IWD Technical Training - Mar. 5, 1984
Introduction to Surface Water Hydrology

W. Kreuder, P. Pilon, E. Fast, R. Leith
A. Smith

Introduction to surface water hydrology : IWD technical training, Mar. 5, 1984, Vancouver, B.C. at Robson Media Centre.

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INTRODUCTION TO SURFACE WATER HYDROLOGY
IWD TECHNICAL TRAINING - MAR. 5, 1984
VANCOUVER, B.C. AT ROBSON MEDIA CENTRE

Course Content: Designed for IWD staff wanting a basic understanding of hydrologic principles and their application.

8:30	1.	Welcome	W.L. Kreuder
8:40	2	Introduction to Hydrologic Cycle	P. Pilon
9:00	3.	Hydrometric Surveys/Field Techniques	E. Fast
	4.	Data Processing	E. Fast
10:30	5.	Film: "Where Did the Colorado Go?"	
11.30		LUNCH	
12:15	6.	Introduction to Hydrologic Analysis and Interpretation	P. Pilon
		Film: "The Water Cycle"	
12:45	7.	Variability of Runoff	R.M. Leith
13:45	8.	Floods and Their Analysis	A.G. Smith
15:00	9.	Networks	W.L. Kreuder
15:45	10.	Wrap up	W.L. Kreuder

THE FOLLOWING LISTS ARE FOR SPECIFIC ASPECTS

NO. 1 'FIELD TECHNIQUES'

EMPLOYEE	BRANCH	TRAINING
R. Princic	WPM	A
John C.Y. Lee	WPM	A
M.P. Clark	WPM	A
N.A. Dalley	WPM	A
J.R. Oakey	WPM	A
D. Bernard	WPM	A
D. Burns	WRB	A
A. Gravel	WRB	A
B.L. Tassone	WRB	A

NO. 2 'LABORATORY TECHNIQUES'

J.R. Oakey	WPM	A

NO. 3 'DATA PROCESSING'

R. Princic	WPM	A
M.P. Clark	WPM	A
J.R. Oakey	WPM	A
D.N. Burns	WRB	A
A. Gravel	WRB	A

NO. 4 'DATA INTERPRETATION'

S.A. D'Aquino	WPM	A
R. Princic	WPM	A
M.P. Clark	WPM	A
M. Frigon	WRB	A
M. Alford	WRB	A
G. Clent	WRB	A
J. Gilbert	WRB	A
J. Harris	WRB	A
P. Langford	WRB	A
C. Watson	WRB	A
I.J. Stewart	WRB	A
B.L. Tassone	WRB	A

NO. 5 'MODELLING'

J.R. Oakey	WPM	A
M. Frigon	WRB	A
R. Keene	WRB	A
I.J. Stewart	WRB	A

EMPLOYEE	BRANCH	TRAINING
NO. 5 'NETWORKS'		
J.R. Oakey	WPM	A
F.M. Braybrooks	WRB	A
M. Frigon	WRB	A
C. MacDonald	WRB	A
M. Alford	WRB	A
K. Barker	WRB	A
G. Clent	WRB	A
J. Gilbert	WRB	A
J. Harris	WRB	A
R. Keene	WRB	A
P. Langford	WRB	A
G. Lopaschuk	WRB	A
E. Mayert	WRB	A
F. Orgnacco	WRB	A
K. Walker	WRB	A
C. Watson	WRB	A
D.N. Burns	WRB	A
NO. 7 'WATER MANAGEMENT'		
S.A. D'Aquino	WPM	A
D. Sherwood	WPM	A
R. Princic	WPM	A
J.R. Oakey	WPM	A
D. Bernard	WPM	A
W.L. Kreuder	WRB	A
NO. 8 'MULTI-ASPECTS'		
S.A. D'Aquino	WPM	A
D. Sherwood	WPM	A
R. McNeill	WPM	A
N.A. Dalley	WPM	A
J.R. Oakey	WPM	A
R.N. Boak	WPM	A
D. Bernard	WPM	A
M.M. Wiggins	WPM	A
L.M. Key	WRB	A
O.L. Nagy	WRB	A
A.J. Dott	WRB	A
L.S. Campo	WRB	A

EVALUATION OF INFORMATION SEMINAR

A. Employee Name: ____________ Phone: ____________

Service: ____________ Branch: ____________ Division: ________

B. Seminar Title: ____________ Date: ____________

Location: ____________ Speakers: ____________

C. 1. Brief outline of content:

2. Please rate the following, on (1 - very poor, 5 - excellent)

		Comments
- Organization:	1 2 3 4 5	
- Quality of content:	1 2 3 4 5	
- Presentation style:	1 2 3 4 5	
- Learning value:	1 2 3 4 5	

The IWD Committee on Technical Training was constituted by the Directors to advise on Directorate technical training requirements and to maintain an efficient system for organizing and coordinating technical training activities.

