Environment Canada
Inland Waters Directorate
supported by the
Federal Panel on Energy R & D (PERD)

Streamflow Analysis Methodology for Ungauged Small-Scale Hydro Sites in Ontario

Study Documentation Report

March 1988

ACRES Acres International Limited

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GLOSSARY OF TERMS

Average Energy - The annual total energy which can be produced on average.

Design Discharge - The maximum discharge capacity of the units at a rated head.

Firm Energy - The energy which can be guaranteed to be reliable at a specified risk of failure. The risk used is dependent on the specific application.

Rated Head - The head at which turbine full gate output equals the rated generator input.

Secondary Energy - The energy which can be generated in excess of firm energy.

Turbinable Discharge (Flow) - The average discharge over the period of flow record which could be passed through the turbines for electricity generation.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Meaning
Physiographic Parameters	
A	drainage basin area (km^2)
ACLS	percent of drainage basin area controlled by lakes and swamps (%)
AG	drainage basin area above gauged location (km^2)
AI	drainage basin area of index gauge (km^2)
BFI	base flow index (dimensionless)
LAT	latitude (decimal degrees)
LEN	stream length (km)
LONG	longitude (decimal degrees)
MAP	mean annual precipitation (mm)
MAR	mean annual runoff at basin centroid (mm)
MARG	mean annual runoff at basin centroid of a gauged basin (mm)
MARI	mean annual runoff at basin centroid of index gauge (mm)
MAS	mean annual snowfall (cm)
SHP	shape factor (dimensionless)
SLP	slope of channel (%)
Discharge Parameter	
Q	discharge (m^3/s)
Q_D	design discharge/mean annual discharge
Q_d	design discharge (m^3/s)
Q_2	flood which will occur, on average, every 2 years

Symbol	Meaning
q_{10}	average daily flow exceeded 10% of the time
$\bar{Q}$	mean annual discharge (m^3/s)
QG	gauge discharge (m^3/s)
QI	index gauge discharge (m^3/s)
Q_T	turbinable discharge/mean annual discharge
Q_t	turbinable discharge (m^3/s)
i, j, k	subscript for year, month and day, respectively

Miscellaneous

C	large value of Q_D where $Q_T = 1$
MW	plant capacity in megawatts
$Z, \emptyset, \theta, \alpha, \beta, \gamma, \kappa$	parameters in 5-degree polynomial turbinable flow curve
CV	coefficient of variation of a variable (expressed as percent of the mean value of the variable)
σ	standard deviation of a variable
$\int$	integral sign

1 - SUMMARY

1 - SUMMARY

The study 'Streamflow Analysis Methodology for Ungauged Small-Scale Hydro Sites in Ontario' was commissioned by the Department of Supply and Services of the Government of Canada in November 1987. The primary direction for the study has resulted from the objectives of the Federal Panel on Energy Research and Development (PERD).

1.1 - Objectives

Based on the Terms of Reference, the objectives of this study have been established as follows.

(a) Develop hydrologic design methodologies for project definition and feasibility level studies in the Province of Ontario. In this report, feasibility level analysis is taken to mean a level sufficiently accurate to commit funding and to implement a project. In particular, emphasis has been given to

- synthetic hydrologic record development for totally ungauged catchments

- adaptation of the techniques to make best use of any available flow data at a site

- development of computer models to incorporate the hydrologic flow methodologies and to determine the statistics of power and energy yield (i.e., firm and average yield, etc) at a site.

(b) Document the methods in a manual which will be easily used by engineers without specialist training.

1.2 - Approach

The general approach to developing regional relationships for the hydrologic parameters of interest has been an innovative application of traditional regional hydrologic methods. Extensive use was made of the computer for data processing and evaluation.

As a first step, recent literature was reviewed to take advantage of present thinking in the field.

The Province of Ontario was divided into 6 primary homogeneous hydrologic regions based on physiographic and climatic characteristics. In each of these selected homogeneous regions, hydrometric gauges were selected to be used for development of appropriate regionalized correlation equations for streamflow hydrology. Gauge selection was based on the length and quality of record, size of drainage basin, degree of regulation, and acceptable accuracy/reliability. Three independent stations were used to test the methodologies.

For the regional analyses, two methods of synthesizing a hydrologic record for ungauged sites were analyzed. These are outlined below.

(a) Proration by Drainage Area and Mean Annual Runoff

This is a commonly used technique whereby key hydrologic characteristics are prorated on the basis of drainage area and mean annual runoff (MAR).

(b) Flow Duration Curve

Nondimensional flow duration curves were prepared from the daily records of each gauge. Nondimensional turbinable flow curves[1] were determined as the integral of the flow duration curves. A polynomial equation was fit to each of the turbinable flow curves. The polynomial fit of the turbinable flow curve for each gauge produced three coefficients. These coefficients were then regressed on physiographic characteristics to establish general regionwide relationships. In some cases, the coefficients were consistent enough from gauge to gauge to use an average regional coefficient.

These regression equations can be used to estimate a turbinable flow curve and, hence, a flow duration curve for ungauged sites in the selected regions.

A representative index streamflow gauge, with a long record length, was selected in each region. By assuming that the probability of exceedance of daily flows at the index gauge and at the ungauged site are equivalent, it is possible to synthesize a record at the ungauged site using the respective flow duration curves (actual at the index gauge and estimated at the ungauged site).

1.3 - Results

The general approach outlined above is followed with a summary of results as presented below.

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[1]A turbinable flow curve is derived by sequentially integrating a flow duration curve up to various maximum discharges. The turbinable flow reflects the average continuous flow or flow volume which can be used for energy generation subject to a peak operating flow.

Separate sets of homogeneous regions were defined for the two regional methodologies examined. Six homogeneous regions were chosen for the flow duration methodology while 14 homogeneous regions were delineated for the proration methodology. The homogeneous regions defined for the flow duration and proration methodologies correspond quite closely to previously defined homogeneous regions defined for floods, using the multiple regression (Moin and Shaw, 1986) and index (Moin and Shaw, 1985) approaches respectively. Index gauges, assumed to be hydrologically representative of homogeneous regions, were selected for each homogeneous region.

Acceptable regression equations for predicting the coefficients of the flow duration curves at ungauged sites were found in northwestern Ontario (Region B)[1], southern Canadian Shield (Region E) and southern Ontario (Region F). The appropriateness of the equations considered both statistical significance and physical criteria. Standard errors of the regression equations varied between 5 to 13% of the mean values while the coefficient of determination (R^2) ranged from 0.66 to 0.91. These regression results were found to be somewhat better than relationships established in similar previous regional studies (Acres, 1985, 1986).

In the other regions identified, Hudson Bay lowlands (Region A), east-central Canadian Shield (Region C) and west-central Canadian Shield (Region D) suitable regression equations were not found and the proration method is recommended.

Potential error from application of the methodology was analyzed in a number of ways.

- The overall error was assessed by comparing estimated and actual turbinable flow for various design flows and storages at all gauges used in the analysis. The errors arising from the flow duration curve

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[1]A definition of region boundaries is presented on the map of Plate 1.

methodology were found to be smaller (in terms of a lower average, maximum and standard deviation) than those of the proration (to an index gauge) methodology. Predicted flow duration curves were found to give the best results at gauges subject to large degrees of natural regulation in the basin. Basins characterized by steep flow duration curves resulted in the largest errors. Detailed comparisons of the error at each streamflow gauge used in the analysis are presented in the report.

- Three test gauges were used for an unbiased examination of potential error in estimating turbinable flows. These results confirmed the conclusions stated above.

- The sensitivity of the estimate of turbinable flows to errors in the measurement of the independent variables in the regression equations was examined. For typical measurement errors of 5 to 10%, results were relatively insensitive. The most significant error occurred where errors in measuring drainage area and MAR of 10% resulted in differences in the turbinable flow estimate of less than 6%.

Finally, it should be noted that the results of the study have been incorporated into an 'Applications Manual' which has been produced in a separate volume. User-oriented microcomputer programs were developed and can be obtained from Environment Canada, Inland Waters Directorate (IWD).

1.4 - Recommendations

Based on the analysis of the study results, the following is recommended.

- If a gauge exists nearby in the same or adjacent basin with similar physiographic characteristics and having an acceptable record length, it is usually best to derive the daily hydrology by proration to the nearby gauge. Otherwise, at ungauged sites with no suitable nearby gauges, the flow duration curve methodology using the regression approach is preferable in Regions B, E and F while the proration to an index gauge method should be used in Regions A, C and D.

- The regression equations were developed from a specific range of independent variables in each region. Hence, the relationships in the flow duration curve methodology should be used with considerable caution if the independent variables of the regression equations are near the limits of or outside the ranges noted in Section 5 of this report.

- This study relied on physiographic and climatic data available from other sources. These data have been adequate, and the relationships developed are satisfactory and comparable to similar work in other parts of Canada. In time, however, it would be worthwhile extracting other physiographic characteristics which may be more representative of factors affecting low and average hydrology. The most important of these are on-channel and off-channel storage expressed as an area of lakes. This is particularly important in central and northern Ontario. If additional physiographic/climatic data are extracted, it is possible that regional regression relationships for dependent variables C, θ and α would be improved. Therefore, the regional equations for these variables should be reevaluated using the updated data base.

- Finally, this and similar studies in other parts of Canada have provided useful tools in estimating the benefit potential of ungauged small-scale hydro plants. Therefore, it is recommended that further regional small hydro benefit studies be conducted in remaining areas of Canada which exhibit significant small hydro potential.

2 - INTRODUCTION

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2.1 - Background

Hydroelectric energy generation is widely accepted as the most practical and viable renewable resource mainly due to its mature technology. Hydrologic variables, such as available flow for electricity generation and its time distribution, and flood magnitudes, represent the major basic variables for evaluation of potential hydro sites.

Economic viability, especially for small-scale hydro sites, is very sensitive to these basic hydrologic variables. Unfortunately, most small-scale hydro sites are located on small ungauged streams. Estimating flow records of ungauged sites for benefit evaluation often poses technical difficulties which in the past could not be resolved without in-depth, site-specific, hydrologic study. Most small-scale hydro developments cannot afford such an in-depth study. This project is therefore intended to develop step-by-step design methodologies for determination of hydrologic variables at ungauged small-scale hydro sites in Ontario. This work has been based on significant research and uses experience from many sites. The results are applicable to sites in Ontario using only readily available data.

2.2 - Presentation

The study results are presented in the following volumes.

(a) The 'Study Documentation Report' is the main report which documents the results of the overall study and presents detailed approaches and techniques used in developing the design methodologies. In this report, results of a literature review are discussed in Section 3. Section 4 describes the selection of the streamflow gauges. Sections 5 and 6 document the methodologies used to determine the streamflow hydrology in each region. Section 7 presents the computer models, and Section 8 presents sample applications for three test stations.

(b) The 'Applications Manual' is a separate volume for user application of the developed methodologies. This volume is intended to be a stand-alone document which provides sufficient background information to enable users to use the techniques. Full details of the reasons for using particular techniques are not presented in the 'Applications Manual', but rather are given only in the 'Study Documentation Report'.

The developed methodologies are also incorporated into a set of computer models. The computer models are written in FORTRAN and incorporate all of the techniques for synthesizing a hydrologic record, estimating the flood flows (based on 'Regional Flood Frequency Analysis for Ontario Streams', 1985-86, by S. M. Moin and M. A. Shaw) and estimating the power and energy statistics for ungauged sites.

2.3 - Acknowledgments

This study was funded by the Federal Panel on Energy R&D (PERD). The project team was assisted throughout the course of the study with expert advice and review by Mr. S. Moin, Mr. E. Park, Mr. A. Perks, Mr. M. Shaw, Mr. D. Smith and Mr. R. Kallio of the IWD of Environment Canada, and Mr. T. Tung of Energy, Mines and Resources Canada. Mr. E. Park was the Scientific Authority for the project and his assistance is appreciated.

The options, suggestions and comments of the numerous people involved with these organizations is gratefully acknowledged.

Streamflow data were provided by Water Survey of Canada (WSC). Mr. H. Goertz and Mr. G. Hansen evaluated the initial list of selected hydrometric gauges and provided guidance with respect to gauge reliability and accuracy. This valuable contribution is appreciated.

3 - LITERATURE REVIEW

3 - LITERATURE REVIEW

A review of recent publications and reports was undertaken for the following categories of information

- previous Ontario regional hydrologic studies
- inventory reports for hydro in Ontario
- generally applicable hydrologic methodologies for average hydrology at ungauged sites
- other hydrology-related studies.

References of particular significance to this study are discussed below for each category of information.

3.1 - Previous Ontario Regional Hydrologic Studies

Several relevant regional studies for the Province of Ontario have been completed in recent years. Table 3.1 lists the appropriate references and provides relevant information on the content of each.

Most of these regional studies have been for the purpose of estimating floods using either the index or multiple regression methods. These studies provide useful information concerning the data base, descriptions of the physiography and climatology of various regions, descriptions of the physiographic and climatic parameters considered, the parameters which have been significant in previous regional regression relationships and the quality of the regression relationships. In addition, one of the studies developed regional relationships for the coefficient of skew at an ungauged site.

In total, these reports have provided an excellent foundation for the work of this study; both from the viewpoint of the data base of information and also as guidance to the methods of analysis.

TABLE 3.1

SUMMARY OF APPLICABLE ONTARIO REGIONAL HYDROLOGIC STUDIES

Reference	Relevance to this Study
'Regional Flood Frequency Analysis for Ontario Streams, Volume 2, Multiple Regression Method' by S. M. Moin and M. A. Shaw of Environment Canada and the Ontario Ministry of Natural Resources as part of the Canada/Ontario Flood Damage Reduction Program, 1986.	- Delineation of 3 homogeneous regions based on residual analysis of floods - Description of physiographic and climatological data - Physiographic and climatological data base for regional regression approach - Recommended regression equations for Q2-, Q5-, Q10-, Q20-, Q50- and Q100-yr instantaneous peak floods in the Province of Ontario
'Regional Flood Frequency Analysis for Ontario Streams, Volume 1, Single Station Analysis and Index Method' by S. M. Moin and M. A. Shaw of Environment Canada and the Ontario Ministry of Natural Resources as part of the Canada/Ontario Flood Damage Reduction Program, 1985.	- Delineation of 12 homogeneous regions based on index method of floods - Regional description of physiography and climatology - 1.25- to 500-yr regional instantaneous peak flood estimates using index approach - Regional Q2 instantaneous peak flood estimate based only on drainage area
'Comparison of Regional Flood Frequency Methods in Southern Ontario Using Analysis of Variance Techniques' by R. Condie, P. J. Pilon, K. D. Harvey, and H. Goertz for presentation at the International Symposium on Flood Frequency and Risk Analysis, 1985.	- Comparative study of regionalization methods but not a regional flood frequency study - Delineation of 3 homogeneous regions in southern Ontario based on regression approach but compatible with index approach
'Working Paper A - Regional Flood Frequency Study (Province of Ontario)' for the Conservation Authorities and Water Management Branch of the Ontario Ministry of Natural Resources, by Cumming-Cockburn & Associates Limited, May 1985.	- Delineation of 4 homogeneous regions based on residual analysis of floods - Description of physiographic and, particularly, hydrometric data
'Snow Hydrology Study - Phase III - Snowmelt and Regional Flood Frequency Analysis' for the Conservation Authorities and Water Management Branch of the Ontario Ministry of Natural Resources, by Cumming-Cockburn & Associates Limited, March 1985.	- Delineation of 2 homogeneous regions based on index method of floods - Regionalization, particularly regression parameters and the quality of equations

Table 3.1

Summary of Applicable Ontario Regional Hydrologic Studies - 2

Reference	Relevance to this Study
'Northern Ontario Hydrology Study, Phase I - Inventory and Assessment of Data' for the Conservation Authorities and Water Management Branch of the Ontario Ministry of Natural Resources, by Cumming-Cockburn & Associates Limited, August 1983.	- Description of climatological data - Discussion on effects of reservoirs
'Statistical Hydrology, Regionalization of the Coefficient of Skew for the Province of Ontario' for the Conservation Authorities and Water Management Branch of the Ontario Ministry of Natural Resources, by MacLaren Engineers, Planners and Scientists Inc., October 1981.	- Delineation of 2 homogeneous regions - Regression parameters and the quality of regression equations for skew - Recommended regional approach for estimating skew
'Magnitude and Frequency of Floods in Southern Ontario', by B. P. Sangal and R. W. Kallio, 1977.	- Delineation of 9 homogeneous regions - Regional description of physiography and climatology

3.2 - Inventory Reports for Hydro in Ontario

Several inventory and reconnaissance level reports have been completed recently in the Province of Ontario. These studies have been done principally by Ontario Hydro and/or the Ontario Ministry of Natural Resources (MNR). The most relevant of these is 'Ontario's Water Power Sites' published in 1985 by the MNR which identifies existing and potential, small and large hydroelectric generation capability across Ontario. A map of undeveloped hydroelectric capacity in the province, presented as Figure 3.1, illustrates that there is still significant potential for small-scale hydro development, particularly in central and northern Ontario.

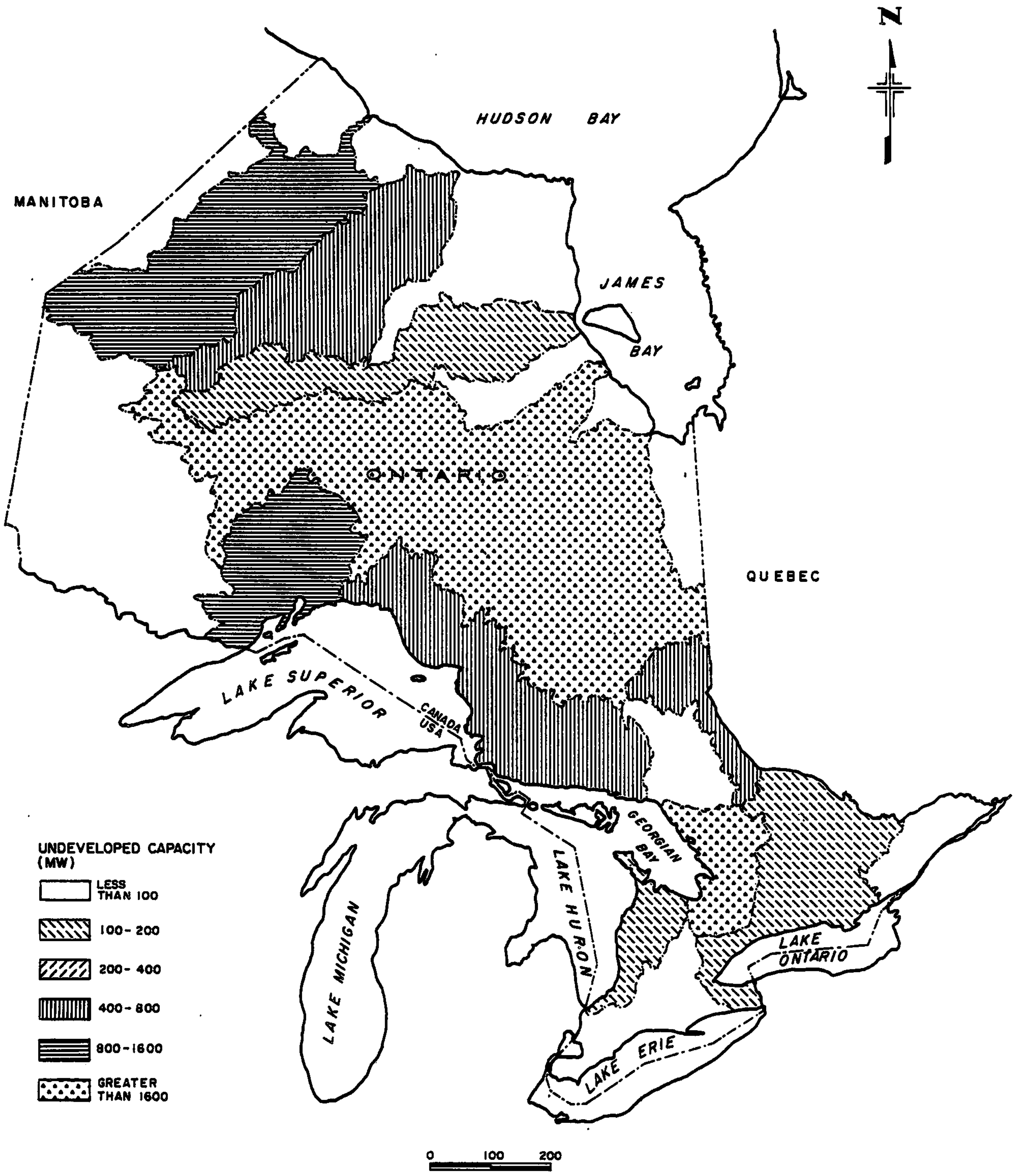
This information was useful in providing representative hydro characteristics at the three ungauged sites used to test the methodologies.

3.3 - Regional Design Flow Methodologies

Evaluation of the economic viability of a hydropower resource requires realistic estimates of the energy yield that can be expected from a proposed project. The most satisfactory procedure for evaluating the generating potential of a site is to simulate the plant operation subject to reservoir operating rules and a suitable 'reference' hydrology. (Reference hydrology is defined herein as a series of historical or synthetic discharge records, at a site, of sufficient length to reflect typical hydrologic variability.)

The reference hydrology can be generated from available streamflow and/or climatic records in the project catchment.

Often hydrologic records are inadequate or nonexistent, especially in the case of small-scale hydro where basins are small. In these circumstances, time series modeling for either data generation or forecasting



TAKEN FROM WATER QUANTITY RESOURCES OF ONTARIO
MINISTRY OF NATURAL RESOURCES (1984)

FIG. 3.1

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

UNDEVELOPED HYDROELECTRICITY IN THE PROVINCE OF ONTARIO

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of hydrologic variables is an important step in the planning and operational analysis of water resource systems.

In general, there are two approaches to create reference hydrologies at ungauged catchments

- physically based computer models
- stochastic techniques.

Both approaches have advantages and disadvantages as discussed below.

3.3.1 - Physically Based Computer Models

Physiographic and climatic data are input directly to physically based continuous simulation models [Hydrologic Simulation Program Fortran (HSPF), Streamflow Synthesis and Reservoir Regulation (SSARR), etc] in this approach. Therefore, the generated time series is dependent on the quality of the climatic and physiographic data over the reference period.

This approach is preferred by some since it describes the physical response of a particular basin to a stochastic input (precipitation). However, the difficulty of estimating a stochastic component is not eliminated but is merely shifted from regionalizing streamflow to regionalizing precipitation. As a result, this approach has the additional error involved in modeling the physics of the runoff process. The approach is preferable only where extensive precipitation and relatively little streamflow data are available or where actual historical or real-time simulation is required. This is not the case in this study.

3.3.2 - Stochastic Techniques

Stochastic processes are sequences characterized by statistical properties. A stochastic process is the mathematical expression of an empirical process governed by probability laws. Nearly all hydrologic processes can be characterized as stochastic processes.

Stochastic techniques previously applied in 'Hydrologic Design Methodologies for Small-Scale Hydro at Ungauged Sites', Phases I or II, include

- regionalized turbinable flow and flow duration curves
- regionalized autoregressive moving average (ARMA) models
- proration by MAR and drainage area.

In previous studies, detailed computer searches were conducted for literature related to stochastic models. A large number of useful references were obtained concerning the generation of synthetic discharge series using stochastic Box-Jenkins autoregressive (AR), moving average (MA) or ARMA models. A summary of these various models is provided in the Hydrologic Design Methodologic Report for the Atlantic region by Acres International Limited (Acres) in 1985. In addition, Acres applied regionalized ARMA models in Atlantic Canada but with limited success. A similar regionalization was done using ARMA models by the IWD Pacific Region Water Resources Branch for British Columbia. This work was also not particularly successful (Leith, 1985). Based on the results of these two previous studies, the stochastic ARMA was not evaluated in this study.

Regional Flow Duration Curve Methodologies

There has been a limited study of this approach. Lane and Lei (1950) presented a methodology for predicting a flow duration curve for an ungauged catchment using a variability index. This variability index is the standard deviation of the logs of the flows obtained by plotting the flow duration curve on lognormal probability paper. However, a lognormal presentation of a flow duration curve has several weaknesses, primarily because the flow duration curve is not usually a straight line on logarithmic probability coordinates. The extreme ends of the curve (the areas of greatest interest) are poorly estimated using this representation.

Acres (1984) developed techniques for predicting flow duration curves at ungauged sites in 'Hydrologic Design Methodologies for Small-Scale Hydro at Ungauged Sites - Phase I'. Results of the Phase I study were intended only for use at reconnaissance or prefeasibility levels; therefore, these flow duration curves were not used to generate a time series.

Since a time series sequence and variability are required at a feasibility level of study, Acres (1985) derived a technique which combines a predicted flow duration curve at an ungauged site with a known flow duration curve and time series at an index station. The results proved to be quite favorable. A similar methodology was described by Searcy (1959) in a discussion of long-term flow duration curves from short-term records. The ability of this approach to model stochastic time series depends primarily on the accuracy of the estimated flow duration curve at an ungauged site and the availability of a representative index station.

Proration on Mean Annual Runoff and Drainage Area

The proration method is a direct adjustment of the record at a representative index gauge using a constant factor. In this study, mean annual runoff (MAR) and drainage area are used as the proration factor. The method assumes that the stochastic behavior at the ungauged site is identical to that at the nearest index gauge location.

With this methodology, no adjustment is possible for such factors as variation in spatial, physiographic or climatological characteristics of the ungauged site. Due to its inherent simplicity, information concerning the applicability of this methodology was not found in the literature. Acres, however, has had a great deal of experience with deriving hydrology at ungauged sites using this method, and has found that it can provide an adequate reference hydrology for power and energy simulations in cases where homogeneous regions are well defined.

3.4 - Other Hydrology-Related Studies

The document entitled 'User's Guide, Regional Flood Frequency Analysis for the Island of Newfoundland' by U. S. Panu, D. A. Smith and D. C. Ambler, conducted jointly by the Department of Environment, Province of Newfoundland, and the IWD, Environment Canada, 1986, provided a useful guideline as to the content of the Applications Manual of this study.

Low flow research reports, completed by the Institute of Hydrology in Wallingford, England (1980), review methods of low flow evaluation and flow duration curves. This report indicates the importance of a base flow index (BFI) parameter in deriving regional relationships for low flow studies.

4 - DATA BASE

4 - DATA BASE

Power and energy evaluations at an ungauged site require the derivation of a reference hydrology representative of the discharge variability at that site. In this study, a reference hydrology is derived using either the proration or regional flow duration curve methodology. Both of these techniques require actual discharge time series as input. The regional flow duration curve methodology also requires physiographic and climatic data for establishing regional regression relationships of mathematical parameters which describe flow duration curves.

4.1 - Discharge Data Base

Our experience indicates that a suitable reference hydrology for small-scale power and energy benefit evaluation must be based on average daily discharge data. Average monthly data have been frequently shown to provide an inadequate representation of the daily variability recorded at a gauge. Of greatest interest for small hydro planning are the low flows which become averaged out using the monthly data.

Therefore, daily mean discharge data were used to calculate flow duration curves at known gauges and for generating synthetic time series at ungauged sites.

Daily mean discharge data for stream gauge stations in Ontario were obtained on magnetic computer tape from WSC. In each case, the period of record was complete to December 1986.

Selection of the gauges to be analyzed in this study was based on the work of Moin and Shaw (1986).

Using this list as a starting point, the selection of the streamflow gauges for this study was based on the following additional criteria.

4.1.1 - Mean Annual Discharge Range

For the purposes of this study, small-scale hydro is defined as capacity ranging from 0.3 to 20 MW. Based on an assumed net head range of 2.5 to 20 m and an overall plant efficiency of 85%, this corresponds to an acceptable average annual flow range between 2 and 1000 m^3/s.

4.1.2 - Period of Record

Short records are often biased by sustained wet or dry periods of hydrology. Therefore, record lengths as long as possible are desirable to minimize bias in the mean annual flow, particularly where periodicities are significant. Record lengths less than 9 years were not considered acceptable. The periods of record used in the analyses do not necessarily correspond to the available record for each gauge. Years with partial records of daily data were not included--to avoid biasing the discharge time series.

4.1.3 - Degree of Regulation

Only natural records or gauges affected by minor regulation were used in the study.

Reservoir storage impounded behind man-made dams can have a significant effect on a daily discharge record, particularly during low flow periods when reservoir storage is often used to supplement the base flow. Some analyses were undertaken (Moin and Shaw, 1985) to determine which of the candidate streamflow gauges are significantly affected by man-made regulation. In general, the regulation effect at a downstream gauge is a function of

- dam operation
- reservoir storage capacity
- contributing basin area above the gauge
- contributing basin area above the dam.

Moin and Shaw (1985) calculated a quantitative regulation factor for each gauge using the following equation.

$$RF = \sum_{i=1}^{n} \frac{AC_i * AR_i}{AG^2}$$

where

RF = regulation factor
AC_i = drainage basin area controlled by dam i
AR_i = surface area of reservoir behind dam i
AG = drainage area at gauge
n = number of dams in basin.

The gauges were designated as

- R1 - (≤ 0.03) negligible impact
- R2 - (0.03 to 0.10) moderate impact
- R3 - (>0.10) significant impact.

The regulation factor expressed as a percent is analogous to percent regulation calculated as the percent of live storage to the MAR at the gauge (Cumming-Cockburn, 1985; Acres, 1987; MacLaren, 1980). From experience in those studies, the effects of reservoir regulation on flood flows was considered insignificant if the total live reservoir storage was less than 10% of the MAR at the gauge. The same criteria are judged to be appropriate for the daily flow records used in this study.

R1 and R2 gauges were considered to have insignificant regulation effects and were used with the natural records. If an R3 gauge had a natural record for an acceptable period either prior to or following the regulated period, it was also used in the analysis.

4.1.4 - Accuracy/Reliability

The Ontario and Winnipeg regions of the Water Resources Branch of WSC made an assessment of the general accuracy and reliability of the candidate stations over the period of record.

All gauges were classified by quality of record, as above average, average, below average or discontinued, based on experience and judgment of the staff involved in the data collection program. Only gauges categorized as above average and average were considered acceptable.

The final 120 selected streamflow gauges are listed in alphanumeric order in Table 4.1. Included in the list are the station description, drainage area, period of record and type of record provided.

4.2 - Physiographic/Climatic Data Base

These data were required for establishing regional regression relationships of mathematical parameters which describe flow duration curves.

