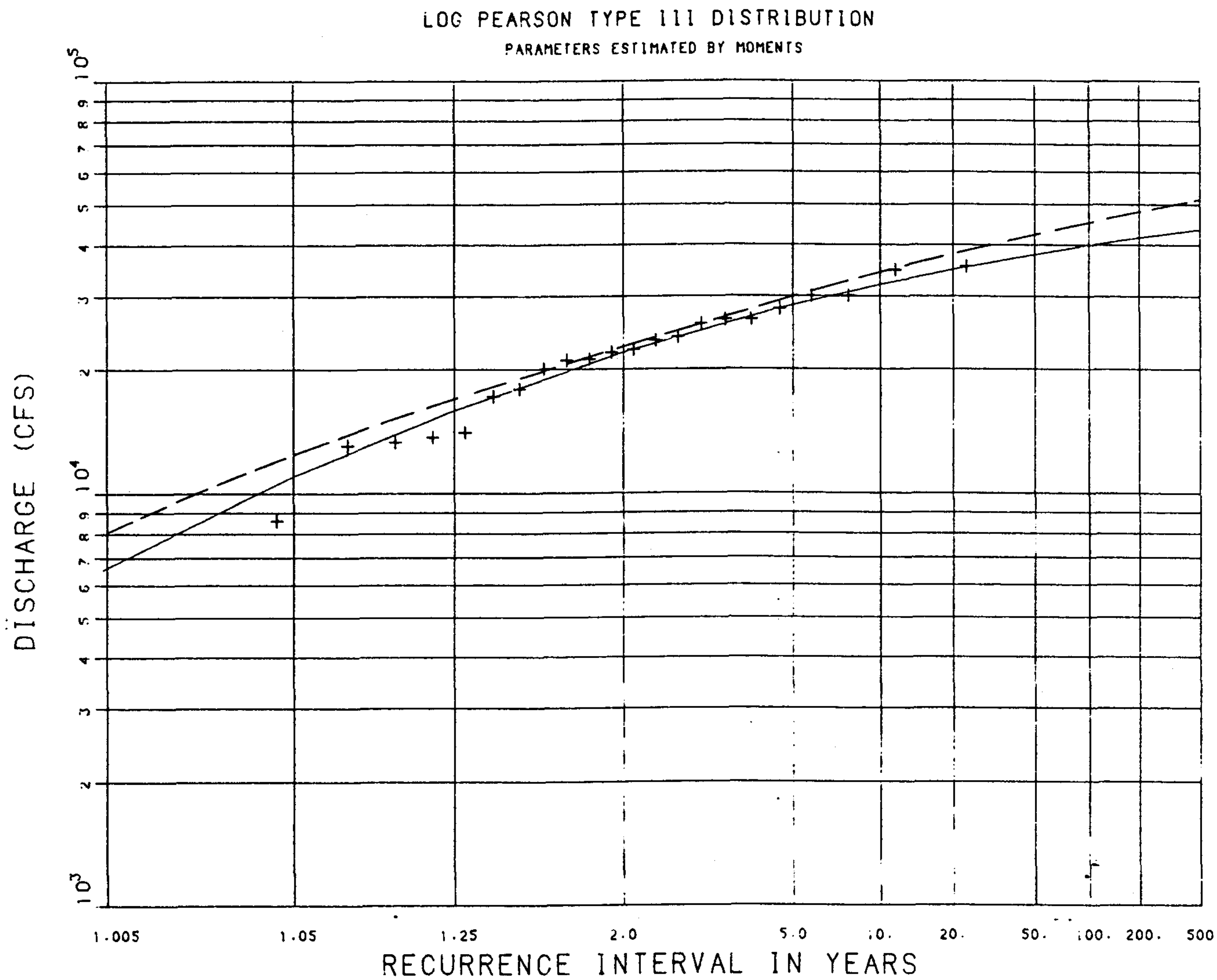
TABLE 7.5

CHANGES IN PEAK FLOWS DUE TO AGRICULTURAL DRAINAGE IMPROVEMENT SCENARIO

% CHANGE FOR RETURN PERIODS

PERIOD	LOCATION	2 Year % Change	5 Year % Change	10 Year % Change	20 Year % Change	50 Year % Change	100 Year % Change
Annual	Plantagenet	-7	-8	-9	-11	-12	-14
	Chesterville	-9	-8	-7	-5	-4	-3
	Bear Brook	-12	-12	-12	-12	-13	-13
	Vernon	-14	-12	-10	-9	-7	-5
May-Oct	Plantagenet	-11	-13	-13	-12	-11	-10
	Chesterville	-6	-12	-14	-15	-16	-17
	Bear Brook	-16	-25	-28	-31	-33	-35
	Vernon	-14	-24	-28	-32	-35	-38

Annual Flood Frequency Curve at Plantagenet with Agricultural Drainage Improvements

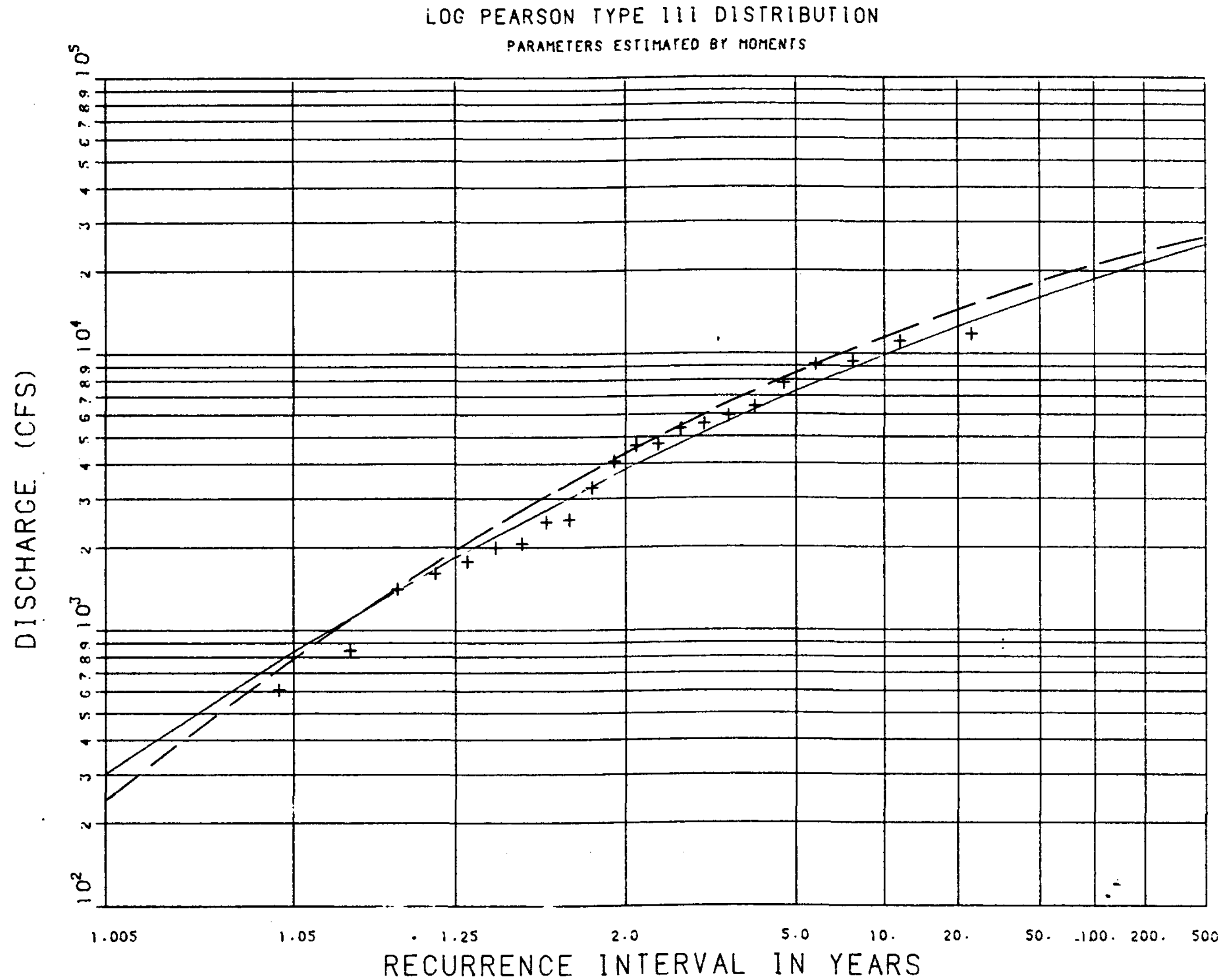


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10 +00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curve at Plantagenet with Agricultural Drainage Improvements

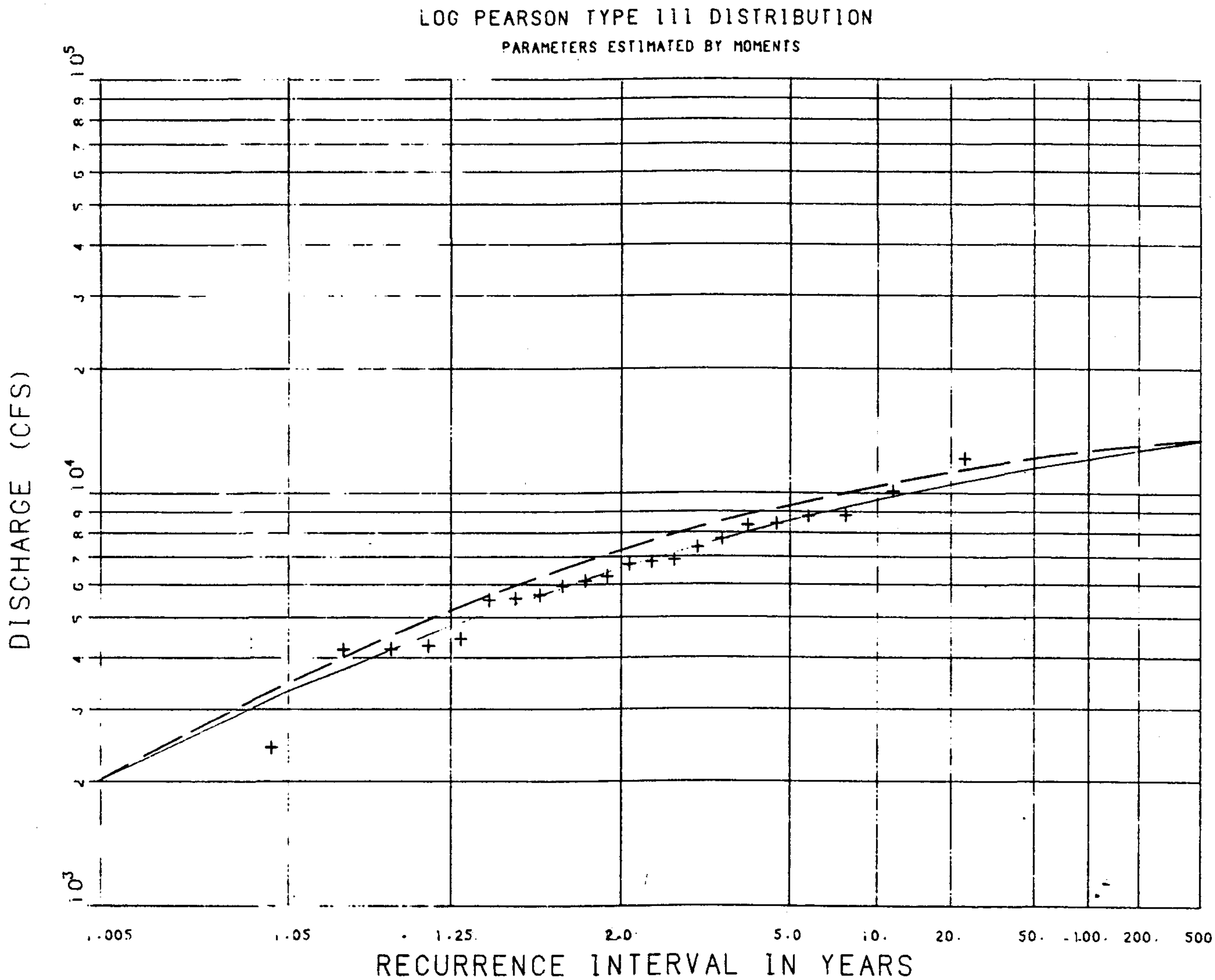


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

Annual Flood Frequency Curve at Chesterville with Agricultural Drainage Improvements

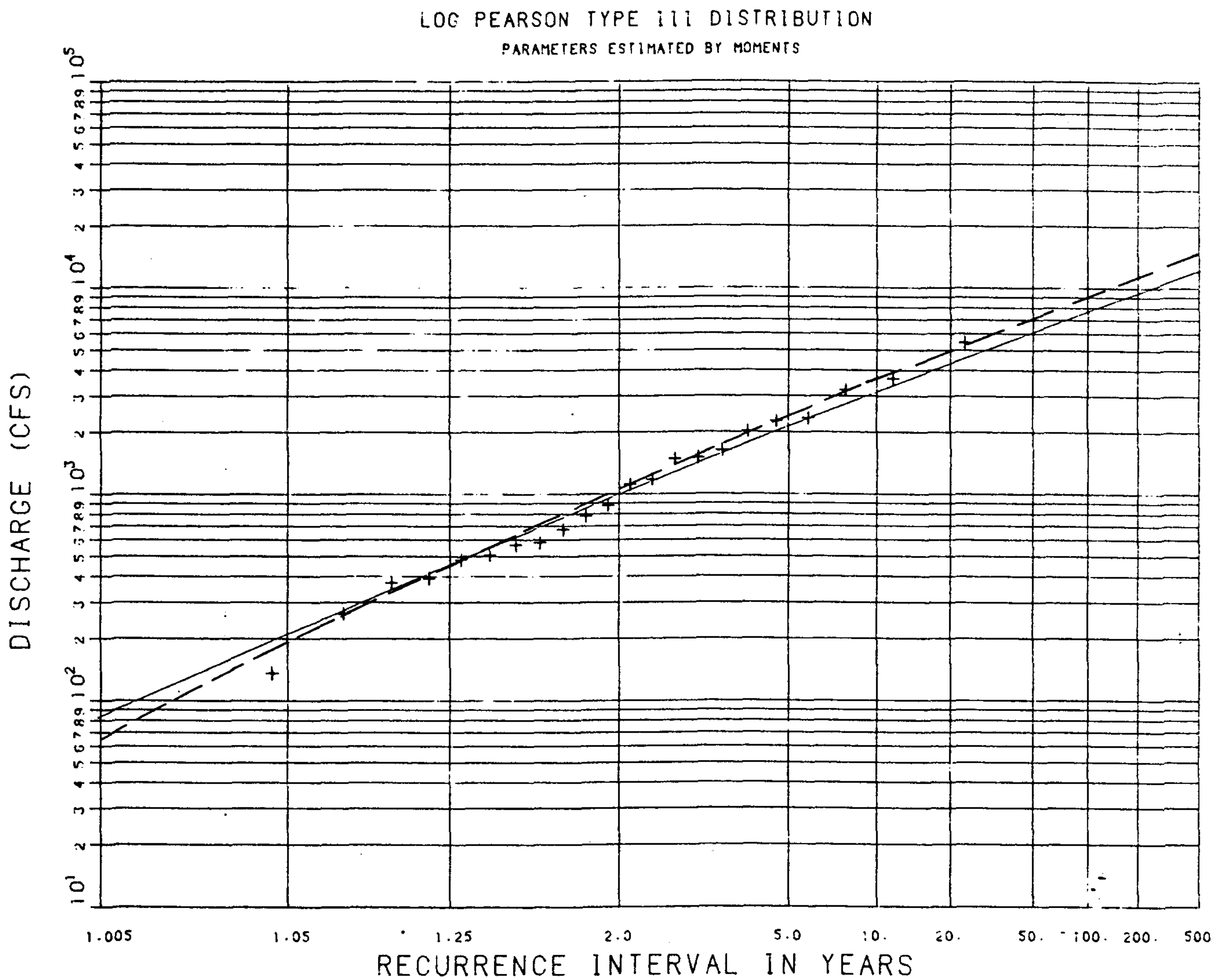


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curve at Chesterville with Agricultural Drainage Improvements