From the training needs survey, a few definite priorities were advanced by the Committee to the Directors and they selected Surface Water for the first training program. They also designated the Water Resources Branch as the lead agency to design and implement the Surface Water training program.

INLAND WATERS DIRECTORATE

COMMITTEE ON TECHNICAL TRAINING

SURVEY OF CURRENT AND IMMEDIATELY FORESEEABLE TECHNICAL TRAINING REQUIREMENTS

MPLOYEE:	EMPLOYEE CLASSIFICATION:	REGION:
	POSITION CLASSIFICATION:	BRANCH:

TOPICS	HYDROLOGY			
	METEOROLOGY/CLIMATOLOGY	SURFACE WATER	SNOW AND ICE	GROUNDWATER
FIELD TECHNIQUES				
ABORATORY TECHNIQUES				
ATA PROCESSING				
DATA INTERPRETATION				
MODELLING				
ETWORKS				
ATER MANAGEMENT				
ULTI-ASPECTS				

) INTRODUCTORY, BASIC PRINCIPLES, GENERALIZED TREATMENT OF THE SUBJECT.

B) IN DEPTH, WORKING LEVEL, DETAILED OR SPECIALIZED TREATMENT OF THE SUBJECT.

) COMPONENT OF THE CAREER DEVELOPMENT PROGRAM FOR WSC HYDROMETRIC TECHNICIAN

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MODELLING				
NETWORKS				
WATER MANAGEMENT				
MULTI-ASPECTS				

A) INTRODUCTORY, BASIC PRINCIPLES, GENERALIZED TREATMENT OF THE SUBJECT.

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C) COMPONENT OF THE CAREER DEVELOPMENT PROGRAM FOR WSC HYDROMETRIC TECHNICIANS.

Pilon, P.J. Introduction to Hydrologic Analysis and Interpretation

Leith, R.M. Variability of Runoff

Smith, A.G. Floods and Their Analysis

Kreuder, W.L. Networks

Pilon, P.J. Introduction to the Hydrologic Cycle

6. Introduction to Hydrologic Analysis and Interpretation - P.J. Pilon

6.1 The Hydrograph

A knowledge of the magnitude and time distribution of streamflows is essential to many aspects of water management and environmental planning. This knowledge is usually contained in what is termed a "hydrograph".

A hydrograph is a graph showing stage, discharge, velocity, or other properties of water flow with respect to time. When the stage is plotted against time, the graph is a stage-time graph or stage hydrograph, which is usually shown on the recorder chart from a recording-gauge station. When the discharge is shown against time, the graph is a discharge hydrograph, or commonly called simply a "hydrograph". Thus, a hydrograph is a continuous graph showing the properties of streamflow with respect to time. It includes the integrated contributions from surface runoff, interflow, groundwater flow and channel precipitation. The term hydrograph will generally be taken herein to indicate a discharge hydrograph.

6.2 Surface Runoff Phenomena

Depending upon the rate at which rain falls, water may either infiltrate into the soil or accumulate and flow from an area as surface runoff. If the intensity of rainfall--neglecting interception and evaporation losses--is less than the rate of infiltration, all water will enter the soil profile. Conversely, when the intensity of rainfall is greater than the rate of infiltration, a sequence of events occurs which ultimately will produce surface runoff.

Excess water produced by a high intensity of rainfall must first satisfy soil and vegetal storage, detention and interception requirements. When the surface depressions are filled, surface water then begins to move down the slopes in thin films and tiny streams. At this stage, the flow overland is influenced greatly by surface tension and friction forces. As precipitation continues, the depth of surface detention increases, and it is distributed according to the distance from the outlet (refer to Fig. 2). With an increase in depth or volume of supply, there is a corresponding increase in the rate of discharge. Therefore, the rate of outflow is a function of the depth of water detained on the area.

The paths of the small streams are tortuous in nature. Every small obstruction causes a delay until sufficient head is built up to overcome such resistance; then upon release, the stream suddenly speeds on its way again. Each time there is a merging of two or more streams, the water is accelerated still more in its downhill path. The culmination of all these small contributions thus produces the ultimate hydrograph of surface runoff. After the excess rain ends, the water remaining on the area (surface detention) disappears progressively from the watershed as a result of the combined action of surface runoff and infiltration.