The data for this study were obtained directly on a microcomputer floppy diskette from Environment Canada. It consisted of physiographic

TABLE 4.1

SELECTED STREAMFLOW GAUGES

Station Number	Station Name	Drainage Area (km²)	Period of Record Used Begins	Period of Record Used Ends	Type of Record	Region[1] Number
02BA002	Steel River near Terrace Bay	1 190	1970	1986	Nat	C
02BA003	Little Pic River near Coldwell	1 320	1973	1986	Nat	C
02BB002	Black River near Marathon	1 980	1968	1986	Nat	C
02BB003	Pic River near Marathon	4 270	1971	1986	Nat	C
02BF001	Batchawana River near Batchawana	1 190	1968	1986	Nat	C
02BF002	Goulais River near Searchmont	1 160	1968	1986	Nat	C
02CE002	Aux Sables River at Massey	1 350	1921	1986	Reg	E
02CF007	Whitson River at Chelmsford	272	1961	1986	Nat	E
02EA005	North Magnetawan River near Burk's Falls	321	1916	1986	Nat	E
02EA008	Magnetawan River at Maple Island	1 850	1946	1956	Reg	E
02EA010	North Magnetawan River Above Pickerel Lake	149	1969	1986	Nat	E
02EC002	Black River near Washago	1 449	1916	1986	Nat	E
02EC011	Beaverton River near Beaverton	282	1967	1986	Nat	F8
02EC012	Black River at Sutton	324	1970	1982	Reg	F8
02ED003	Nottawasaga River near Baxter	1 180	1950	1986	Nat	F2
02ED005	Mad River near Glencairn	295	1964	1986	Reg	F2
02ED007	Coldwater River at Coldwater	177	1966	1986	Nat	F8
02ED103	Pine River near Everett	195	1970	1985	Nat	F2
02FA001	Sauble River at Sauble Falls	927	1958	1986	Nat	E
02FB007	Sydenham River near Owen Sound	181	1949	1986	Nat	F2
02FB010	Bighead River near Meaford	293	1958	1986	Reg	F2
02FC001	Saugeen River near Port Elgin	3 960	1915	1986	Nat	F2
02FC002	Saugeen River near Walkerton	2 150	1915	1986	Nat	F2
02FC004	Rocky Saugeen River near Traverston	249	1916	1940	Nat	F2
02FC011	Carrick Creek near Carlsruhe	163	1954	1986	Nat	F2
02FC012	South Saugeen River near Hanover	635	1972	1986	Reg	F2
02FC015	Teeswater River near Paisley	663	1972	1986	Nat	F2
02FE002	Maitland River below Wingham	1 630	1954	1986	Reg	F3
02FE004	Maitland River near Donnybrook	1 760	1948	1986	Reg	F3
02FE005	Maitland River above Wingham	528	1954	1986	Reg	F3
02FE007	Little Maitland River at Bluevale	326	1968	1986	Reg	F3
02FE008	Middle Maitland River near Belgrave	648	1968	1986	Nat	F3
02FE009	South Maitland River at Summerhill	376	1968	1986	Nat	F3
02FE010	Boyle Drain near Atwood	197	1968	1978	Nat	F3
02FF007	Bayfield River near Varna	466	1967	1986	Nat	F4
02GA010	Nith River near Canning	1 030	1948	1986	Nat	F3
02GA017	Conestogo River at Drayton	324	1951	1972	Nat	F3
02GA018	Nith River at New Hamburg	552	1951	1986	Nat	F3
02GA022	Grand River at Waldemar	655	1953	1963	Reg	F3

[1] Regions described in Section 5.1 and shown on Plate 1.

Table 4.1
Selected Streamflow Gauges - 2

Station Number	Station Name	Drainage Area (km^2)	Period of Record Used Begins	Period of Record Used Ends	Type of Record	Region Number[1]
02GA029	Eramosa River above Guelph	236	1963	1986	Reg	F3
02GA038	Nith River above Nithburg	326	1973	1986	Nat	F3
02GA040	Speed River near Armstrong Mills	167	1974	1986	Reg	F3
02GB001	Grand River at Brantford	5 210	1948	1986	Reg 1942	F3
02GB008	Whitemans Creek near Mount Vernon	383	1962	1986	Reg	F3
02GC002	Kettle Creek at St. Thomas	329	1968	1986	Nat	F5
02GC004	Big Otter Creek near Vienna	697	1949	1975	Reg	F5
02GC006	Big Creek near Delhi	363	1956	1986	Reg	F5
02GC010	Big Otter Creek at Tillsonburg	342	1961	1986	Nat	F5
02GC018	Catfish Creek near Sparta	287	1965	1986	Nat	F5
02GD001	Thames River near Ealing	1 340	1916	1966	Reg 1967	F3
02GD003	North Thames River below Fanshawe Dam	1 450	1954	1986	Reg 1953	F3
02GD004	Middle Thames River at Thamesford	306	1949	1986	Reg	F3
02GD005	North Thames River at St. Marys	1 080	1952	1986	Reg	F3
02GD008	Medway River at London	200	1971	1986	Nat	F3
02GD012	Thames River at Woodstock	254	1953	1986	Reg	F3
02GD014	North Thames River near Mitchell	319	1955	1986	Reg	F3
02GD015	North Thames River near Thorndale	1 340	1954	1986	Reg	F3
02GE002	Thames River at Byron	3 110	1956	1986	Reg 1953	F3
02GE003	Thames River at Thamesville	4 300	1956	1986	Reg 1953	F3
02GE006	Thames River near Dutton	3 760	1972	1986	Reg 1953	F4
02GG002	Sydenham River near Alvinston	730	1949	1986	Nat	F4
02GG004	Bear Creek above Wilkesport	609	1965	1983	Nat	F4
02GG006	Bear Creek near Petrolia	267	1967	1986	Nat	F4
02GG007	Sydenham River near Dresden	1 240	1968	1983	Nat	F4
02HA006	Twenty Mile Creek at Balls Falls	293	1958	1986	Nat	F6
02HB002	Credit River at Erindale	795	1949	1983	Reg	F7
02HB011	Bronte Creek near Zimmerman	235	1967	1986	Reg	F6
02HC003	Humber River at Weston	800	1949	1986	Reg	F7
02HC024	Don River at Todmorden	316	1963	1986	Nat	F7
02HC025	Humber River at Elder Mills	303	1963	1986	Nat	F7
02HD002	Ganaraska River near Dale	232	1951	1975	Nat	F7
02HJ003	Ouse River near Westwood	282	1968	1986	Reg	F8
02HL004	Skootamatta River near Actinolite	671	1959	1986	Nat	E
02HL005	Moira River near Deloro	308	1966	1986	Nat	E
02HM001	Napanee River near Napanee	777	1949	1973	Reg	E
02HM003	Salmon River near Shannonville	891	1959	1986	Reg	E
02JC008	Blanche River above Englehart	1 780	1974	1986	Nat	D
02KC014	Indian River near Pembroke	443	1969	1984	Nat	E
02KF011	Carp River near Kinburn	269	1972	1986	Nat	E

[1]Regions described in Section 5.1 and shown on Plate 1.

Table 4.1
Selected Streamflow Gauges - 3

Station Number	Station Name	Drainage Area (km²)	Period of Record Used Begins	Period of Record Used Ends	Type of Record	Region[1] Number
02LA006	Kemptville Creek near Kemptville	409	1970	1986	Reg 1951	E
02LA007	Jock River near Richmond	559	1970	1986	Nat	E
02LB006	Castor River at Russell	433	1968	1986	Nat	F1
02LB007	South Nation River at Spencerville	246	1950	1986	Nat	F1
02MC001	Raisin River near Williamstown	358	1961	1986	Nat	F1
04CA003	Roseberry River above Roseberry Lakes	619	1968	1986	Nat	B
04CB001	Windigo River above Muskrat Dam Lake	10 800	1968	1986	Nat	B
04CD001	Sachigo River below Beaverstone River	21 100	1967	1976	Nat	B
04CD002	Sachigo River below outlet of Sachigo Lake	4 270	1971	1986	Nat	B
04CE002	Fawn River Below Big Trout Lake	4 350	1968	1986	Nat	B
04DA001	Pipestone River at Karl Lake	5 960	1967	1986	Nat	B
04DA002	Winisk River at Kanuchuan Rapids	19 000	1968	1976	Nat	B
04DB001	Asheweig River at Straight Lake	7 950	1967	1985	Nat	B
04DB002	Asheweig River above Long Dog Lake	3 240	1968	1976	Nat	B
04DC001	Winisk River below Asheweig R. tributary	50 000	1966	1986	Nat	A
04DC002	Shamattawa R. at outlet of Shamattawa Lake	4 710	1972	1986	Nat	A
04EA001	Ekwan River below North Washagami River	10 400	1968	1986	Nat	A
04FA001	Otoskwin River below Badesdawa Lake	9 010	1967	1986	Reg	B
04FA002	Kawinogans River near Pickle Crow	1 540	1968	1986	Reg	B
04FA003	Pineimuta River at Eyes Lake	4 900	1968	1986	Nat	B
04FB001	Attawapiskat River below Attawapiskat Lake	24 200	1966	1986	Nat	B
04FC001	Attawapiskat River below Muketei River	36 000	1968	1986	Nat	A
04GA002	Cat River below Wesleyan Lake	5 390	1971	1986	Nat	B
04GB004	Ogoki River above Whiteclay Lake	11 200	1972	1986	Nat	B
04JA002	Kabinakagami River at Highway No. 11	3 780	1951	1986	Nat	D
04JC003	Shekak River at Highway No. 11	3 290	1951	1986	Nat	D
04JD005	Pagwachuan River at Highway No. 11	2 020	1968	1986	Nat	D
04JF001	Little Current River at Percy Lake	5 360	1972	1986	Nat	B
04KA001	Kwataboahegan River near the mouth	4 250	1973	1986	Nat	A
04LD001	Groundhog River at Fauquier	11 900	1921	1986	Reg	D
04LF001	Kapuskasing River at Kapuskasing	6 760	1919	1986	Reg	D
04LG001	Mattagami River at Smoky Falls	34 700	1927	1962	Reg	D
04LJ001	Missinaibi River at Mattice	8 940	1921	1986	Nat	D
04LM001	Missinaibi River below Waboose River	22 900	1973	1986	Nat	D
04MF001	North French River near the mouth	6 680	1967	1986	Nat	D
05PA006	Namakan River at outlet of Lac La Croix	13 400	1923	1986	Nat	B
05PA012	Basswood River near Winton	4 510	1930	1986	Reg	B
05PB014	Turtle River near Mine Centre	4 870	1921	1986	Nat	B
05QC003	Troutlake River below Big Falls	2 370	1970	1986	Nat	B
05QE008	Cedar River below Wabaskang Lake	1 690	1970	1986	Nat	B
05QE009	Sturgeon River at outlet of Salvesen Lake	1 530	1965	1986	Nat	B

[1]Regions described in Section 5.1 and shown on Plate 1.

and climatic data presented in Tables H1, H2 and H3 of Appendix H from Moin and Shaw (1986). The physiographic and climatic data included the following

- drainage area (A) (km^2)
- mean annual precipitation (MAP) (mm)
- mean annual snowfall (MAS) (cm)
- mean annual runoff (MAR) (mm)
- base flow index (BFI) (southern Ontario)
- percentage of drainage area controlled by lakes and swamps (ACLS) (%)
- slope of the main channel (SLP) (m/km)
- length of the main channel (LEN) (km)
- latitude (LAT) (degrees)
- longitude (LONG) (degrees)
- equation for shape factor (SHP) calculated from basin drainage area and main channel length.

The definition of the above data, as well as a detailed description of the basis for deriving these data, is provided in Appendix A.

This data base did not include some parameters considered useful for low and average flow hydrology such as those used by Acres (1985) for the Atlantic Region Study, and by Panu, Smith and Ambler (1985) for the regional studies in Newfoundland, namely

- on-channel lake area (areas of all lakes which lie on the main river channel)

- off-channel lake area (areas of all lakes which do not lie on the main river channel)

- swamp area (areas designated as swamps on the topographic maps)

- forest area (areas designated symbolically as forests on topographic maps)

- barren area (determined by subtracting total lake area, forest area, and swamp area from the drainage area).

Nonetheless, the physiographic and climatic data base has been shown to be adequate, particularly with the inclusion of the BFI parameter in southern Ontario.

5 - DESIGN FLOW HYDROLOGY FOR UNGAUGED CATCHMENTS

5 - DESIGN FLOW HYDROLOGY FOR UNGAUGED CATCHMENTS

5.1 - Introduction

Evaluation of the economic viability of a hydropower resource requires realistic estimates of the energy yield that can be expected from a proposed project. To this end an adequate sample, statistically representative of the hydrology that might be expected during the project life, is required as the basis for making such estimates. At the feasibility level of study, the variation of flow with time, both seasonally and from year to year, must be properly represented in order to clearly define the reliability of the flow for electricity generation, either as a run-of-river project or with whatever reservoir storage can be made available.

The most satisfactory basis for evaluating the generating potential of a site with or without storage is to undertake energy calculations with a mathematical (computer) model of the reservoir operations and generation at the proposed development using a reference hydrology. Such a hydrology is assumed to be statistically characteristic of the hydrology that would be experienced by the project during its anticipated economic life.

The reference hydrology for this purpose clearly does not need to be tied to actual calendar dates as it represents a sample of future hydrology to estimate future yield and installed capacity of potential developments. It must, however, have a representative mean flow and periods of wet and dry departures from the mean which have cumulative magnitudes, durations and patterns that are truly characteristic of the project site. It is suggested that the maximum possible length of record be generated as a reference hydrology. This record length should only be limited by the length of data available for use.

Where long periods of actual streamflow records are available at a site, the recorded flow time series is generally used as the reference hydrology. Where such a record does not exist, a reference hydrology is generated by other means.

Storage can be an important component of a small hydro development as it affects yield directly. Additional storage enables flows to be regulated and thereby reduces the quantity of water spilled. As well, flow regulation increases firm energy by taking water out of storage when natural flows are low. The effects of storage regulation on turbinable flow depend, to a large extent, on the size and variability of the daily inflows in comparison to the volume of available storage.

In basins which have multiple flood peaks, a storage reservoir may partially empty and fill a number of times each year, ultimately making greater use of storage than a basin with only one significant flood each year (say as a result of snowmelt). In order to estimate additional energy generation attributable to incremental storage volumes, a computer program (ENERGY) is used to simulate the operation of the hydroelectric plant subject to the daily inflow time series. This program is described further in Section 7.

The purpose of this section is to describe techniques which have been developed in this study for generating synthetic hydrology (daily flow series) for ungauged catchments in Ontario. Section 6 presents additional techniques for developing a hydrology at sites having either a short period of recorded flows or a gauge located somewhere in the basin.

The following information is presented in the subsections of this section

- selection of homogeneous hydrologic regions
- flow duration curve methodology

- proration methodology
- evaluation and comparison of methodologies.

5.2 - Selection of Homogeneous Hydrologic Regions

A homogeneous region is an area in which the river basins exhibit similar hydrologic behavior. In this study, attention is focused on the hydrologic behavior of the low flow and average flow characteristics. Flood hydrology has been studied and regionalized by others.

Two regional methodologies for developing continuous streamflow records at ungauged sites are investigated and compared--a flow duration curve approach and a proration methodology based on an index gauge. The flow duration curve methodology is based on the regression of coefficients describing a flow duration curve (dependent variables) against physiographic and climatic data (independent variables). The proration approach develops a daily flow record at the point of interest by prorating the daily flow record of an index gauge using the drainage area and estimated MAR (i.e., flow volume) at the point of interest.

It is important to recognize that the two approaches are quite different. By utilizing regional regression analyses for the flow duration methodology, the need to define homogeneous regions is reduced. The reason for this reduction is that variability in the hydrologic characteristics from gauge to gauge will be explained by the independent variables included in the regression equation. Regionalization is therefore an attempt to account for neglected characteristics not included in the regression analysis which may be common to a region. The result of regionalization is a unique set of equations defining the flow duration curve for each region.

On the other hand, when adopting a nonregression-based approach such as the proration methodology, where average hydrology is represented only by drainage area and MAR, there is a need to define a greater number of homogeneous regions to account for other factors affecting the discharge record.

As a result, it was necessary to define two separate sets of homogeneous regions for the flow duration and proration methodologies.

5.2.1 - Region Selection - <u>Flow Duration Curve Methodology</u>

There are several approaches commonly used to define homogeneous regions for regression-based regional hydrology studies

- physical basin characteristics (physiographic and climatic properties)
- statistical homogeneity test
- analysis of residuals (cluster analysis)
- minimization of standard error of the prediction equations.

The approach adopted for this study was a combination of all the noted methods with less emphasis placed on the homogeneity tests used in previous flood studies.

The general approach therefore consisted of the following steps

- broad regionalization based on physiographic parameters and the work of other researchers

- evaluation of the standard error of prediction equations for the regions. Where the standard errors were poor, the regions were further subdivided, again on the basis of physiographic characteristics. The analysis was repeated for the new subdivisions.

- final checking of residuals to ensure random distribution throughout the region.

Initially, three coarse regions were defined across the province on the basis of broad physiographic characteristics. In the following discussion, the reader is referred to Plate 1 which illustrates the homogeneous regions.

Hudson Bay/James Bay Lowlands

The Hudson Bay/James Bay lowlands region (Region A of Plate 1) is characterized by very flat basins having vegetative cover rooted in peat deposits of depths normally between 2 to 5 m. Till deposits generally found beneath the vegetative cover are underlain by limestone and dolomite sedimentary bedrock. Rock outcrops are not found in this region except at the outlets of some rivers at sea level.

This region was defined previously by Moin and Shaw (1985) (in a regional flood study which utilized the statistical homogeneity test) as a basis for region definition. While Moin and Shaw (1986) could not statistically justify separating this region from the Canadian Shield, it was recognized that there were few samples on which to base this conclusion.

For the purposes of average hydrology, however, the pronounced differences in physiography and geology between this region and the bordering Canadian Shield, justify it as a separate region.

Canadian Shield

The Canadian Shield physiographic region (Regions B, C, D and E of Plate 1) occupies the majority of Ontario. Its predominant characteristic, of course, is the very shallow surficial soils overlying Precambrian rock which outcrops frequently. This region is also characterized by numerous lakes, rugged relief and forested lands. This region was chosen initially as the combination of two separate Canadian Shield regions identified in the regional regression study by Moin and Shaw (1986) as there appeared no strong physical or statistical basis for separating these regions. In a slight departure from the previous study, the Bruce Peninsula and Manitoulin Island were considered part of the Canadian Shield region as opposed to southern Ontario, as they exhibit limestone plains and sedimentary rock similar to that found in the Canadian Shield.

Southern Ontario

Southern Ontario (Region F of Plate 1) is classed as the region with surficial soils extending to a substantial depth. It has a well-marked line of demarcation from the Canadian Shield, as illustrated in Plate 1. For the purpose of the initial evaluation, the St. Lawrence lowlands in the southern Ontario region are also included. These lowlands are comprised predominantly of clay, till and sand plains, similar to southern Ontario, as opposed to the Canadian Shield just west of the Rideau River which is made up of limestone plains, shallow till and rock ridges. The validity of this definition is discussed below.

Numerous homogeneous regions of southern Ontario defined in previous studies (Moin and Shaw, 1986; Moin and Shaw, 1985; Sangal and Kallio, 1977) were differentiated largely on the basis of their surficial soils. We concur that variations in the type and depth of surficial soils in southern Ontario will be among the major factors influencing average hydrology. An inspection of the BFI characteristic has shown that variations in this variable match variations in the surficial soils and groundwater contribution to streamflow volume. By using the BFI as an independent variable in the regression relationships, a major source of hydrologic variability within the region has been adequately explained. There is little justification in separating southern Ontario into additional homogeneous regions for this methodology.

Initial evaluations of the standard error of prediction equations for these three major regions led to the following conclusions.

- There are insufficient stream gauges within the Hudson Bay/ James Bay lowlands region for application of the regression-based flow duration curve methodology.

- The regression equations for the southern Ontario region were very good, providing low standard errors. The residuals of the 6 gauges in the St. Lawrence lowlands subregion of southern Ontario (the isolated portion of Region F in Plate 1 located in the extreme southeast corner of the province) were consistent with residuals from the rest of the region. There was, therefore, no reason to separate the lowlands subregion.

- The regression relationships in the Canadian Shield were not satisfactory and further subdivision was necessary as discussed below.

The Canadian Shield region was subdivided into a southern Canadian Shield region (Region E of Plate 1), a central Canadian Shield region (Regions C and D), and a northwestern Canadian Shield region (Region B). The locations of these regional boundaries coincided with those determined in previous studies (Moin and Shaw, 1985, 1986). Good regression relationships were obtained for the dependent variables which describe the flow duration curve in the southern and northwestern Canadian Shield regions. These were therefore accepted for further application.

Adequate regression relationships were not found in the central Canadian Shield region. It was therefore further subdivided into the east (Region D) and west-central (Region C) Canadian Shield regions. The natural Lake Superior drainage divide was taken as the regional boundary and the regression analysis repeated.

Again, suitable regression equations were not found for the dependent variables in either region.

As climatic factors (snowfall) and drainage basin areas differ significantly between these regions, it was considered appropriate that they be defined separately and not recombined into a single larger region. The user will have only the option of the proration methodology in these cases.

The final 6 homogeneous regions established for the regression-based regional flow duration curve methodology are illustrated on Plate 1.

5.2.2 - Region Selection - Proration Methodology

Characteristics affecting flood hydrology, such as basin slope, area of lakes, etc, are not necessarily those which affect average hydrology. The definition of homogeneous regions for each is therefore not necessarily the same. This notwithstanding, physiographic and climatic delineations used in previous regional flood frequency analyses will provide guidance in the selection of regions for average hydrology analysis. All information found from prior studies (Moin and Shaw, 1985; Acres, 1984; Sangal and Kallio, 1977; Cumming-Cockburn, 1985a, 1985b, 1983; and MacLaren, 1981) concerning the definition of homogeneous regions relates to flood hydrology.

The proration methodology is quite similar to the index method for floods. In both cases, the regionalization attempts to account for all physiographic and climatic factors (other than drainage area and MAR) which significantly affect the hydrologic characteristics of interest (temporal and spatial variability of daily hydrology).

Thirteen regions were identified as homogeneous for the proration methodology in this study. These are identified on Plate 1 as Regions A to E and Regions F1 to F8. Their selection was based on the work and results of others as discussed above, and on physiographic characteristics and the nature of the surficial soils (Chapman and Putman, 1984; Sangal and Kallio, 1977). Consideration was also given to climatic conditions and land use. In general, an attempt was made to define regions to include whole basins.

The homogeneous regions chosen for the proration methodology correspond closely to those defined by Moin and Shaw (1985) where homogeneous regions were selected for floods on the basis of a statistical homogeneity test. The only notable difference is that Regions C and D chosen in this study were considered by Moin and Shaw (1985) as a single homogeneous region.

5.3 - Flow Duration Curve Prediction Methodology

The purpose of this section is to describe techniques developed for estimating a flow duration curve for ungauged catchments in Ontario. The estimated flow duration curve for the ungauged catchment can then be used with the daily time series of flow data at an index gauge in order to synthesize a daily time series of flows at the ungauged site. This method, as compared to the proration method, can account for the effects of physiography or other basin characteristics on the flow pattern. The following three subsections present the methodology.

5.3.1 - Theoretical Aspects of Flow Duration Curve Prediction

In order to predict the flow duration curve for an ungauged catchment, it is necessary to relate physical properties of the basin to coefficients of a mathematical function which describe the flow duration curve.

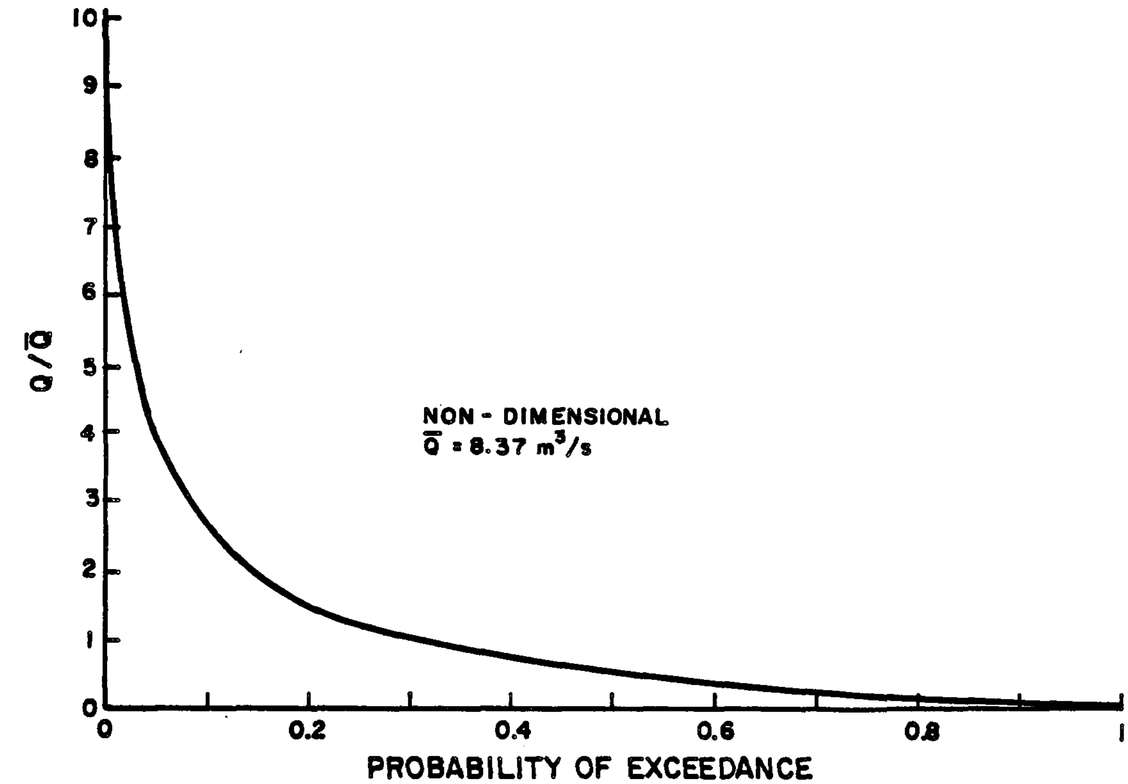
After reviewing the nature of the flow duration curves, it was concluded that the turbinable flow curve would be more useful for small-hydro analysis than the flow duration curve because it has a shape more amenable for fitting a mathematical function. The probability density function of flows, the flow duration curve and the turbinable flow curve all are uniquely related, as explained below.

The flow duration curve is defined as

$$F(Q_d) = \int_{Q_d}^{\infty} f(Q)\, dQ \qquad (5\text{-}1)$$

where $f(Q)$ is the probability density function of all daily flows. The cumulative probability $F(Q_d)$ is therefore the probability that any flow, Q_d, will be equalled or exceeded.

If Equation 5-1 is evaluated for Q_d ranging from zero to infinity, the resultant set of values can be used to generate a flow duration curve. A flow duration curve shows the percentage of time a particular flow is equaled or exceeded. In order to obtain curves within a region which would be easily compared with one another, nondimensional flow duration curves were developed by dividing each discharge by the mean annual flow for the period of record of the particular gauge. Daily nondimensional flow duration curves were developed by ranking and sorting all of the nondimensional daily mean flows. Figure 5.1 illustrates both the actual and nondimensional flow duration curves for Station 02HL004, named Skootamatta River, near Actinolite.



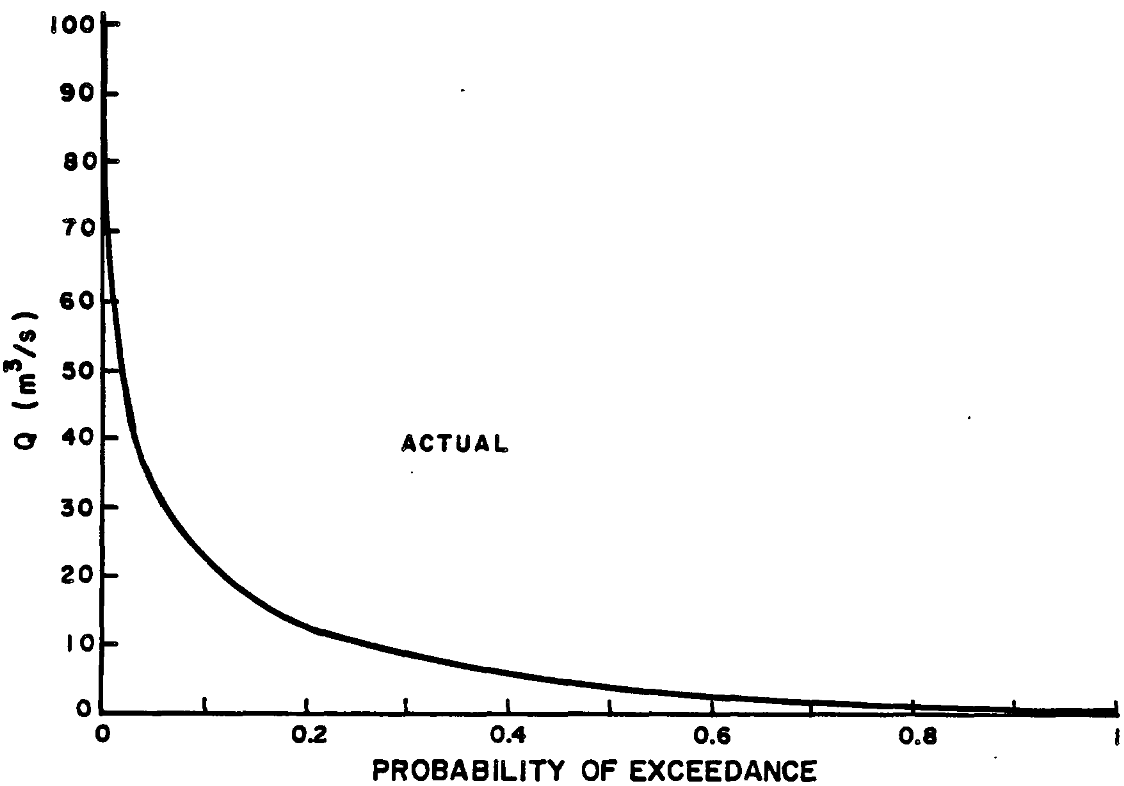


FIG. 5.1

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

DAILY FLOW DURATION CURVES - STATION 02HL004

ACRES

The mathematical relationship between the probability density function and a flow duration curve can be understood easily with the aid of Figure 5.2.

The derivation of a turbinable flow curve from a flow duration curve is also explained with the aid of Figure 5.2. The shaded area of the flow duration curve represents the average discharge which can be passed through the turbines for a given design discharge, Q_d. Therefore, the area under the flow duration curve up to a certain installed capacity is the turbinable flow.[1] The turbinable flow can be expressed mathematically as

$$Q_t = \int_0^{Q_d} \left[\int_{Q_d}^{\infty} f(Q)\ dQ\right]\ dQ \tag{5-2}$$

The turbinable flow curve is thus a curve of Q_t versus Q_d that can be calculated by evaluating the above integral over a range of Q_d from zero to infinity. Practically, the maximum value of Q_d used is 3 or 4 times the mean annual flow. Beyond this practical limit, increases in Q_d normally have little effect as Q_t approaches the mean annual discharge. Economically, the benefit/cost ratio would certainly decrease in this range as the marginal energy benefit will become less than the incremental cost of additional installed capacity.

As explained previously, the turbinable flow curve is a relatively smooth, easily definable function. Therefore, prediction equations for the turbinable flow curve are developed and the

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[1]When the flow duration curve is expressed using flow and percent time coordinates, the area under the curve has the units of discharge. Hence the area under the curve is the turbinable flow. Alternatively, if the flow duration curve is expressed in flow and time coordinates, the area under the curve will have the units of volume. Hence the area under such a curve would be the turbinable volume.