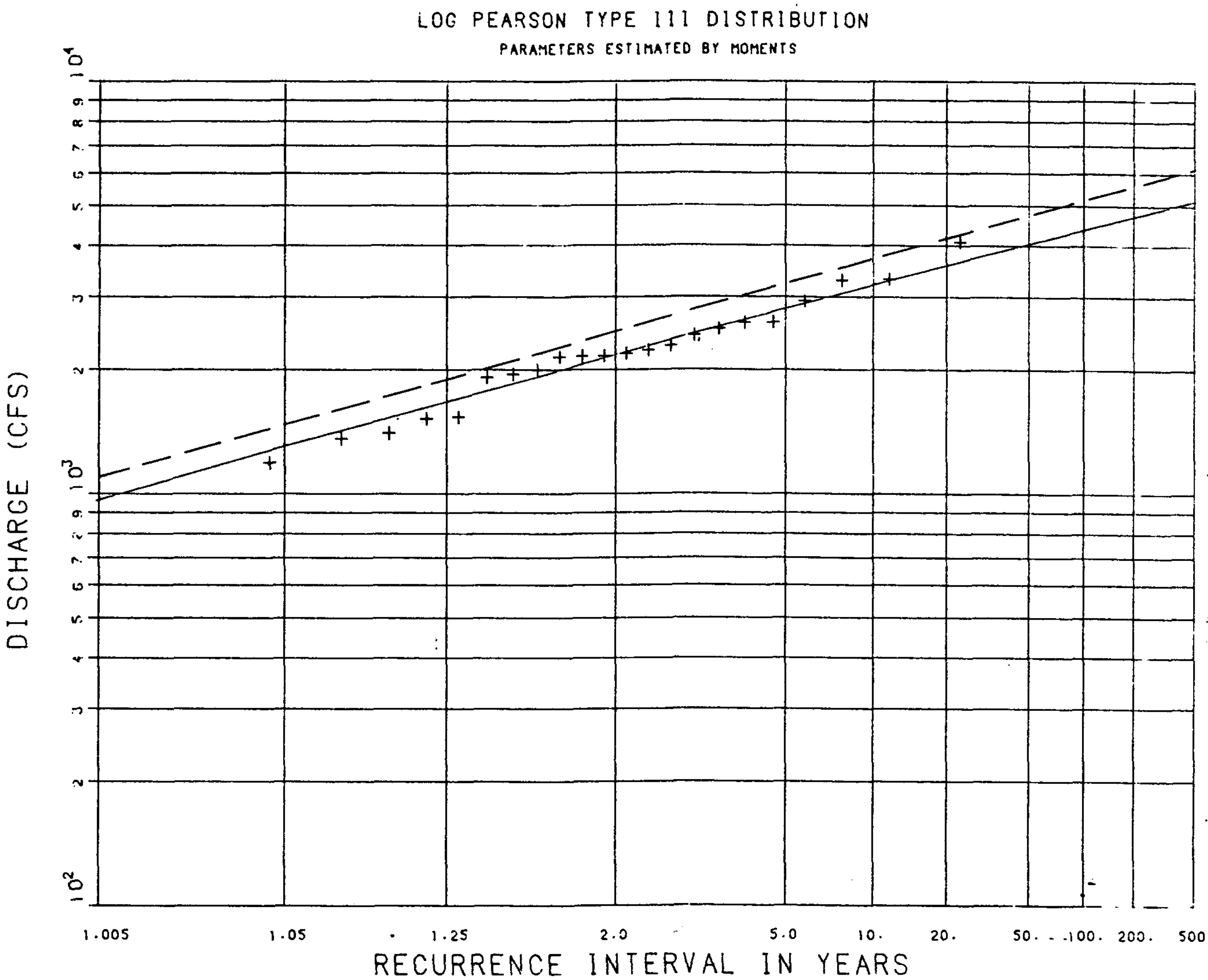


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

Annual Flood Frequency Curve at Bear Brook with Agricultural Drainage Improvements

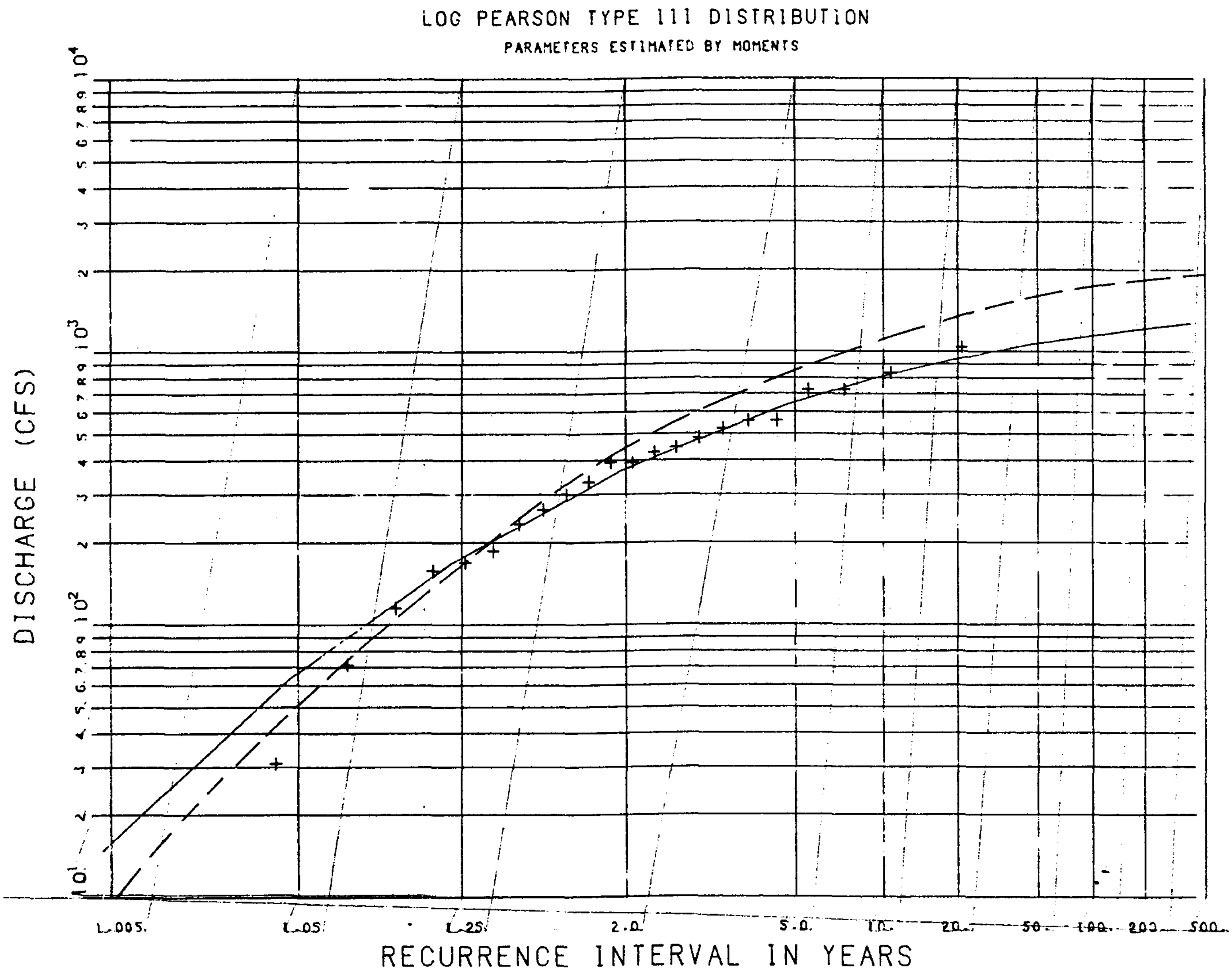


— — — Existing conditions with Chesterville channel to 10+00

———— Future scenario with Chesterville channel to 10 +00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curve at Bear Brook with Agricultural Drainage Improvements

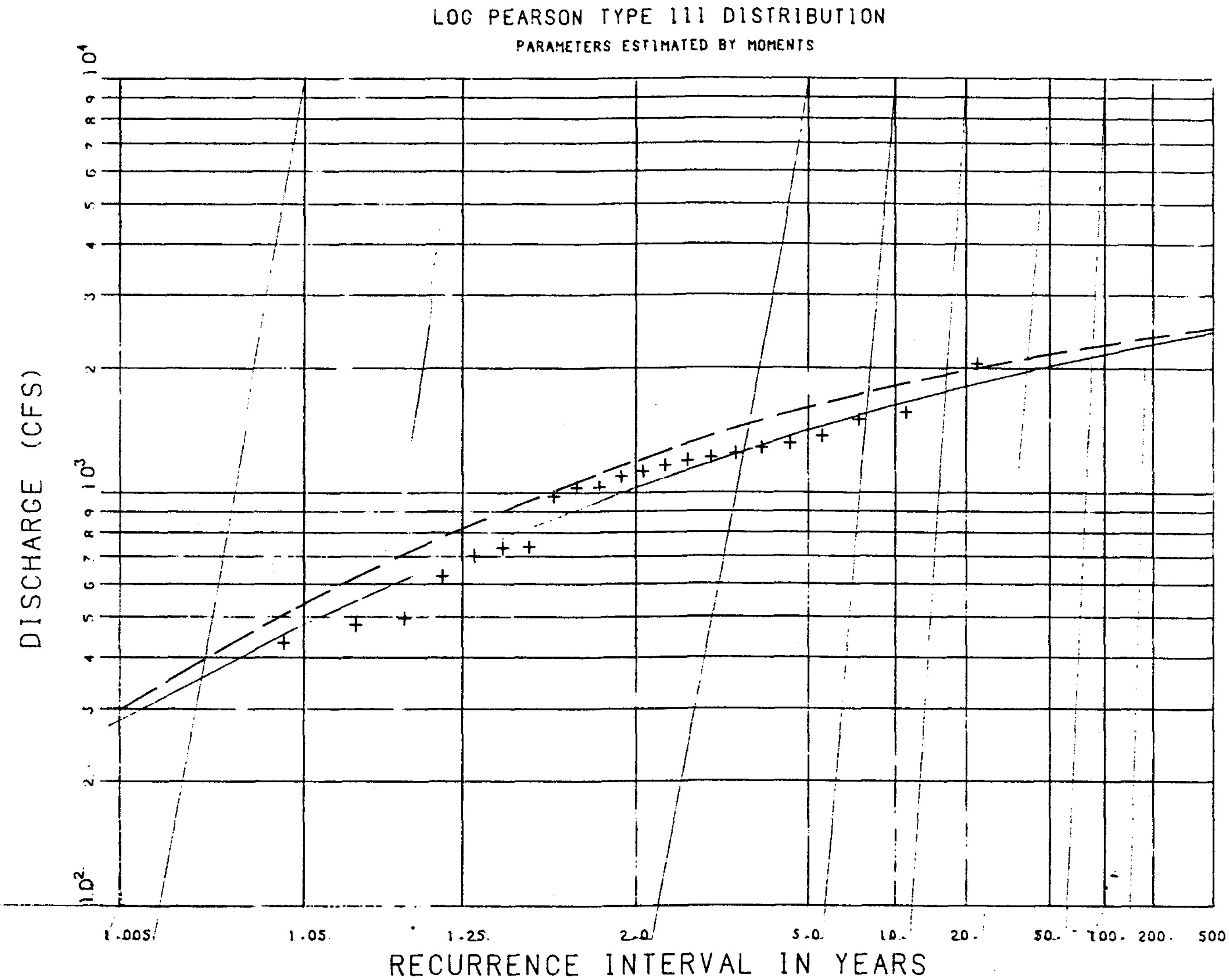


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

Annual Flood Frequency Curve at Vernon with Agricultural Drainage Improvements



— — — Existing conditions with Chesterville channel to 10 +00

——— Future scenario with Chesterville channel to 10 +00

NOTE: Points shown are for future scenario

There does not seem to be any significance to these trends beyond the fact that the flow reductions in nearly all cases are relatively large. The degree of agricultural drainage improvement in the area upstream of each of these sites is given in Table 7.6. While there is considerable variation in land use changes in each PERLAND area, the weighted average values for each site are very similar. The variations in impacts at each location is due to basin geometry and flow routing effects. It is also evident that the storage effect of the subsurface field drainage more than compensates for the marginal downstream flow increases that were predicted as a result of the hydraulic improvement to municipal drains throughout the watershed.

The detailed drainage modelling results outlined in Chapter 6 have shown that the storage effects of tile drainage are quite significant for small volume summer events. Simulations during the growing season from May to October confirmed this observation on a watershed basis. Large peak flow reductions were noted at the Chesterville, Bear Brook and Vernon flood areas. A smaller attenuation of peak discharges at Plantagenet was evident possibly due to the delay of runoff from the lower portions of the basin. Soil storage effects associated with the additional tile drainage are a major factor.

7.3 Channelization Works for Flood Control

7.3.1 Method

Major channel works are proposed on the Payne, South Castor and Bear Brook Drains together with the continuation of the Chesterville channel to station 17+000 at Salter's Bridge.

TABLE 7.6

LAND USE CHANGES FOR EACH SITE SELECTED FOR

EVALUATION OF IMPACTS

SITE	PERLND#	TOTAL AREA km²	AGR. DRAIN EXIST %	AGR. DRAIN FUTURE %	FOREST EXIST %	FOREST FUTURE %
1. Vernon	20	179	10	49	33	72
2. Bear Brook	8	283	7	41	40	77
(Bourget)	19	91	9	48	33	60
	23	56	5	26	44	97
Average		430	7	41	39	76
3. Chesterville	7	238	2	25	64	91
	9	685	10	47	37	70
	17	80	1	26	64	94
Average		1,003	7	40	46	77
4. Plantagenet	5	776	5	45	38	74
	13	508	12	53	27	48
*Average		2,896	8	44	39	71

* Includes whole watershed

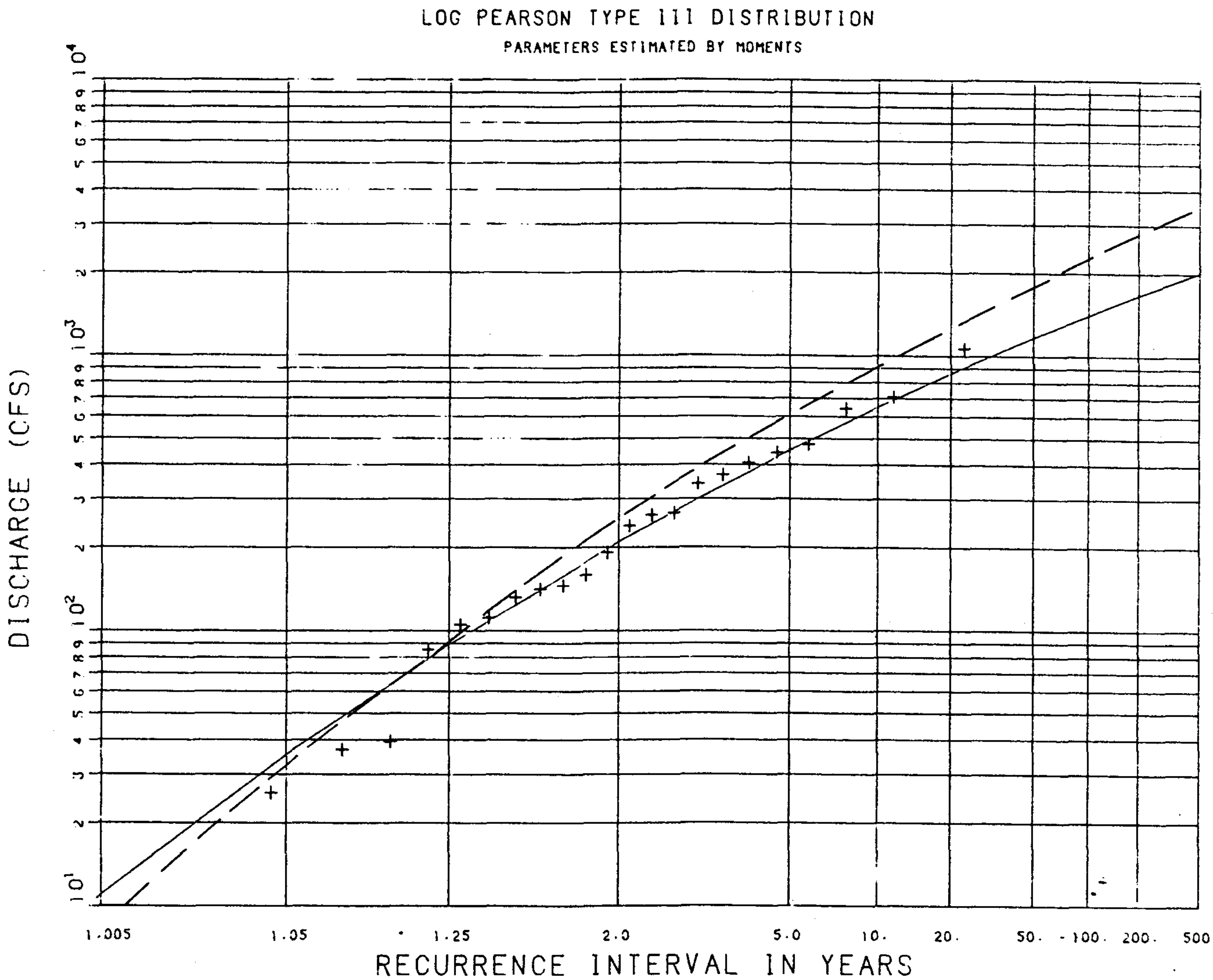
These large-scale improvements are primarily for flood control as opposed to agricultural drainage. The impact of these measures was evaluated as an incremental effect assuming that all agricultural drainage improvements discussed in section 7.2 were installed.