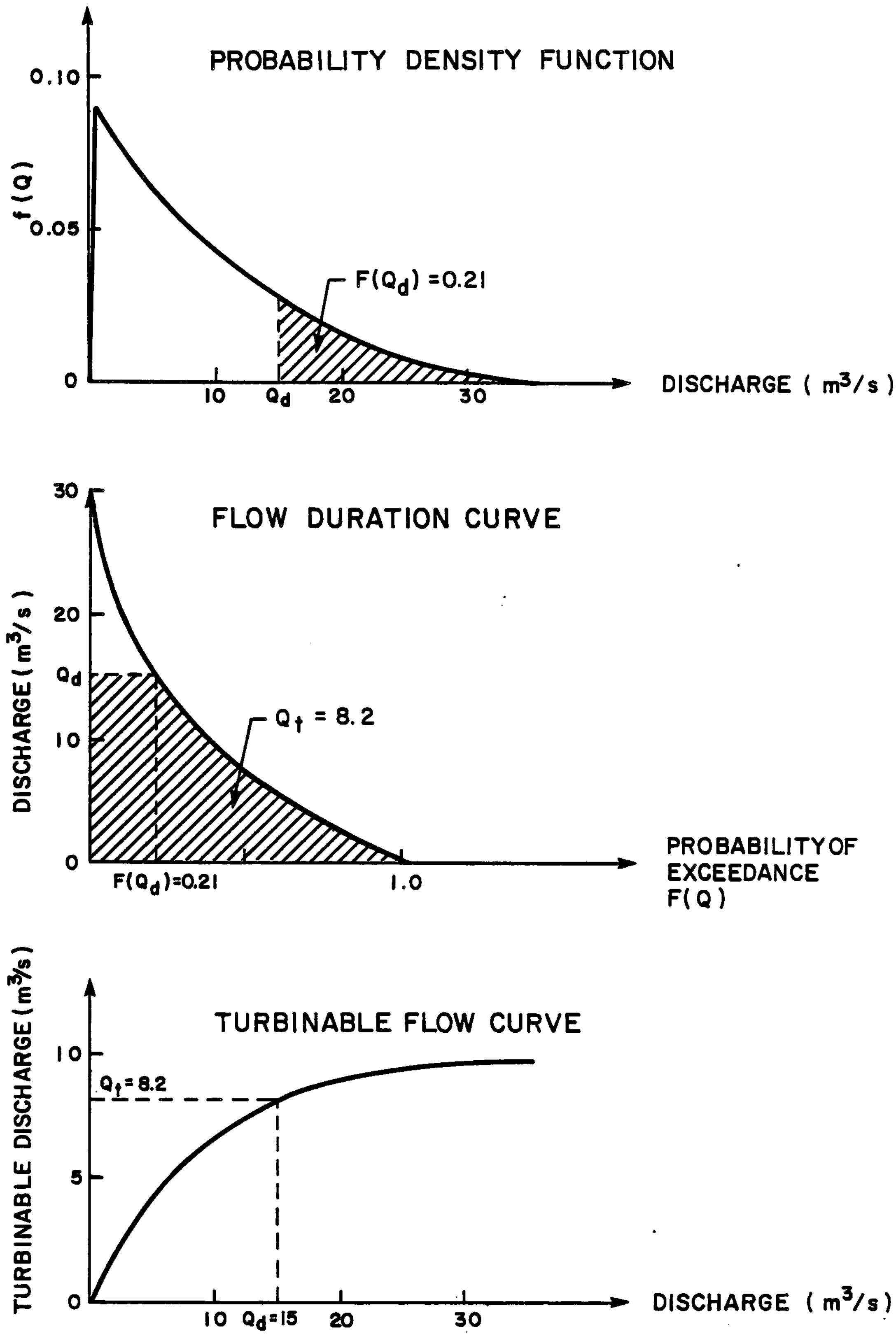


FIG. 5.2

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

INTERRELATIONSHIPS OF PROBABILITY DENSITY FUNCTION, FLOW DURATION CURVE AND TURBINABLE FLOW CURVE

ACRES

corresponding flow duration curve is generated by differentiating the turbinable flow curve function. The techniques which have been developed were done using nondimensional flows ($Q/\overline{Q}$) in order to bound the functions within reasonable limits ($Q_T = Q_t/\overline{Q}$, $Q_D = Q_d/\overline{Q}$). Actual flows can be obtained by multiplying the flow duration curve by the estimated mean annual discharge ($\overline{Q}$).

As presented in Acres (1984), several functions have been fitted to the turbinable flow curve including the power transformation, the Michaelis Menton equation, hyperbolic functions, lognormal and 3-, 4- and 5-degree polynomials. Of these functions, it was found that the 5-degree polynomial best reproduced the characteristics of the curves over the range of interest in nondimensional design discharge.

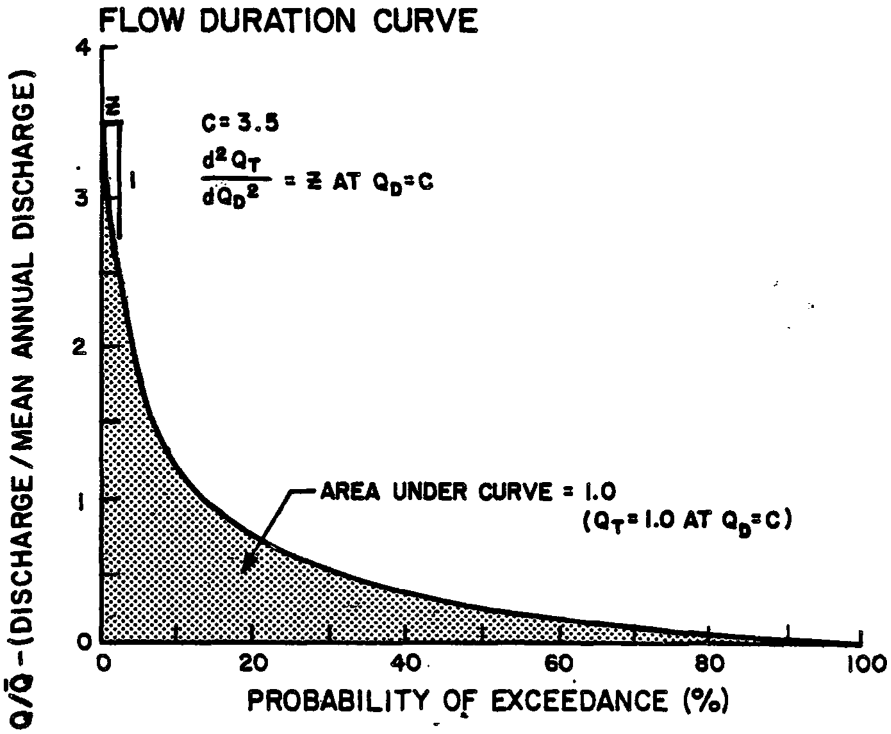
Certain constraints were imposed on the mathematical functions to force the curve to satisfy necessary physical properties of turbinable flow curves and the corresponding flow duration curves. These constraints are shown in Figure 5.3 for flows nondimensionalized by the mean annual flow and are described as follows.

(a) Turbinable flow must be zero at a design discharge of zero, i.e., $Q_T = 0$ at $Q_D = 0$.

(b) Continuity must be satisfied such that the total volume under the nondimensional flow duration curve is unity. Mathematically, this is written as

$$Q_T = 1 \text{ at } Q_D = C$$

where C is a large design discharge theoretically equal to the largest flow of record and practically equal to a design discharge with an extremely low probability of exceedance (<1%).



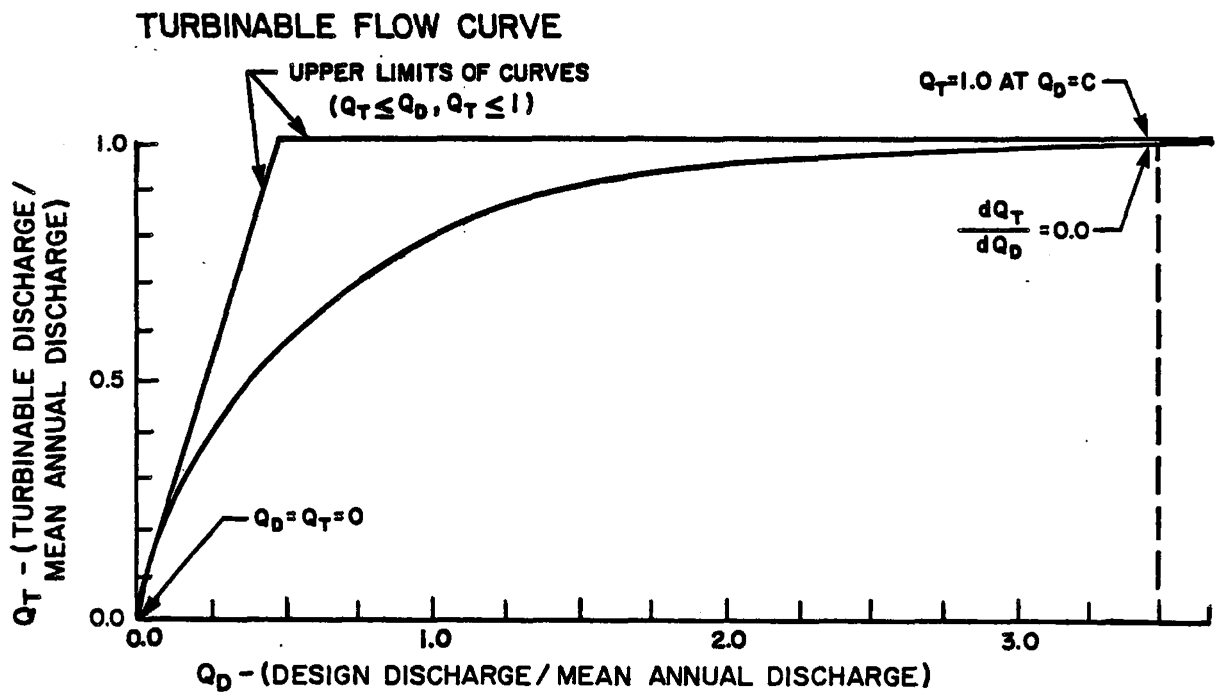


FIG. 5.3

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

PHYSICAL CONSTRAINTS IMPOSED ON FLOW DURATION AND TURBINABLE FLOW CURVES

ACRES

(c) The turbinable flow curve must have a zero slope at the design discharge, C, where continuity is satisfied.

$$\frac{d(Q_T)}{d(Q_D)} = 0 \text{ at } Q_D = C$$

This constraint is equivalent to forcing the probability of exceedance to equal zero at the design discharge C.

(d) The slope of the flow duration curve must equal 1/Z at the design discharge, C, i.e.,

$$\frac{d^2(Q_T)}{dQ_D^{\,2}} = Z \text{ at } Q_D = C$$

The general form of the 5-degree polynomial used to fit the turbinable flow curve is

$$Q_T = \emptyset + \theta\, Q_D + \alpha(Q_D)^2 + \beta(Q_D)^3 + \gamma(Q_D)^4 + \kappa(Q_D)^5 \qquad (5\text{-}3)$$

Based on the previously described constraints (four boundary conditions) and by differentiating (first and second derivatives) the above equation, the following simultaneous equations can be established.

$$\emptyset = 0 \qquad (5\text{-}4)$$

$$\theta C + \alpha C^2 + \beta C^3 + \gamma C^4 + \kappa C^5 - 1 = 0 \qquad (5\text{-}5)$$

$$\theta + 2\alpha C + 3\beta C^2 + 4\gamma C^3 + 5\kappa C^4 = 0 \qquad (5\text{-}6)$$

$$2\alpha + 6\beta C + 12\gamma C^2 + 20\kappa C^3 - Z = 0 \qquad (5\text{-}7)$$

By solving the above simultaneous equations, the following relationships were obtained.

$$\beta = [(Z - 6\alpha)C^2 - 12C\theta + 20] / 2C^3 \qquad (5\text{-}8)$$

$$\gamma = [(3\alpha - Z)C^2 + 8C\theta - 15] / C^4 \qquad (5\text{-}9)$$

$$\kappa = [(Z - 2\alpha)C^2 - 6C\theta + 12] / 2C^5 \qquad (5\text{-}10)$$

Therefore, it is only necessary to establish values for Z, C, θ and α to predict either the turbinable flow curve or the flow duration curve. Normally, errors from the curve fitting were less than 2% of the turbinable flow estimate.

The nondimensional flow duration curve can be estimated by differentiating the turbinable flow curve with the following result.

Probability of exceedance

$$= \theta + 2\alpha\ (Q/\bar{Q}) + 3\beta(Q/\bar{Q})^2 + 4\gamma(Q/\bar{Q})^3 + 5\kappa(Q/\bar{Q})^4 \qquad (5\text{-}11)$$

For any selected values of $Q/\bar{Q}$, the probability of exceedance can be computed. The nature of the calculated curves is generally such that the upper end of the curve (at low probability of exceedance) is somewhat 'wavy'. This can be smoothed out by an interpolation of the curve through the wavy portion extending to intercept the ordinate at probability equal to zero. The computer program HYSIMONT described in Section 7 does this smoothing automatically. Any error introduced by the interpolation is insignificant for energy studies as it is the lower portion of the curve which is of significance.

5.3.2 - Development and Presentation of Flow Duration Curve Prediction Results

The approach to regionalizing the turbinable flow curve for each region in the study was taken in three steps.

(a) Flow Duration and Turbinable Flow Curves

The first step in the regionalization is to evaluate the actual nondimensional flow duration curves at each of the streamflow gauges chosen for analysis.

Next, a power and energy computer simulation program was used to evaluate natural or additional man-made storage turbinable flow estimates for various assumed hydroplant design discharges. The result is a turbinable flow curve calculated for each selected gauge.

(b) Curve Fitting

The turbinable flow curve was fit by a 5-degree polynomial equation to each selected gauge in the region, and the coefficients Z, C, θ and α were calculated.

Using the flow duration curves, the regional mean value of Z (defined in Figure 5.3) was calculated by averaging the slopes for every basin in the region. In general, it was found that Z was fairly consistent within a region and a mean value ($\bar{Z}$) was satisfactory. Given $\bar{Z}$ for a region, the values of coefficients C, θ and α were calculated for each gauge using a curve-fitting computer program which minimized the standard error of the estimate (of turbinable flow) for design discharges between 0 and 4 times the mean annual flow.

The coefficient C is treated as the intercept of the flow duration curve on the discharge axis and reflects a discharge which is seldom exceeded. This coefficient therefore has a larger value for basins with little or no natural regulation, as compared with those which are more regulated.

Conversely, the coefficient θ is an indicator of the height of the knee of the flow duration curve and reflects the degree of natural regulation in a river basin.

It is difficult to interpret the physical significance of the coefficient α and hence the effect of basin characteristics on the calculated value of this coefficient.

(c) Determination of Regional Relationships for the Coefficients

In order that estimates can be made of the turbinable flow curve at ungauged sites, it is necessary to relate the coefficients of the polynomial equation to physiographic and/or climatic characteristics which can be measured in the ungauged basin. The physical characteristics used in the regression analysis were listed in Section 4.2 while a detailed description is provided in Appendix A.

As noted above, a regional average value was selected for the coefficient Z. Regression analysis was performed with the other polynomial coefficients (C, θ and α) as dependent variables seeking appropriate regional relationships against physical and climatic characteristics as the independent variables.

If significant regression equations existed for all three dependent variables, these equations were used to obtain estimates of the dependent variables for ungauged catchments within the region.

If significant relationships were not found for all three dependent variables, a process of progressively assigning a regional average value to a polynomial coefficient and then reevaluating the polynomial curve fitting was followed. In each case, the order of removing a coefficient from the polynomial curve fitting and hence a dependent variable for regression equations was C first, θ second and α last.

As part of this progressive process, a multiple regression computer program was used to determine the regression relationships between the basin characteristics and the coefficients C, θ and α. The program computed regression equations for both transformed and nontransformed data and presented statistically significant criteria for all combinations of independent variables taken one, two or three at a time.

The appropriateness of the equations was reviewed considering both statistical and physical criteria.

Statistical Significance

- Significance of individual regression coefficients as well as the overall regression equation significance must be at a level of not more than 10% and preferably less than 5%. The measure of goodness of the equation is given by R^2 values (the multiple correlation coefficient) and the standard error of the estimate.

- Regression equations with spurious relationships caused by highly intercorrelated independent variables were not acceptable.

Physical Appropriateness

- The equation must 'make sense'. Variables which appear in the equations should be explainable when compared with the physiographic and climatic characteristics of the region. The signs must be in the right direction and the expected range of the estimated dependent variables must be realistic when subject to an extreme range in independent variables.

- All variables in the regression equation should be readily obtainable in the particular region.

- The variables selected in the final form of the equations should be as consistent as possible from one region to another without sacrificing the predictive accuracy of the equations.

The selected regression equations for parameters C, θ and α are summarized in Table 5.1 for Regions B, E and F. As noted previously, there were insufficient data to develop regional regression relationships in Region A.

The multiple correlation coefficients, standard error of the estimate and the coefficient of variation are also given in Table 5.1. It should be noted that the standard error of estimate as well as the coefficient of variation (CV) are expressed as a percent of the mean value of the dependent variable.

No acceptable regressions were identified for Regions A, C or D. In these regions, the standard deviations of the polynomial coefficients were found to be similar to the standard errors of the dependent variables in Regions B, E and F, indicating limited variability in the dependent

TABLE 5.1

REGIONAL REGRESSION EQUATION SUMMARY

Region	Number of Stations in Region	Equation	Coefficient of Determination (R^2)	Coefficient of Variation (% of mean)	Standard Error of Estimate (% of mean)
B	22	$C = 5$	-	-	-
		$\theta = 0.0707\ MAR^{-0.37040}\ ACLS^{0.12540}\ LAT^{1.08795}$	0.66	11	7
		$\alpha = -\sqrt{0.45970 - 2.04 \times 10^{-6}\ MAR^{2}}$	0.70	12	9
E	15	$C = e^{12.2505 - 0.07497 \ln A - 0.23401 \ln MAR - 1.9535 \ln LONG}$	0.74	12	7
		$\theta = (-2.252 + 0.02583\sqrt{MAS} + 0.09190\sqrt{SLP} + 0.40197\sqrt{LAT})^2$	0.91	15	5
		$\alpha = -(-4.618 + 0.02340\sqrt{MAS} + 0.0718\sqrt{SLP} + 0.72005\sqrt{LAT})^2$	0.91	23	8
F	62	$C = 9.533 - 6.137\ BFI$	0.88	14	5
		$\theta = 0.3057 + 1.1641\ BFI + 0.036\ SLP$	0.89	22	8
		$\alpha = -0.0851 - 0.7346\ BFI - 0.0273\ SLP$	0.80	28	13

variables for the independent variables to explain. Since acceptable regional regression relationships were not determined in Regions A, C or D, synthetic time series are generated using proration at a representative index or nearest gauge.

The following should be noted from an examination of the regression results in Tables 5.1 and 5.2.

- As expected, the BFI was the dominant variable in southern Ontario - Region F.

- In northwest Ontario - Region B, also as expected, the percentage drainage area controlled by lakes and swamps and the MAR were the dominant factors in the regression equations.

- Summary statistics relating to the range of dependent and independent variables associated with the regression analyses are presented for Regions B, E and F in Table 5.2. These ranges of independent variables used in the development of regression equations become the limiting values of the variables which can be safely used in these equations. The equations have all proved to be stable giving reasonable estimates of C, β and $-\alpha$ for the extreme combinations of variables as illustrated in Table 5.2.

5.3.3 - Technique for the Generation of Synthetic Daily Flow Series

Using this methodology, the synthetic time series of flow at an ungauged site is developed from the predicted flow duration curve and a daily flow time series at an index station. Assuming that the same probability of occurrence of daily flows can be expected

TABLE 5.2

SUMMARY OF INDEPENDENT AND DEPENDENT REGRESSION VARIABLES

Region	Description	Drainage Area (km^2)	Mean Annual Precip. (mm)	Mean Annual Snowfall (cm)	Mean Annual Runoff (mm)	Base Flow Index	Area Controlled by Lakes and Swamps (%)	River Slope (m/km)	River Length (km)	Latitude (degrees)	Longitude (degrees)	Shape Factor	C	θ	α
		Independent Variables											Dependent Variables		
B	Minimum	619	540	190	**195**		**20.00**	0.018	59.1	**48.08**	86.53	2.2	5.00	0.88	0.388
	Maximum	24 200	770	300	**389**		**100.00**	0.838	358.8	**54.99**	94.46	26.8	5.00	1.27	0.618
	Mean	7 603	675	229	**291**		**80.00**	0.281	192.0	**51.83**	90.47	7.1	5.00	1.10	0.530
	σ	6 427	72	28	**56**		**29.00**	0.231	84.0	**1.85**	2.14	5.8	0.00	0.10	0.060
	CV (%)	85	11	12	**19**		**36**	82	44	**4**	2	82	0	9	12
	Extreme Min												5.00	0.76	0.388
	Extreme Max												5.00	1.39	0.618
E	Minimum	**149**	795	**170**	**344**		0.01	**0.138**	24.5	**44.21**	**75.66**	1.4	5.40	0.71	0.324
	Maximum	**1 850**	930	**300**	**626**		98.00	**2.472**	128.0	**46.57**	**81.25**	14.2	7.30	1.08	0.576
	Mean	**709**	864	**228**	**425**		49.00	**1.290**	66.1	**45.24**	**78.35**	7.4	6.40	0.89	0.430
	σ	**485**	44	**49**	**82**		36.00	**0.656**	30.0	**0.73**	**1.91**	3.7	0.60	0.12	0.090
	CV (%)	**68**	5	**21**	**19**		73	**51**	45	**2**	**2**	49	9	14	22
	Extreme Min												4.90	0.63	0.251
	Extreme Max												7.80	1.17	0.662
F	Minimum	163	780	100	225	**0.15**	0.01	**0.208**	20.0	42.46	74.64	1.5	4.60	0.50	0.213
	Maximum	5 206	1000	300	516	**0.81**	100.00	**4.824**	227.5	48.31	82.34	21.8	8.60	1.32	0.738
	Mean	841	882	203	376	**0.45**	19.00	**1.482**	59.9	43.69	80.44	5.8	6.80	0.88	0.460
	σ	1 066	61	59	62	**0.14**	31.00	**0.896**	42.2	0.89	1.49	3.7	0.88	0.18	0.120
	CV (%)	127	7	29	17	**32**	170	**60**	70	2	2	63	13	21	26
	Extreme Min												4.60	0.49	0.200
	Extreme Max												8.60	1.42	0.810

Note: Variables shown in bold were significant in the regression equations.

at both sites, the time series of flows at the ungauged sites can be derived.

The generation of a synthetic flow time series is explained as follows with the aid of Figure 5.4.

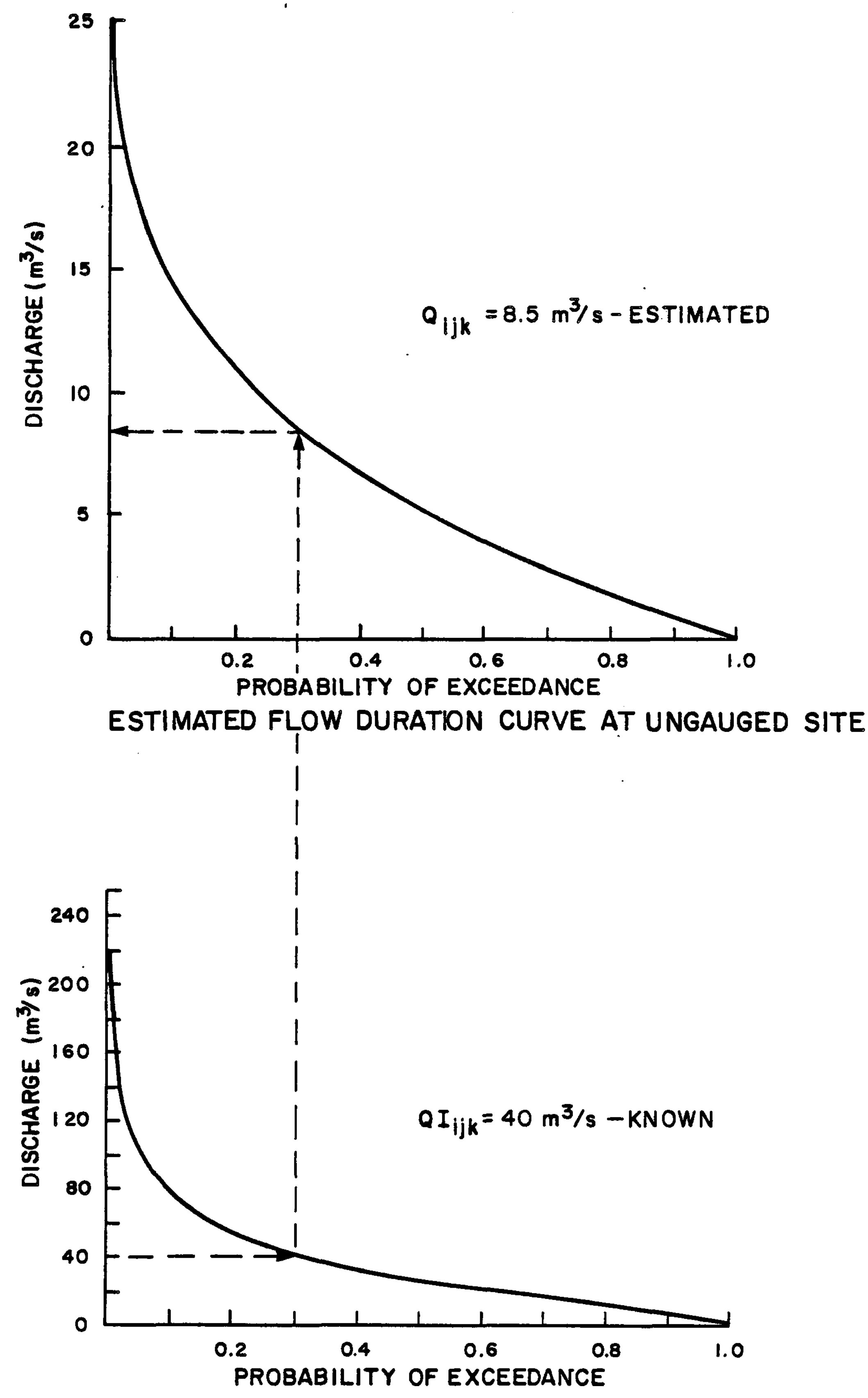
First the daily flow duration curve is derived using the regional regression relationships to estimate the polynomial coefficients C, θ and α, and subsequently to calculate β, δ and κ, the coefficients of Equation 5-11. This derived flow duration curve is then automatically adjusted such that

- the probability of exceedance does not exceed 1 for design discharges at a site with a high degree of natural regulation

- a wavy shape to the flow duration curve is eliminated at low probabilities of exceedance for steep flow duration curves.

Experience indicates that the modified form of the predicted flow duration curves are most accurate at ungauged sites with a high degree of natural regulation. Flashy basins with steep flow duration curves result in the largest error, particularly at design discharges greater than 4 times the mean flow both for natural and additional man-made regulation.

The actual daily time series at the index station drives the process of generating daily flow data at the ungauged site. For each daily discharge of the index time series, the probability of exceedance is determined at the index gauge from the known index flow duration curve, as shown in Figure 5.4. The discharge at the ungauged site is then estimated from its own derived flow duration curve by assuming the same probability of exceedance as the index station. The discharge record at the ungauged site is created by repeating this process for each flow in the index time series.



ESTIMATED FLOW DURATION CURVE AT UNGAUGED SITE

FLOW DURATION CURVE AT INDEX GAUGE 02YS001

FIG. 5.4

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

DAILY FLOW SYNTHESIS USING FLOW DURATION CURVES

ACRES

Although the derived time series will not correspond exactly with the actual historic time series, the probability density function will be as accurate as the estimated flow duration curve. The implicit assumption is that the serial correlations of flows at the ungauged site are identical to those at the index station. It is therefore important that the index station be hydrologically representative of the particular homogeneous hydrologic region.

Potential index gauges in each region were identified and screened using the following characteristics

- long period of continuous daily record
- quality of streamflow record at gauge
- proximity to region centroid
- average or representative drainage basin area
- representative MAR
- representative descriptors of the flow duration curve, C, θ and α.

The selected index stations for each region for the flow duration methodology are listed in Table 5.3.

5.4 - Proration on Drainage Area and Mean Annual Runoff

Proration is a second common technique for developing synthetic hydrology for capacity and energy benefit evaluations at ungauged locations. Discharge data from a known gauge with a long record are prorated (multiplied by a constant factor) based on drainage area and MAR. In many cases, the technique can be used with satisfactory reliability where an index gauge or nearest gauge exists with a long record on the same river, in the same basin, or in a basin adjacent to the ungauged site. The proration technique is described below on the basis

TABLE 5.3

INDEX GAUGE SUMMARY FOR
FLOW DURATION CURVE METHODOLOGY

Region	Station	Period of Record	Length of Record (years)	Type	Drainage Area (km^2)	Record Quality
B	04DA001	1967-1986	20	natural	5960	average
E	02HL004	1959-1986	28	natural	671	above average
F	02GG002	1949-1986	38	natural	730	above average

of a single long-term index gauge in each region. Proration to the nearest gauge can be done using the same general equation by replacing the area and MAR at the index gauge with that of the nearest gauge. This is discussed further in Section 6.1.

$$Q_{ijk} = QI_{ijk} \; (A * MAR) \; / \; (AI * MARI) \qquad (5\text{-}12)$$

where

i	= year
j	= month
k	= day
Q	= generated discharge time series at an ungauged site (m^3/s)
QI	= known discharge time series at the index station (m^3/s)
A, AI	= basin drainage area at the ungauged site, index station, respectively (km^2)
MAR, MARI	= mean annual runoff at the basin centroid of the ungauged site, index station, respectively (mm).

The record which is generated using this technique will not be correct on a specific day but will be representative of the long-term record. Inherent assumptions in the approach are that the serial correlation of flows and the coefficient of variation are identical between the ungauged site and the index or nearest gauge.

More generally, the synthetic flow pattern is identical to that at the index gauge. The only difference is that a constant factor is applied to the index gauge record.

As described in Section 5.2.2, homogeneous regions have been defined separately for the proration methodology, and Plate 1 identifies the 13 regions selected.

Index stations for each of the designated homogeneous regions were then chosen. The need to define more than one index gauge per homogeneous region to compensate for the large spatial area of some regions as well as the large variation in drainage basin size was considered. Numerical estimates of the q_{90} and q_{10} flows (exceeded 90% and 10% of the time, respectively) were obtained from the flow duration curves of every station in each of the 13 homogeneous regions. These estimates were regressed against drainage area as well as latitude/longitude to determine whether more than one index station should be selected on the basis of basin size or spatial location within a region.

The only significant relationships (R^2 >0.84) involved both q_{90} and q_{10} to drainage area in Region A. Therefore, two index stations, 04DC002 (A = 4710 km^2) and 04FC001 (36 000 km^2), were selected in Region A corresponding to a small basin and a large basin, respectively. A summary of the selected proration index stations for each region are listed in Table 5.4.

5.5 - Evaluation and Comparison of Alternative Methodologies

There are several sources of error in the methodologies presented in this section. In the following subsections, these errors are discussed in general and an evaluation and comparison of the alternative methodologies are presented.

5.5.1 - Sources of Error

The errors which can influence the accuracy of the methodologies are as follows.