Information on the proposed enlargement of the Payne Drain was obtained from the Engineer's report. For the other 3 channels, storage-discharge routing curves for the HSP-F model were derived from a HEC-2 model backwater analyses performed by DelCan Ltd. This model was established for the flood line mapping work which was previously completed in these areas. The 10 year summer flow was selected for sizing the improved channel. The HEC-2 analysis provided estimates of the reduction in flood storage for the proposed works, while the HSP-F model was used to determine the downstream impacts on flows.

7.3.2 Impacts of Channel Works

The impacts of the major channel works were evaluated on the basis of both flow-frequency curves and change in area flooded. The same 23 year period was simulated as before and revised flood frequency curves were computed as shown in Figure 7.24 to 7.31. Table 7.7 summarizes these results.

May-October Flood Frequency Curve at Vernon with Agricultural Drainage Improvements

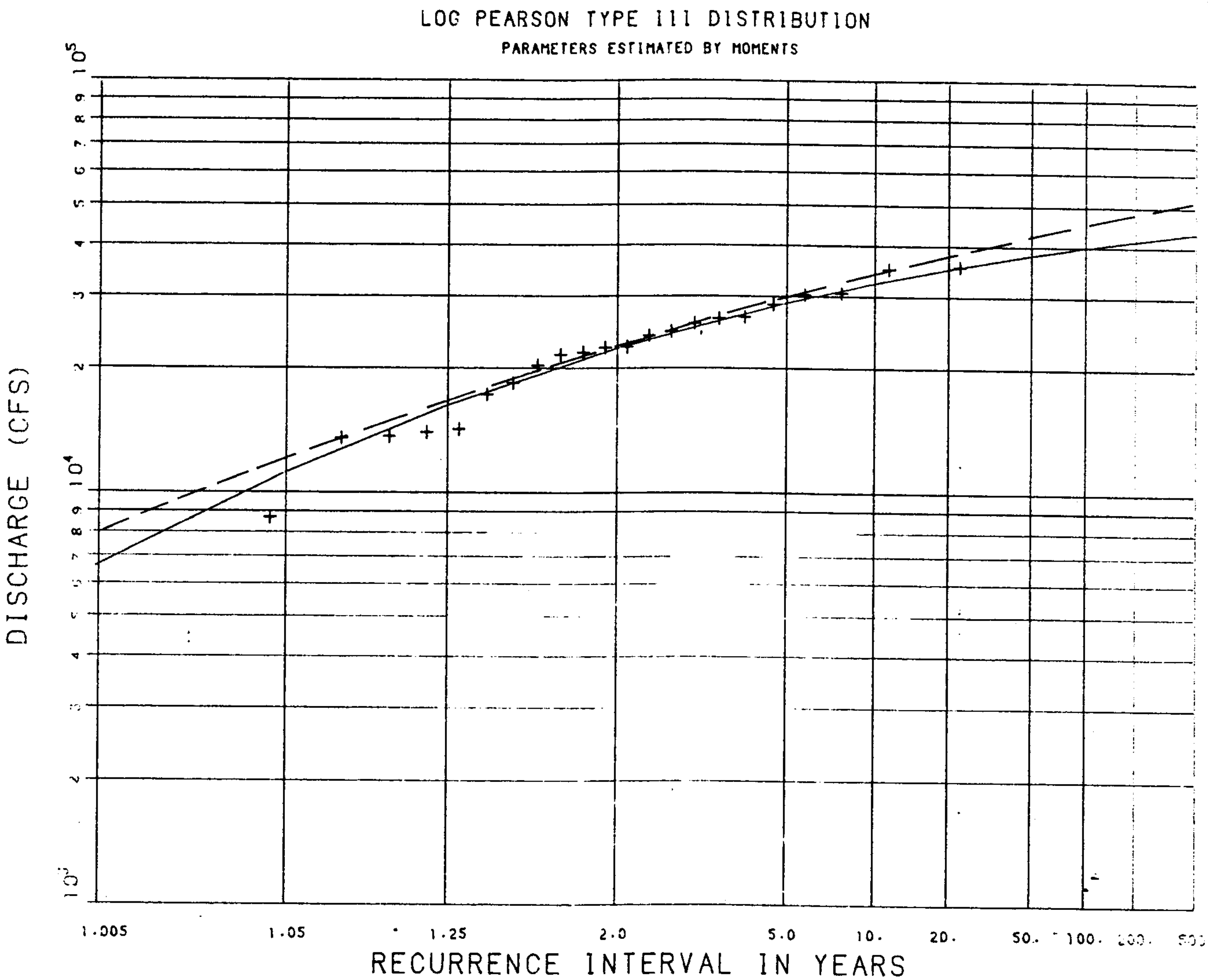


— — — Existing conditions with Chesterville channel to 10 +00

———— Future scenario with Chesterville channel to 10 +00

NOTE: Points shown are for future scenario

Annual Flood Frequency Curves at Plantagenet with Major Channel Works and Agricultural Drainage Improvements

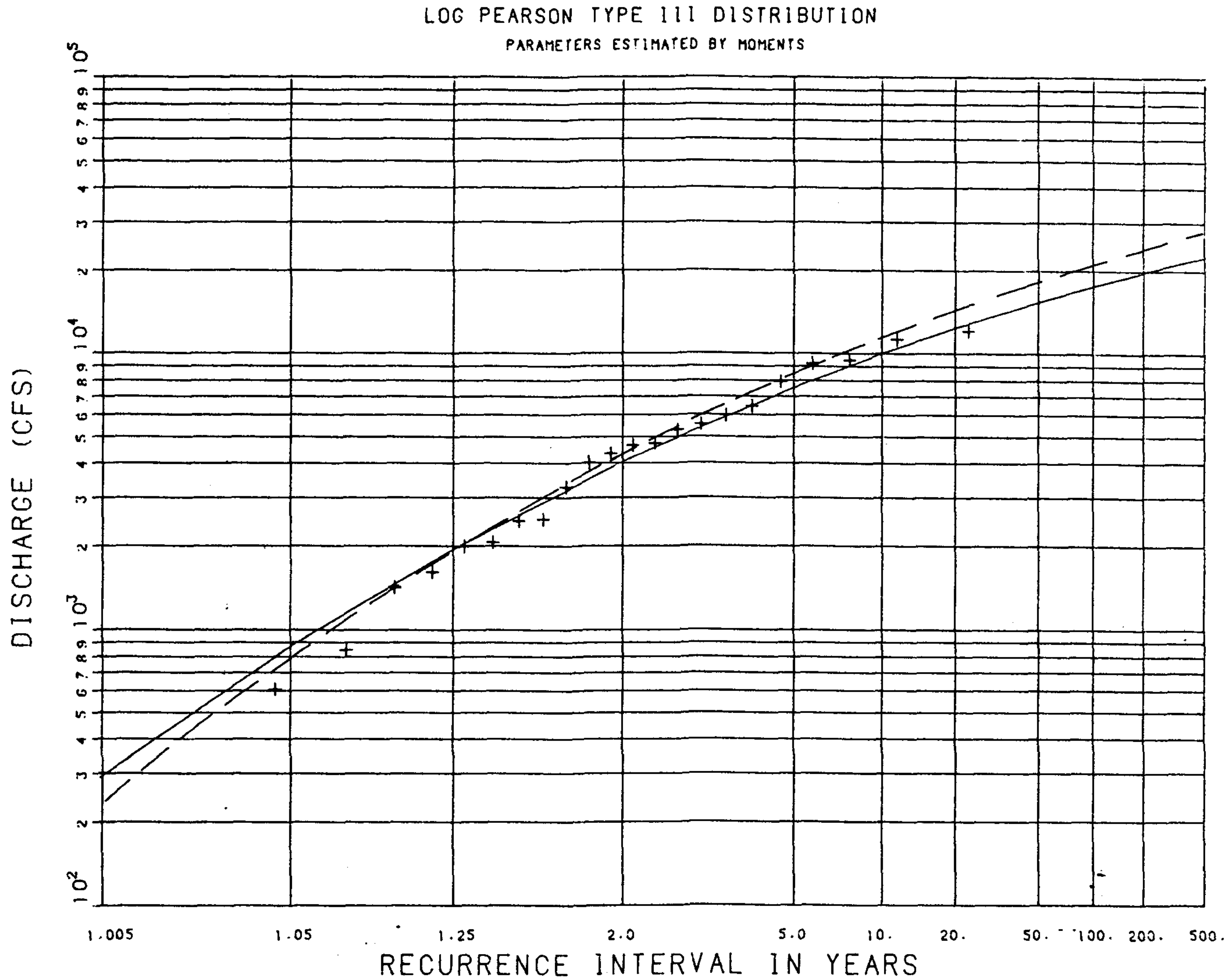


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curves at Plantagenet with Major Channel Works and Agricultural Drainage Improvements



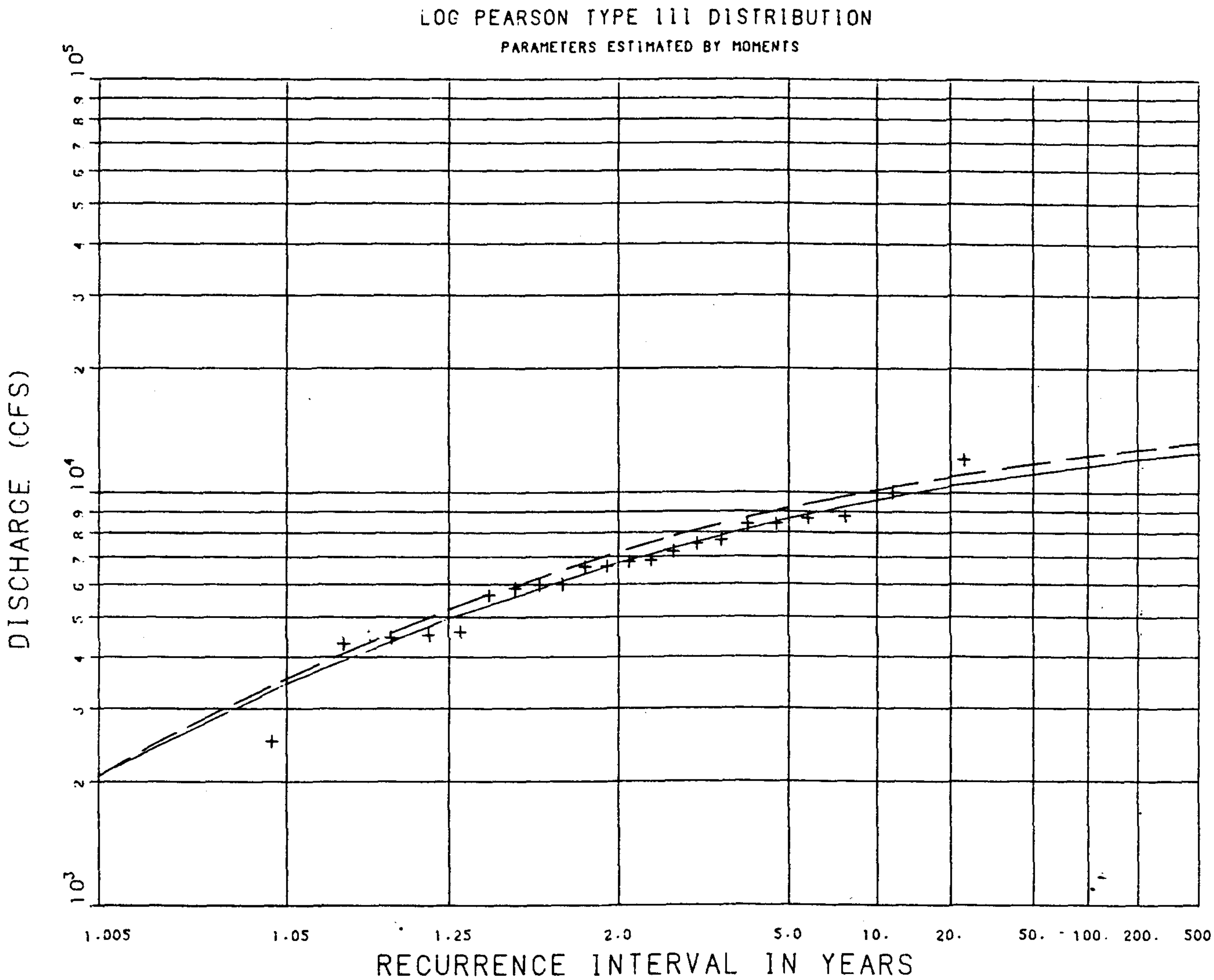
— — — — Existing conditions with Chesterville channel to 10 + 00

———— Future scenario with Chesterville channel to 10 + 00

NOTE: Points shown are for future scenario

Figure 7-26

Annual Flood Frequency Curves at Chesterville with Major Channel Works and Agricultural Drainage Improvements

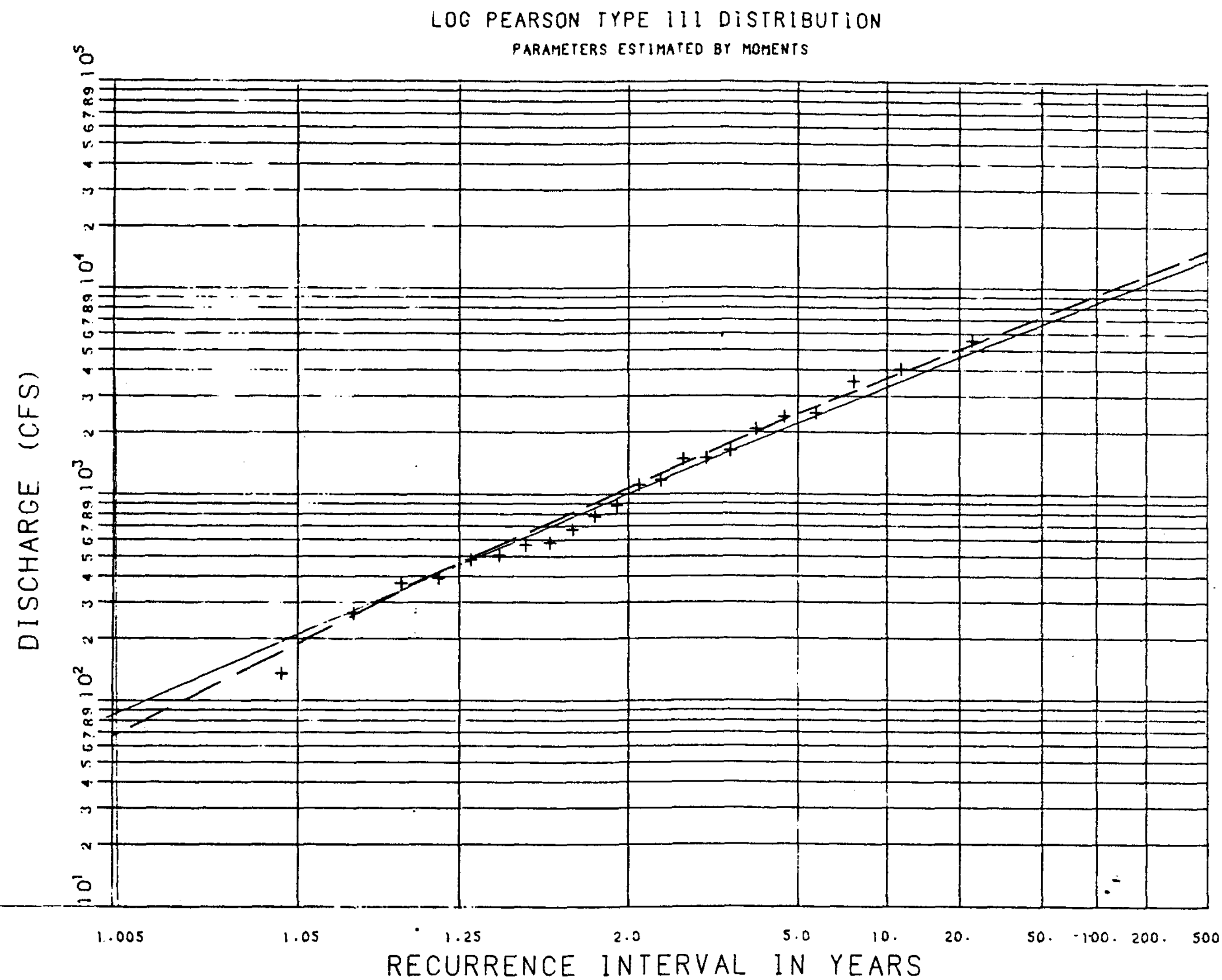


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curves at Chesterville with Major Channel Works and Agricultural Drainage Improvements

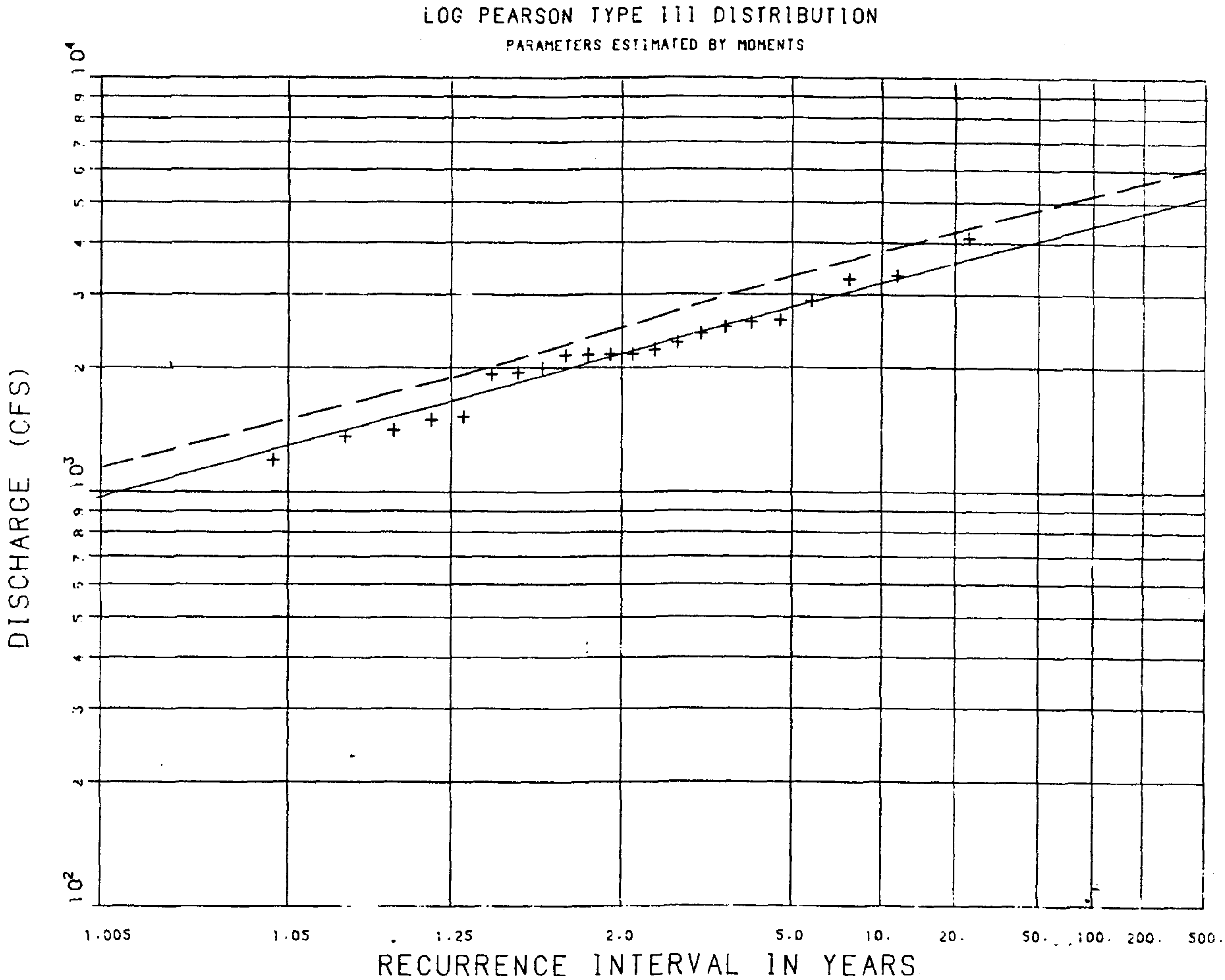


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

Annual Flood Frequency Curves at Bear Brook with Major Channel Works and Agricultural Drainage Improvements

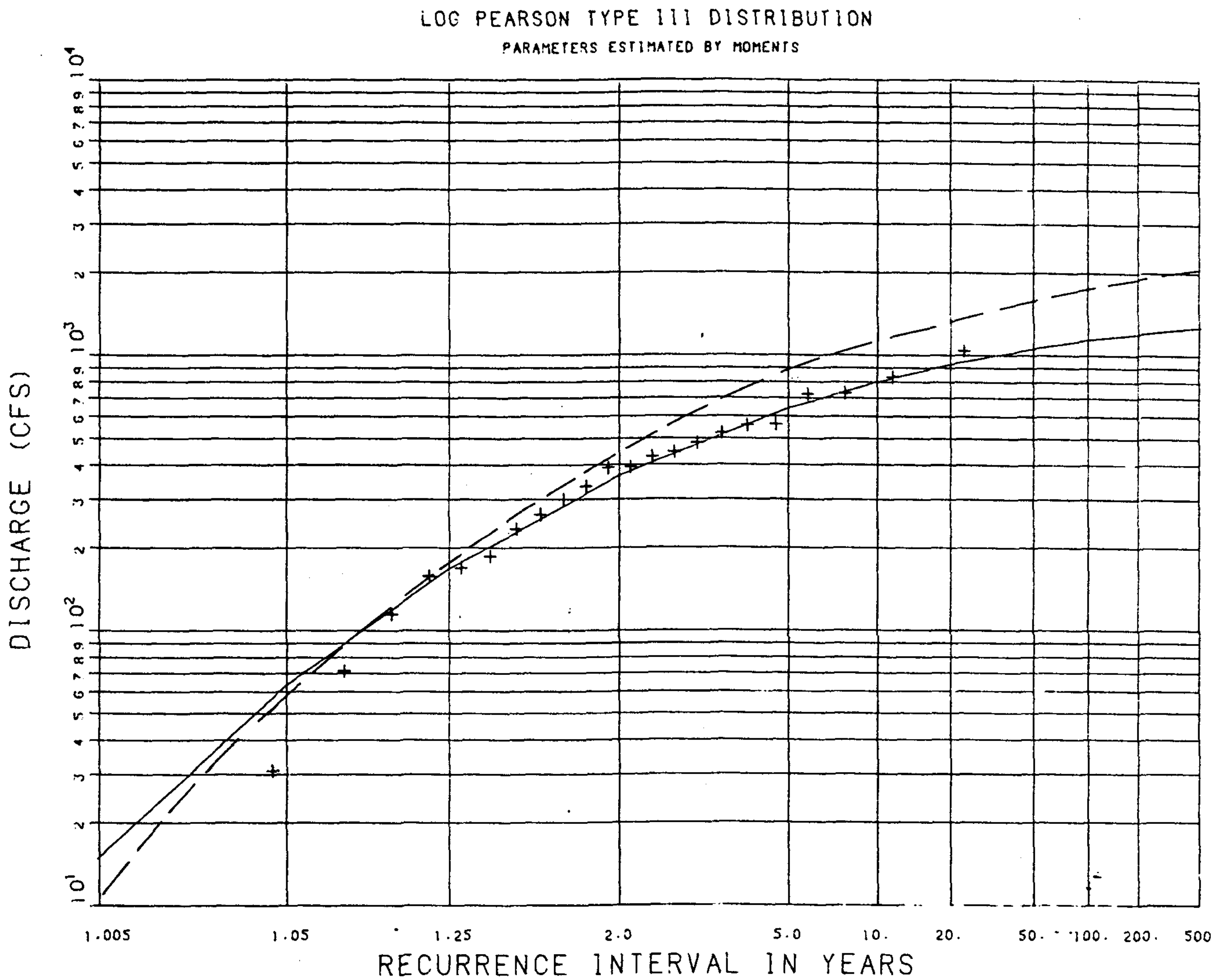


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curves at Bear Brook with Major Channel Works and Agricultural Drainage Improvements

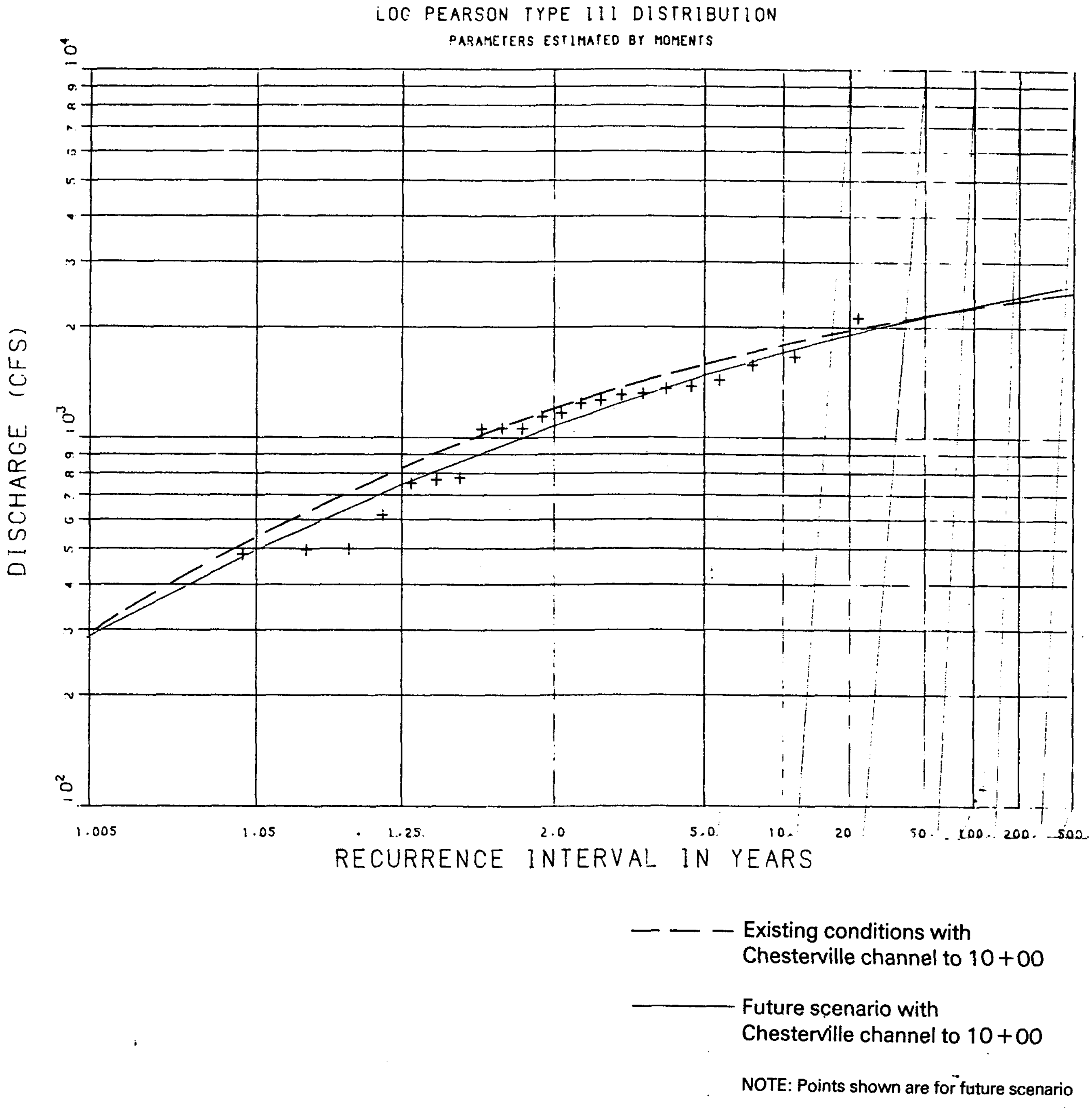


— — — Existing conditions with Chesterville channel to 10+00

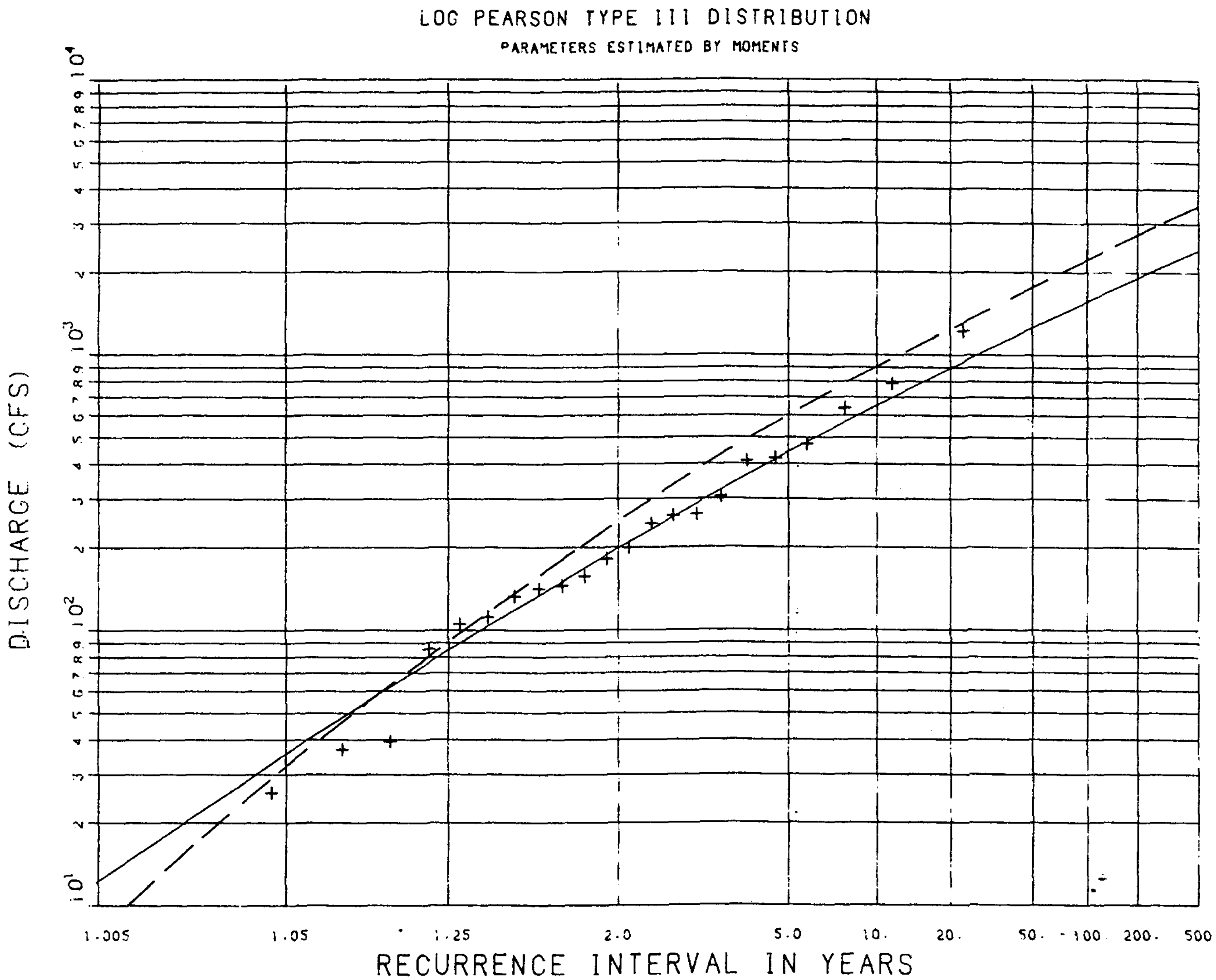
——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

Annual Flood Frequency Curves at Vernon with Major Channel Works and Agricultural Drainage Improvements



May-October Flood Frequency Curves at Vernon with Major Channel Works and Agricultural Drainage Improvements



— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

TABLE 7.7

CHANGES IN PEAK FLOWS DUE TO AGRICULTURAL DRAINAGE IMPROVEMENTS AND MAJOR CHANNEL WORKS

% CHANGE FOR RETURN PERIODS

PERIOD	LOCATION	2 YR % Change	5 YR % Change	10 YR % Change	20 YR % Change	50 YR % Change	100 YR % Change
Annual	Plantagenet	-6	-7	-8	-10	-12	-14
	Chesterville	-6	-7	-7	-6	-7	-7
	Bear Brook	-13	-12	-13	-12	-12	-12
	Vernon	-10	-8	-6	-4	-2	0
May-October	Plantagenet	-6	-11	-12	-13	-14	-15
	Chesterville	-6	-9	-10	-10	-9	-8
	Bear Brook	-16	-25	-28	-31	-33	-34
	Vernon	-18	-26	-28	-30	-30	-31

Channelization of natural waterways which improves the flow capacity of a stream cross-section and reduces the volume of floodplain storage will commonly increase flood peaks at downstream locations. This effect was generally observed within the South Nation basin at the four major flood prone locations.