(a) Errors in fitting the 5-degree polynomial curves to the actual turbinable flow curves. Curve-fitting coefficients were chosen (C, θ and α) which minimized the sum of the squared residuals between actual and estimated turbinable flow for design discharges as high as 4 times the mean

TABLE 5.4

INDEX GAUGE SUMMARY
FOR PRORATION METHODOLOGY

Region	Station	Period of Record	Length of Record (years)	Type	Drainage Area (km^2)	Record Quality
A	04DC002	1972-1986	15	natural	4 710	average
	04FC001[1]	1968-1986	19	natural	36 000	average
B	04DA001	1967-1986	20	natural	5 960	average
C	02BA002	1970-1986	17	natural	1 190	above average
D	04LJ001	1921-1986	66	natural	8 940	above average
E	02HL004	1959-1986	28	natural	671	above average
F1	02MC001	1961-1986	26	natural	358	average
F2	02ED003	1950-1986	37	natural	1 180	average
F3	02FE008	1968-1986	19	natural	648	above average
F4	02GG002	1949-1986	38	natural	730	above average
F5	02GC010	1961-1986	26	R2	342	average
F6	02HA006	1958-1986	29	natural	293	average
F7	02HC025	1963-1986	24	natural	303	average
F8	02EC011	1967-1986	20	natural	282	average

[1]Assumed to be representative of all stations having drainage area greater than 25 000 km^2.

annual discharge. Typically this error was not greater than 5% and often was less than 1%.

(b) Errors in estimating the coefficients (C, θ, α) required for ungauged catchments. Errors involved in predicting these coefficients include the following.

- Measurement of basin physiographic and climatic data. Although not measurable, errors of this type can occur. As well, these types of errors could have been included with the independent variables used for regression analyses.

- From the regression equations. The errors that result from not being able to explain 100% of the variation of the dependent variable for a given sample. Their magnitude varies depending on the quality of the regression equations.

(c) Errors in estimating the mean annual flow at an ungauged site.

The sensitivity of either the regression equations for C, θ, α or the resulting turbinable flow estimate as a function of extraction/estimation errors in the independent variables was not analyzed for all the gauges in each region. Sensitivity analysis of this type was, however, completed for the three test gauges selected in Regions B, E and F as discussed in Section 8.

5.5.2 - Comparison of Methodologies

The overall error resulting from the application of the recommended methodologies was assessed by comparing estimated and actual turbinable flow for various design flows and storages at all gauges used in the analysis. (This does not in any way limit the analysis only to hydropower applications; rather, it is also applicable to requirements of other water users). The actual turbinable flow was computed from daily simulation analyses of the data. The estimated turbinable flow was determined by daily simulation of each synthetic record using both techniques (proration and flow duration).

One gauge in each of Regions B, E and F was initially set aside for verification. The data for these gauges were not included in any of the regression equations or related analyses. These gauges thus serve as a completely independent means to test the methodologies in these regions. The results of this independent testing are discussed fully in Section 8.

The simulation analyses evaluated turbinable flow for installed capacities ranging from 0.25 to 4 times the mean annual flow and for additional live storage volumes varying from 0 to 0.2 times the mean annual flow volume. For each of the storages and installed capacities, the turbinable flow was calculated using each methodology and compared with the value derived using the actual flow records. Tables 5.5, 5.6 and 5.7 contain comparisons of the absolute errors for both methodologies in Regions B, E and F. Index stations were neglected from the error comparison as the zero errors associated with prorating an index station to itself would unfairly bias the results. The errors given include all incurred errors in the methodology such as those attributable to differences between actual and map (Plates 3 and 4) estimates of MAR. The differences associated with MAR are shown separately.[1]

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[1]These differences in MAR may or may not be actual errors. The differences may well reflect the 'wet' or 'dry' biasing that is possible for short records and, as a result, the values of MAR contained on Plates 3 and 4 may be better indicators of the long-term basin MAR than the actual gauge records.

TABLE 5.5

REGION B -
AVERAGE ABSOLUTE ERROR
(expressed as a percent)

		Proration Methodology					Flow Duration Curve Methodology				
		Storage (Ratio to Mean Flow Volume)					Storage (Ratio to Mean Flow Volume)				
Station	MAR Difference (%)	0	0.05	0.1	0.2	Average	0	0.05	0.1	0.2	Average
04CA003	0.1	8.7	6.4	4.3	2.2	5.4	2.2	1.9	1.5	1.6	1.8
04CB001	1.9	12.6	7.1	4.9	1.6	6.6	9.0	4.5	2.6	0.3	4.1
04CD001	0.1	1.6	1.7	2.2	1.5	1.8	1.4	0.3	0.2	0.1	0.5
04CD002	-1.3	15.0	10.1	7.7	4.1	9.2	0.8	0.2	0.9	1.3	0.8
04CE002	-2.0	18.5	12.0	8.8	4.8	11.0	4.8	2.4	2.1	2.1	2.8
04DA002	-0.1	12.3	8.2	6.3	3.1	7.5	1.2	0.1	0.0	0.1	0.4
04DB001	-0.2	3.5	2.2	1.7	1.1	2.1	7.6	6.1	4.7	1.9	5.1
04DB002	0.1	2.2	2.9	2.6	1.8	2.4	8.7	5.6	3.9	1.2	4.9
04FA001	4.2	0.6	1.4	1.7	2.9	1.7	7.5	6.6	6.0	5.9	6.5
04FA002	5.3	1.2	1.2	2.0	3.5	2.0	0.9	0.4	1.0	3.1	1.4
04FA003	3.4	3.6	1.9	0.8	1.4	1.9	0.8	1.5	1.5	0.1	0.9
04FB001	3.2	1.0	0.3	0.6	1.6	0.9	7.4	6.2	5.9	4.7	6.0
04GA002	-11.9	23.3	17.7	15.8	13.7	17.6	14.2	12.5	12.0	12.2	12.7
04GB004	-1.0	16.7	13.5	12.6	12.7	13.9	6.7	9.5	10.7	12.7	9.9
04JF001	4.4	2.0	1.1	0.3	2.2	1.4	2.2	1.9	2.4	4.4	2.7
05PA006	-0.7	6.0	3.3	2.8	1.7	3.4	5.9	3.3	2.3	1.0	3.1
05PA012	-0.5	0.6	1.3	0.8	0.4	0.8	1.4	0.1	0.3	0.4	0.5
05PB014	-0.8	3.8	1.7	1.1	0.1	1.7	1.1	0.2	0.7	1.4	0.8
05QC003	-1.2	14.2	9.4	6.7	3.4	8.4	4.6	3.3	1.9	0.9	2.7
05QE008	-2.8	10.9	6.5	4.4	1.9	5.9	2.8	2.7	1.8	0.6	2.0
05QE009	1.5	0.0	1.3	1.7	1.5	1.1	1.7	0.1	1.2	1.5	1.1
Average		7.5	5.3	4.3	3.2	5.1	4.4	3.3	3.0	2.7	3.4
Maximum		23.3	17.7	15.8	13.7	17.6	14.2	12.5	12.0	12.7	12.7
σ		6.9	4.8	4.0	3.4	4.6	3.6	3.3	3.2	3.5	3.2

TABLE 5.6

REGION E -
AVERAGE ABSOLUTE ERROR
(expressed as a percent)

		Proration Methodology					Flow Duration Curve Methodology				
		Storage (Ratio to Mean Flow Volume)					Storage (Ratio to Mean Flow Volume)				
Station	MAR Difference (%)	0	0.05	0.1	0.2	Average	0	0.05	0.1	0.2	Average
02CE002	0.6	12.1	10.0	8.4	4.4	8.7	5.195	4.406	3.285	0.557	3.4
02CF007	0.1	1.8	1.8	1.9	0.9	1.6	6.228	4.294	3.783	2.208	4.1
02EA005	4.1	4.8	4.2	3.6	1.6	3.6	7.537	5.423	4.823	4.082	5.5
02EA008	-0.0	13.7	11.4	9.9	5.1	10.0	1.182	1.305	1.019	0.634	1.0
02EA010	1.3	3.6	6.3	6.0	4.6	5.1	7.962	2.803	1.925	0.728	3.4
02EC002	-6.0	11.9	10.7	10.1	8.3	10.2	6.234	5.851	5.643	5.067	5.7
02FA001	-2.7	9.7	9.8	8.8	6.5	8.7	2.172	3.394	2.995	2.323	2.7
02HL005	-2.6	2.6	1.3	0.8	0.5	1.3	1.394	2.992	3.099	3.268	2.7
02HM001	1.0	3.6	3.4	3.3	3.9	3.6	0.068	0.038	0.327	2.154	0.6
02HM003	-2.2	5.7	5.2	4.4	3.2	4.6	8.576	7.889	6.750	4.403	6.9
02KC014	-1.8	1.2	1.8	1.5	0.4	1.2	0.197	0.651	1.057	1.593	0.9
02KF011	-0.4	20.9	16.1	14.4	10.7	15.5	13.742	8.389	7.108	4.801	8.5
02LA006	1.3	11.5	9.4	8.8	6.2	9.0	2.033	2.520	1.883	1.960	2.1
02LA007	0.3	19.5	15.7	14.1	11.1	15.1	12.248	8.288	7.322	5.907	8.4
Average		8.8	7.7	6.9	4.8	7.0	5.300	4.200	3.600	2.800	4.0
Maximum		20.9	16.1	14.4	11.1	15.5	13.700	8.400	7.300	5.900	8.5
σ		6.2	4.8	4.3	3.4	4.6	4.200	2.600	2.300	1.700	2.6

TABLE 5.7

REGION F -
AVERAGE ABSOLUTE ERROR
(expressed as a percent)

Station	MAR Difference (%)	Proration Methodology Storage (Ratio to Mean Flow Volume) 0	0.05	0.1	0.2	Average	Flow Duration Curve Methodology Storage (Ratio to Mean Flow Volume) 0	0.05	0.1	0.2	Average
02EC012	0.1	3.3	4.0	3.9	3.0	3.6	6.0	8.7	8.1	3.1	6.5
02ED005	-2.0	8.3	6.0	5.6	4.7	6.2	0.2	4.3	3.5	0.5	2.1
02ED007	-1.2	25.3	22.7	19.3	8.6	19.0	5.5	2.3	2.2	1.4	2.9
02FB007	-3.2	6.7	6.8	6.8	5.8	6.5	3.2	0.9	0.8	2.1	1.8
02FB010	-2.7	3.2	4.4	4.3	3.8	3.9	0.6	3.1	3.2	0.2	1.8
02FC001	-0.9	5.9	4.6	4.4	3.2	4.5	1.5	5.6	4.8	1.1	3.3
02FC002	-1.4	8.7	5.1	4.9	3.7	5.1	0.7	4.8	4.1	0.5	2.5
02FC004	-0.0	20.3	14.1	10.7	4.1	12.3	0.7	2.3	1.3	0.7	1.2
02FC011	-3.0	0.1	2.5	2.7	3.1	2.1	9.0	7.2	5.6	0.6	5.6
02FC012	-1.4	7.6	4.5	2.7	0.3	3.8	3.9	6.3	6.0	1.6	4.4
02FC015	-1.7	1.4	0.3	1.0	1.6	1.1	3.4	8.3	7.2	2.4	5.3
02FE002	-3.3	10.4	8.9	6.8	4.9	7.7	8.0	7.8	7.0	3.1	6.5
02FE004	-2.5	13.6	10.5	8.0	5.7	9.5	7.6	8.1	7.4	3.2	6.6
02FE005	-2.5	18.0	14.0	10.4	7.4	12.5	4.4	5.5	5.5	1.6	4.2
02FE007	-3.6	15.5	11.6	9.4	7.5	11.0	4.0	5.6	4.7	0.5	3.7
02FE009	-5.6	2.7	5.3	5.0	4.9	4.5	8.4	6.3	5.0	0.9	5.1
02FE010	0.1	14.2	9.1	8.3	6.7	9.6	14.8	12.9	12.3	9.1	12.3
02FF007	-4.3	8.3	7.2	5.2	0.4	5.3	10.9	8.1	6.0	1.4	6.6
02GA017	0.6	18.0	9.0	8.0	7.6	10.6	22.5	15.3	13.7	11.0	15.6
02GA018	-4.3	4.0	3.0	2.7	1.8	2.9	10.6	5.7	5.3	3.1	6.2
02GA022	-0.2	8.8	6.7	7.2	7.9	7.6	14.5	13.9	13.7	12.0	13.5
02GA029	-4.6	40.8	28.3	22.0	14.3	26.4	3.8	0.4	0.8	3.8	2.2
02GA038	-6.0	14.7	2.1	0.8	1.2	4.7	13.9	4.9	4.0	0.6	5.9
02GA040	-7.2	20.8	17.1	14.4	12.2	16.1	8.5	5.5	2.9	3.5	5.1
02GB001	-4.5	32.9	24.1	18.8	12.5	22.1	3.0	0.6	0.6	2.4	1.7
02GB008	-5.6	29.9	22.3	18.0	11.8	20.5	0.4	2.0	1.2	2.2	1.4
02GC002	-2.2	23.9	11.1	7.2	2.1	11.1	12.2	2.7	1.3	1.0	4.3
02GC006	-6.1	18.7	12.0	9.5	7.7	12.0	6.3	2.2	2.5	5.1	4.0
02GC018	-3.8	19.9	7.8	4.5	0.2	8.1	8.6	0.1	0.7	2.2	2.9
02GD001	6.1	15.8	10.7	7.2	2.1	9.0	9.3	10.8	10.7	9.0	10.0
02GD004	-3.8	11.2	11.3	9.3	6.5	9.6	8.0	8.0	4.9	1.5	5.1
02GD005	-3.6	5.4	7.7	6.5	5.0	6.1	4.5	3.2	3.0	0.8	2.9
02GD012	-3.8	16.4	14.6	12.0	8.3	12.8	3.4	3.3	2.7	0.2	2.4
02GD014	-5.8	13.3	6.0	4.7	3.8	6.9	18.5	13.1	11.3	7.7	12.7
02GD015	-4.2	7.6	9.1	7.9	6.2	7.7	5.9	4.6	3.8	0.7	3.8
02GE003	-5.0	10.7	5.1	3.9	4.5	6.0	2.8	0.7	1.1	1.4	1.5
02GE006	-4.6	11.8	6.3	5.1	5.2	7.1	3.3	0.1	0.3	1.8	1.4
02GG004	0.6	18.6	12.9	9.5	5.3	11.6	9.5	5.9	4.4	2.7	5.6
02GG006	-4.4	18.1	9.3	5.3	0.7	8.4	2.8	2.2	3.1	3.6	2.9

Table 5.7
Region F - Average Absolute Error
(expressed as a percent) - 2

		Proration Methodology					Flow Duration Curve Methodology				
		Storage					Storage				
	MAR	(Ratio to Mean Flow Volume)					(Ratio to Mean Flow Volume)				
Station	Difference (%)	0	0.05	0.1	0.2	Average	0	0.05	0.1	0.2	Average
02GG007	0.2	2.3	2.2	0.9	0.1	1.4	2.3	2.2	0.9	0.1	1.4
02HB002	-0.6	5.5	3.7	3.1	1.4	3.4	5.1	5.3	4.4	1.3	4.0
02HB011	-4.7	83.5	45.9	33.0	20.2	45.7	1.7	0.3	1.0	3.8	1.7
02HC003	-4.4	16.5	11.5	9.0	4.5	10.4	7.4	7.3	6.5	3.0	6.1
02HC024	-3.9	0.5	7.5	6.3	4.1	4.6	0.2	6.8	5.7	4.6	4.3
02HD002	-12.2	12.3	13.9	13.0	13.8	13.2	10.0	10.7	11.5	13.8	11.5
02HJ003	-3.5	5.8	3.3	2.6	1.2	3.2	7.9	12.5	11.0	4.6	9.0
02LB006	0.3	6.4	5.6	4.9	3.8	5.2	29.3	27.5	24.9	17.3	24.7
02LB007	0.0	0.2	0.9	1.1	1.5	0.9	4.8	9.7	11.3	9.7	8.9
02ED103	-0.0	16.6	12.8	10.7	4.8	11.2	30.8	16.3	11.0	4.6	15.7
02GA010	-3.8	19.5	17.2	13.8	9.8	15.1	21.6	13.1	8.2	0.9	10.9
02GC004	0.1	8.4	4.5	3.3	1.3	4.4	8.9	2.9	0.9	0.2	3.2
02GD003	-9.6	8.5	10.1	9.1	8.1	9.0	16.0	11.9	8.1	0.1	9.0
02GD008	-11.1	9.8	12.6	11.6	9.9	11.0	5.1	2.1	0.8	3.7	2.9
02GE002	-5.8	19.2	16.2	13.1	9.6	14.5	0.3	0.2	0.2	2.5	0.8
Average		13.9	10.1	8.1	5.8	9.4	7.7	6.3	5.4	3.3	5.7
Maximum		83.5	45.9	33.0	20.2	45.7	30.8	27.5	24.9	17.3	24.7
σ		12.7	7.7	5.9	4.1	7.3	6.8	5.2	4.6	3.7	4.6

Representative errors associated with average energy generation were evaluated by examining the case where the installed capacity is based on a flow twice the mean annual flow. At larger installed capacities and at larger storage volumes, errors in estimating turbinable flows are generally damped out. The extreme example is the case of 100% regulation on the river with all flow passing through the turbine. Under these circumstances, error is attributable only to error in estimating the MAR. An inspection of Tables 5.5 to 5.7 indicates that regional errors arising from the flow duration curve methodology are consistently smaller than those of the proration methodology for any storage condition in terms of

- lower maximum error
- lower average error
- lower standard deviation.

Therefore, it is concluded that the flow duration methodology is preferable to the proration approach in Regions B, E and F.

6 - DESIGN FLOW HYDROLOGY FOR GAUGED CATCHMENTS

6 - DESIGN FLOW HYDROLOGY FOR GAUGED CATCHMENTS

The emphasis in this study has been directed toward hydrologic evaluations at ungauged sites. In some cases, the chosen sites may be located on the same river or in a basin containing streamflow measurements. In these circumstances, it is usually preferable to make use of the data from the gauged location. The balance of this section discusses hydrologic methodologies for the following two cases

- ungauged sites with a gauge in the basin which has a long record length
- ungauged sites with a gauge in the basin which has a short record length.

6.1 - Methodology for Sites with a Long Record Length Gauge in the Basin

If a particular site has a gauge in the same basin which has a long record length, it is likely that proration based on drainage area and MAR will be most suitable especially if the site is located on the same river as a gauge with a long record length. However, engineering judgment must be applied in order to assess the similarity in physiographic characteristics of the gauged and ungauged portions of the basin. If they are quite different, it is possible that the suggested approach will require some modification. However, even if they are significantly different, the approach is still likely to yield results which are similar in quality to those generated using the regional techniques.

The appropriate equation for prorating the discharge is

$$Q_{ijk} = QG_{ijk} \, (A * MAR)/(AG * MARG) \qquad (6\text{-}1)$$

where

QG = measured discharge at the gauged location

AG = drainage area to the gauged location

MARG = mean annual runoff at the centroid of the gauged basin.

Note that if there is no discernable difference in the MAR of the gauged and ungauged locations, then the flow sequence at the ungauged site may be obtained directly by the ratio of drainage areas.

6.2 - Methodology for Sites with a Short Record Length Gauge in the Basin

Prior to constructing any but the smallest hydroelectric facility, it is common to install a hydrometric gauge at or near the site (or sites) of interest. Typically there will be fewer than 5 years of data available from these gauges. The following subsections explain how to extend this short record in order to create a reference hydrology for power and energy simulations. These techniques are general guidelines and a specific situation may require the application of alternative methodologies.

6.2.1 - Flow Duration Curve Methodologies

The techniques for synthesizing a hydrologic record at an ungauged site using flow duration curves are explained in detail in Section 5.3. The component of this methodology which has the largest inherent error is the estimation of a flow duration curve for an ungauged site. The easiest way to use the short record of data is to develop a flow duration curve from the available daily data. Because the record length is short, it is possible that the two extreme ends of the curve will require adjustment. The reason for the adjustment is because the short record will not likely contain a suitable sampling of extreme events (both low flows and flood flows).

As shown in Figure 6.1, the short-term hydrology at the site of interest is adjusted by prorating hydrology of the equivalent period to long-term record at a nearby or index gauge.

It should always be remembered that any site-specific data are better than none and maximum use should be made of these data.

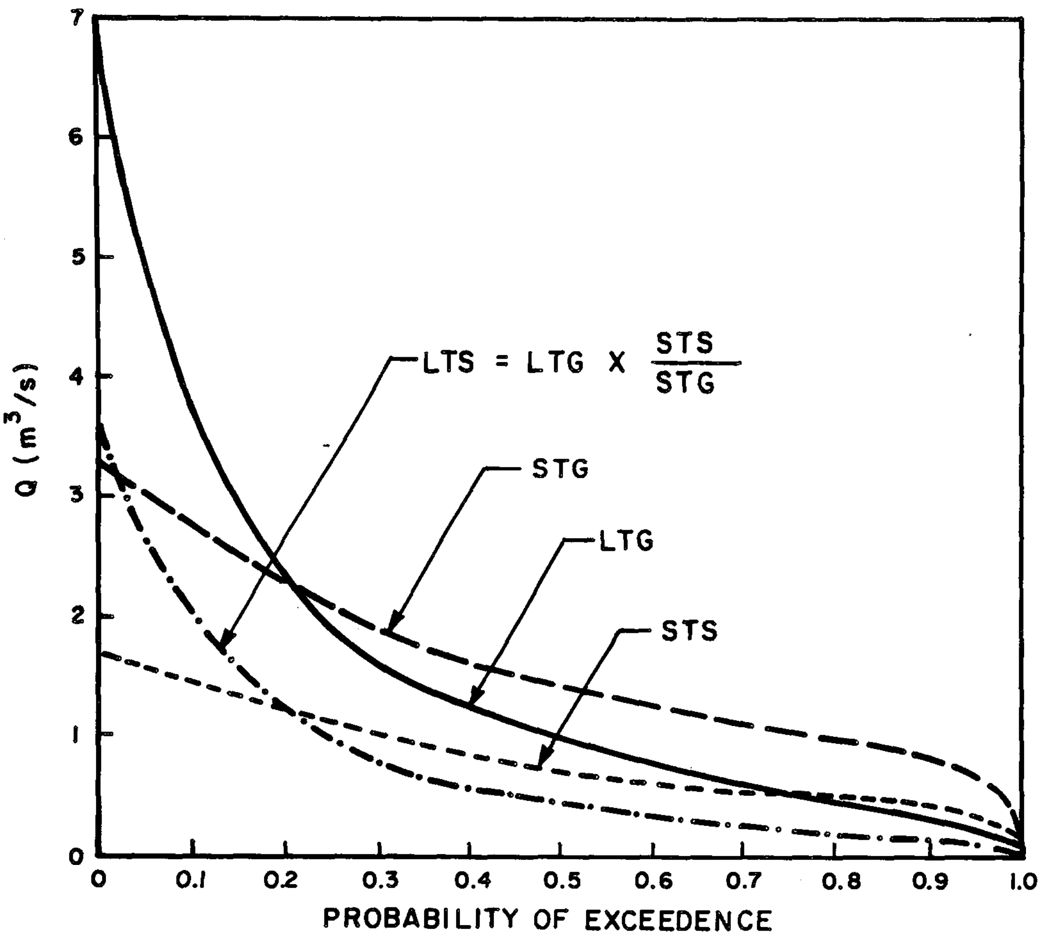
The techniques of Section 5.3.3 for generating a synthetic daily flow series can be used with the site-specific flow duration curve in order to synthesize a long period reference hydrology. These techniques rely on the use of an index gauge in each region.

If the specific location, for which the short record flow duration curve is to be developed, is not at the project site (but still commands a substantial part of the catchment) then the synthesized record should be prorated based on drainage area (and possibly MAR).

6.2.2 - Cross-Station Correlations

It is not possible, within the context of the current study, to explain this technique in detail. It requires site-specific engineering judgment and hydrologic evaluation. It is explained conceptually, however, so that users will be aware of its potential.

In many cases where a short record is available at a particular site, a long record gauge can be found in an adjoining or nearby basin. In these situations, it is frequently possible to develop correlations between monthly, seasonal or annual flows for the period of overlapping record. The developed relationships are



LEGEND

GIVEN — LONG TERM DAILY DISCHARGE RECORD AT NEARBY OR INDEX GAUGE (m^3/s)

— — SHORT TERM DAILY DISCHARGE RECORD AT SITE OF INTEREST (m^3/s)

- - - SHORT TERM DAILY DISCHARGE RECORD AT NEARBY OR INDEX STATION (m^3/s) (CORRE- SPONDS TO SAME PERIOD OF RECORD AS RECORDED AT THE SITE OF INTEREST)

ESTIMATED -·-·- LONG TERM DAILY DISCHARGE RECORD AT SITE OF INTEREST (m^3/s)

Fig. 6.1

ENVIRONMENT OF CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

FLOW DURATION CURVE FOR SHORT TERM PERIOD OF RECORD

ACRES

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then applied using data from the longer record length gauge to generate an equally long, partially synthetic record at the gauge of interest.

There are techniques which are available to further decompose the partially synthetic monthly, seasonal, or annual flow series into a synthetic daily flow series.

7 -- COMPUTER MODELS

7 - COMPUTER MODELS

The methodologies for generating hydrologic data at ungauged or sparsely gauged sites (Sections 5 and 6) have been incorporated into one computer program. A second computer program uses the generated flow data to estimate the power and energy capabilities of a proposed plant.

In addition, a program to estimate flood flows of the various magnitudes in the Province of Ontario is provided.

These programs are summarized below and in the following subsections. For a more complete discussion on the application methodology, the input requirements and the output of these computer programs, the reader is referred to Volume 2 of this study - 'Applications Manual'.

(a) HYSIMONT - A program to generate synthetic hydrologic data in the Province of Ontario using the techniques of Sections 5 and 6.

(b) ENERGY - A program to estimate the power and energy capabilities of a site using

- output from HYSIMONT
- plant characteristics
- plant operating rules
- storage characteristics.

(c) FLOODONT - This program was written by Acres (1988) to estimate flood peaks for various return periods using either the index flood method, a composite index flood method or a regional regression approach. The program is based entirely on the studies by Moin and Shaw (1985, 1986).

The following reports should be reviewed prior to applying this program.

- 'Regional Flood Frequency Analysis for Ontario Streams - Volume 1, Single Station Analysis and Index Method' (1985)

- 'Regional Flood Frequency Analysis for Ontario Streams - Volume 2, Multiple Regression Method' (1986)

These programs are all written in FORTRAN specifically for use on an IBM-PC or compatible microcomputer with a minimum of 512 K RAM. The programs are written to be compatible with the Ryan McFarlane compiler. This version of FORTRAN is a subset of FORTRAN-77, and therefore the programs can be run on any computer with this capability. However, it is anticipated that minor changes to statements may be required if the programs are used on other types of computers. The program listings are quite lengthy and, therefore, are not presented in this report. However, the programs are available in a set of floppy diskettes (double sided/double density, 360 K) from the Inland Waters Directorate, Ottawa or Ontario Region (Burlington). Sample data files and output are also included on the diskettes. This information should be used to check the accuracy of the programs, if they are altered for use on another computer.

The next three subsections present the programs in detail.

7.1 - Hydrologic Data Generation in the Province of Ontario - HYSIMONT

This program incorporates the techniques of Sections 5 and 6. The program structure is mainly interactive; however, two data files are required for two of the four available program options. All pertinent data and data files are prompted on the screen by the computer for whichever region and technique is selected.

Figure 7.1 is a general program flowchart showing the available program options and interactive commands. The program output is directed to two computer files.

(a) Daily Data - This file contains generated daily data in a format suitable for use in the ENERGY program (Section 7.2).

(b) Summary - This file contains a summary of the generated data at a monthly level. Monthly means and standard deviations of daily data within each month are included.

7.2 - Power and Energy Simulation - ENERGY

This program uses the generated hydrologic data to estimate the power and energy characteristics of a plant of interest. The program is based on a water balance simulation model. For each day of the generated data period, the model determines whether water is spilled, turbined or stored, depending on the operating characteristics which are included in the model. The program then calculates monthly summaries of the water balance and the power and energy capabilities of the site.

Table 7.1 lists the data required for the model in two separate categories (plant characteristics and operating policies). Table 7.2 lists the output summaries which can be provided by the model.

7.3 - Flood Estimation in Ontario - FLOODONT

This program was written by Acres (1988) but is based entirely on the studies by Moin and Shaw (1985, 1986). The flood peak estimation routines can be used for either the index flood or the regional

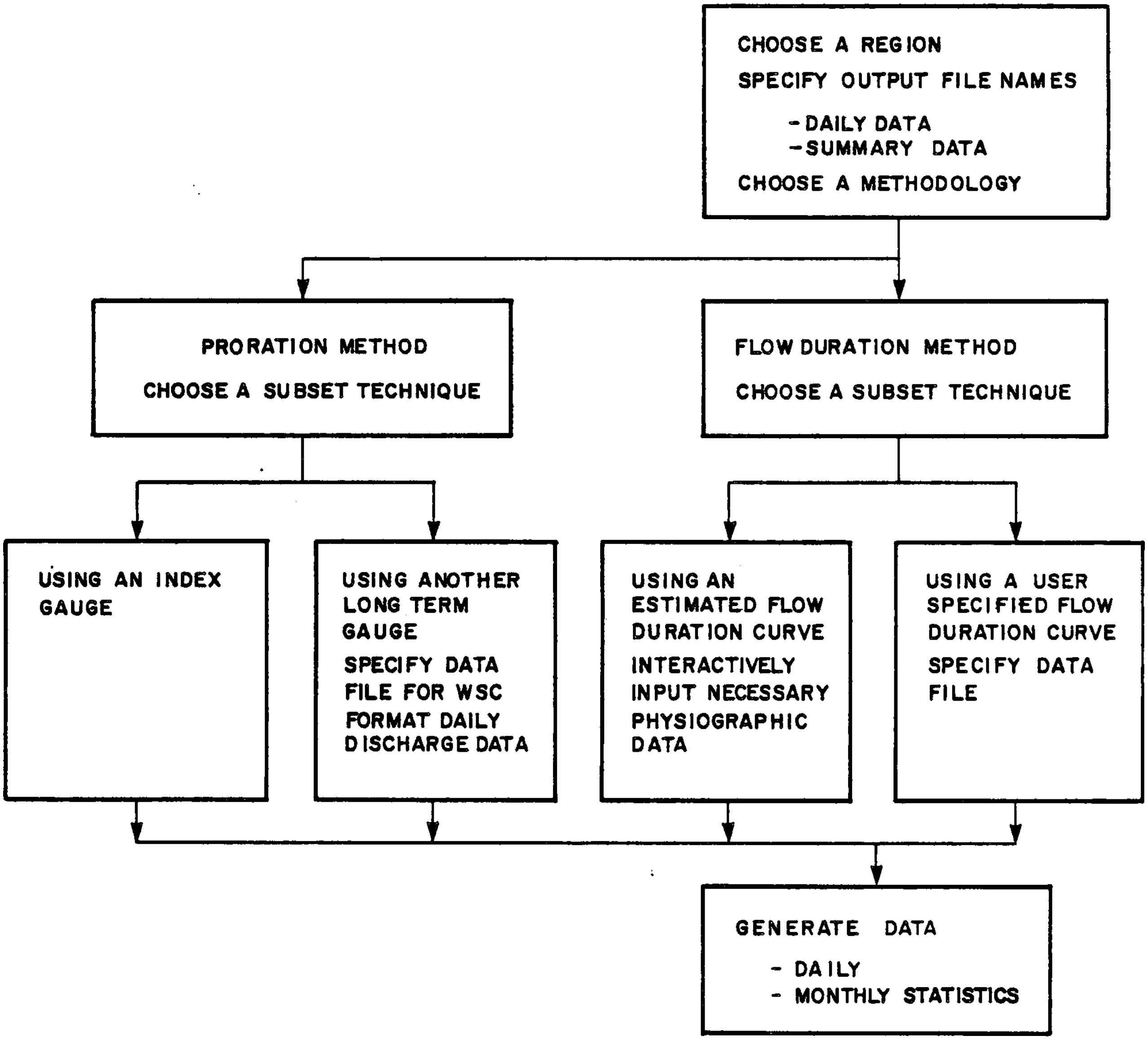


FIG. 7.1

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

HYSIMONT- GENERAL FLOW CHART

ACRES

TABLE 7.1

REQUIRED DATA FOR THE ENERGY PROGRAM

Plant Characteristics

- Installed capacity
- Gross design head
- Percent head loss
- Efficiency
- Reservoir elevation/area curve
- Reservoir elevation/spillway discharge curve
- Tailwater elevation/discharge curve

Plant Operating Policy

- Firm energy demand
- Value of firm energy
- Value of secondary energy
- Cost of not meeting firm energy
- Monthly rule curves of
    - maximum reservoir elevation
    - minimum reservoir elevation
    - secondary reservoir elevation (above this elevation, secondary energy is produced; below this elevation, only firm energy is produced)
- Monthly minimum release requirement
- Monthly rainfall and evaporation on the reservoir surface

TABLE 7.2

OUTPUT SUMMARIES FOR THE ENERGY PROGRAM

- Overall characteristics (total, secondary and firm energy; water balance data and revenue data)
- Monthly reservoir outflows
- Monthly energy generation
- Monthly firm energy generation
- Monthly deficit between achieved and demanded firm energy
- Monthly secondary energy generation
- Minimum daily energy within month
- Number of days per month where firm demand was not achieved
- Monthly power flow
- Monthly spill flow
- Monthly reservoir release
- Month end reservoir volumes
- Maximum reservoir elevation in each month
- Minimum reservoir elevation in each month
- Monthly value of total energy
- Monthly value of firm energy
- Monthly cost of not achieving firm demand
- Monthly value of secondary energy

regression methods. Maximum instantaneous flood flows are estimated. The flood peak routines are completely interactive with screen prompts for the necessary physiographic data.

Figure 7.2 is a general program flowchart showing the available program options and interactive commands.

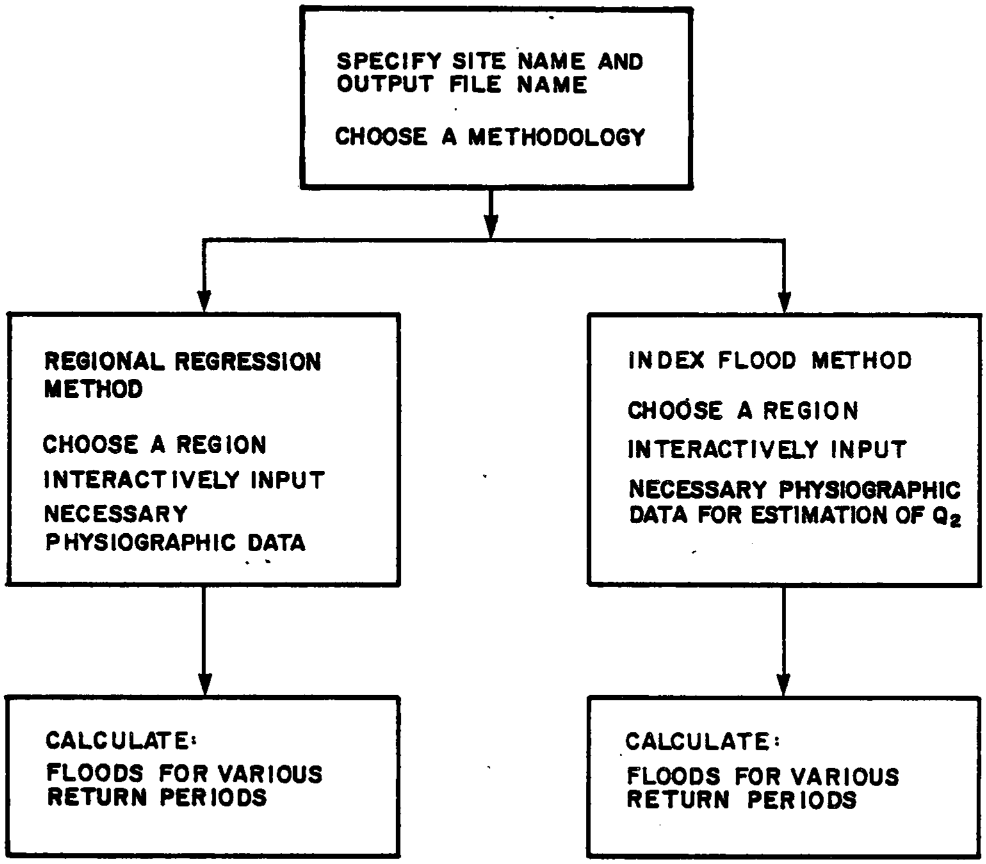


FIG. 7.2

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

FLOODONT - GENERAL FLOW CHART

ACRES

8 - SAMPLE APPLICATIONS AND SENSITIVITY ANALYSIS

8 - SAMPLE APPLICATIONS AND SENSITIVITY ANALYSIS

Three stations were selected to demonstrate the application of the design flow methodologies in estimating potential power and energy generation. The three gauges have been chosen in Regions B, E and F. Table 8.1 lists their basic characteristics and those of the gauges nearest to them. To eliminate bias in demonstrating and testing the methodologies, the three sites were not used in developing the regional regression relationships.

This section of the report has two purposes

- to demonstrate the methodologies

- to provide the reader with a sense of the potential error incurred using the methodologies. Errors resulting both from approximations of the methodologies and from inaccuracies in the estimates of physical and climatic characteristics are examined.

8.1 - Applications

The three test gauges are located in Regions B, E and F where the regression-based methodology was found appropriate. For the purposes of demonstration, however, the basins were tested using the methodologies presented in Table 8.2. In each case, the inventory of hydroelectric potential compiled by MNR was used to choose characteristic design heads for the sites.

8.1.1 - Site at Gauge 02GA039 - Conestoga River

The Conestoga River is located in Region F in the southwestern part of Ontario. The selected site was assumed to have a representative gross design head of about 3.6 m.

TABLE 8.1

DESCRIPTION OF NEAREST GAUGES TO TEST GAUGES

Test Gauge				Nearest Gauge					
Station	**Description**	**Drainage Area (km^2)**	**Mean Annual Runoff (mm)**	**Station**	**Description**	**Drainage Area (km^2)**	**Mean Annual Runoff (mm)**	**Proration Factor**[1]	**Comments**
02GA039	Conestoga River above Drayton	265	350	02GA017	Conestoga River at Drayton	324	352	0.81	Nearest gauge is slightly downstream of the test gauge on the same river in the same basin.
02EA006	Magnetawan River near Burk's Falls	640	525	02EA005	North Magnetawan River near Burk's Falls	321	552	1.90	Nearest gauge is a tributary to the test gauge in the same basin.
05QA004	Sturgeon River at McDougal Mills	4455	275	04GA002	Cat River below Wesleyan Lake	5390	256	0.89	Nearest gauge is in a nearby basin to test gauge.

---

[1] Proration factor is calculated as $\frac{A * MAR}{AG * MARG}$

where

A, AG = basin drainage area at the ungauged site, nearest gauge respectively (km^2)
MAR, MARG = mean annual runoff at the centroid of the ungauged site basin, nearest gauge basin respectively (mm).

TABLE 8.2

HYDROLOGIC METHODOLOGIES
USED IN SAMPLE APPLICATIONS

Region	Site	Proration Index Gauge	Proration Nearest Gauge	Flow Duration
B	05QA004			X
E	02EA006	X	X	X
F	02GA039		X	

The flow duration methodology was the recommended regional approach for synthetic streamflow generation in Region F. Gauge 02GA039 has a nearby gauge in the basin. Based on the conclusions of Section 6, the proration to the nearest gauge methodology is expected to be the most accurate approach. Station 02GA017 is the nearest gauge on the Conestoga River which has 22 years of record from 1951 to 1972. The proration factor was calculated in the following manner using estimates at the ungauged sites of drainage area [from 1:50 000-scale National Topographic System (NTS) maps] and MAR (at the basin centroid from Plate 3).

- drainage area above Gauge 02GA017 — 324 km^2
- MAR of 02GA017 catchment — 352 mm
- drainage area above site — 265 km^2
- MAR of site catchment — 350 mm
- proration factor $= \frac{(265)(350)}{(324)(352)} =$ 0.814

The daily flows at the test site were generated by multiplying the daily flows at the nearest gauge by the proration factor.

Table B.1 of Appendix B is a monthly summary table of the hydrologic data generated using HYSIMONT.

To estimate the potential power and energy, it was assumed that this site would develop significant storage of 19 $m^3 x10^6$ amounting to about 20% of the mean flow volume of 93 $m^3 x10^6$/yr.

It was also assumed the potential power plant would have the following characteristics

- efficiency — 85%
- gross design head — 3.6 m
- head loss — 5%

- net design head	3.4 m
- maximum reservoir elevation (full supply level)	100 m
- minimum reservoir elevation (dead storage level)	98 m
- constant tailwater level	95.4 m.

Table 8.3 is a summary table of results from a series of runs with the computer program ENERGY using various installed capacities. Figure 8.1 is a plot of the annual energy production versus installed capacity. Note, at larger capacities, the power flow increases without a corresponding increase in energy. In fact, for an installed capacity greater than 0.4 MW, the average energy actually decreases. Here, the average operating reservoir level decreases while less additional water is 'captured' for incremental increases in installed capacity.

In feasibility study applications, this information would be used in an economic analysis to determine the optimum installed capacity. Normally such analysis would also include an assessment of the firm energy capability of the site. In this example, the firm energy demand was specified in the program ENERGY to be zero.

8.1.2 - Site at Gauge 05QA004 - Sturgeon River

The Sturgeon River is located in Region B in the northwest part of Ontario. A hypothetical run-of-river, small-scale hydro site having 2.5-m gross head was assumed to exist near the gauge, as no potential sites were identified along this river.

As outlined in Section 5.5.2, the flow duration curve methodology was selected as the best technique in this region and, in particular, for this site. There were no nearby streamflow gauges in the same river basin with acceptable periods of record.

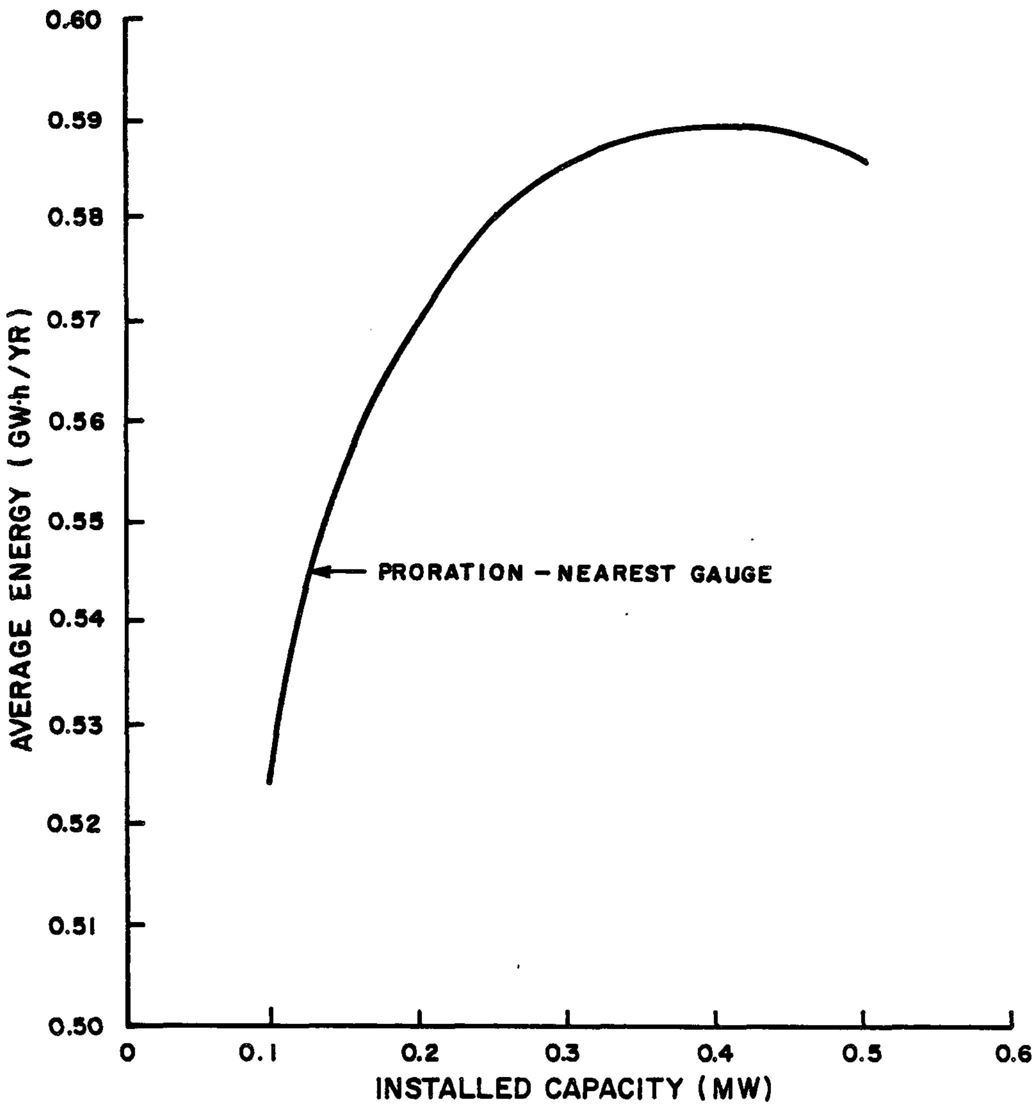


FIG. 8.1

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

POWER AND ENERGY FOR STATION 02GA039

ACRES

TABLE 8.3

POWER AND ENERGY EVALUATION - 02GA039

Installed Capacity (MW)	Average Energy (GW·h/yr)	Power (m^3/s)	Spill (m^3/s)
0.10	0.524	2.12	0.82
0.20	0.570	2.51	0.44
0.25	0.581	2.60	0.34
0.30	0.587	2.67	0.27
0.50	0.586	2.81	0.13

In Region B, the regression relationships require that the MAR, drainage area, drainage area controlled by lakes and swamps, and latitude be estimated. The MAR values were obtained from Plate 4 while the remainder of the data were estimated from 1:250 000-scale NTS maps. The values obtained for Site 05QA004 are as follows

- drainage area	4455 km^2
- MAR	275 mm
- latitude	50.122 degrees
- area controlled by lakes and swamps	100%.

The computer program HYSIMONT was run to generate a daily time series at this site. Table 5.2 or Table A.2 of Appendix A show each of the independent variables to lie within the ranges experienced in fitting the regression relationships. We therefore have some confidence in the estimated values. Table B.2 in Appendix B is a monthly summary of the generated data.

It is assumed that this run-of-river plant has daily storage capabilities. Other assumed plant characteristics include

- efficiency	85%
- gross design head	2.5 m
- head loss	5%
- net design head	2.4 m
- constant head pond level	100 m
- constant tailwater level	97.6 m.

Table 8.4 is a summary table of the results from a series of runs with computer program ENERGY using various installed capacities. Figure 8.2 is a plot of the expected annual energy generation versus installed capacity.

TABLE 8.4

POWER AND ENERGY EVALUATION - 05QA004

Installed Capacity (MW)	Average Energy (GW·h/yr)	Power (m^3/s)	Spill (m^3/s)
0.4	2.99	17.20	21.65
0.8	4.67	26.91	11.94
1.2	5.55	31.99	6.87
1.5	5.91	34.05	4.80
2.3	6.36	36.64	2.21
3.1	6.63	38.21	0.65

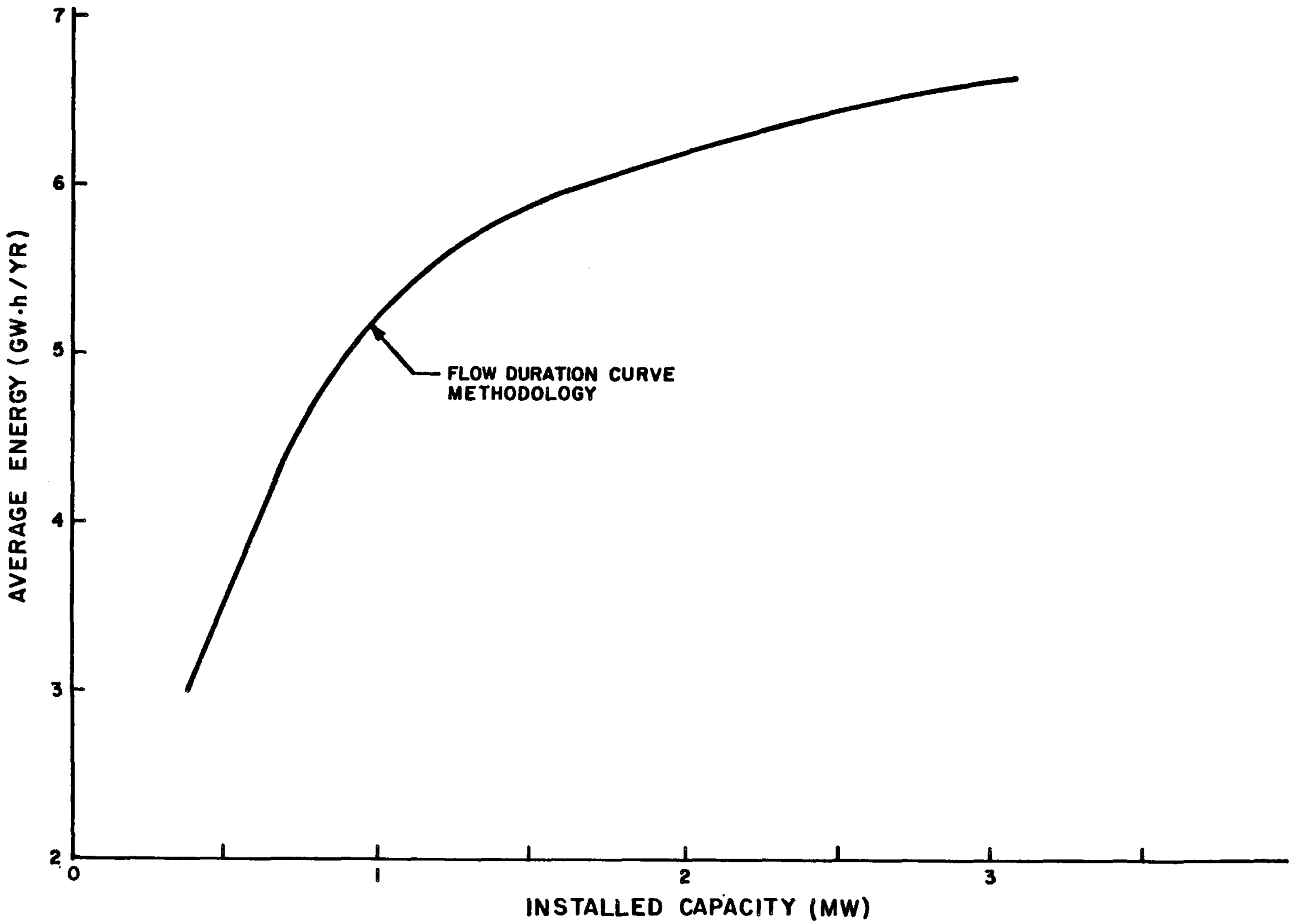


FIG. 8.2

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

POWER AND ENERGY FOR STATION 05QA004

ACRES

8.1.3 - Site at Gauge 02EA006 - Magnetawan River

The Magnetawan River site is located in Region E in the southern part of the Canadian Shield region in Ontario. The selected plant is assumed to have a gross design head of about 8.6 m.

For comparison purposes, the daily time series were derived using all three methodologies

- proration to the nearest gauge (Equation 6-1)
- proration to the index station (Equation 5-12)
- flow duration curve.

(a) Proration to a Nearby Gauge

The nearest gauge is 02EA005 on the North Magnetawan River (tributary to the Magnetawan River) near Burk's Falls.

To apply the proration methodology, the drainage area was estimated from 1:50 000-scale NTS mapping for Gauges 02EA005 and 02EA006, and the MAR was estimated at the basin centroid from Plate 3.

Therefore, the following data contributed to the calculation of the proration factor

- drainage area above Gauge 02EA005 — 321 km^2
- MAR of 02EA005 catchment — 552 mm
- drainage area above site (02EA006) — 640 km^2
- MAR of site catchment (02EA006) — 525 mm
- proration factor $= \frac{(640)(525)}{(321)(552)} = 1.9.$

The hydrologic data generated using HYSIMONT are shown in Table B.3 of Appendix B.

(b) Proration to an Index Station Gauge

The index gauge for Region B is 02HL004 located on the Skootamatta River near Actinolite.

Since the computer program HYSIMONT contains both the drainage area and MAR values for the index gauge, it is only necessary to specify the drainage area and the MAR of the site of interest [given in Section 8.1.3 (a)]. A proration factor of 1.28 was calculated using Equation 5-12.

The monthly hydrologic time series summary generated in this fashion using HYSIMONT is shown in Table B.4 of Appendix B.

(c) Flow Duration Curve Methodology

In Region E, the regression relationships require that the following variables be estimated

- drainage area
- MAS
- MAR
- slope
- latitude
- longitude.

The MAR value was obtained from Plate 3; the MAS value was estimated from Plate 5; while the slope, drainage area, latitude and longitude were measured from 1:50 000-scale NTS maps. The estimated values for Site 02EA006 are

- drainage area	640 km^2
- MAS	290 cm
- MAR	525 mm
- slope	1.33 m/km

- latitude	45.617 degrees
- longitude	79.388 degrees.

The computer program HYSIMONT was used to generate the daily flow series. Table 5.2 and Table A.5 of Appendix A show that each of the independent parameters lie within the ranges experienced in fitting the regression relationships. Therefore, there is reason for confidence in the estimated values. Table B.5 of Appendix B is a monthly summary of the generated data.

It was assumed that this site would develop a storage of about 34 m^3x10^6 corresponding to about 10% of the mean flow volume (340 m^3x10^6/yr).

It was also assumed that a plant for this site would have the following characteristics

- efficiency	85%
- gross design head	8.6 m
- head loss	5%
- net design head	8.2 m
- maximum reservoir elevation (full supply level)	100 m
- minimum reservoir elevation (dead storage level)	98 m
- constant tailwater level	90.4 m.

Table 8.5 is a summary table of results from a series of runs with the computer program ENERGY using various installed capacities. Figure 8.3 is a plot of the annual energy production versus installed capacity. This figure shows that the turbinable flow estimates do not vary by more than 12% for the three methodologies.

TABLE 8.5

POWER AND ENERGY EVALUATION - 02EA006

Installed Capacity (MW)	Average Energy (GW·h/yr)	Power (m^3/s)	Spill (m^3/s)
Proration to Index Gauge			
0.4	3.10	4.99	5.87
0.6	3.93	6.43	4.43
0.7	4.24	6.99	3.86
1.1	5.04	8.51	2.38
1.5	5.41	9.34	1.55
2.2	5.81	10.24	0.66
3.0	5.91	10.69	0.21
Proration Nearest Gauge			
0.4	3.58	5.68	5.00
0.5	4.10	6.64	4.05
0.7	4.78	7.96	2.73
1.1	5.34	9.19	1.51
1.5	5.58	9.79	0.91
2.2	5.75	10.34	0.36
2.9	5.78	10.58	0.12
Flow Duration			
0.4	3.42	5.49	4.97
0.5	3.90	6.34	4.12
0.7	4.62	7.70	2.75
1.1	5.20	9.00	1.49
1.4	5.40	9.47	1.03
2.2	5.72	10.23	0.26
2.9	5.72	10.49	0.00

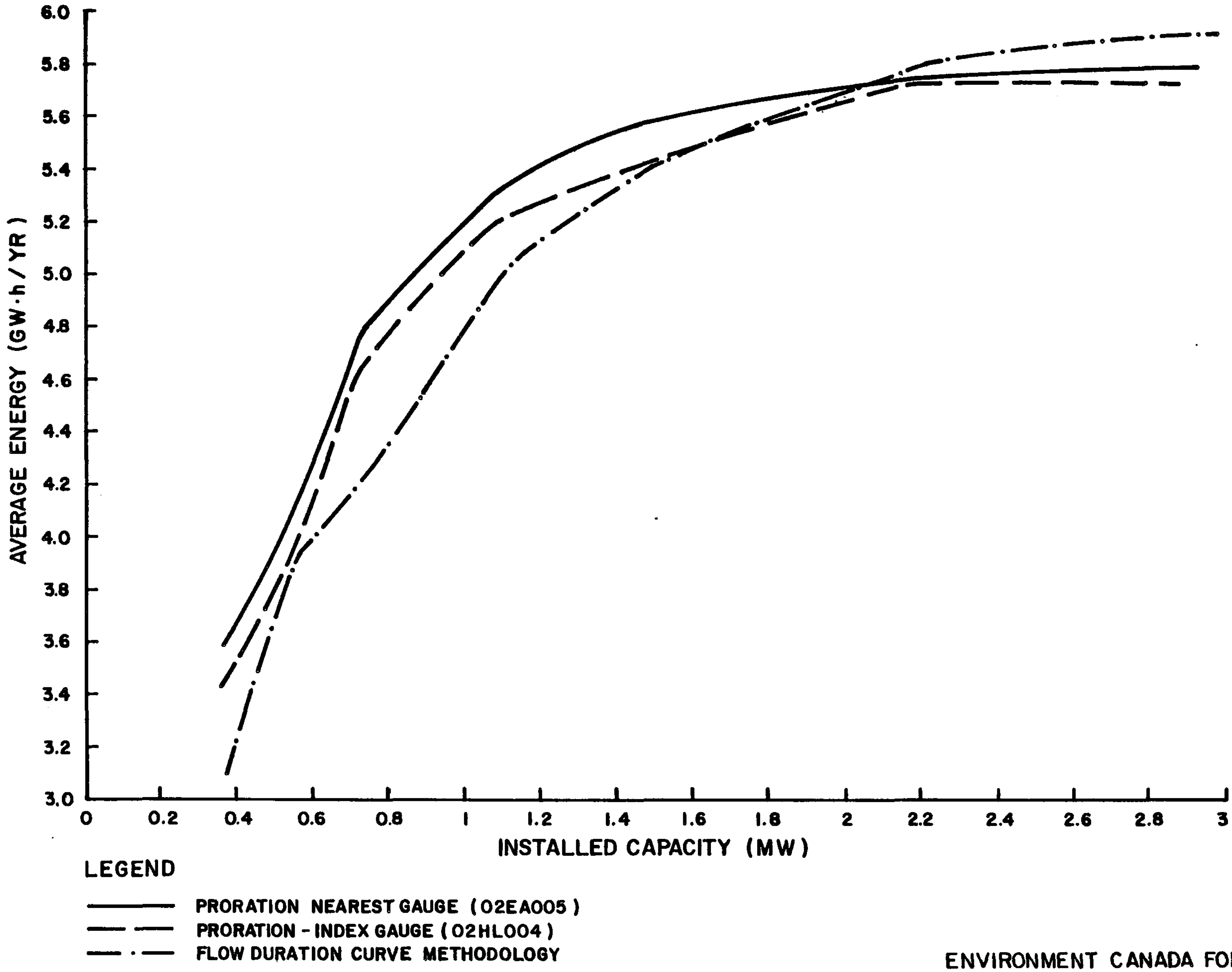


FIG. 8.3

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

ACRES

POWER AND ENERGY FOR STATION 02EA006

8.2 - Sensitivity Analysis

Two types of sensitivity testing of the methodologies are described in this section.

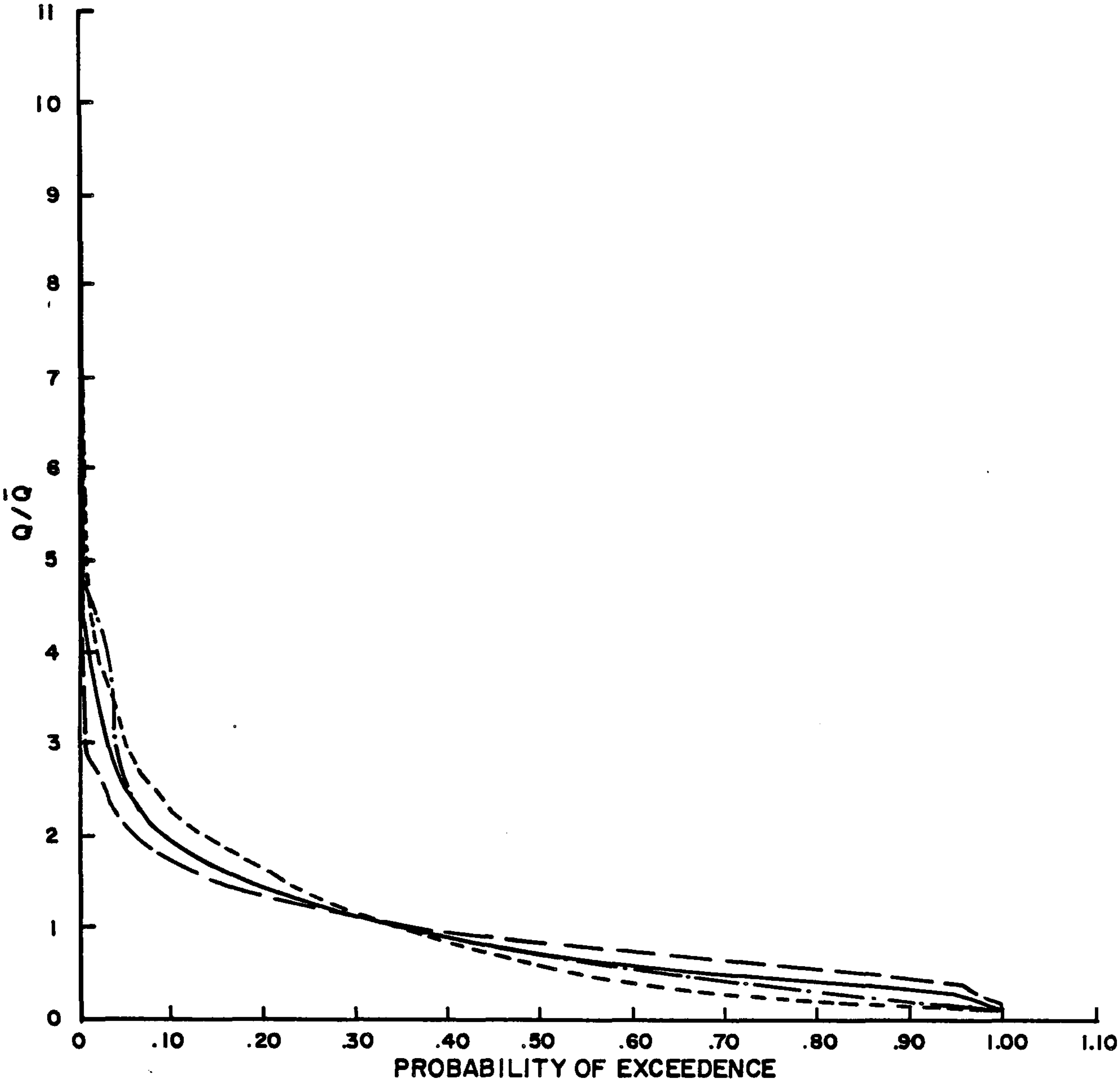
First, using the results of the applications presented in the previous section, the generated hydrologic time series are compared with the actual records at the test gauges. It is expected that this will give the reader a sense of the accuracy of his estimates in actual application.