Table 7.7 summarizes the overall decrease in peak annual daily flows resulting from the installation of additional agricultural drainage outlined in Section 7.2 plus the channelization at Chesterville, Bear Brook at Carlsbad Springs, the Payne River and the South Castor River at Vernon. For both the annual period and growing season from May to October flood peaks are reduced and will be smaller than experienced at the present time especially during the summer period when the storage effects of subsurface drainage are more dramatic.

Changes in flood peaks due to channelization at the latter four locations after agricultural drainage is improved throughout the watershed can be inferred by comparing Tables 7.5 and 7.7. Peak flows are increased on the South Castor River at Vernon both during the annual and growing season periods while on Bear Brook flows appear unchanged. The flows presented in Tables 7.5 and 7.7 for Bear Brook are experienced upstream of South Indian Creek near the downstream limit of proposed channelization on Bear Brook. No impact on peak flows due to the channelization apparently reflects the relatively small scale of this project.

The consequences of extending the Chesterville channelization to Salter's Bridge are significant during the summer growing season since higher flood peaks will occur. Frequency analysis indicates that larger magnitudes will range between five to nine percent for more severe events. Annual flood peaks primarily reflecting spring snowmelt and rainfall occurrences are only marginally influenced. A review of annual peak flows indicates a one percent increase due to the routing effect. The largest event in 1978 is actually decreased by a similar amount as a result of changes in floodplain storage over the week preceding the highest runoff. In summary, the additional channelization at Chesterville will not materially alter annual peak flows; the percentage changes noted in Tables 7.5 and 7.7 mainly arise from frequency curve fitting procedures. It is again emphasized that if the Chesterville channelization is accompanied by tile drainage within 75 percent of agricultural lands in the upstream watershed, flow magnitudes will be smaller than at present.

Peak flows at Plantagenet reflect the combined effect of the increased flows which may be attributed to channelization at the four upstream locations within the watershed and any modifications in the flow travel time from tributaries of the basin arising from the channelization.

Estimates of peak flows at Plantagenet remain unchanged for the range of frequencies considered during the study for the annual period. However, the largest flows during the summer growing season will increase by one to two percent for events with magnitudes equal to the 5 year to 20 year occurrence. A detailed review of simulations between 1957 and 1979 indicates that the largest flows are increased by a maximum 2%.

Channelization effects for less frequent events cannot be determined accurately by extrapolation of the flood frequency curves since the extreme values are significantly influenced by curve-fitting techniques.

7.4 Hydrologic Impacts of Forestry

The effect of forestation on peak flows and runoff volumes is not well understood and is still the subject of diverse opinion. Within the South Nation watershed, about 39% of the area is currently forested. However, there are areas of marginal farm land and scrub forests which could be converted to commercial forest production. **It is emphasized that reforestation of this magnitude represents an upper limit that was selected to clearly illustrate the impact of this land use change on streamflows within the South Nation River basin.** The hydrologic impacts caused by changing these marginal lands to forest production was investigated with the HSP-F model and findings are outlined in the following report sections.

7.4.1 Background

The question of forest influence upon streamflow often arises particularly within the context of changes which may be experienced as wooded areas are eliminated. The most authoritative information on this matter has been assembled from research studies on forested watersheds carried out in the United States since 1909. There is general agreement in the literature(3) that forest cover reduces yield from a watershed, thus resulting in lower annual streamflow and decreased groundwater recharge.

Although evapotranspiration rates and soil water moisture storage are reportedly diminished during the growing season by the removal of wooded areas, summer streamflow rates are usually only marginally greater. The most significant increase in watershed yield following forest clear cutting is experienced during the spring snowmelt season with incremental runoff volumes reportedly approaching 30% of annual yield(3). The greater snow accumulation and resultant runoff is most often linked to smaller interception losses especially after the removal of coniferous forest cover. Reported changes in watershed yield represent clear cutting of fully forested areas.

There is little question that stormflow is higher from cut over forest land during the growing season. A documented case(7) of a four to five fold increase in peak magnitudes probably represents the upper extreme with an average response difference between 10 and 200% being more representative (4, 5, 8).

The effect of the removal of cover on peak flows will vary depending on the soil disturbances and the treatment of the land after forest removal. Larger infiltration and soil storage capacities commonly found in forests are known to eliminate overland flow. Neverthless, these forest processes are relatively more important for stormflow resulting from small storms. During severe rainfalls, forest discharges to stream channels via subsurface flow can be significant. Forest cutting evidently does not drastically affect major rainfall floods(9).

Forest cover may either increase or decrease individual flood peaks caused by snowmelt or rainfall plus snowmelt related events. Although wooded areas will prolong snow cover during the spring period, the most rapid snowmelt of the year may be late in the season when high temperatures and radiation occur. If combined with rainfall, forest cover can be a liability rather than a flood control asset.

Maintaining dissimilar land uses over a watershed appears to be the accepted practice of desynchronizing snowmelt related peak flows and thereby reducing flood potential throughout the snowmelt season.

7.4.2 Method

The maximum potential area of future forest cover in the South Nation River basin was estimated by the Conservation Authority on the basis of converting all marginal farm land and suitable idle land to forest production. Resultant watershed flows were evaluated for the 23 year period between 1957 and 1979 with the HSP-F watershed model. Table 7-8 gives the forest area assumed for each PERLND segment in the HSP-F model, while Table 7-6 gives the weighted average values for each stream site selected to evaluate the impacts of increased forestry. The HSP-F model parameters which relate to forest cover, interception storage (INTCEP), Manning's 'n' for overland flow, shade (SHADE), and lower zone evapotranspiration (LZET) were modified according to suggested literature values and previous application of the model.

TABLE 7.8

% FOREST BY PERLND SEGMENT

FOR EXISTING AND FUTURE CONDITIONS

PERLND SEGMENT NO.	NAME	% FOREST EXISTING	% FOREST* FUTURE
5	Plantagenet	38	74
6	Russell	35	79
7	Spencerville	64	91
8	Bourget	40	77
9	Chesterville	37	70
12	St. Isidore	42	71
13	Cassellman	27	48
16	Embrun	15	33
17	Heckston	64	94
18	W. Scotch River	38	65
19	Limoges	33	60
20	Kenmore	33	72
21	E. Castor River	19	42
22	Berwick	35	59
23	Carlsbad Springs	44	97

* as in 'Maximum Forest Alternative'

Notes:

- forest includes: idle, woodlot, swamp (i.e. all non-agricultural land)
- all figures based on SNRCA maps (land use) and tabular data

Revised flood frequency curves representing the maximum forest cover option are presented in Figures 7.32 to 7.39. No drainage improvements were considered in conjunction with this alternative.

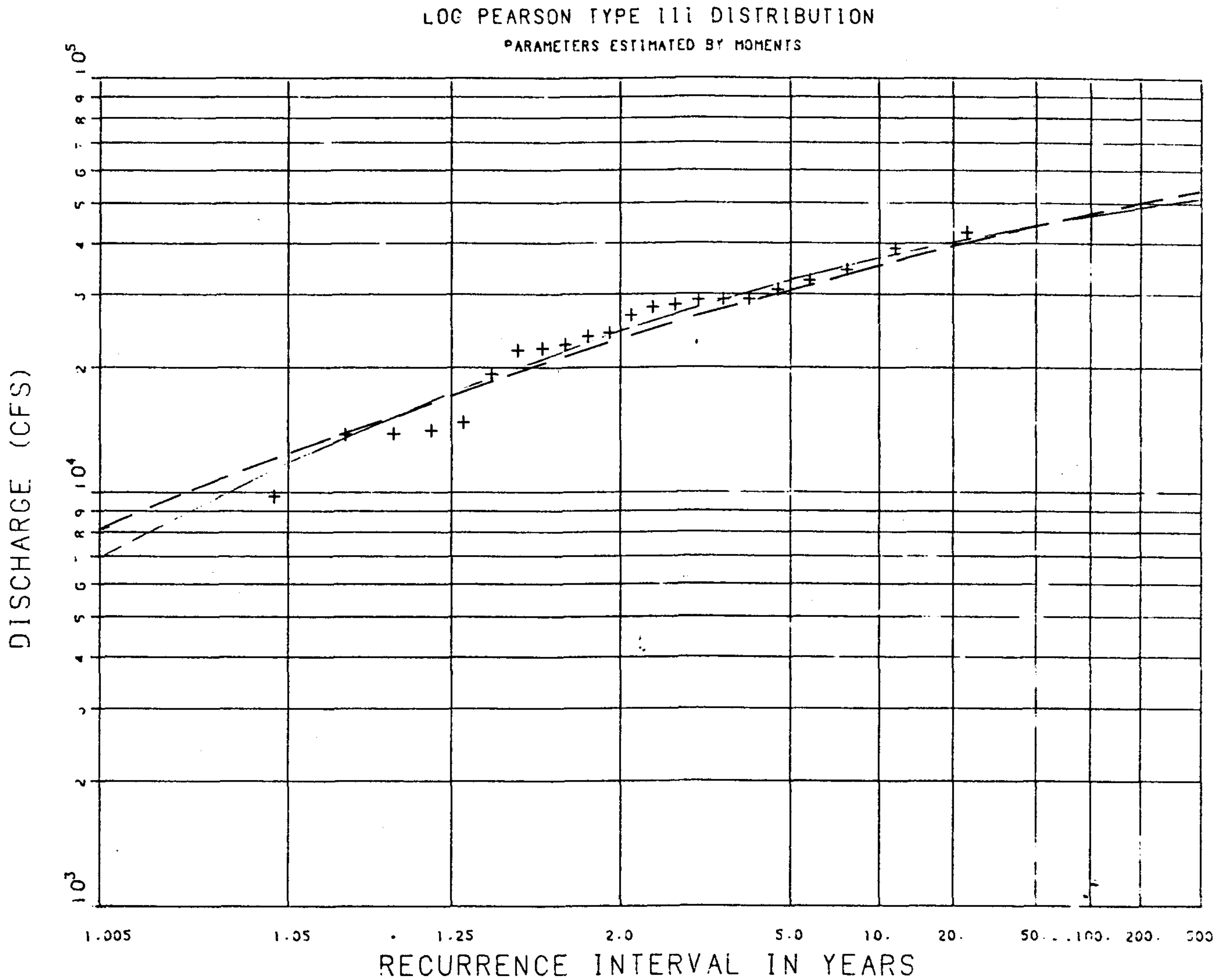
7.4.3. Impacts of Maximizing Forest Production

Table 7.9 summarizes the simulation results for this land use change. In general, the increase in annual peak flows will range up to a maximum of 11% at Vernon while at Plantagenet flows increase by only a small percentage.

For the summer period, a wide variation in peak flows was evident with larger flow increases occurring during more severe events. For example, at Plantagenet the 2 year summer event is reduced by 9 percent while the additional forest cover causes the 100 year event to increase by 21 percent. The delay in the melt of the winter snow pack into May is cited as the major reason for increased peak flows during the May to October summer growing season particularly at the 50 year and 100 year magnitude. More frequent flood events are usually caused by mid-summer thunderstorms and forest cover tends to attenuate these flows. The deep rooted vegetation depletes the soil storage by increased evapotranspiration thereby reducing base flows and increasing soil storage capacity. Increased infiltration serves to diminish surface runoff and peak flows during the summer period.

Figure 7-32

Annual Flood Frequency Curves at Plantagenet with Maximum Forest

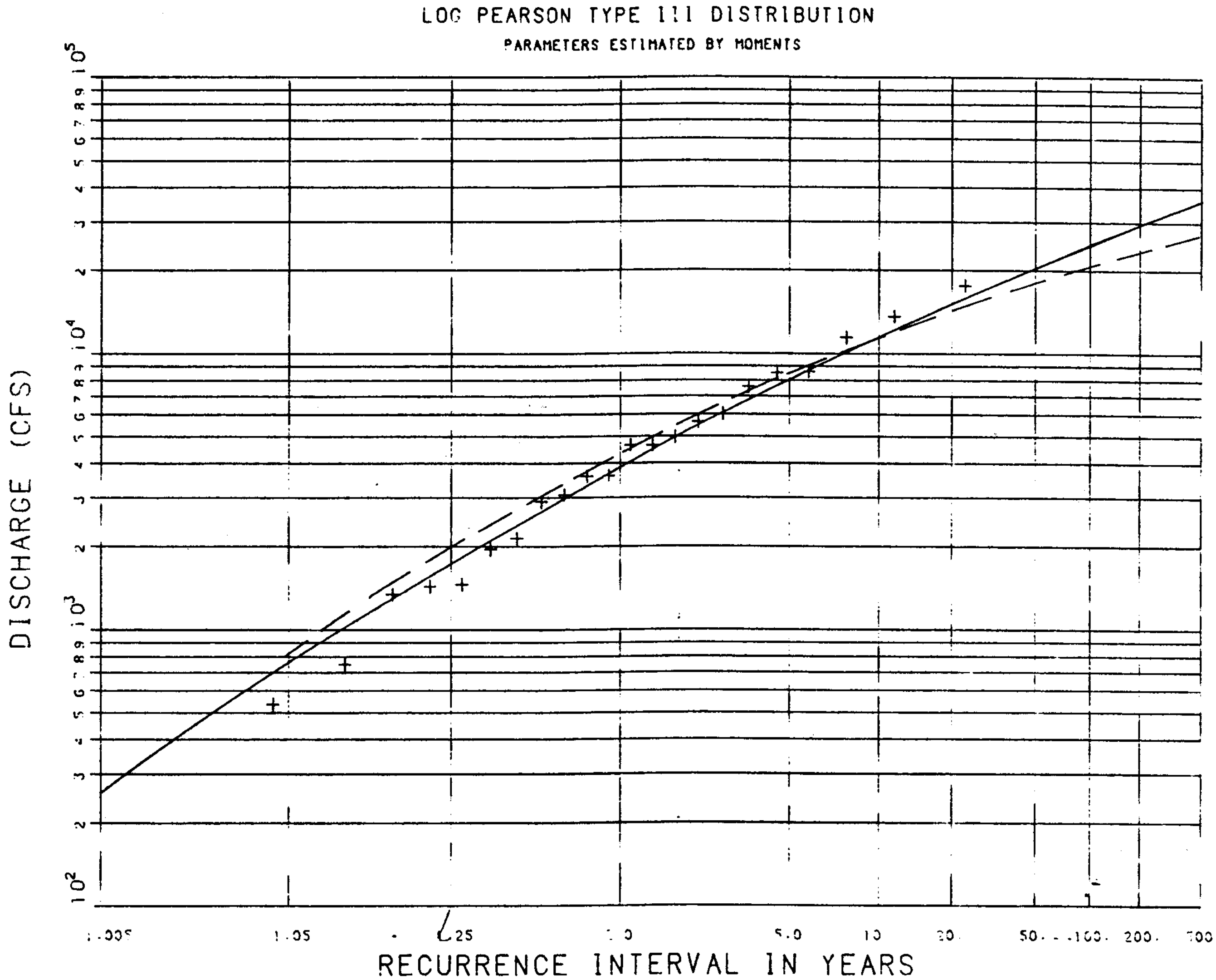


— — — Existing conditions with Chesterville channel to 10+00

———— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curves at Plantagenet with Maximum Forest