Second, the sensitivity of the final turbinable flow estimate (Q_t) as well as the regional regression estimates of C, θ and α is evaluated for variations in the independent variables. The purpose of this calculation is to illustrate the magnitude of the error to be expected from imprecise extraction of physiographic and climatic data.

8.2.1 - Comparison of Generated Time Series

The comparison utilizes two measures of error to judge the hydrologic methodologies applied to the three test cases: the first is a visual examination of the flow duration curves for each methodology compared with the actual, and the second is a direct comparison of turbinable flows at various storage levels. These comparisons are presented below followed by observations and conclusions.

Figures 8.4, 8.5 and 8.6 compare the nondimensional flow duration curves corresponding to the actual and generated daily discharge series at Stations 05QA004 (Region B), 02EA006 (Region E) and 02GA039 (Region F), respectively. While the flow duration curve methodology is recommended for each of these three regions (except in cases where there is a long-term gauge in the same basin), we have chosen to calculate the curves using all three approaches to provide the appropriate comparison.



LEGEND

—— ACTUAL RECORD (05QA004)

— — PRORATION NEAREST GAUGE (04GA002)

- - - - PRORATION - INDEX GAUGE (04DA001)

— · — FLOW DURATION CURVE METHODOLOGY

FIG. 8. 4

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL - SCALE HYDRO SITES IN ONTARIO

ACRES

COMPARISON OF FLOW DURATION CURVES
FOR GENERATED TIME SERIES - STATION 05QA004 (REGION B)

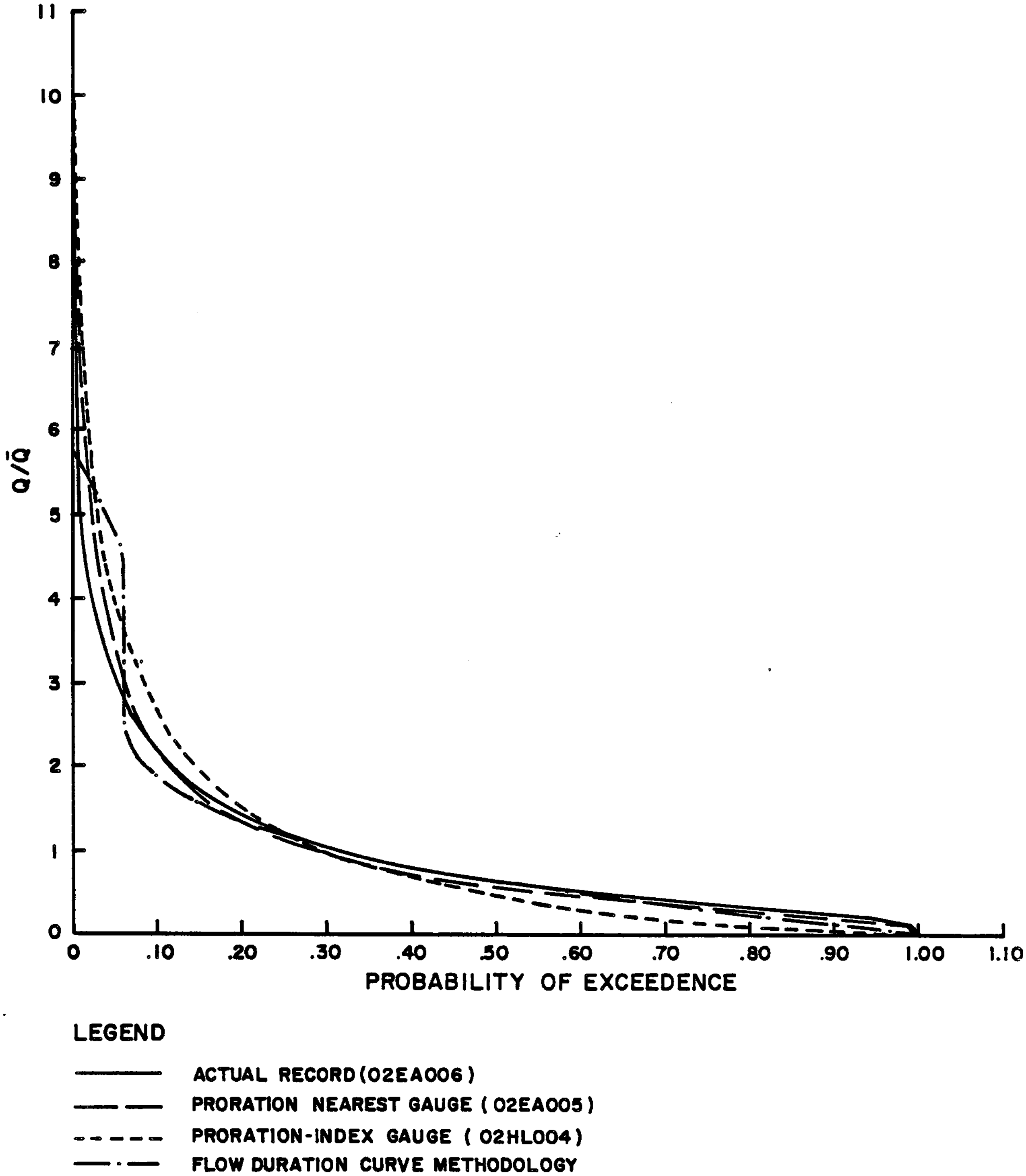


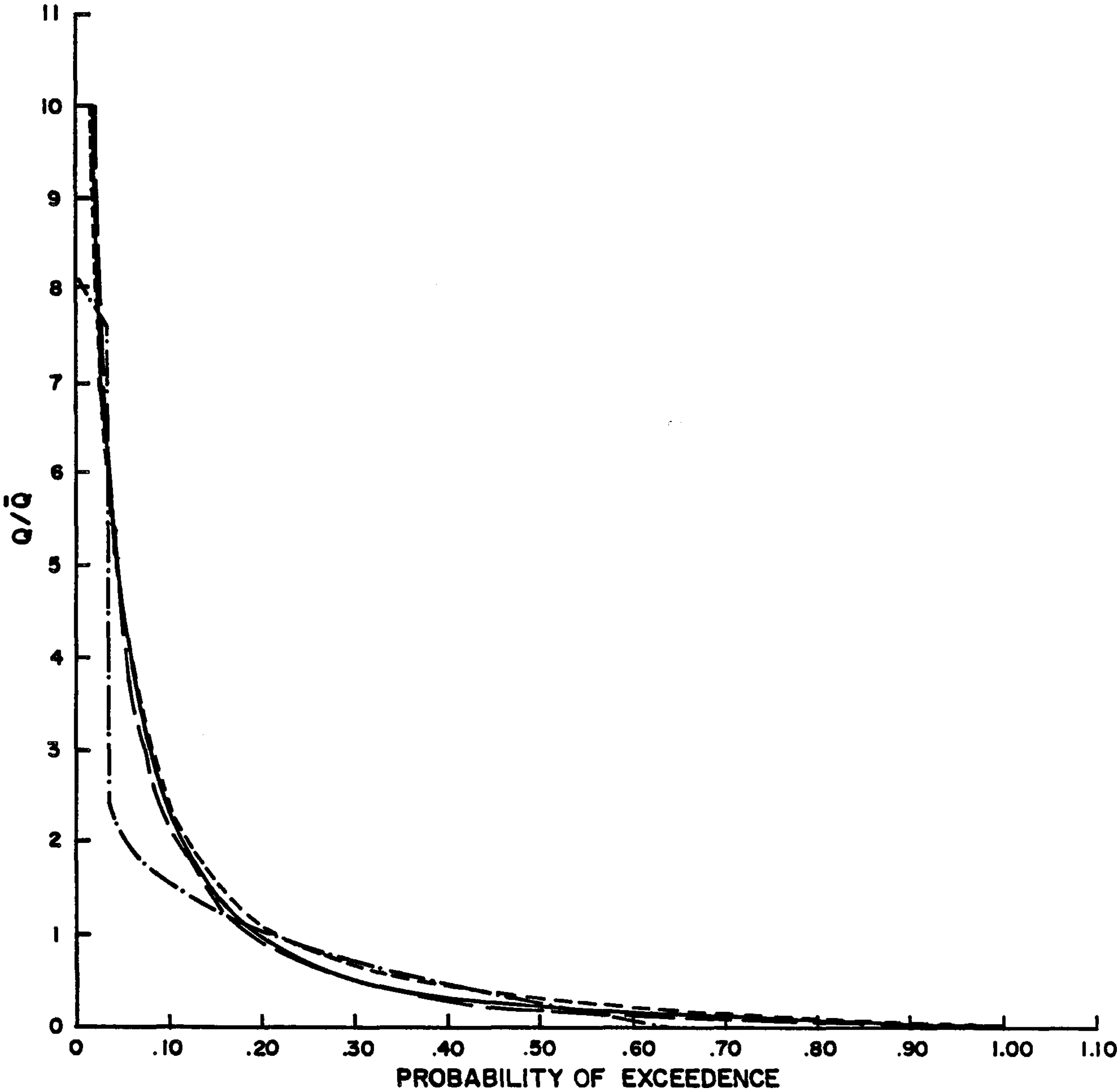
FIG. 8.5

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

COMPARISON OF FLOW DURATION CURVES FOR GENERATED TIME SERIES - STATION 02GA006 (REGION E)

ACRES



LEGEND

- ACTUAL RECORD (02GA039)
- PRORATION NEAREST GAUGE (02GA017)
- PRORATION - INDEX GAUGE (02FE008)
- FLOW DURATION CURVE METHODOLOGY

FIG. 8.6

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL - SCALE HYDRO SITES IN ONTARIO

COMPARISON OF FLOW DURATION CURVES
FOR GENERATED TIME SERIES - STATION 02GA039 (REGION F)

ACRES

The analysis was then carried one step further, to the calculation of the turbinable flow curves based on the flow duration curves illustrated in Figures 8.4, 8.5 and 8.6. The turbinable flow was determined at four levels of storage from 0 to 0.20 times the mean annual flow and assuming the design discharge of twice the mean annual flow.

Table 8.6 provides a summary of the calculations, in particular showing the percent deviation of the turbinable flow calculated with the synthetic methodologies when compared with the turbinable flows calculated using the actual hydrologic record. In examining the table of errors, one fact should be kept in mind. The percentage errors include the differences in estimating the MAR from Plates 3 and 4 versus the actual historic MAR of the gauge itself. For example, consider the results of Gauge 02GA039. The error in estimating the MAR is -21%. This error is also included in the deviations of the turbinable flow estimates for the values calculated using the actual flow duration curve.

A number of observations can be drawn from an examination of the flow duration curves of Figures 8.4, 8.5 and 8.6, and from the error analysis of Table 8.6.

- The flow duration curve methodology accurately reproduces the actual curve for Test Gauge 05QA004 in Region B. This is apparent both in Figure 8.4 and in the error analysis of Table 8.6. Note that proration to the nearest gauge was not as effective since the nearest gauge (04GA002) was not in the same basin.

- Proration to the nearest gauge methodology is shown to be the most accurate for Test Gauges 02EA006 and 02GA039 in Regions E and F, respectively. Each had gauges in the same basin on which to base the proration. In the case of Gauge 02GA039, the

TABLE 8.6

TURBINABLE FLOW ERROR

					Estimated Q_T at Q_D = 2 Storage (Ratio to Mean Flow Volume)												
		Mean Annual Runoff			0			0.05			0.1			0.2			Average
Station	Technique	Actual	Est	Difference (%)	Actual	Est	Error (%)	Actual	Est	Error (%)	Actual	Est	Error (%)	Actual	Est	Error (%)	Error
02GA039	Proration - Index	3.7	2.9	-21.0	1.9	2.0	2.7	2.5	2.4	-5.9	2.8	2.6	-6.8	3.2	2.9	-9.1	-4.8
	- Nearest Gauge	3.7	2.9	-21.0	1.9	1.6	-20.8	2.5	2.1	-18.6	2.8	2.4	-18.1	3.2	2.6	-20.0	-19.4
	Flow Duration	3.7	2.9	-21.0	1.9	1.6	-22.4	2.5	2.0	-29.4	2.8	2.1	-35.4	3.2	2.1	-50.3	-34.4
02EA006	Proration - Index	10.8	10.6	-1.9	9.3	8.0	-16.1	9.9	8.8	-12.7	10.3	9.3	-10.5	10.7	10.1	-5.3	-11.2
	- Nearest Gauge	10.8	10.6	-1.9	9.3	8.5	-9.3	9.9	9.3	-6.8	10.3	9.8	-5.3	10.7	10.4	-2.2	-5.9
	Flow Duration	10.8	10.6	-1.9	9.3	8.4	-10.4	9.9	9.1	-8.9	10.3	9.6	-7.5	10.7	10.2	-4.2	-7.8
05QA004	Proration - Index	38.3	38.8	1.4	35.1	32.4	-8.2	36.2	34.5	-4.9	36.8	35.5	-3.6	37.6	36.9	-2.0	-4.7
	- Nearest Gauge	38.3	38.8	1.4	35.1	38.4	8.6	36.2	38.9	6.9	36.8	39.2	6.1	37.6	39.7	5.2	6.7
	Flow Duration	38.3	38.8	1.4	36.1	34.1	-2.7	36.2	36.0	-0.6	36.8	37.0	0.5	37.6	38.3	1.8	-0.3

results clearly favor the nearest gauge approach when the error in the MAR is considered. The proration factor between the test gauge and the nearest gauge was close to 1 (0.81). In the case of Gauge 02EA006, the results are not as clear. Both the nearest gauge and the flow duration methodologies produced similar results. In this case, the proration factor between the test gauge and the nearby gauge was 1.9, that is, a more significant deviation from 1. This, nonetheless, supports the finding that the nearest gauge proration methodology as discussed in Section 6 is a preferred alternative in most cases when there is an actual record in the basin of interest.

In summary, the above observations generally confirm basic conclusions drawn earlier in the study.

- It is usually best to prorate to the nearest gauge when there is one in the same basin which has similar physiographic characteristics.

- At ungauged sites with no nearby gauges, the flow duration curve methodology using the regression approach is preferable in Regions B, E and F while the proration to an index gauge method should be used in Regions A, C and D.

8.2.2 - Sensitivity of Regression Methodology

It is important that a user have an understanding of the error in his results which may be caused by inaccuracies in extracting data. With this information, the user will know where to emphasize accuracy in data collection.

The three test stations discussed above were analyzed for their sensitivity to errors in the measurement of physical and climatic characteristics. First, the C, θ and α coefficients, the turbinable flow curve, and the daily time series for the test stations were generated using the regional regression relationships and the best estimates of the physiographic and climatic characteristics. The analysis was then repeated using reasonable variations in the independent variable of the regression equations, as might be caused by measurement errors or inaccuracies of the isoline maps. The selected variations in the independent variables were

- drainage area	±5%
- MAS	±20 cm
- MAR	±25 mm
- BFI	±0.025 (units of Plate 2)
- area controlled by lakes and swamps	±10%
- slope	±10%
- latitude/longitude	-.

Table 8.7 summarizes results of the sensitivity analysis on the dependent variables. The errors in this table are expressed as a percent deviation from the best estimate and have been evaluated for a design discharge equal to twice the mean flow and no additional man-made storage.

In general, independent variables subject to greater measurement error, such as slope, drainage area, area controlled by lakes and swamps, MAS and BFI, have little impact on the final turbinable flow estimate.

Drainage area and MAR both have greater impact on errors in the turbinable flow estimates. The errors in all cases, however, are generally less than 6%, and it is concluded that the impact of minor errors in extracting data is also relatively minor.

TABLE 8.7

SENSITIVITY OF DEPENDENT VARIABLES
(expressed as percent deviation from the best estimate)

Station	Dependent Parameter	Best Estimate	Drainage Area +5%	Drainage Area -5%	Slope +10%	Slope -10%	Mean Annual Runoff +7.1%	Mean Annual Runoff -7.1%	Base Flow Index +10%	Base Flow Index -10%
02GA039	C	8.1	0.00	0.00	0.00	0.00	0.00	0.00	-1.88	1.88
	θ	0.6	0.00	0.00	1.18	-1.22	0.00	0.00	4.51	-4.51
	α	-0.3	0.00	0.00	1.84	-1.94	0.00	0.00	5.92	-5.95
	Q_t[1]		4.10	-4.10	0.00	0.00	5.90	-5.90	3.80	-2.80

Station	Dependent Parameter	Best Estimate	Drainage Area +5%	Drainage Area -5%	Slope +10%	Slope -10%	Mean Annual Runoff +4.8%	Mean Annual Runoff -4.8%	Mean Annual Snowfall +6.9%	Mean Annual Snowfall -6.9%
02EA006	C	5.7	-0.36	-4.16	0.00	0.00	-1.08	1.15	0.00	0.00
	θ	1.0	0.00	0.00	1.03	-1.08	0.00	0.00	2.98	-3.04
	α	-0.5	0.00	0.00	1.12	-1.17	0.00	0.00	3.75	-3.81
	Q_t[1]		4.00	12.80	0.60	-0.60	4.80	-4.10	1.40	-1.50

Station	Dependent Parameter	Best Estimate	Drainage Area +5%	Drainage Area -5%	Mean Annual Runoff +9.1%	Mean Annual Runoff -9.1%	Area of Lakes and Swamps +10%	Area of Lakes and Swamps -10%
05QA004	C	5.0	0.00	0.00	0.00	0.00	-	0.00
	θ	1.1	0.00	0.00	-3.17	3.59	-	-1.30
	α	-0.5	0.00	0.00	-1.92	4.29	-	0.00
	Q_t[1]		3.80	-3.90	5.70	-6.10	-	-1.40

[1]Evaluated at $Q_d = 2$, $\Delta s = 0$.

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APPENDIX A

MEASURED AND TABULATED BASIN DATA

A1 - DESCRIPTION OF INDEPENDENT REGRESSION VARIABLES

A1 - DESCRIPTION OF INDEPENDENT REGRESSION VARIABLES

A1.1 - General

The independent variables used in this study are taken directly from the work of Moin and Shaw (1986). For the most part, the variable descriptions contained in the following paragraphs are from the same reference. These variables are shown in Appendix A2, and the methods used to derive them are discussed in the following sections.

A1.2 - Physiographic Variables

The physiographic variables which are summarized below include

- drainage area (A)
- slope of the main channel (SLP)
- percentage of drainage area controlled by lakes and swamps (ACLS)
- length of the main channel (LEN)
- shape factor (SHP)
- latitude (LAT)/longitude (LONG).

The variables not included in any regression equations are identified by double asterisks.

Drainage Area (A)
(km^2)

This variable is a strong indicator of the potential flow volume, and as expected is a significant parameter.

For this analysis, the drainage basin areas were obtained directly from WSC publications. Published areas were modified to reflect revised drainage boundaries due to urbanization and other changes to the drainage regime.

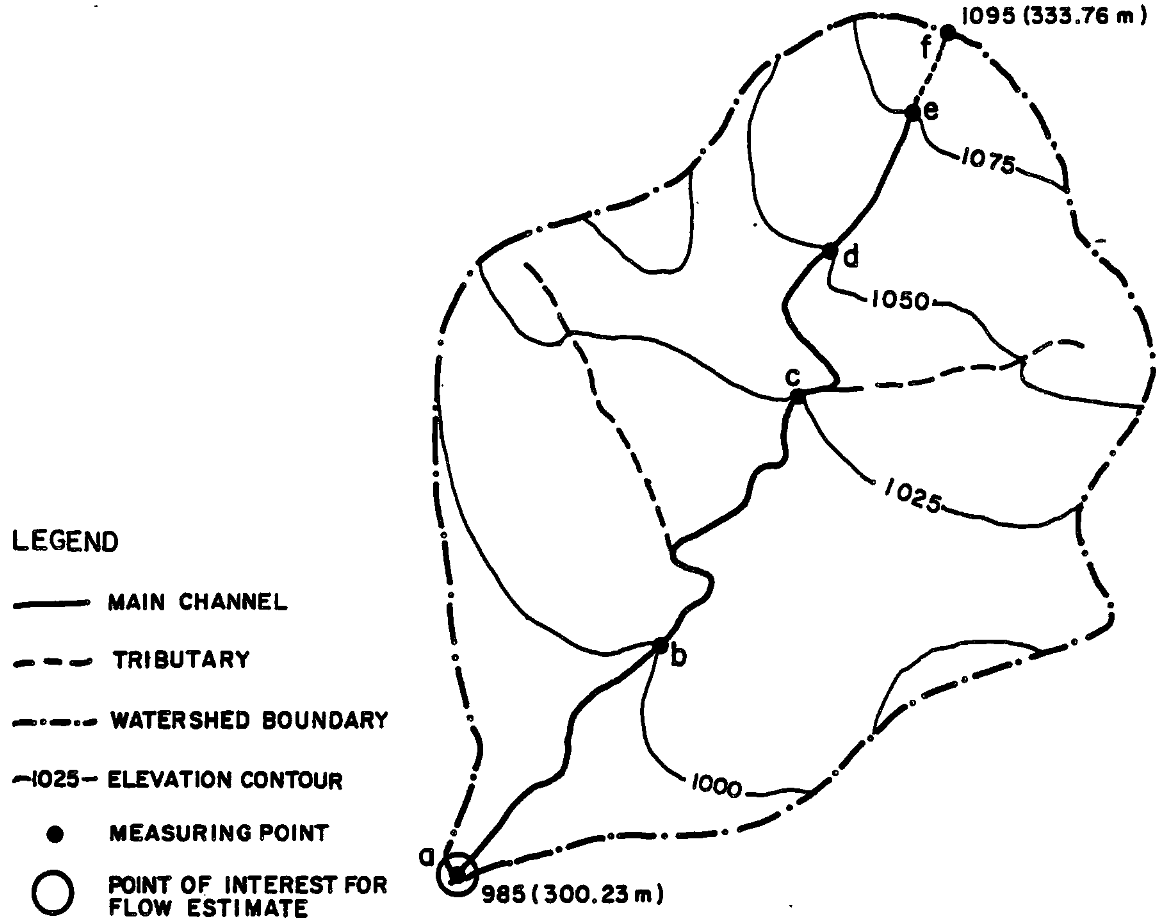
Areas were measured using 1:50 000-scale NTS mapping for southern Ontario (Region F) while in northern Ontario (Regions A to E), the majority of the drainage areas were delineated using 1:250 000-scale NTS maps. In northern Ontario, a few basins were delineated using either 1:50 000- or 1:500 000-NTS maps. Since there are no consistent guidelines to indicate which scale map(s) should be used at an ungauged site, it is recommended that 1:250 000-NTS maps be used throughout northern Ontario.

Slope of Main Channel (SLP)
(m/km)

This variable is an indicator of the potential velocity at which runoff can be conveyed to the gauge location, and was expected to influence peak daily flows. Channel slopes were determined using 1:50 000-NTS mapping for southern Ontario and primarily 1:250 000-NTS mapping for northern Ontario. Elevations and distances were measured along the main channel from the gauge to the uppermost drainage boundary. Several techniques were used to compute the slope; however, a weighted slope determined using the 'Modified Equivalent Slope Method' (Sangal, 1984) was used for this study. The distances (Li) between contours crossing the main channel and between contours and boundary adjacent to the upstream drainage boundary and the gauge are measured. Stream slopes are determined between these contours and boundaries. The total slope is computed using the expression.

$$SLP = [\Sigma Li \;/\; \Sigma(Li/Si^{1/2})\;]^2$$

The method used to compute this variable is shown in Figure A.1.



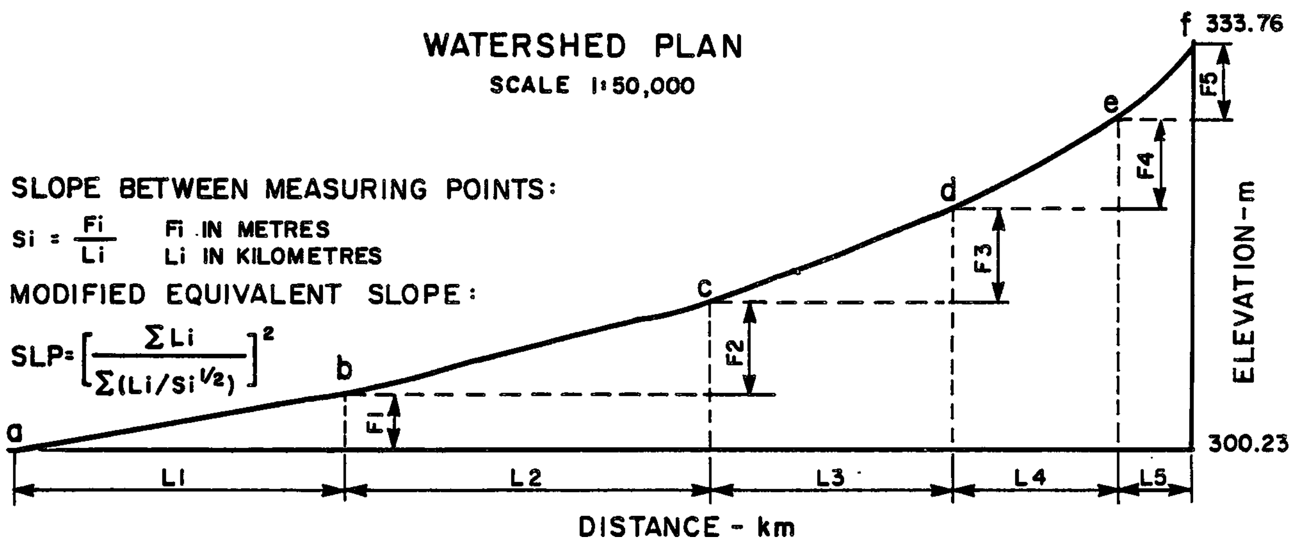
WATERSHED PLAN
SCALE 1:50,000

SLOPE BETWEEN MEASURING POINTS:

$Si = \frac{Fi}{Li}$ Fi IN METRES, Li IN KILOMETRES

MODIFIED EQUIVALENT SLOPE:

$$SLP = \left[\frac{\Sigma Li}{\Sigma (Li/Si^{1/2})}\right]^2$$



SECTION a - f : ALONG MAIN CHANNEL

FIG. A- 1

ENVIRONMENT CANADA FOR PERD
STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL - SCALE HYDRO SITES IN ONTARIO

SLOPE OF MAIN CHANNEL - DEFINITION

ACRES

Percentage of Drainage Area
Controlled by Lakes and Swamps (ACLS)
(%)

This variable is an indicator of the potential attenuating effect that lake and swamp storage have on daily flows. The lake or swamp has to have a surface area of at least 1% of the area draining to the outlet of the lake or swamp in order to be considered as controlling discharges. If the lakes and swamps are in series and close together, their combined surface area is used. This parameter is determined as shown in Figure A.2 using 1:50 000-NTS mapping for southern Ontario and primarily 1:250 000-NTS mapping for northern Ontario.

The addition of 0.01 to the value of ACLS was necessary to avoid problems when taking logs if ACLS = 0.

Length of the Main Channel (LEN)**
(km)

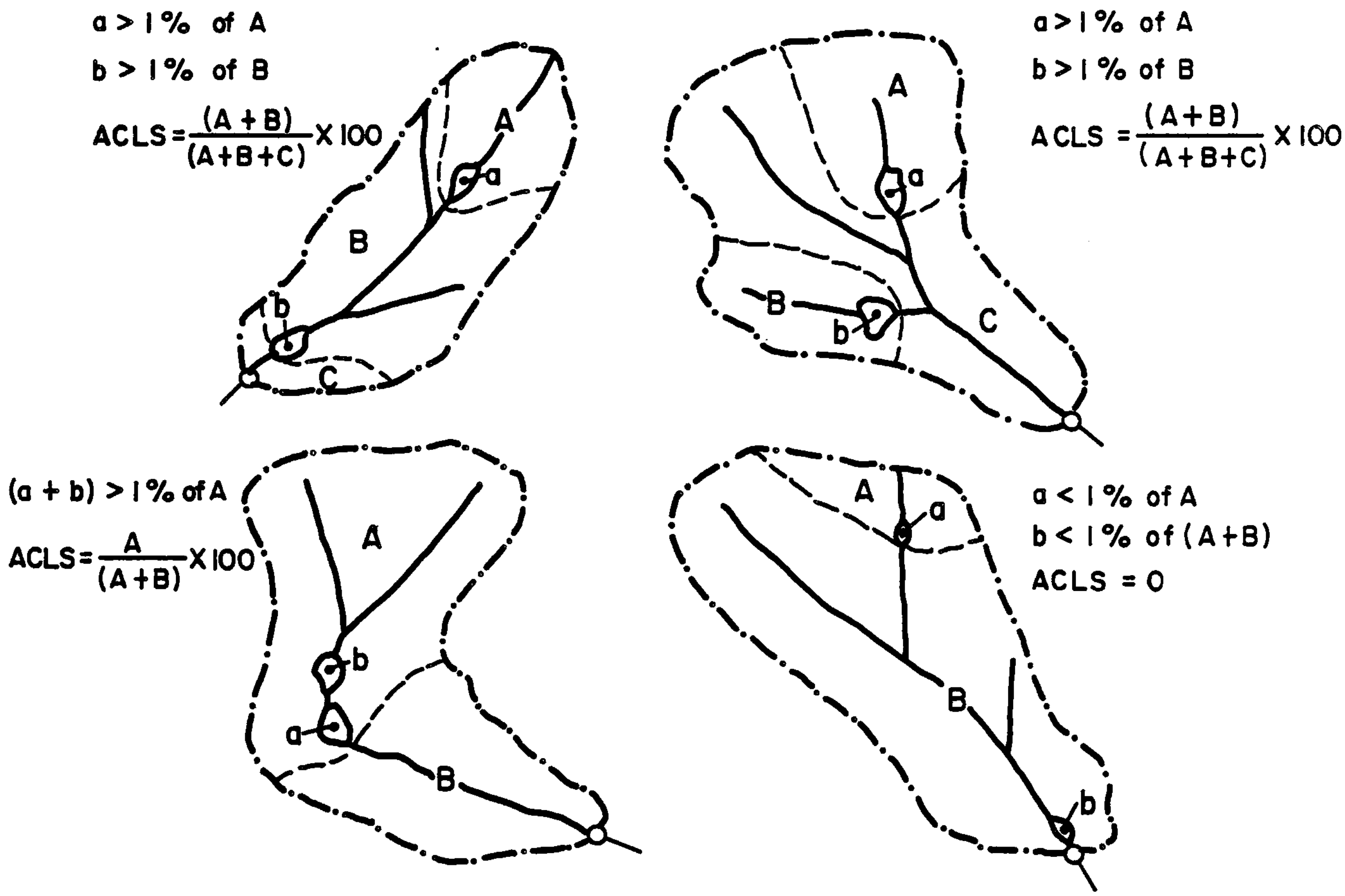
This variable may also be an indicator of the degree of attenuation of daily flow and was determined from the same maps used to determine the parameter ACLS.

Shape Factor (SHP)**
(dimensionless)

This variable helps to account for the effects of drainage basin configuration on the daily flow characteristics.