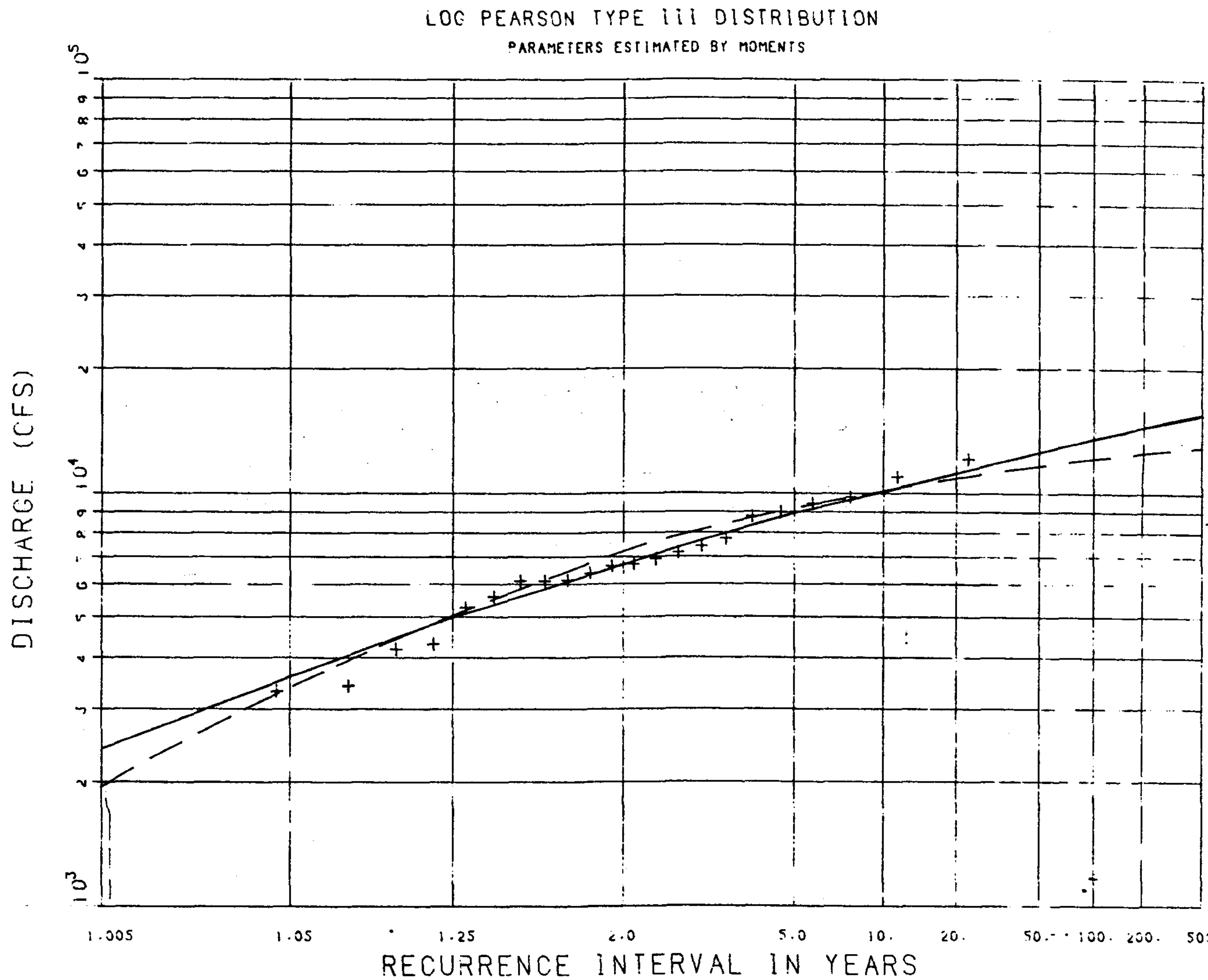


— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

Annual Flood Frequency Curves at Chesterville with Maximum Forest

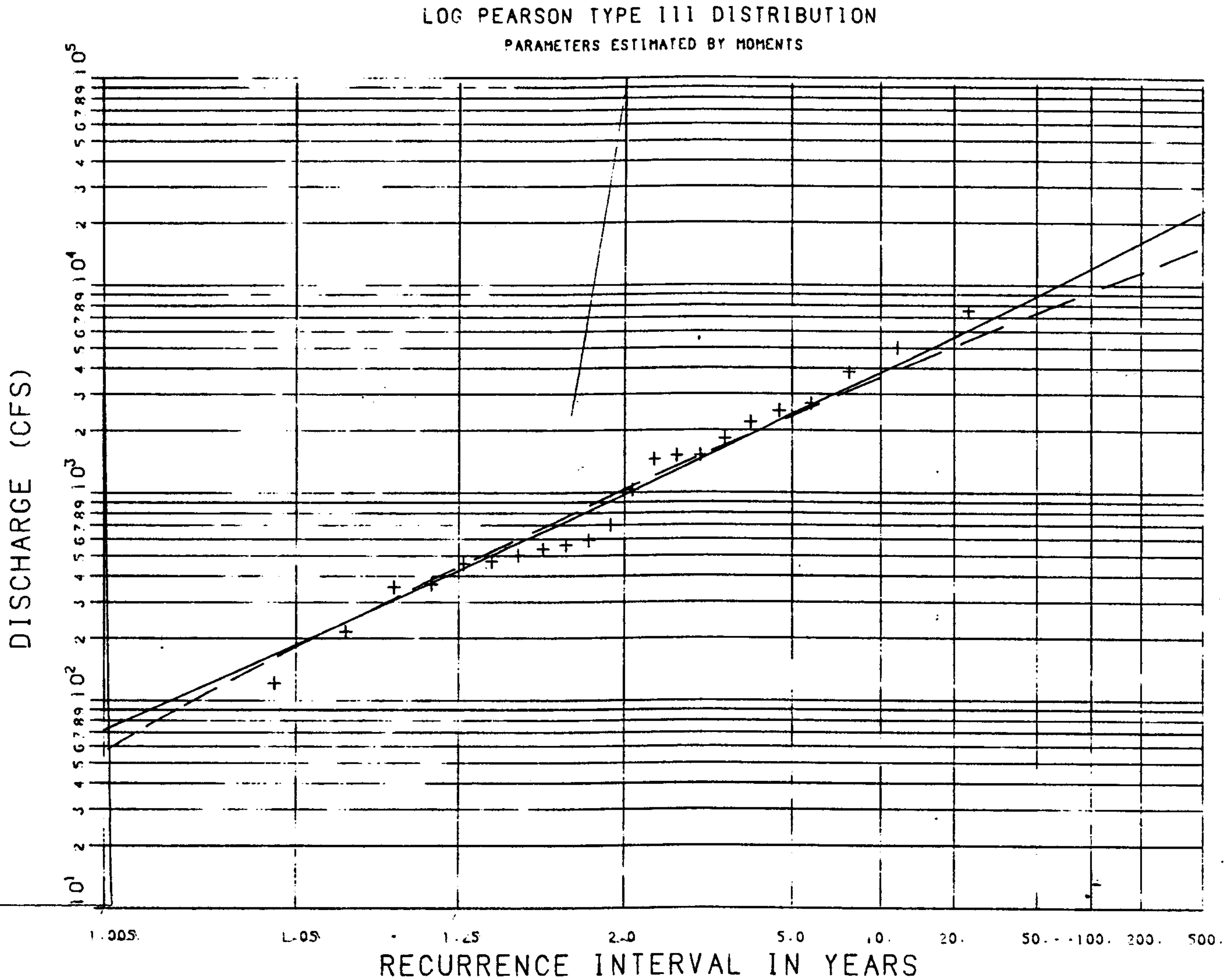


— — — Existing conditions with Chesterville channel to 10 + 00

———— Future scenario with Chesterville channel to 10 + 00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curves at Chesterville with Maximum Forest



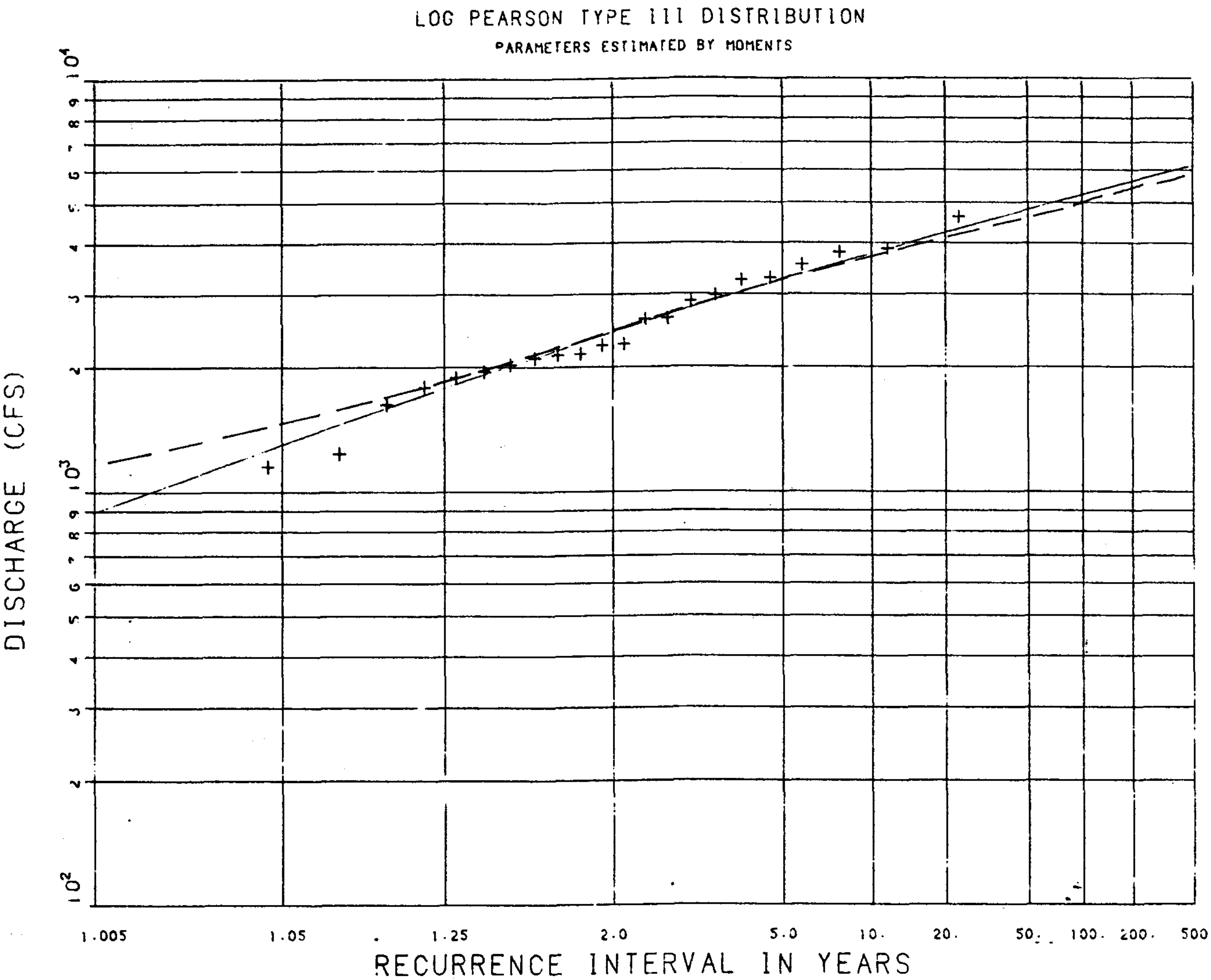
— — — Existing conditions with Chesterville channel to 10+00

——— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

Figure 7-36

Annual Flood Frequency Curves at Bear Brook with Maximum Forest

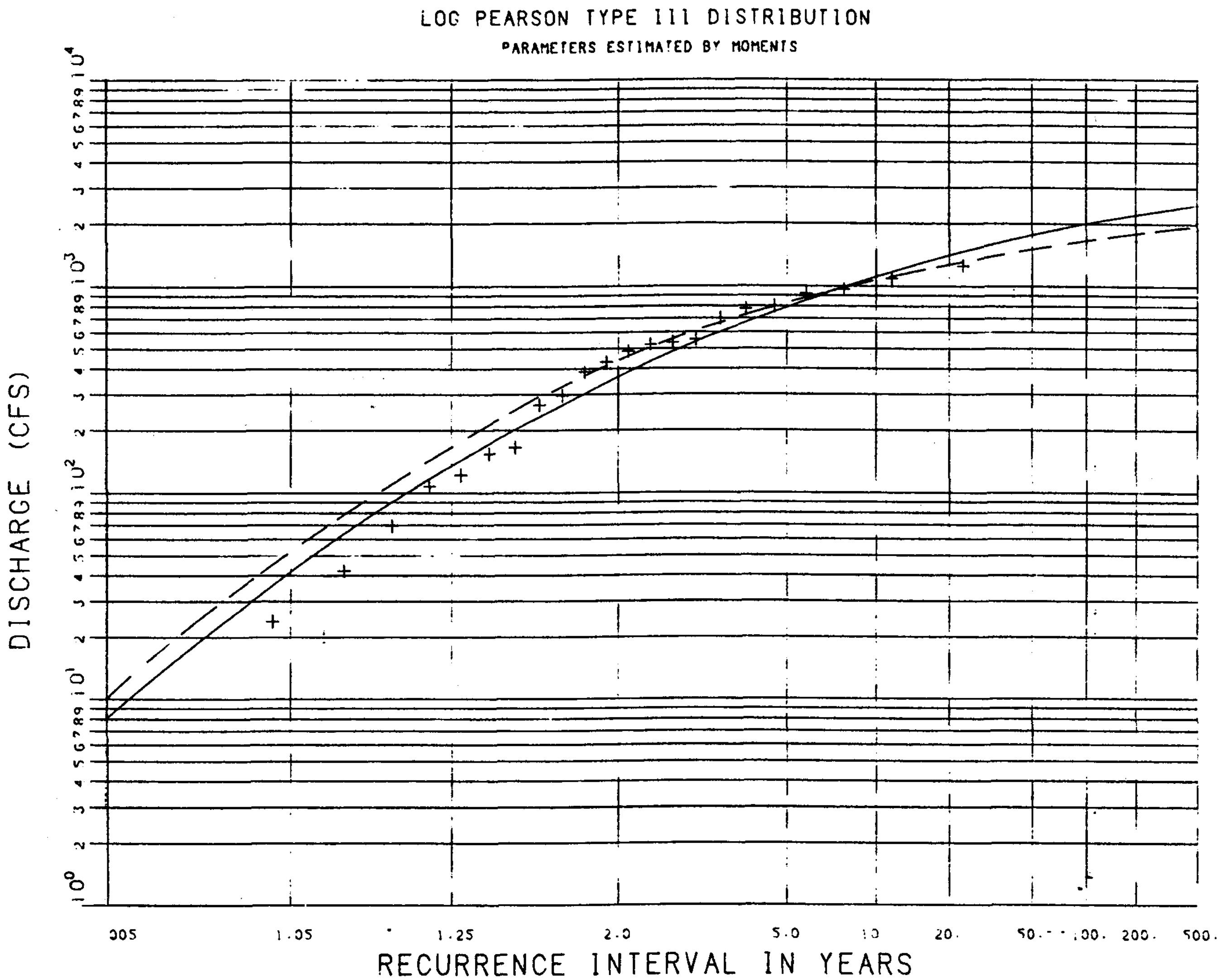


— — — Existing conditions with Chesterville channel to 10+00

———— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curves at Bear Brook with Maximum Forest

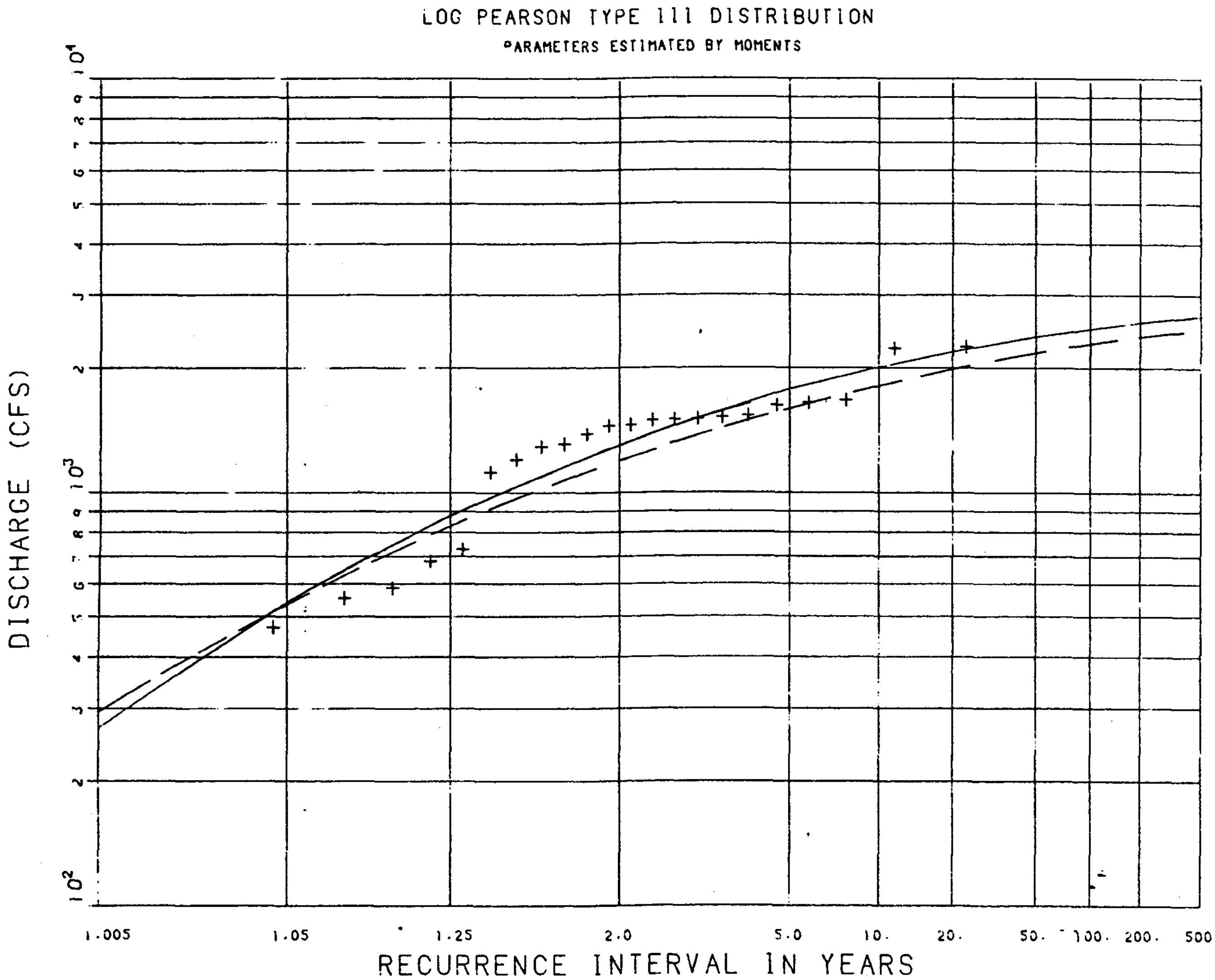


— — — Existing conditions with Chesterville channel to 10 + 00

——— Future scenario with Chesterville channel to 10 + 00

NOTE: Points shown are for future scenario

Annual Flood Frequency Curves at Vernon with Maximum Forest



— — — — Existing conditions with Chesterville channel to 10+00

———— Future scenario with Chesterville channel to 10+00

NOTE: Points shown are for future scenario

May-October Flood Frequency Curves at Vernon with Maximum Forest

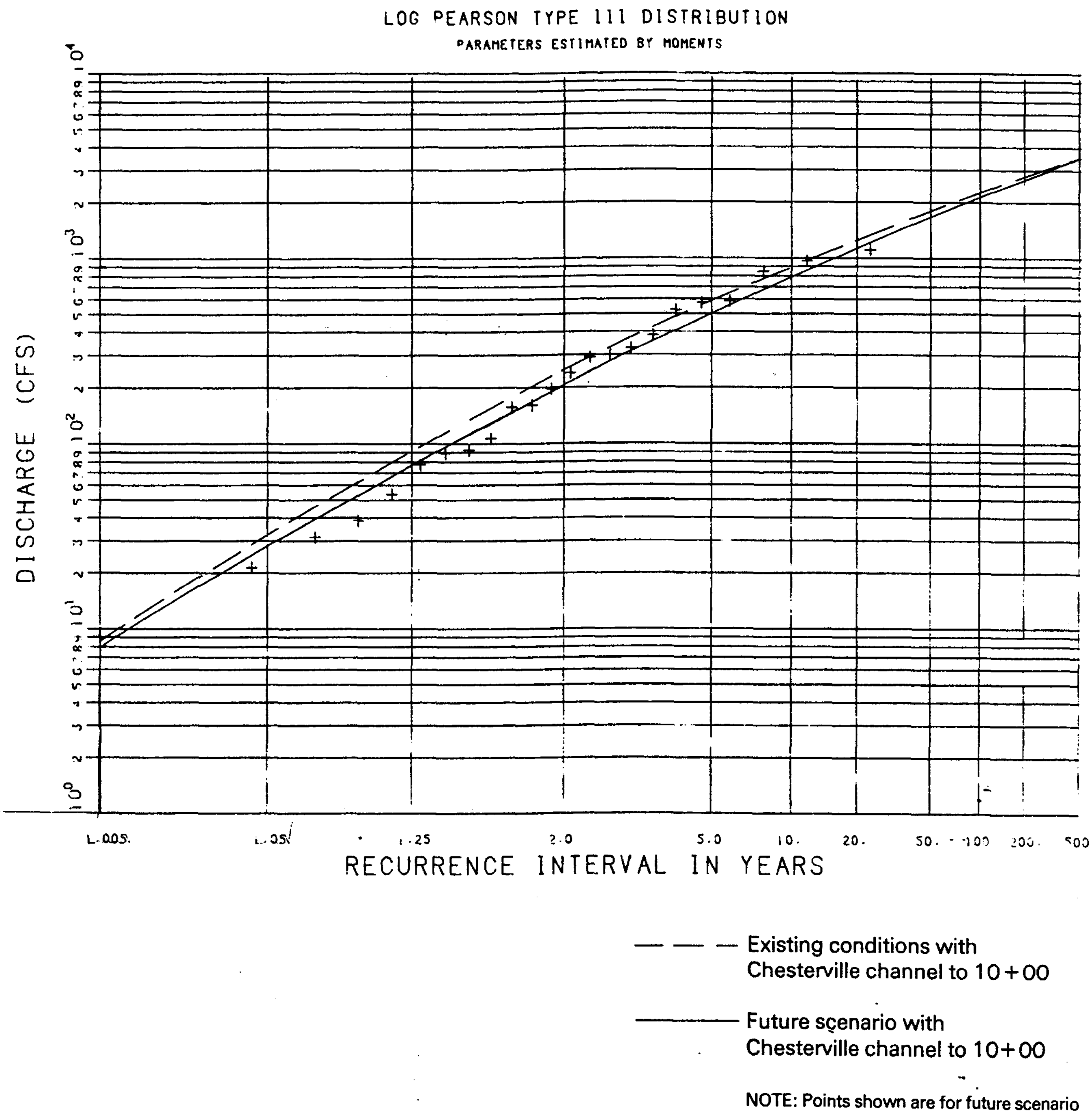


TABLE 7.9

CHANGES IN PEAK FLOWS DUE TO MAXIMUM FORESTRY SCENARIO

% CHANGE FOR RETURN PERIODS

PERIOD	LOCATION	2 YR % Change	5 YR % Change	10 YR % Change	20 YR % Change	50 YR % Change	100 YR % Change
Annual	Plantagenet	+4	+5	+4	+3	+2	+1
	Chesterville	-6	-4	-2	+1	+5	+8
	Bear Brook	-2	+2	+3	+4	+4	+4
	Vernon	+10	+11	+11	+11	+10	+9
May-October	Plantagenet	-9	-3	+3	+8	+14	+21
	Chesterville	-10	-3	+4	+11	+22	+32
	Bear Brook	-14	-5	+1	+6	+12	+16
	Vernon	-17	-15	-13	-10	-7	-5

7.5 Evaluation of Reservoir Scenarios

7.5.1 Introduction

During the preliminary screening of structural alternatives for the South Nation River Basin, the major proposed reservoirs were assessed for flood control and low flow augmentation. The performance of these reservoirs was evaluated using the HEC-5 Reservoir Operations model. From this analysis, the following preliminary ranking of reservoirs was determined together with their primary function.

- North Castor Reservoir - flood control and low flow augmentation.
- Scotch Reservoir - flood control
- Spencerville Reservoir - low flow augmentation
- Bear Brook Reservoir - flood control and low flow augmentation

Specific flow sequences were selected from historical streamflow records during the preliminary investigation for the purpose of modelling the effectiveness of the proposed reservoirs. Due to the limited number of flow gauges within the basin, the flow data was distributed to the various points of interest by using drainage area prorating techniques.

The HSP-F watershed simulation provided more representative flow sequences for the various parts of the South Nation River basin. It was therefore possible to conduct a more detailed evaluation of the reservoirs using these flows. The investigation of the reservoirs focussed on the potential flood reduction at Plantagenet.

7.5.2 Selection of High Flow Events

Flood events producing the two highest peak flows at Plantagenet Springs during the period May to October were chosen from 22 years (1958-1979) of daily flow simulations. The events selected represent two different types of runoff patterns with one occurring in May and the other in September. The high flows in May were produced by rainfall on fairly wet ground conditions whereas dry antecedent conditions preceded the September rainfall event.

The magnitude of the simulated peak flows at Plantagenet Springs for the two events selected is presented in Table 7.10, together with their associated recurrence interval. In order to assess the performance of the reservoirs under more severe flow conditions, these 23 year and the 12 year events were increased to produce the 1:100 and the 1:50 year recurrence interval floods, respectively. Each event was modified by inputting an appropriate factor derived from the flood frequency analysis into the HEC-5 model. The resultant peak flows for these events are also presented in Table 7.10.

For purposes of accurate streamflow routing within the lower portions of the South Nation River system, six-hourly flows were required for the Reservoir Operations model. The HSP-F watershed model was used to generate the six-hourly flows necessary for input, however, the numerical results obtained from the HEC-5 model were averaged into daily flows in order to be consistent with other analyses undertaken during the study.

TABLE 7.10

SELECTED FLOW EVENTS

Flow Sequence	Recurrence Interval (years)	Simulated Daily Peak Flow at Plantagenet Springs m^3/s	(cfs)
Sept 1979	1:12	326.4	(11,530)
May 1976	1:23	392.6	(13,867)
Sept 1979 (scaled-up)	1:50	509.6	(18,000)
May 1976 (scaled-up)	1:100	586.7	(20,700)

7.5.3 Method

The preliminary screening of alternatives determined that the North Castor River, Scotch River and Bear Brook reservoirs would provide a moderate reduction in flood potential within the Plantagenet area. These three reservoirs together with an additional control structure located on the South Nation River at Lemieux were considered during the subsequent detailed investigation.

A partial schematic diagram of the South Nation River system showing the data input points into the HEC-5 model is shown in Figure 7.40. The gross storages and the surface areas at maximum water surface elevation area are presented in Table 7.11.

Prior to modelling the proposed structural alternatives, the HEC-5 model was calibrated by comparing the hydrographs at various locations in the basin with those from the HSP-F model. Adjustments to the HEC-5 model routing parameters were made to obtain an acceptable agreement with the HSP-F.

The two meteorologic events were subsequently modelled under existing watershed conditions with current levels of agricultural drainage and the Chesterville channelization extended to Cass Bridge. The four reservoirs were included in the analysis to determine the reduction in flooding within the Plantagenet area.

Releases from the dams were restricted whenever possible during the high runoff period to maintain flows within the Plantagenet area below threshold damage levels. After the flood discharges into the reservoirs started to recede, the

Figure 7-40

Partial Schematic of South Nation River System

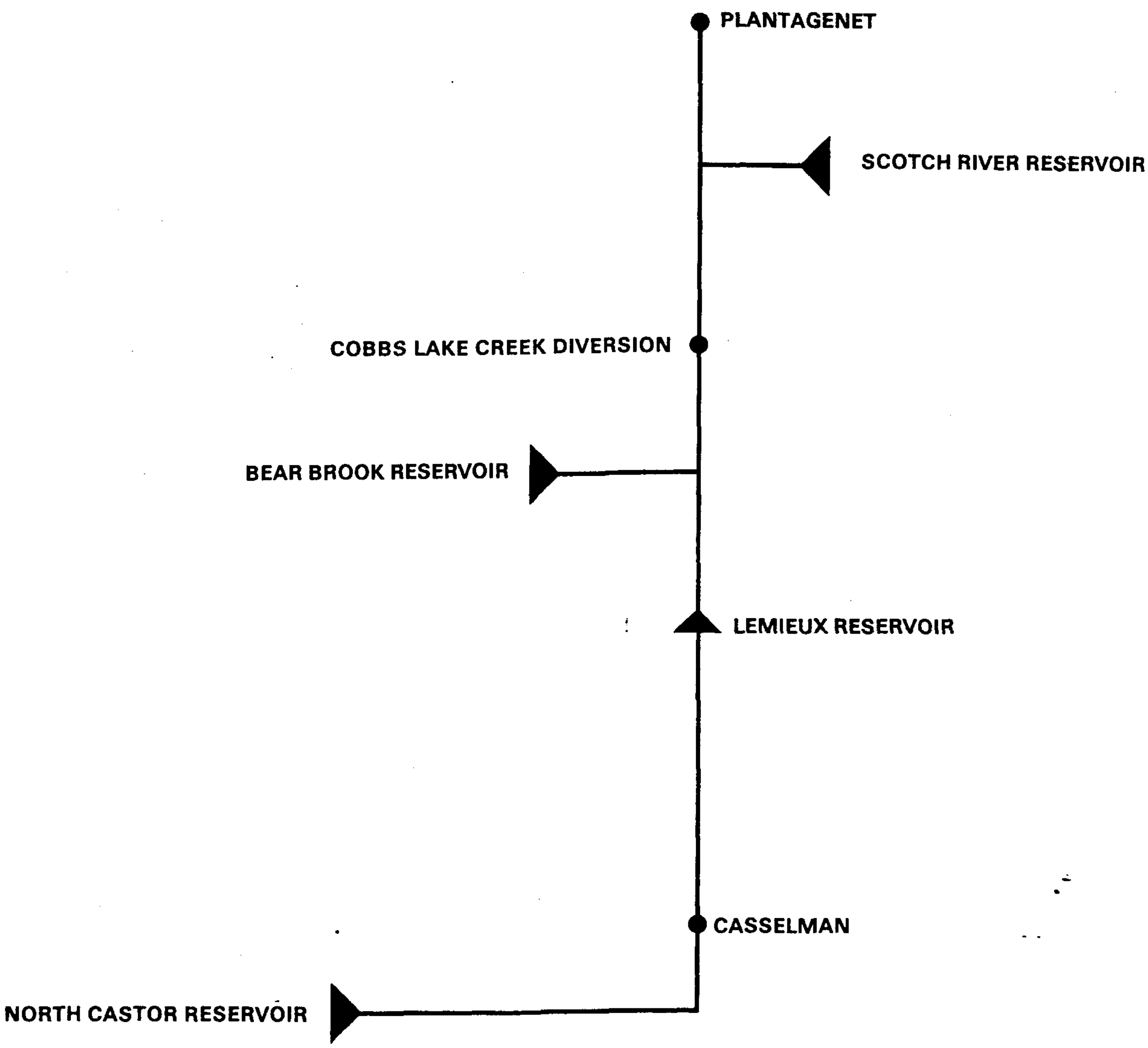


TABLE 7.11

RELEVANT DATA FOR PROPOSED RESERVOIRS

Location of Dam	Name of Reservoir	Flooded Area at Max. W.S. Elevation hectares	(acres)	Gross Reservoir Storage $10^6 m^3$	(ac-ft)
North Branch of Castor River above Russell	North Castor River	1546	(3820)	21.7	(17,600)
Scotch River at Riceville	Scotch River	2400	(5930)	48.7	(37,000)
Bear Brook near Bourget	Bear Brook	332	(820)	11.1	(9,000)
South Nation River above Lemieux	Lemieux*	462	(1140)	25.5	(20,700)
	TOTAL	4740	(11710)	$107x10^6$	(84,300)

* Estimates based on 1:50,000 scale topographic mapping.

water from storage was again released gradually at a rate not exceeding the non-damage channel capacity. For planning purposes agricultural flooding was assumed to start at Plantagenet when flows exceed 226.5 m^3/s (8000 cfs).