The drainage basin main channel length and area were used to compute this parameter as follows

$$SHP = (LEN)^2/A$$



LEGEND

a , b	AREA OF LAKE OR SWAMP
A , B	AREA CONTROLLED BY LAKE OR SWAMP
C	UNCONTROLLED AREA

FIG. A-2

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

AREA CONTROLLED BY LAKES AND SWAMPS - DEFINITION

ACRES

Latitude (LAT)/Longitude (LONG)
(degrees)

The latitude and longitude of the gauge location were both included as variables in the regional regression relationships.

A1.3 - Hydrometeorologic Variables

The following variables have a direct effect on the daily flow characteristics of a drainage basin

- base flow index (BFI)
- mean annual runoff (MAR)
- mean annual precipitation (MAP)
- mean annual snowfall (MAS).

Variables not used in the final equations are identified by double asterisks.

Base Flow Index (BFI)
(dimensionless)

This variable is an indicator of the hydrogeological effects of the drainage basin soil and geology and also the retention characteristics (primarily due to lakes and swamps) of the drainage basin. This variable is strongly influenced by the latter characteristic in northern Ontario and to a somewhat lesser extent in the Canadian Shield area of southern Ontario.

The BFI was calculated directly from daily mean discharge data for each station as described in Moin and Shaw (1986) and is defined as

BFI = total volume of base flow/total volume of runoff.

The median values calculated for all Ontario gauging stations having at least 2 years of continuous daily discharge data were plotted at the corresponding drainage basin centroids using 1:2 000 000- and 1:600 000-scale base maps for northern and southern Ontario respectively, and isolines drawn. The centroids were located by eye after delineating the drainage area. The isolines map was prepared to help provide estimates of BFI for ungauged basins when applying the regression equations. Due to the effect of lake and swamp storage on the value of BFI, the BFI calculated for a basin containing considerable storage primarily along the main channel may influence the BFI interpolated from the isoline map in the surrounding area. To alleviate this problem, the isolines affected in this way are drawn close to the main channel having large storage effects. Also, all estimates of BFI from the isoline maps must be made by first locating the basin centroids and then projecting this point to the closest point on the main channel. The BFI is then interpolated from the isolines at this location on the main channel. A better BFI estimate will be obtained for large basins and in areas where the isolines are very close together if an average value of BFI, weighted by the area between isolines, is taken over the entire drainage basin. The isolines for BFI were prepared for both northern and southern Ontario; however, due to the sparse data coverage and problems of regionalizing the BFI values in highly retentive basins, the map for northern Ontario was not published. The isoline map for southern Ontario is shown on Plate 2.

Mean Annual Runoff (MAR)
(mm)

This variable is an indicator of the mean annual precipitation input to the basin and its runoff potential. It was computed in the following two ways:

- directly from all of the available daily mean discharge for each station as a volume and converted to an equivalent depth over the basin by dividing by the drainage area

- using the value of MAR from a map of MAR isolines. The value is based on the value at the geometric centroid of each basin.

Isoline maps of MAR were prepared in a manner similar to that for BFI except that no allowance was required for retentive areas.

Therefore, estimates of MAR are to be taken at the basin centroid (no projection to main channel required). However, a better estimate may also be obtained for large basins and in areas where the isolines are very close together, if an areal weighted mean value is estimated. The isolines for MAR are shown on Plates 3 and 4 for southern and northern Ontario respectively.

The gauge values of MAR were used for all regression equation developments while the runoff was determined using the MAR map (Plates 3 or 4) for ungauged catchments.

Mean Annual Precipitation (MAP)**
(mm)

This parameter is obviously indicative of the magnitude of the gross input to the runoff process.

MAP was determined by others (Cumming-Cockburn, 1985) from isoline maps of MAP by interpolating the value at the gauge location.

Mean Annual Snowfall (MAS)
(cm)

This parameter is an indicator of the magnitude of spring floods due to snowmelt. MAS was determined by others from isoline maps published by the Ministry of Natural Resources (1984). The values were interpolated from the map at the gauge location. The isolines for MAP are shown on Plate 5 for the Province of Ontario.

A2 - SUMMARY OF PHYSIOGRAPHIC BASIN CHARACTERISTICS

TABLE A.1

REGION A - SUMMARY OF
PHYSIOGRAPHIC BASIN CHARACTERISTICS

Basin	Drainage Area (km^2)	Mean Annual Precip. (mm)	Mean Annual Snowfall (cm)	Mean Annual Runoff (mm)	Area Controlled By Lakes and Swamps (%)	River Slope (m/km)	River Length (km)	Latitude (degrees)	Longitude (degrees)	Shape Factor
04DC001	50 000	590	220	299	80.00	0.254	419.7	54.52	87.23	3.5
04DC002	4 710	500	210	289	0.01	3.217	155.0	54.28	85.65	5.1
04EA001	10 400	520	220	298	10.00	0.576	290.8	53.81	84.92	8.1
04FC001	36 000	650	230	334	95.00	0.464	317.5	53.09	85.01	2.8
04KA001	4 250	720	220	277	0.01	0.627	229.9	51.15	80.87	12.4
Minimum	4 250	500	210	277	0.01	0.254	155.0	51.15	80.87	2.8
Maximum	50 000	720	230	334	95.00	3.217	419.7	54.52	87.23	12.4
Mean	21 072	596	220	299	37.00	1.028	282.6	53.37	84.74	6.4
σ	18 570	82	8	19	41.70	1.102	88.5	1.21	2.10	3.5
CV (%)	88	14	3	6	113	107	31	2	2	55

TABLE A.2

REGION B - SUMMARY OF
PHYSIOGRAPHIC BASIN CHARACTERISTICS

Basin	Drainage Area (km^2)	Mean Annual Precip. (mm)	Mean Annual Snowfall (cm)	Mean Annual Runoff (mm)	Area Controlled By Lakes and Swamps (%)	River Slope (m/km)	River Length (km)	Latitude (degrees)	Longitude (degrees)	Shape Factor
04CA003	619	590	200	294	20	0.706	59.1	53.66	92.54	5.6
04CB001	10 800	590	200	325	60	0.054	294.0	53.35	91.79	8.0
04CD001	21 100	540	200	217	30	0.513	358.8	54.99	89.34	6.1
04CD002	4 270	550	190	273	100	0.498	161.9	53.99	92.15	6.1
04CE002	4 350	600	230	287	100	0.070	98.4	53.77	89.55	2.2
04DA001	5 960	650	240	337	40	0.153	203.2	52.58	90.19	6.9
04DA002	19 000	660	230	360	100	0.326	216.5	52.96	87.70	2.5
04DB001	7 950	610	230	328	100	0.264	304.2	53.72	87.94	11.6
04DB002	3 240	610	230	345	100	0.302	294.6	53.53	89.29	26.8
04FA001	9 010	700	260	341	100	0.090	227.3	51.82	89.60	5.7
04FA002	1 540	700	260	354	50	0.018	165.0	51.64	89.89	17.7
04FA003	4 900	690	260	389	30	0.051	273.1	52.31	88.75	15.2
04FB001	24 200	700	260	364	100	0.393	317.5	52.08	87.08	4.2
04GA002	5 390	720	230	234	100	0.057	163.8	51.17	91.60	5.0
04GB004	11 200	740	260	250	100	0.113	187.3	50.87	88.93	3.1
04JF001	5 360	770	300	308	100	0.620	182.9	50.66	86.53	6.2
05PA006	13 400	750	220	255	100	0.169	196.9	48.38	92.18	2.9
05PA012	4 510	750	220	276	100	0.116	128.3	48.08	91.65	3.6
05PA014	4 870	760	220	238	100	0.359	125.7	48.85	92.73	3.2
05QC003	2 370	650	225	219	90	0.075	85.1	50.90	93.09	3.1
05QE008	1 690	750	190	195	100	0.838	87.6	50.51	93.26	4.5
05QE009	1 530	760	190	223	50	0.400	92.7	50.36	94.46	5.6
Minimum	619	540	190	195	20	0.018	59.1	48.08	86.53	2.2
Maximum	24 200	770	300	389	100	0.838	358.8	54.99	94.46	26.8
Mean	7 603	675	229	291	80	0.281	192.0	51.83	90.47	7.1
σ	6 427	72	28	56	29	0.231	84.0	1.85	2.14	5.8
CV (%)	85	11	12	19	36	82	44	4	2	82

TABLE A.3

REGION C - SUMMARY OF PHYSIOGRAPHIC BASIN CHARACTERISTICS

Basin	Drainage Area (km^2)	Mean Annual Precip. (mm)	Mean Annual Snowfall (cm)	Mean Annual Runoff (mm)	Area Controlled By Lakes and Swamps (%)	River Slope (m/km)	River Length (km)	Latitude (degrees)	Longitude (degrees)	Shape Factor
02BA002	1190	840	230	389	98	1.015	107.5	49.77	86.88	9.7
02BA003	1320	850	230	365	69	0.822	128.5	48.82	86.61	12.5
02BB002	1980	875	240	449	71	0.731	150.0	48.69	86.21	11.4
02BB003	4270	860	240	367	55	0.111	465.0	48.66	85.74	50.6
02BF001	1190	1000	300	598	58	1.289	103.0	46.99	84.53	8.9
02BF002	1160	895	300	516	83	1.173	84.5	46.30	83.20	6.2
Minimum	1160	840	230	365	55	0.111	84.5	46.30	83.20	6.2
Maximum	4270	1000	300	598	98	1.289	465.0	49.77	86.88	50.6
Mean	1852	887	257	447	72	0.857	173.1	48.20	85.53	16.5
σ	1118	54	31	86	15	0.384	132.2	1.18	1.29	15.4
CV (%)	60	6	12	19	20	45	76	2	2	93

TABLE A.4

REGION D - SUMMARY OF
PHYSIOGRAPHIC BASIN CHARACTERISTICS

Basin	Drainage Area (km^2)	Mean Annual Precip. (mm)	Mean Annual Snowfall (cm)	Mean Annual Runoff (mm)	Area Controlled By Lakes and Swamps (%)	River Slope (m/km)	River Length (km)	Latitude (degrees)	Longitude (degrees)	Shape Factor
02JC008	1 780	790	280	390	80.00	0.174	95.3	47.89	79.88	5.1
04JA002	3 780	810	300	403	74.00	0.108	188.0	49.74	84.10	9.3
04JC003	3 290	810	300	347	1.00	0.760	107.7	49.78	84.53	3.5
04JD005	2 020	820	300	336	8.00	0.176	117.5	49.77	85.23	6.8
04LD001	11 900	820	260	384	30.00	0.460	218.4	49.32	82.04	4.0
04LF001	6 760	820	300	363	0.01	0.596	236.9	49.42	82.44	8.3
04LG002	60 100	760	220	410	0.01	0.657	476.3	50.81	81.29	3.8
04LJ001	8 940	820	300	370	18.00	0.475	335.6	49.62	83.26	12.6
04LM001	22 900	780	250	339	7.00	0.873	396.6	50.58	82.12	6.9
04MF001	6 680	720	220	430	0.01	1.076	123.8	51.08	80.77	2.3
Minimum	1 780	720	220	336	0.01	0.108	95.3	47.89	79.88	2.3
Maximum	60 100	820	300	430	80.00	1.076	476.3	51.08	85.23	12.6
Mean	12 815	795	273	377	21.80	0.536	229.6	49.80	82.57	6.3
σ	16 848	32	32	30	29.10	0.304	125.9	0.86	1.62	3.0
CV (%)	131	4	12	8	133	57	55	2	2	48

TABLE A.5

REGION E - SUMMARY OF PHYSIOGRAPHIC BASIN CHARACTERISTICS

Basin	Drainage Area (km^2)	Mean Annual Precip. (mm)	Mean Annual Snowfall (cm)	Mean Annual Runoff (mm)	Area Controlled By Lakes and Swamps (%)	River Slope (m/km)	River Length (km)	Latitude (degrees)	Longitude (degrees)	Shape Factor
02CE002	1350	880	250	430	72.00	1.822	128.0	46.50	81.25	12.1
02CF007	272	795	250	356	19.00	0.746	24.5	46.57	81.21	2.2
02EA005	321	930	290	576	91.00	1.970	43.6	45.67	79.38	5.9
02EA008	1850	910	300	490	97.00	1.839	51.0	45.71	79.88	1.4
02EA010	149	920	280	626	28.00	1.838	36.0	45.75	79.20	8.7
02EC002	1445	890	270	454	0.01	1.020	94.3	44.71	79.28	6.2
02FA001	927	910	300	463	98.00	0.812	82.4	44.67	81.25	7.3
02HL004	671	850	170	368	55.00	2.472	67.0	44.55	77.31	6.7
02HL005	308	850	170	374	17.00	1.710	53.3	44.50	77.62	9.2
02HM001	777	900	180	371	87.00	1.431	100.9	44.28	76.93	13.1
02HM003	891	850	180	366	79.00	1.530	112.4	44.21	77.21	14.2
02KC014	443	800	190	344	10.00	1.155	40.0	45.79	77.14	3.6
02KF011	269	810	200	358	2.00	0.263	35.0	45.42	76.20	4.6
02LA006	409	820	200	412	63.00	0.138	63.0	44.99	75.66	9.7
02LA007	559	850	190	380	17.00	0.608	60.5	45.25	75.79	6.5
Minimum	149	795	170	344	0.01	0.138	24.5	44.21	75.66	1.4
Maximum	1850	930	300	626	98.00	2.472	128.0	46.57	81.25	14.2
Mean	709	864	228	425	49.00	1.290	66.1	45.24	78.35	7.4
σ		485	44	49	4.4	36.00	0.656	30.0	0.73	1.91 3.7
CV (%)	68	5	21	19	73	51	45	2	2	49

TABLE A.6

REGION F - SUMMARY OF
PHYSIOGRAPHIC BASIN CHARACTERISTICS

Basin	Drainage Area (km^2)	Mean Annual Precip. (mm)	Mean Annual Snowfall (cm)	Mean Annual Runoff (mm)	Base Flow Index	Area Controlled By Lakes and Swamps (%)	River Slope (m/km)	River Length (km)	Latitude (degrees)	Longitude (degrees)	Shape Factor
02EC011	282	820	230	323	0.46	74.00	0.415	55.3	44.40	79.07	10.8
02EC012	324	860	240	254	0.50	95.00	1.636	32.5	48.31	79.36	3.3
02ED003	1180	870	260	255	0.55	51.00	1.900	61.8	44.25	79.82	3.2
02ED005	295	880	270	424	0.61	35.00	2.229	50.5	44.30	80.00	8.6
02ED007	177	1000	300	408	0.63	0.01	1.989	28.0	44.71	79.64	4.4
02ED103	195	850	260	380	0.71	0.01	4.824	37.5	44.20	79.96	7.2
02FB007	181	1000	300	503	0.56	58.00	1.430	27.6	44.70	80.95	4.2
02FB010	293	940	300	481	0.55	49.00	1.730	33.3	44.57	80.65	3.8
02FC001	3960	900	300	449	0.64	0.01	1.128	190.5	44.46	81.33	9.2
02FC002	2150	1000	280	443	0.62	11.00	1.600	81.0	44.12	82.10	3.1
02FC004	249	1000	290	445	0.81	82.00	1.892	37.8	44.26	80.77	5.7
02FC011	163	1000	280	404	0.51	0.01	3.750	29.5	44.11	81.02	5.3
02FC012	635	1000	280	473	0.42	5.00	1.538	97.5	44.10	80.99	15.0
02FC015	663	900	290	516	0.62	91.00	0.662	83.0	44.27	81.27	10.4
02FE002	1630	960	260	421	0.41	5.00	1.395	76.9	43.89	81.33	3.6
02FE004	1760	920	260	436	0.46	0.01	1.253	97.9	43.83	81.49	5.4
02FE005	528	960	260	425	0.46	100.00	1.349	32.4	43.92	81.26	2.0
02FE007	326	950	260	464	0.40	0.01	1.590	50.4	43.85	81.25	7.8
02FE008	648	940	260	432	0.33	2.00	0.908	81.7	43.81	81.31	10.3
02FE009	373	900	250	485	0.32	0.01	1.340	46.5	43.68	81.54	5.8
02FE010	197	910	250	389	0.24	0.01	0.870	24.4	43.68	81.08	3.0
02FF007	466	900	240	397	0.33	0.01	1.656	52.5	43.30	81.80	5.9
02GA010	1008	900	170	334	0.49	18.00	0.950	39.4	43.19	80.45	1.5
02GA017	326	890	250	352	0.23	0.01	1.746	40.5	43.76	80.67	5.0
02GA018	552	890	200	342	0.30	0.01	0.900	67.9	43.38	80.71	8.4
02GA022	655	890	250	298	0.27	19.00	1.232	59.5	43.90	80.28	5.4
02GA029	236	820	180	336	0.56	20.00	2.780	42.0	43.55	80.18	7.5
02GA038	326	900	200	399	0.19	0.01	1.608	27.0	43.48	80.84	2.2
02GA040	167	830	200	398	0.39	4.00	3.524	22.5	43.64	80.27	3.0
02GB001	5206	900	150	333	0.55	40.00	1.342	190.5	43.13	80.27	7.0
02GB008	382	900	150	345	0.55	0.01	1.480	26.4	43.13	80.38	1.8
02GC002	329	890	120	369	0.26	0.01	1.560	45.5	42.78	81.21	6.3
02GC004	697	900	100	349	0.60	0.01	0.699	90.0	42.69	80.80	11.6
02GC006	363	900	140	328	0.69	2.00	0.868	23.0	42.84	80.51	1.5
02GC010	342	900	140	354	0.52	0.01	1.056	40.5	42.86	80.72	4.8
02GC018	287	890	110	395	0.28	0.01	1.418	31.5	42.75	81.04	3.5
02GD001	1340	900	160	336	0.51	10.00	1.160	89.7	42.97	81.21	6.0
02GD003	1450	900	200	354	0.39	9.00	1.150	78.8	43.04	81.18	4.3
02GD004	306	900	200	369	0.40	0.01	1.690	37.9	43.06	80.99	4.7
02GD005	1080	890	220	380	0.32	13.00	1.030	45.9	43.26	81.15	2.0

Table A.6
Region F - Summary of
Physiographic Basin Characteristics - 2

Basin	Drainage Area (km^2)	Mean Annual Precip. (mm)	Mean Annual Snowfall (cm)	Mean Annual Runoff (mm)	Base Flow Index	Area Controlled By Lakes and Swamps (%)	River Slope (m/km)	River Length (km)	Latitude (degrees)	Longitude (degrees)	Shape Factor
02GD008	200	900	180	387	0.35	0.01	1.954	36.4	43.01	81.28	6.6
02GD012	254	890	180	347	0.41	100.00	1.520	36.8	43.14	80.75	5.3
02GD014	319	890	240	416	0.26	0.01	1.420	22.7	43.45	81.21	1.6
02GD015	1340	900	210	386	0.37	10.00	0.963	66.5	43.15	81.19	3.3
02GE002	3110	900	160	375	0.45	9.00	1.049	105.8	42.96	81.33	3.6
02GE003	4300	820	150	368	0.49	9.00	0.413	227.5	42.46	81.97	12.0
02GE006	3760	880	120	436	0.51	10.00	0.208	172.5	42.73	81.58	7.9
02GG002	730	840	140	320	0.42	0.01	0.660	79.0	42.83	81.85	8.5
02GG004	609	780	140	288	0.27	0.01	0.341	88.8	42.76	82.34	12.9
02GG006	267	800	140	299	0.20	0.01	0.735	36.5	42.91	82.12	5.0
02GG007	1240	800	120	312	0.37	0.01	0.323	57.5	42.59	82.11	2.7
02HA006	293	800	120	302	0.15	0.01	0.654	80.0	43.13	79.39	21.8
02HB002	795	780	130	316	0.57	0.01	2.884	64.0	43.55	79.66	5.2
02HB011	235	790	140	361	0.64	3.00	2.870	30.0	43.44	79.25	3.8
02HC003	800	790	150	225	0.45	3.00	1.684	58.0	43.70	79.52	4.2
02HC024	316	780	140	380	0.49	3.00	3.563	37.5	43.70	79.35	4.5
02HC025	303	780	170	254	0.59	5.00	1.571	45.0	43.81	79.63	6.7
02HD002	232	800	140	405	0.64	11.00	2.975	20.0	43.99	78.30	1.7
02HJ003	282	790	170	320	0.62	77.00	1.065	28.5	44.30	78.05	2.9
02LB006	427	820	190	420	0.30	0.01	0.650	36.3	45.26	75.34	3.1
02LB007	246	850	190	392	0.39	96.00	0.436	28.0	44.84	75.54	3.2
02MC001	358	830	180	404	0.37	0.01	0.670	51.2	45.16	74.64	7.3
Minimum	163	780	100	225	0.15	0.01	0.208	20.0	42.46	74.64	1.5
Maximum	5206	1000	300	516	0.81	122.00	4.824	227.5	48.31	82.34	21.8
Mean	841	882	203	376	0.45	19.00	1.482	59.9	43.69	80.44	5.8
σ	1066	61	59	62	0.14	31.00	0.896	42.2	0.89	1.49	3.7
CV (%)	127	7	29	17	32	170	60	70	2	2	63

APPENDIX B

MONTHLY HYDROLOGY SUMMARIES FOR SAMPLE APPLICATIONS

TABLE B.1

SYNTHETIC MONTHLY HYDROLOGY SUMMARY
FOR CONESTOGA RIVER ABOVE DRAYTON
(m^3/s)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
1	5.372	4.094	13.351	14.191	0.406	0.381	0.476	0.055	0.090	1.881	7.410	2.545	4.188
2	5.674	1.473	7.996	10.855	0.463	0.069	0.066	0.150	0.082	0.054	0.568	3.085	2.545
3	2.377	2.556	9.052	2.423	4.962	1.743	0.635	0.108	0.097	0.095	0.155	0.724	2.077
4	0.392	10.105	9.881	10.571	0.592	0.125	0.043	0.051	0.153	7.794	1.324	1.948	3.581
5	2.260	0.649	8.467	10.950	1.294	0.288	0.043	0.024	0.058	0.490	4.244	1.517	2.524
6	0.558	0.327	3.379	24.337	6.880	0.581	2.226	2.677	1.091	0.605	0.749	3.107	3.876
7	1.836	3.115	4.846	5.912	1.330	4.706	1.445	0.058	0.614	1.352	5.600	7.084	3.158
8	0.552	0.166	4.187	2.312	0.294	0.062	0.051	0.045	0.091	0.085	0.362	0.346	0.713
9	0.221	0.173	4.879	24.650	4.337	0.214	0.191	1.575	1.647	2.892	7.448	2.975	4.267
10	1.592	2.276	1.689	24.046	8.476	1.306	0.087	0.031	0.020	0.059	0.299	0.120	3.333
11	0.110	3.168	6.743	4.584	2.333	0.803	0.122	0.097	0.115	0.062	0.370	1.480	1.666
12	0.244	0.230	8.889	7.042	0.358	0.116	0.048	0.054	0.054	0.234	3.068	2.179	1.876
13	0.518	0.254	13.735	3.469	2.765	0.189	0.028	0.057	0.037	0.047	0.149	0.112	1.780
14	1.800	1.119	8.432	6.636	0.605	0.152	0.038	1.177	0.115	0.099	0.194	4.095	2.039
15	1.765	6.052	2.918	16.302	3.223	0.104	0.055	0.040	0.099	2.938	7.129	10.056	4.223
16	1.623	3.309	8.933	4.642	2.119	1.510	0.022	0.042	0.079	0.087	1.712	5.864	2.495
17	4.784	1.102	8.592	9.868	0.897	5.332	4.065	1.003	1.003	6.686	8.061	9.273	5.056
18	0.691	6.087	14.290	2.500	0.888	0.257	0.111	0.806	1.395	3.351	7.431	3.853	3.472
19	2.461	2.732	8.206	15.540	4.295	0.476	0.121	0.051	0.027	0.090	1.264	0.569	2.986
20	0.542	1.036	1.036	19.098	1.640	0.290	0.334	0.050	0.130	0.587	3.025	5.454	2.768
21	1.198	0.864	3.608	24.410	0.828	0.401	0.048	0.060	0.075	0.052	0.168	1.888	2.800
22	2.111	0.720	3.059	25.538	2.010	1.060	0.287	0.045	0.042	0.892	2.649	3.179	3.466
Mean	1.758	2.346	7.099	12.267	2.318	0.917	0.479	0.375	0.323	1.383	2.881	3.248	2.950
σ	1.625	2.479	3.813	8.271	2.232	1.417	0.962	0.679	0.491	2.169	2.939	2.787	

TABLE B.2

SYNTHETIC MONTHLY HYDROLOGY SUMMARY
FOR STURGEON RIVER AT MCDOUGALL MILLS
(m^3/s)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
1	15.325	7.789	4.883	12.666	92.564	105.961	38.700	30.719	11.568	11.922	20.216	16.413	30.727
2	11.737	8.545	6.381	16.288	94.353	126.925	73.647	90.131	66.406	53.493	51.989	30.533	52.536
3	20.277	17.878	13.228	29.850	68.906	70.837	97.193	46.663	108.848	129.983	40.590	28.993	56.104
4	21.181	15.115	10.620	10.253	80.062	64.379	64.568	34.234	60.748	67.923	61.413	34.393	43.741
5	25.341	19.291	14.941	54.282	144.892	40.496	41.971	70.068	23.927	40.548	56.726	32.141	47.052
6	23.202	17.671	13.198	14.425	132.814	47.342	47.372	41.784	28.376	59.748	39.449	24.638	40.835
7	18.395	13.194	10.322	19.234	79.827	41.655	43.606	25.155	38.804	48.976	36.899	24.536	33.384
8	16.079	10.649	8.514	11.563	105.038	171.435	61.589	88.648	78.371	46.284	32.281	27.230	54.807
9	22.486	19.333	15.686	16.582	106.773	60.343	39.839	42.008	35.666	27.248	29.045	21.535	36.379
10	15.419	11.383	8.488	30.103	74.180	35.142	19.578	15.487	22.063	22.665	18.883	11.384	23.731
11	8.126	7.129	6.335	25.053	63.972	37.339	34.453	44.867	44.001	38.176	28.475	19.795	29.810
12	12.260	8.515	7.004	8.270	109.529	70.584	79.379	67.542	67.572	45.304	39.242	23.157	44.863
13	14.210	9.889	8.441	20.704	98.573	48.940	36.270	39.043	63.620	59.728	52.651	27.553	39.969
14	17.854	11.687	7.895	19.222	65.515	26.370	12.869	12.409	38.328	57.387	31.987	17.805	26.611
15	10.807	6.293	4.833	10.488	50.630	64.587	33.387	12.216	30.463	45.523	36.095	22.373	27.308
16	12.774	8.650	7.959	8.389	150.530	108.676	43.711	31.959	39.517	60.270	33.436	18.617	43.707
17	12.048	8.537	6.529	9.508	38.111	41.326	89.779	23.321	13.753	19.818	24.887	19.024	25.553
18	14.386	10.575	6.799	31.331	63.397	50.020	39.902	23.818	18.683	33.393	35.403	26.180	29.491
19	18.322	10.721	7.114	30.617	171.277	89.630	84.724	49.242	55.020	77.688	39.876	21.433	54.639
20	13.770	10.024	7.661	33.854	111.615	31.881	28.477	28.308	32.310	42.878	27.929	20.724	32.453
Mean	16.200	11.643	8.842	20.634	95.128	66.693	50.551	40.881	43.902	49.448	36.874	23.423	38.685
σ	4.582	4.090	3.171	11.644	34.921	37.085	23.771	22.831	24.533	25.214	11.528	5.699	

TABLE B.3

SYNTHETIC MONTHLY HYDROLOGY SUMMARY
FOR MAGNETAWAN RIVER NEAR BURK'S FALLS
(INDEX GAUGE PRORATION)
(m^3/s)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
1	2.046	2.701	7.779	51.187	14.195	1.955	0.882	0.563	0.439	1.692	6.880	10.610	8.411
2	5.031	8.966	6.741	74.505	20.220	4.865	0.971	0.320	0.438	0.982	0.612	0.727	10.365
3	0.519	0.652	5.548	22.407	24.290	9.724	2.589	0.705	0.352	1.648	0.444	3.026	5.992
4	1.840	1.127	13.678	30.603	9.990	2.767	0.679	0.328	0.424	1.938	11.991	10.912	7.190
5	4.587	3.267	14.963	30.148	15.248	4.073	0.391	0.245	0.199	0.215	5.600	7.617	7.213
6	6.789	6.246	15.839	23.692	15.205	3.888	0.593	0.228	1.728	0.660	0.620	4.379	6.656
7	4.393	9.724	9.733	45.342	18.483	2.775	0.827	0.515	1.489	10.621	21.253	23.595	12.396
8	13.149	5.424	27.128	19.069	13.090	6.965	0.927	0.290	0.604	1.563	13.672	33.386	11.272
9	10.592	9.341	9.464	39.907	13.940	5.853	7.000	2.200	2.438	15.598	28.746	18.047	13.594
10	10.210	10.366	24.245	24.102	6.485	7.262	4.914	0.867	0.817	0.671	4.118	8.718	8.565
11	8.590	13.197	20.902	43.878	40.493	8.784	2.405	1.076	2.113	0.586	2.938	5.989	12.579
12	3.156	4.173	6.553	40.706	19.513	5.038	3.817	2.217	0.939	0.774	5.563	8.914	8.447
13	6.320	6.024	10.654	57.573	18.536	2.921	1.920	1.809	1.944	2.177	3.097	12.323	10.442
14	10.356	8.087	8.066	52.824	33.191	6.973	9.068	5.101	2.046	4.984	18.101	16.656	14.621
15	21.155	15.266	50.117	32.223	13.018	4.084	1.792	1.559	1.181	0.858	3.035	9.721	12.834
16	14.604	11.001	25.293	48.306	32.294	6.019	1.743	1.459	1.611	2.145	6.191	10.110	13.398
17	10.470	7.358	26.683	45.207	17.246	3.089	1.319	1.233	0.461	0.329	0.583	5.532	9.959
18	5.180	10.721	41.668	47.490	11.261	3.040	1.148	0.970	0.866	1.397	2.986	3.560	10.857
19	3.466	3.575	37.564	21.852	4.407	1.301	0.382	1.890	1.563	2.343	5.226	17.021	8.382
20	16.313	11.353	12.696	56.697	21.068	2.669	0.968	0.920	0.839	0.827	4.517	9.212	11.507
21	12.175	8.205	43.320	46.682	16.607	5.587	1.140	0.826	0.762	2.461	8.868	21.726	14.030
22	15.079	4.227	28.042	36.769	14.894	4.826	1.877	1.225	1.117	3.243	8.425	14.410	11.178
23	3.917	43.957	27.480	14.263	10.022	9.384	3.180	2.060	12.447	11.519	17.342	9.834	13.784
24	7.208	4.044	11.119	51.337	13.563	5.615	1.893	1.356	1.029	1.201	11.749	31.157	11.773
25	17.416	11.499	22.615	27.579	32.576	7.414	0.875	0.792	0.507	0.610	3.792	12.963	11.553
26	6.526	28.598	21.159	53.068	22.682	3.788	0.968	0.988	0.784	0.680	3.127	6.888	12.438
27	11.342	10.830	34.979	37.577	9.667	2.048	1.302	1.006	3.983	3.907	20.558	12.260	12.455
28	11.167	8.272	24.264	23.732	9.656	12.537	3.602	5.689	13.950	29.213	9.940	12.278	13.692
Mean	8.700	9.579	21.010	39.240	17.566	5.187	2.113	1.373	2.038	3.744	8.213	12.199	10.914
σ	5.229	8.642	12.308	14.313	8.571	2.695	2.024	1.282	3.261	6.211	7.282	7.812	