7.5.4 Results of Analysis

The reduction in peak flows in the Plantagenet area for the 1:12, 1:23, 1:50 and 1:100 year events due to the presence of the reservoirs is shown in Figure 7.41 and 7.43. Specific events are summarized in Figure 7.42. Although the reservoirs are able to significantly reduce the 1:12 and 1:23 year events, computations indicate that they do not have the storage capacity which is required to attenuate the 1:50 and 1:100 year floods. The computer simulations reveal that the reservoirs are at almost full storage capacity before peak inflows reach the storage sites.

Implications regarding the reduction in flooded area at Plantagenet are discussed in Section 7.6.

7.6 Analysis of Flooded Areas

Water resources planning within the South Nation River basin which attempts to mitigate flood losses must be primarily directed to the reduction of agricultural flooding. Damages to farm activities are experienced in terms of surface flooding which may result in:

- structural damage to buildings and their contents
- disruption of transportation routes thereby interferring with access and market delivery

Summary of HEC-5 Runs for May-October Events

Recurrence Interval (years)	Peak Flow on South Nation River in the Plantagenet Area (cms)		Percent Reduction in Peak Flow
	existing condition	with Castor, Lemieux, Scotch and Bear Reservoirs	
May 1976 1:23 year	392.6 cms (13867 cfs)	215.8 cms (7620 cfs)	43.0%
September 1979 1:12 year	326.4 cms (11530 cfs)	224.1 cms (7913 cfs)	31.4%
May 1976 1:100 Year	586.2 cms (20700 cfs)	480.7 cms (16977 cfs)	18.0%
September 1979 1:50 year	509.7 cms (18000 cfs)	331.8 cms (11719 cfs)	34.9%

- reduction in crop yield

Prolonged saturation of soils due to abnormal subsurface water levels may also inhibit root growth of planted crops and lower production. This may occur within the area which is inundated by surface flooding and within a larger fringe area that is not flooded but which is affected by the adjacent higher water levels.

In order to assess the magnitude of flooding within the four major floodprone areas at Chesterville, Vernon, Carlsbad Springs and Plantagenet, the average annual flooded area was calculated. The average annual flooded area represents the average area which may be expected to flood during each year over a long-term period taking into account the random occurrence of floods of various severities and the corresponding flood stage caused by the peak flood discharge.

In determining the average annual flood area for a selected stream location, flooded area-probability of occurrence relationships were derived in the standard manner by first evaluating and then combining the water elevation-probability and elevation-flooded area curves. Subsequently, the sum of flooded area resulting from all floods each weighted by its probability of occurrence in any year was obtained. Water elevation-probability curves for each stream reach were determined from water profiles estimated by a HEC-2 backwater model for various flood recurrence intervals while elevation flood area curves were also computed by the backwater model from flood plain cross-sections.

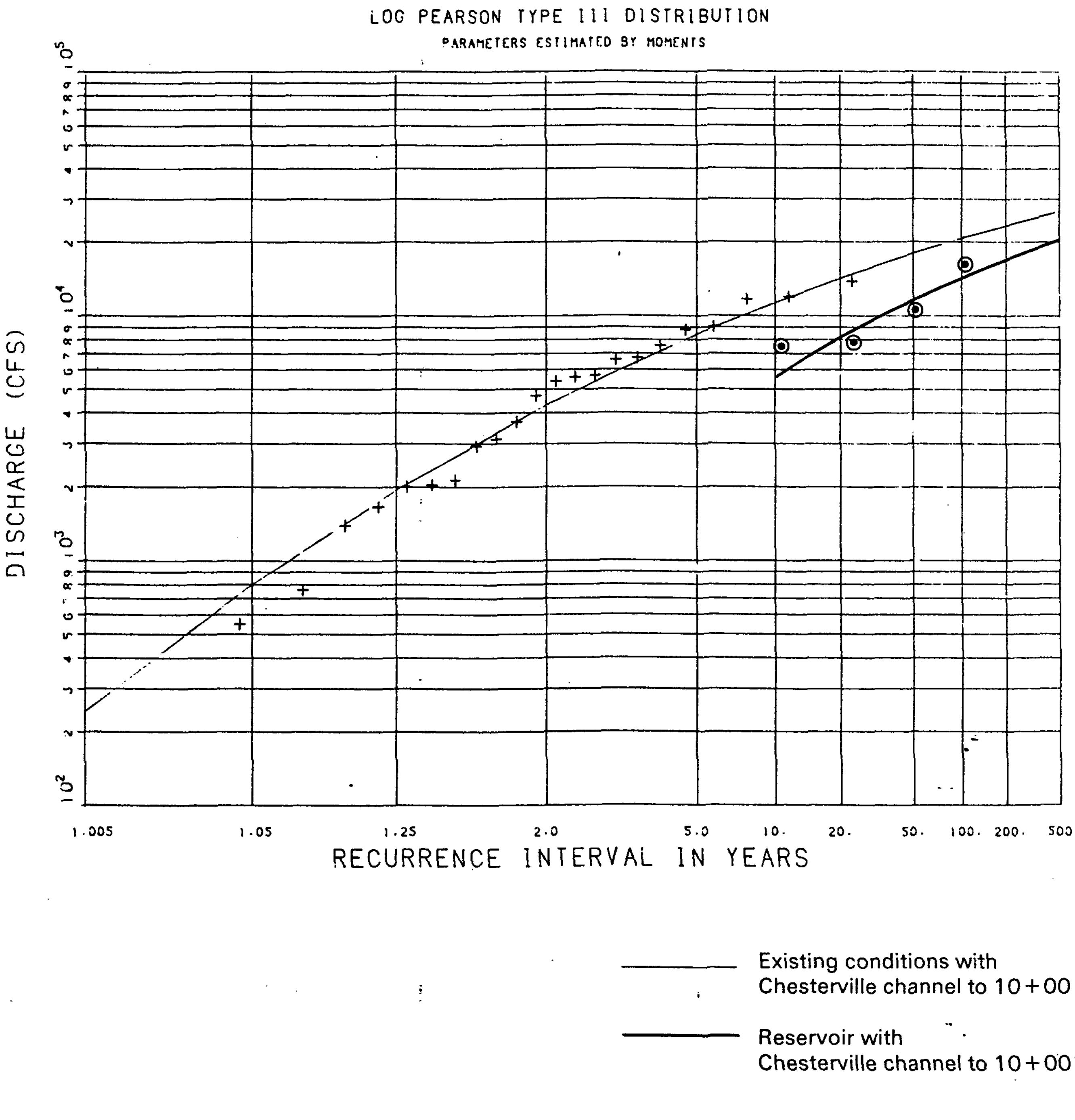
The average annual flood fringe area representing lands which are subject to subsurface saturation and loss of crop produc-

Area Flooded for May-October Events

Recurrence Interval (years)	Area Flooded in the Plantagenet Area (hectares)		Reduction in Area Flooded	
	existing	with Castor, Lemieux, Scotch & Bear Reservoirs	Hectares	Percent
May 1976 1:23 year	1547.5 ha 3600 (acres)	No Flooding	1547.5 ha (3600 acres)	100%
September 1979 1:12 year	1057.6 ha (2600 acres)	No Flooding	1052.6 ha (2600 acres)	100%
May 1976 1:100 year	3077.0 ha (7600 acres)	2307.7 ha (5700 acres)	769.3 ha (1900 acres)	25%
September 1979 1:50 year	2550.6 ha (6300 acres)	1113.4 ha (2750 acres)	1437.2 ha (3550 acres)	56.3%

Figure 7-43

Shift in May-October Frequency Curve at Plantagenet due to Reservoir Operation



tion due to water levels in adjacent streams was estimated at Chesterville in a similar manner. The actual fringe area which is affected for each water level was compiled by the Authority in conjunction with Ontario Ministry of Agricultural and Food representatives.

Two periods, the entire year or annual period and the growing season from May to October, were selected for the calculation of average annual flood fringe and flood area. Final evaluation of monetary damages will require application of unit damages to the average annual flooded area and fringe area during the preparation of the Basin Plan. Unit damage values reflecting type of crops within the flood plain and flood fringe, the depth and duration of flooding and the time of flood occurrence were under preparation by the Provincial and Federal Agricultural Ministries in parallel with this study.

Table 7.12 summarizes the average annual area flooded at the four flood prone agricultural areas for two levels of agricultural drainage within the South Nation River Basin and various channelization alternatives. The total flood area including surface flooding and fringe areas subject to subsurface saturation is presented in Table 7.13 for Chesterville. A number of conclusions can be drawn:

1) Further upstream channelization at Chesterville to Salter's Bridge will provide a net reduction in flooded area. However, the decrease in floodprone lands at Chesterville from 289 ha to 199 ha (715 ac to 491 ac) is partially offset by additional flooding at Plantagenet which increases from 285 ha to 294 ha (606 ac to 727 ac) during the growing season.

2) Improved drainage in seventy-five percent of existing agricultural lands consisting of subsurface tile and municipal drain outlets will decrease the areas flooded at the four floodprone centres.

Further investigation of the flood control potential of the four reservoirs noted in Section 7.5 indicates that the average annual flooded area at Plantagenet will be reduced from 245 ha to 78 ha (606 ac to 193 ac) during the summer period under current land use conditions. However, as indicated in Table 7.14, the total surface area flooded at the reservoirs the total reduction in area flooded at Plantagenet by a factor of two. Due to storage constraints at the reservoir sites, the structures appear to be most effective in attenuating flows which are less than the 25 year magnitude.

7.7 Water Supply

Groundwater supplies which are available to municipal and industrial water users within the South Nation River watershed have been identified in report Section 9.4. This report section outlines the demands which will be placed upon the surface water resources of the basin when groundwater supplies are inadequate.

7.7.1 Surface Water Requirements

A summary of water demands to the year 2001 is presented in Table 9.1. For planning purposes, it has been assumed that 50 percent of possible additional groundwater supplies will be developed to augment present groundwater sources. While detailed field investigations are required to confirm groundwater availability, the maximum day demand required from

TABLE 7.12

AVERAGE ANNUAL AREA FLOODED AT FOR FLOOD PRONE SITES

LOCATION	EXISTING LAND USE (ha(ac))						AGRICULTURAL DRAINAGE INCREASED TO 75 PERCENT OF EXISTING AGRICULTURAL LAND USE (ha(ac))	
	No Channelization at Four Major Flood Areas		1981 Existing Channelization at Chesterville to Station 10+000		Chesterville Channelization to Station 17+000: Van Camp, Mullen, Ferguson and Payne Drains Improved		1)Chesterville Channelization to Station 17+000 2)Vernon & Carlsbad Springs Channel for 10 yr Summer Design 3)Van Camp, Mullen, Ferguson and Payne Drains Improved	
	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual
Bear Brook at Carlsbad Springs	114 (282)	446 (1102)	114 (282)	446 (1102)	114 (282)	446 (1102)	63 (155)	370 (915)
South Castor River at Vernon	85 (209(	362 (894)	85 (209)	362 (894)	85 (209)	362 (894)	22 (55)	180 (444)
South Nation River at Chesterville	492 (1216)	2966 (7328)	289 (715)	2134 (5272)	199 (491)	1831 (4525)	157 (388)	1629 (4026)
South Nation River at Plantagenet	345 (852)	3589 (8865)	312 (771)	3698 (9134)	374 (924)	3768 (9307)	227 (561)	3402 (8403)

NOTE:
1. Flooded area considered land inundated by surface flooding
2. Summer period May to October inclusive
3. Recent alterations to Rock cut at Plantagenet have not been accounted for
4. Increased agricultural drainage includes both tile and municipal drains

TABLE 7.13

AVERAGE ANNUAL TOTAL FLOODED AREA AT CHESTERVILLE (MAY TO OCTOBER)

Stage at Salters Bridge [m (ft)] Stn 17 + 000	Corresponding Total Flooded Area ha (ac)	Frequency of Flooding (years)			Total Average Annual Flooded Area [ha (ac)]		
			Channelization to			Channelization to	
		Natural Waterway	Cass Bridge Stn 10 + 000	Salters Bridge Stn 17 + 000	Natural Waterway	Cass Bridge Stn 10 + 000	Salters Bridge Stn 17 + 000
69.2 (227)	10 500 (26 000)	1.5	2.1	6.2	2284	1469	1002
70.1 (230)	12 500 (31 000)	3.4	5.4	15.3			
71.0 (233)	14 200 (35 000)	13.3	33.0	52.5			
71.6 (235)	16 600 (41 000)	59.0	189.0	180			

NOTE: Present land use within tributary drainage area.

watercourses by communities and industrial users is based on the foregoing assumed development of groundwater resources. The projected surface water requirements are given in Table 7.15 by community together with the most likely source of water.

The permissible withdrawal of surface water for consumptive use is governed by guidelines which are administered by the Ontario Ministry of the Environment. These are basically developed to ensure that downstream riparian requirements are not unduly affected by the reduction in stream flows. Water quality considerations and assimilative capacities dictate further constraints upon water use. In assessing the quantity of which is available for supply purposes within the South Nation River basin, the following Ministry guidelines were followed:

i) Streamflows are not to be reduced below the 7 day 20 year discharge at any time.

ii) A maximum of one-third of the streamflow may be withdrawn from a watercourse.

In establishing available surface water supplies from the South Nation River and its tributaries, seven day annual low flows were computed at each community from the simulated flow record between 1958 and 1978 and a log-normal frequency distribution was fitted to the data points. Basin yields reflect current land use and drainage practices within the watershed. The simulated low flow frequency distributions were subsequently adjusted to reflect corrections which are required at Water Survey of Canada streamflows gauges to make simulated and recorded frequency curves compatible.

TABLE 7.14

COMPARISON OF SURFACE AREA FLOODED BY ADDITIONAL RESERVOIRS AND REDUCTION IN FLOODED AREA AT PLANTAGENET

Recurrence Interval (years)	Total Surface Area Flooded by North Castor, Scotch, Bear Brook and Lemieux Reservoirs		Total Reduction in Area Flooded in the Plantagenet Area with the Reservoirs in Operation	
	hectares	(acres)	hectares	(acres)
1:12	1651.1	(4078)	1052.7	(2600)
1:23	2267.3	(5600)	1456.6	(3600)
1:50	2678.3	(6615)	1437.3	(3550)
1:100	3769.4	(9310)	769.3	(1900)

TABLE 7.15

COMMUNITY SURFACE WATER DEMANDS AND FIRM SUPPLY

Community	Required Surface Water Supply 1/s (cfs) 1981	Required Surface Water Supply 1/s (cfs) 2001	Watercourse	Average Frequency of Failure to Meet Demand (Years) 1981	Average Frequency of Failure to Meet Demand (Years) 2001
Winchester	14.7 (0.52)	20.7 (0.73)	South Nation River	2.0	1.7
Chesterville(1)	3.1 (0.11)	6.8 (0.24)	South Nation River	6.7	3.3
Casselman		26.1 (0.92)	South Nation River		
Bourget	4.8 (0.17)	9.9 (0.35)	Bear Brook	15.6	11.8
St. Isidore	4.2 (0.15)	5.7 (0.20)	Scotch River	1.7	1.2
Hammond	4.8 (0.17)	7.4 (0.26)	Bear Brook	15.6	13.3
St. Pascal	2.5 (0.09)	5.4 (0.19)			

(1) Industrial demand by Nestle is not included in consumptive demand since not available.

Adjusted low flow curves are presented in Figures 5.43 to 5.48.

Ministry withdrawal guidelines, surface water supplies required by the communities and low flow frequency curves at the point of proposed water removal provide an estimate of the reliability of the supply as given in Table 7.15. The surface water supply at Winchester has been obtained from the South Nation River at Chesterville which represents the nearest watercourse with a significant firm yield. In evaluating the reliability of surface water supplies to meet minicipal and industrial demands, each withdrawal has been considered separately. The reduction in available water at downstream communities due to upstream requirements has not been taken into account in the analysis.

From Table 7.15, it is apparent that water supplies for the communities of Winchester, Chesterville, St. Isidore and St. Pascal are most susceptible to shortages due to inadequate groundwater and surface water sources. The latter community is considered too remote from a watercourse with adequate summer flows to make surface supplies a viable alternative. The existing stream impoundment at Chesterville with a storage capacity of 345 Ml (280 ac-ft) has sufficient capacity to supply the requirements of Chesterville and Winchester, with shortfalls anticipated less than once every twenty years. However, consumptive demands imposed by Nestle may alter this conclusion. At St. Isidore additional water supplies must be provided by a surface water impoundment on the Scotch River or individual domestic wells in the northern part of the village.