TABLE B.4

SYNTHETIC MONTHLY HYDROLOGY SUMMARY
FOR MAGNETAWAN RIVER NEAR BURK'S FALLS
(NEAREST GAUGE PRORATION)
(m^3/s)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
1	4.570	1.710	8.567	8.401	10.174	10.211	15.206	7.939	46.204	27.656	18.589	5.170	13.700
2	1.616	3.750	12.094	15.168	21.495	5.387	4.846	5.478	40.206	19.680	11.285	19.435	13.370
3	4.341	2.254	7.067	7.875	4.029	2.357	1.904	7.303	31.984	17.587	7.284	3.545	8.127
4	2.195	4.148	15.638	14.802	14.049	8.556	4.982	15.779	34.506	26.378	11.391	2.227	12.887
5	2.167	3.498	6.753	16.813	13.745	4.315	3.185	18.297	30.110	17.915	4.565	6.090	10.621
6	2.740	3.468	4.232	11.067	11.195	9.233	5.190	36.572	31.924	12.306	4.934	2.207	11.256
7	3.100	1.550	3.479	9.546	16.148	6.885	5.727	9.925	55.788	12.619	4.013	5.319	11.175
8	2.798	1.457	1.865	4.240	3.815	2.847	2.524	3.532	39.135	37.435	10.380	2.525	9.379
9	1.628	3.384	1.809	3.331	9.896	4.558	4.252	6.300	33.587	35.828	10.064	2.424	9.755
10	1.952	1.700	2.490	2.729	6.277	2.865	4.862	8.175	44.571	13.410	11.778	5.092	8.825
11	1.816	1.313	2.402	10.212	9.048	4.443	3.701	2.943	12.642	47.898	12.631	9.865	9.909
12	3.263	2.304	3.187	28.934	11.559	4.517	4.195	17.654	22.970	16.944	12.028	7.994	11.296
13	3.557	1.791	7.198	14.891	13.528	8.204	5.549	6.751	61.789	33.980	15.586	11.750	15.381
14	12.911	12.855	36.711	19.376	11.753	9.833	7.010	14.539	58.579	29.853	8.599	4.072	18.841
15	2.020	1.758	2.029	3.806	3.018	4.669	6.074	8.864	31.872	18.739	10.249	4.555	8.138
16	2.021	2.191	2.412	3.459	2.695	1.881	1.613	1.973	26.598	12.658	3.544	2.446	5.291
17	1.111	1.488	2.857	8.220	8.598	18.012	10.913	5.865	32.606	12.877	5.681	3.941	9.347
18	2.082	6.212	22.169	23.571	14.406	12.793	6.776	4.387	47.744	13.309	5.616	2.308	13.448
19	1.572	1.295	3.164	4.525	5.694	5.163	4.517	4.263	36.038	28.976	6.980	3.352	8.795
20	1.591	2.011	3.341	11.464	10.279	4.346	3.815	10.463	27.698	13.413	11.680	13.546	9.471
21	4.413	1.706	3.899	9.161	6.131	2.790	1.828	6.684	26.346	31.065	8.098	1.930	8.671
22	1.184	3.481	11.279	14.635	9.963	26.120	10.031	6.886	35.687	20.397	6.062	2.187	12.326
23	1.733	2.201	4.825	15.145	6.605	4.195	6.985	21.661	41.543	15.646	5.845	2.766	10.762
24	1.842	3.474	3.958	5.952	5.791	5.751	4.517	4.897	36.478	28.640	6.215	2.761	9.190
25	2.823	2.101	5.989	9.400	4.192	2.410	1.720	1.505	17.713	29.478	10.198	4.076	7.632
26	6.037	9.112	9.093	15.331	9.243	6.719	3.701	2.904	46.318	9.654	3.353	2.013	10.290
27	1.883	1.655	8.222	22.651	9.736	6.453	3.284	10.659	46.216	21.846	6.828	1.694	11.761
28	0.872	2.759	6.356	17.850	6.933	4.517	3.340	3.929	34.699	40.929	14.963	5.630	11.898
29	3.052	5.555	3.525	8.557	4.574	3.056	2.790	2.900	26.812	20.736	4.203	2.827	7.382
30	1.617	2.522	10.590	7.430	5.218	3.113	2.524	27.776	21.175	16.115	12.610	2.943	9.469
31	1.066	1.525	8.204	11.691	4.726	11.976	6.131	31.464	18.380	11.138	5.638	1.913	9.488
32	1.179	1.141	1.660	6.604	11.973	6.605	5.163	4.861	54.733	37.335	15.383	10.266	13.075
33	4.324	5.102	4.782	8.981	7.352	4.403	2.961	16.345	43.133	20.697	5.796	2.135	10.501
34	1.566	1.069	4.067	16.451	9.538	9.623	8.389	13.479	48.184	15.561	7.930	3.809	11.639
35	1.751	1.301	2.401	3.943	12.676	20.498	8.066	7.537	27.165	14.519	7.268	2.544	9.139
36	4.807	5.278	2.898	12.300	11.265	8.389	5.876	10.244	68.410	17.435	4.302	3.884	12.924
37	2.204	1.887	10.076	21.396	12.408	9.502	7.307	5.238	46.331	14.073	5.595	3.103	11.593
38	4.542	7.961	3.235	6.761	12.218	6.548	7.473	26.783	23.329	12.243	5.374	2.279	9.895
39	1.106	2.797	4.507	5.781	10.992	5.960	6.037	16.018	39.503	16.654	17.832	4.240	10.952
40	2.799	4.185	26.946	15.069	9.440	6.071	5.066	6.965	44.230	9.090	4.189	1.809	11.321
41	1.295	1.051	3.959	12.532	5.297	2.871	2.129	2.627	24.627	24.562	8.914	5.628	7.958
42	4.580	16.539	9.470	9.928	8.307	6.675	6.395	7.947	28.991	15.032	10.337	21.880	12.173

Table B.4
Synthetic Monthly Hydrology Summary
for Magnetawan River Near Burk's Falls
(Nearest Gauge Proration) (m^3/s) - 2

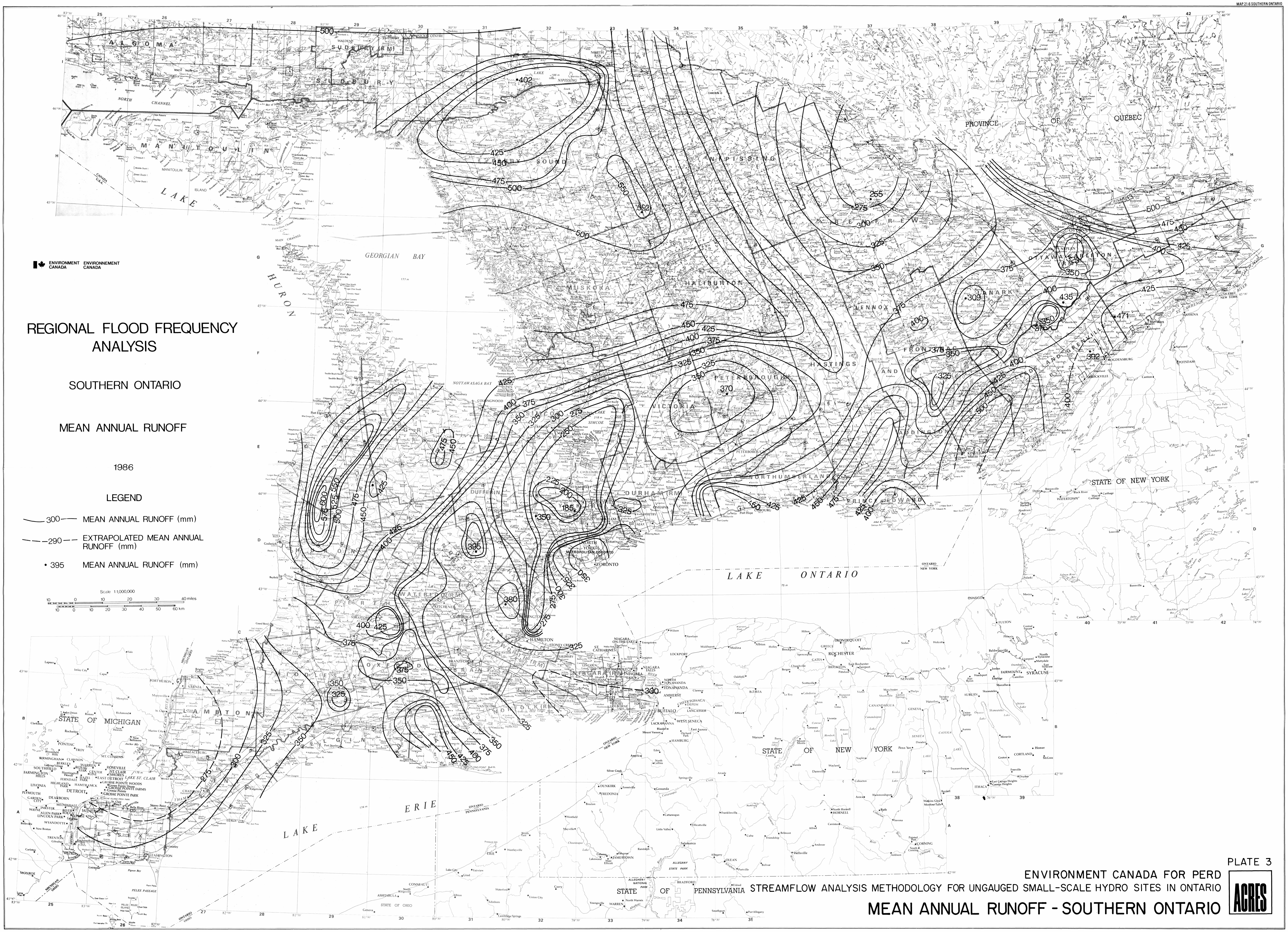
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
43	1.704	9.120	14.456	20.899	19.422	9.148	4.949	4.331	23.762	7.854	6.525	13.498	11.306
44	2.505	3.242	7.851	7.856	5.269	4.813	4.172	4.792	43.946	20.688	5.328	2.794	9.438
45	3.566	4.494	11.760	22.915	12.708	5.820	5.553	4.855	52.390	25.946	6.860	7.386	13.688
46	3.576	1.973	2.856	9.696	6.512	4.316	2.730	4.377	26.477	14.872	6.585	6.881	7.571
47	3.779	2.604	2.801	6.146	11.068	5.204	3.435	3.810	32.863	17.157	4.243	2.073	7.932
48	1.102	0.810	1.606	2.793	2.966	2.619	2.188	4.047	33.329	15.276	7.589	2.505	6.402
49	2.703	2.855	2.224	4.550	5.343	3.982	3.960	6.549	23.216	12.186	3.965	1.340	6.073
50	1.122	5.173	4.185	4.364	10.113	6.946	3.441	4.546	16.787	37.708	4.030	3.607	8.502
51	5.170	6.993	15.350	15.977	15.022	11.618	6.818	9.050	27.797	14.064	11.423	2.662	11.828
52	1.327	1.182	3.738	13.613	20.979	6.415	5.983	3.707	42.466	11.113	13.134	4.701	10.697
53	2.015	1.856	10.242	22.946	11.903	6.222	8.320	6.709	32.941	8.904	6.446	5.445	10.329
54	3.186	4.803	2.866	4.258	7.200	4.970	4.850	4.726	35.706	27.523	10.163	6.039	9.691
55	5.235	8.230	10.895	21.863	9.503	4.782	4.045	3.775	33.981	21.722	9.491	16.737	12.522
56	5.225	5.490	11.326	10.018	9.937	4.790	3.107	5.066	41.306	20.820	6.894	3.039	10.585
57	3.200	3.054	3.703	6.469	11.749	5.071	3.127	2.712	29.750	34.511	11.125	8.603	10.256
58	8.627	5.206	8.348	11.546	5.984	6.250	5.291	26.898	30.330	15.388	9.384	6.954	11.684
59	6.249	3.101	6.033	8.549	11.168	6.822	7.458	7.994	41.149	23.314	9.102	4.438	11.281
60	2.578	2.801	9.583	17.186	8.354	6.786	5.142	7.028	28.906	25.697	4.754	2.459	10.106
61	2.055	7.241	10.208	10.355	18.210	5.013	4.432	24.317	39.607	16.786	5.796	5.092	12.426
62	1.510	1.696	2.901	4.427	6.232	2.928	1.885	15.916	37.634	8.060	2.105	2.668	7.330
63	1.633	5.917	16.750	18.364	12.526	5.574	3.311	2.333	21.981	27.311	6.073	2.009	10.315
64	2.731	4.794	11.027	8.049	7.133	5.213	3.951	21.346	39.238	18.609	6.628	2.575	10.941
65	3.517	3.453	9.776	17.190	13.293	10.381	4.333	7.136	47.577	12.542	13.419	12.245	12.905
66	9.201	12.725	15.101	16.740	9.549	4.438	15.345	15.472	39.513	16.186	10.271	8.823	14.447
67	6.483	23.617	21.957	8.726	7.916	5.347	3.935	4.983	43.763	13.382	4.765	2.424	12.275
68	0.959	6.522	11.282	16.593	24.777	15.082	5.180	15.062	19.926	29.988	10.736	2.178	13.190
69	1.442	2.262	5.820	11.087	9.326	4.298	15.532	9.629	36.346	19.612	12.778	9.609	11.479
70	4.055	3.539	5.349	15.708	12.510	11.223	5.055	10.223	51.273	16.938	6.106	7.095	12.423
71	11.859	12.173	10.019	15.715	11.671	6.045	4.489	13.792	44.494	15.815	10.171	3.944	13.332
Mean	3.153	4.246	7.738	11.755	9.920	6.724	5.219	9.739	36.127	20.314	8.306	5.211	10.704
σ	2.336	3.907	6.324	6.085	4.469	4.192	2.883	7.655	11.205	8.769	3.642	4.213	

TABLE B.5

SYNTHETIC MONTHLY HYDROLOGY SUMMARY
FOR MAGNETAWAN RIVER NEAR BURK'S FALLS
(FLOW DURATION)
(m^3/s)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
1	3.664	4.380	8.448	43.485	12.311	3.455	1.915	1.267	1.007	2.779	8.034	10.580	8.444
2	6.674	9.533	7.993	54.655	15.989	6.361	1.995	0.736	0.995	2.089	1.375	1.613	9.167
3	1.167	1.265	6.481	17.224	20.419	9.917	4.250	1.536	0.808	2.880	1.000	4.631	5.965
4	3.386	2.386	12.810	29.620	10.275	4.377	1.443	0.749	0.955	3.220	11.229	10.739	7.599
5	6.243	4.963	13.309	24.881	13.528	5.575	0.848	0.563	0.458	0.495	6.661	8.546	7.173
6	7.896	7.573	13.715	17.672	13.444	5.518	1.283	0.483	3.193	1.451	1.353	5.631	6.601
7	5.999	9.623	9.907	43.665	14.989	4.401	1.734	1.160	2.635	9.955	18.183	17.758	11.667
8	11.928	6.933	22.609	15.621	12.229	8.057	1.858	0.669	1.284	2.907	12.614	28.942	10.471
9	10.636	9.800	10.151	34.350	12.759	7.266	8.139	3.750	3.761	12.713	20.188	15.016	12.377
10	10.424	10.439	24.902	23.090	7.784	8.269	6.120	1.828	1.689	1.431	5.664	9.470	9.259
11	9.051	12.218	20.424	48.015	34.055	9.224	3.965	2.212	3.418	1.241	4.544	7.358	12.977
12	4.851	5.927	7.508	42.217	15.710	6.521	5.487	3.865	1.954	1.699	6.739	9.633	9.343
13	7.658	7.435	10.879	48.053	17.670	4.620	3.499	3.184	3.474	3.709	4.789	11.500	10.539
14	10.705	9.003	8.974	41.460	33.003	8.121	9.592	6.545	3.411	6.245	16.438	14.299	13.983
15	16.586	13.179	41.994	29.200	12.179	5.636	3.275	2.992	2.475	1.870	4.667	9.999	12.004
16	12.947	10.620	23.284	44.247	29.047	7.397	3.020	2.874	3.076	3.753	7.315	10.459	13.170
17	10.565	8.330	25.302	36.503	15.258	4.740	2.600	2.473	1.054	0.759	1.305	6.854	9.645
18	6.789	10.527	29.652	34.606	11.194	4.620	2.332	2.083	1.899	2.694	4.672	5.272	9.695
19	5.171	5.235	32.503	19.098	6.044	2.461	0.879	3.456	3.014	3.967	6.502	14.500	8.569
20	14.101	11.102	11.443	52.189	17.157	4.273	2.116	2.000	1.825	1.813	5.644	9.794	11.121
21	11.695	9.088	34.697	40.195	14.121	6.883	2.353	1.806	1.679	3.924	8.978	19.078	12.875
22	13.274	5.916	23.145	32.676	12.983	6.311	3.386	2.517	2.336	4.439	9.205	12.917	10.759
23	5.560	25.872	24.153	13.043	10.203	9.821	4.633	3.533	11.413	10.707	14.587	10.243	11.981
24	8.315	5.813	10.573	48.679	12.360	7.077	3.424	2.732	2.204	2.456	11.001	27.624	11.855
25	14.536	11.136	17.524	19.757	28.955	8.036	1.896	1.741	1.147	1.367	5.188	12.015	10.275
26	7.817	30.261	16.548	45.730	18.084	5.200	2.095	2.096	1.731	1.509	4.808	7.746	11.969
27	11.045	11.670	29.894	33.356	9.654	3.595	2.640	2.176	5.010	5.478	16.021	11.720	11.855
28	10.574	9.084	23.271	20.564	9.116	11.645	5.080	6.878	12.188	26.348	10.347	11.863	13.080
Mean	8.902	9.618	18.646	34.066	15.733	6.406	3.281	2.425	2.860	4.425	8.180	11.636	10.515
σ	3.738	6.000	9.506	12.380	7.242	2.204	2.084	1.558	2.747	5.242	5.237	6.051	

PLATES


MAP 21-6 SOUTHERN ONTARIO
ENVIRONMENT CANADA ENVIRONNEMENT CANADA
REGIONAL FLOOD FREQUENCY ANALYSIS
SOUTHERN ONTARIO
MEAN ANNUAL RUNOFF
1986
LEGEND
300 MEAN ANNUAL RUNOFF (mm)
290 EXTRAPOLATED MEAN ANNUAL RUNOFF (mm)
• 395 MEAN ANNUAL RUNOFF (mm)
Scale 1:1,000,000
40 miles
60 km
GEORGIAN BAY
LAKE HURON
LAKE ONTARIO
LAKE ERIE
PROVINCE OF QUEBEC
STATE OF NEW YORK
STATE OF MICHIGAN
STATE OF PENNSYLVANIA
METROPOLITAN TORONTO
PLATE 3
ENVIRONMENT CANADA FOR PERD
STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO
MEAN ANNUAL RUNOFF - SOUTHERN ONTARIO
ACRES

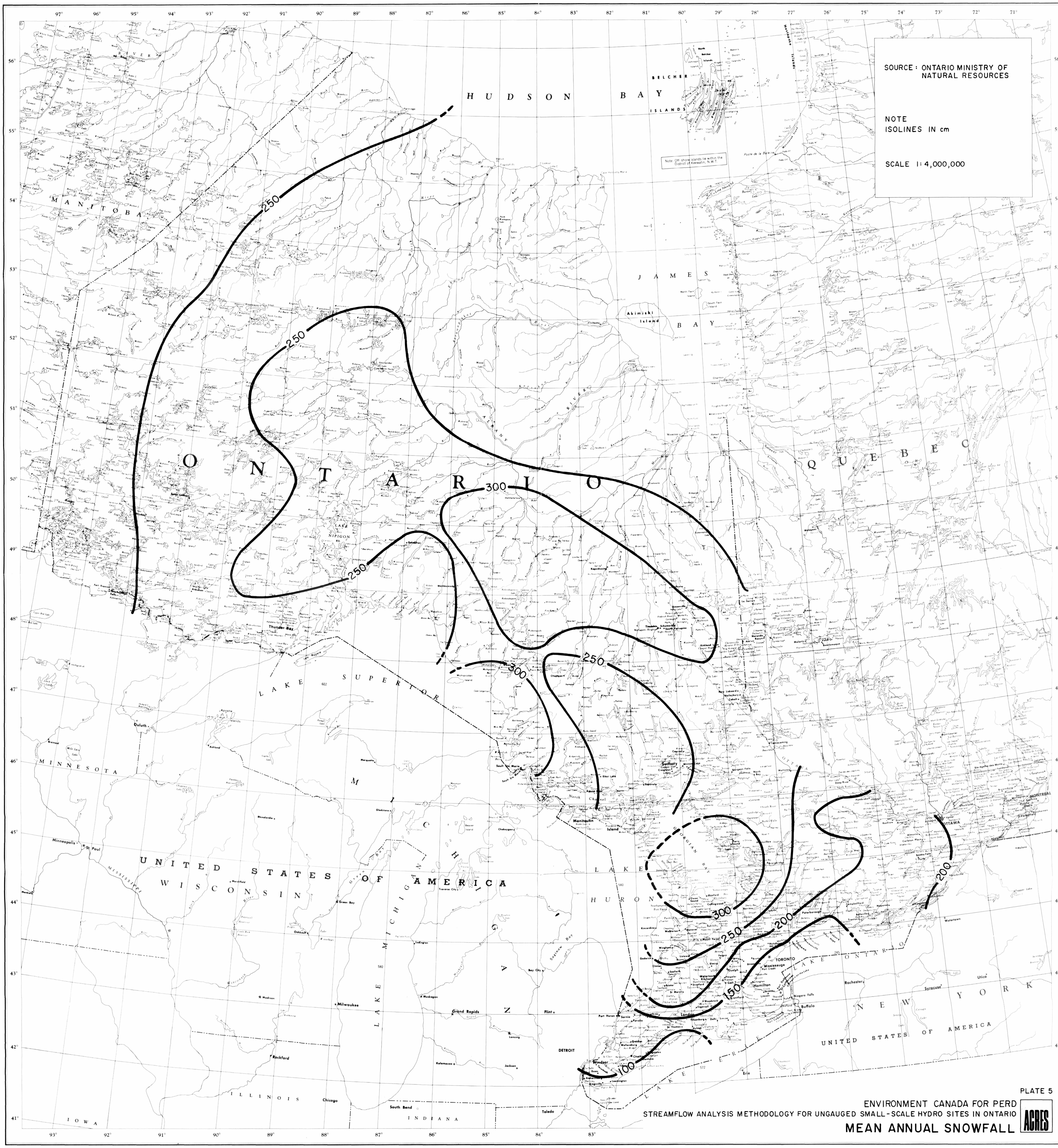


PLATE 5

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

MEAN ANNUAL SNOWFALL

ACRES

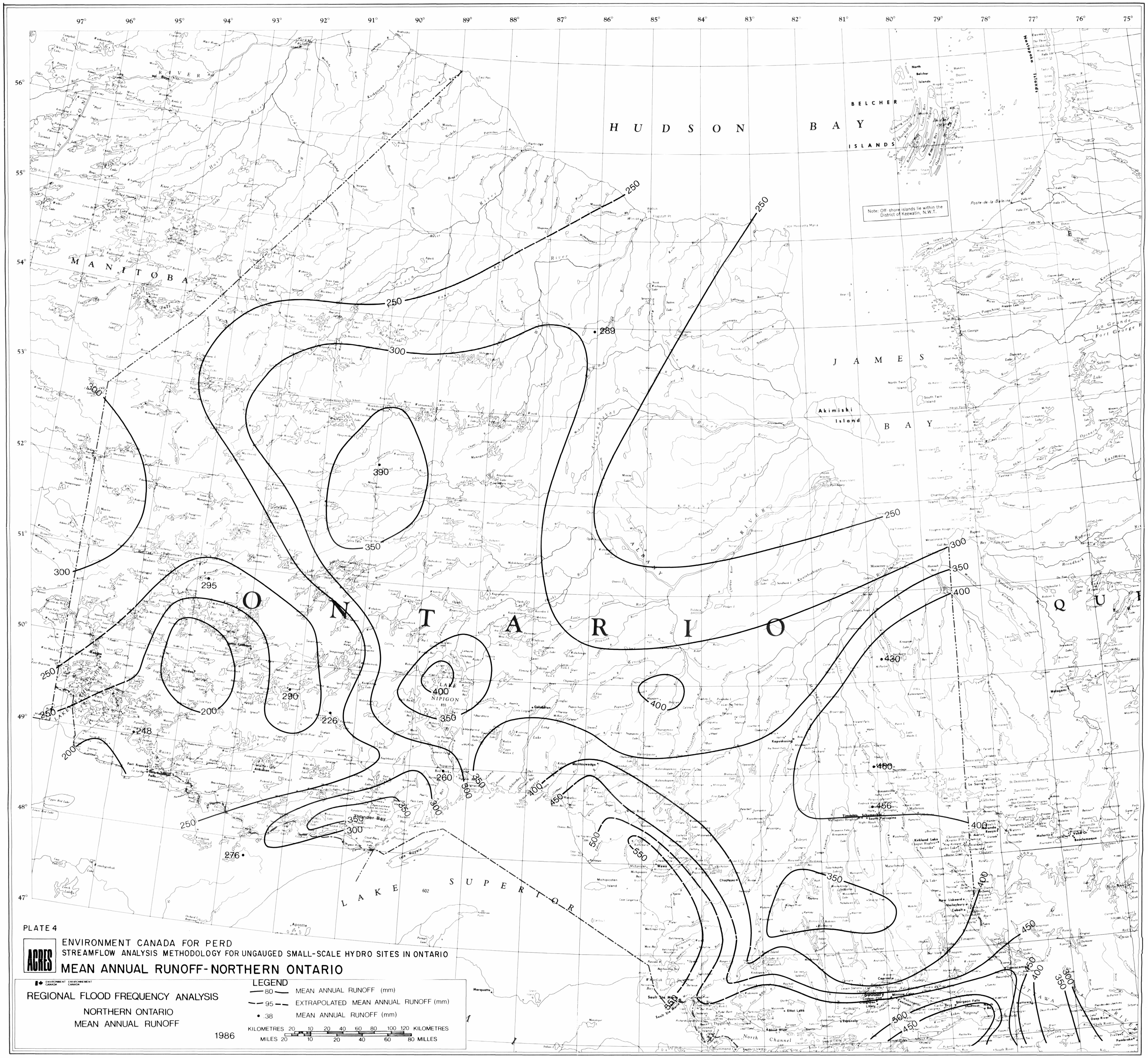


PLATE 4

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

MEAN ANNUAL RUNOFF - NORTHERN ONTARIO

REGIONAL FLOOD FREQUENCY ANALYSIS

NORTHERN ONTARIO

MEAN ANNUAL RUNOFF

1986


MAP 21-6 SOUTHERN ONTARIO
REGIONAL FLOOD FREQUENCY ANALYSIS
SOUTHERN ONTARIO
BASE FLOW INDEX
1986
LEGEND
.35 BASE FLOW INDEX ISOLINE
.35 EXTRAPOLATED BASE FLOW INDEX ISOLINE
•.80 BASE FLOW INDEX
Scale 1:1,000,000
ENVIRONMENT CANADA ENVIRONNEMENT CANADA
GEORGIAN BAY
LAKE HURON
LAKE ONTARIO
LAKE ERIE
PROVINCE OF QUÉBEC
STATE OF NEW YORK
STATE OF MICHIGAN
STATE OF PENNSYLVANIA
PLATE 2
ENVIRONMENT CANADA FOR PERD
STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO
BASE FLOW INDEX - SOUTHERN ONTARIO
ACRES

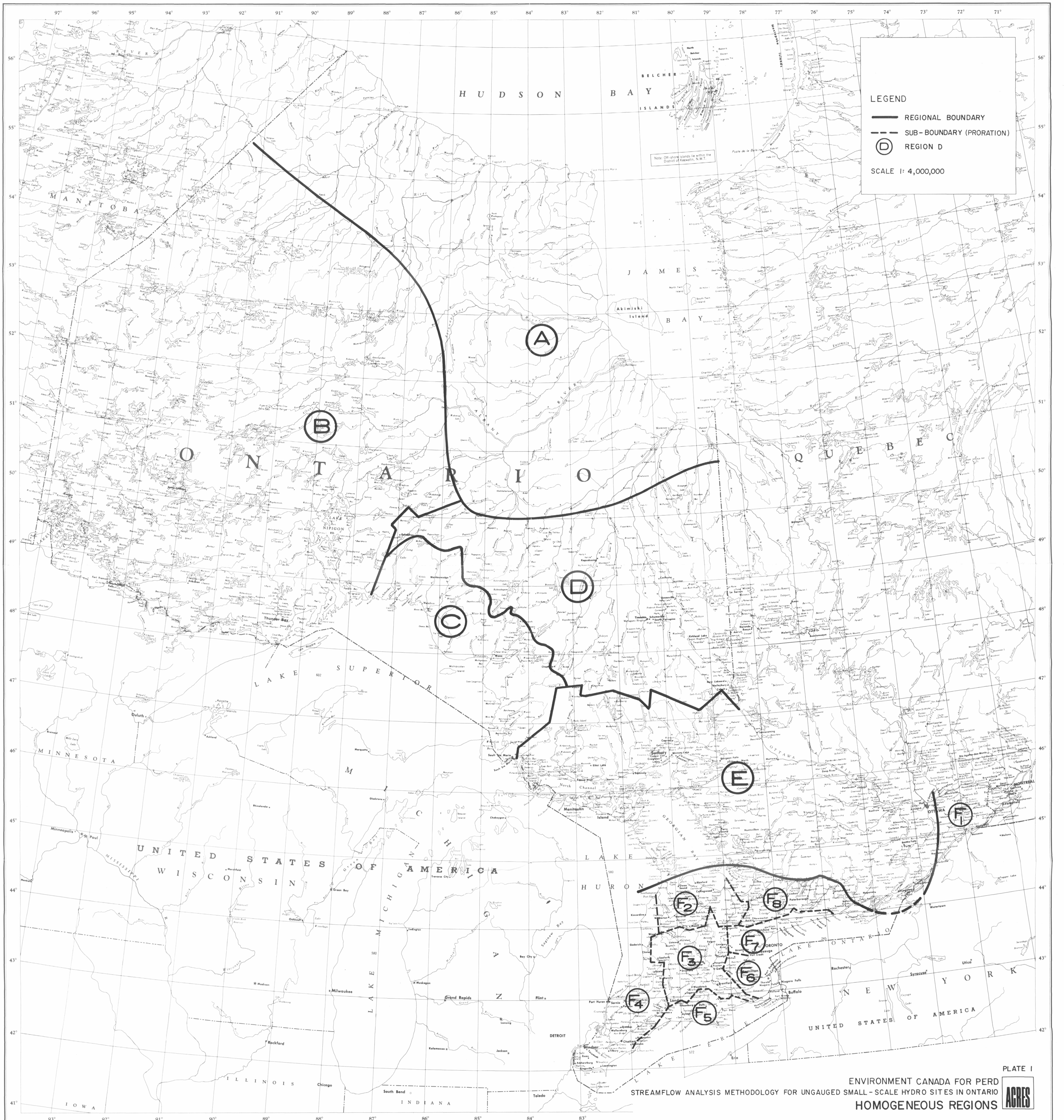


PLATE I

ENVIRONMENT CANADA FOR PERD

STREAMFLOW ANALYSIS METHODOLOGY FOR UNGAUGED SMALL-SCALE HYDRO SITES IN ONTARIO

HOMOGENEOUS REGIONS

ACRES