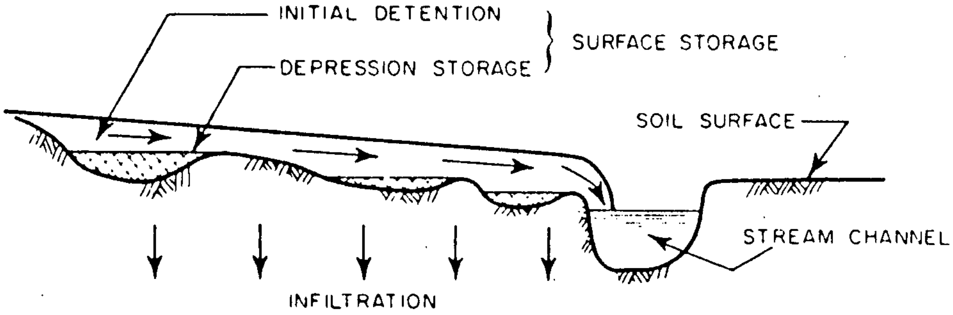


Fig. 2 Surface Runoff Phenomena

It should be mentioned that, frequently, the relative times-of-travel in overland and channel flow are used for hydrologic categorization of the size of the watershed. That is, a small watershed is an area in which the time involved in overland flow is significant (and thus cannot be neglected); whereas a large watershed is an area in which the time of travel by surface runoff in channel flow predominates, being much greater than the travel time in overland flow.

6.3 Interflow

Water infiltrating the soil surface and moving laterally through the upper horizons of the soil until it returns to the surface at some point downslope (from its point of infiltraton) to flow to the stream as surface runoff, or to be intercepted in its course by a stream channel, is known as interflow. This water does not become part of the characteristic groundwater flow system. Geologic conditions which favour interflow are those where the porous surface layers are underlain by relatively impervious strata. Under such conditions, the contribution of interflow to streamflow may be very significant.

The primary effect of the interflow component is that it tends to lengthen the time elements of the hydrograph; that is, the times of arrival of interflow contributions are delayed, and thus lag surface runoff contributions.

6.4 Groundwater Flow

Groundwater flow is that component of streamflow which originates from flow occurring below the groundwater table. This flow, which comes from accretions of water that have been built up during any storm event, occurs over a long period of time. As a result, this component is extremely important to watershed yield.

Streams may be categorized as being either effluent or influent depending on the direction of movement of water from the stream channel. During those periods when the water-surface level in the stream intersects the water table at the bank, such that groundwater flow occurs to the stream (because of the slope of the water table), the stream is considered to be effluent. On the other hand, if the water table falls below the bottom of the channel and the water level in the stream is higher than the groundwater level, or if either occur, then flow from the stream to groundwater begins, and the stream is considered to be influent.

6.5 Channel Precipitation

The component of streamflow originating from precipitation that falls directly on the water surfaces of lakes and streams is known as channel precipitation. This amount can be computed by multiplying the average rainfall by the area of the basin covered by water surfaces which are connected with the stream system.

Obviously, the percentage of channel precipitation varies from basin to basin, and from time to time within a given basin depending on the water level in the streams. However, the water surface area for most basins does not exceed 5 per cent of the total area at fairly high stages.

Generally, channel precipitation is not considered as a separate component of runoff, since it is usually a relatively small amount and is thus included with surface runoff. In reservoirs, however, significant inflow may occur from precipitation falling directly on the lake surface.

6.6 Hydrograph Shape

The shape of a hydrograph of a single, short-duration storm occurring over the drainage area follows a general pattern. This pattern shows a period of rise, or a period of increasing discharge, that culminates in a peak or crest. Following is a period of decreasing discharge (recession limb) which may or may not decrease to zero discharge, depending on the amount of groundwater flow. A typical hydrograph, divided into three principal parts, is shown in Fig. 3. For small watershed areas, the total contributions to the runoff hydrograph by groundwater flow, channel precipitation and interflow are usually small in comparison to the amount received from surface runoff.

6.6.1 Rising Limb or Concentration Curve

The rising limb extends from the time of beginning of surface runoff to the first inflection point on the hydrograph, and represents the increase in discharge produced by an increase in storage or detention on the watershed. Its geometry is characterized by the shape of the basin, and by the duration, intensity and uniformity of the rain. The initial portion is concave as a result of two factors: the greater concentration of area lies within the middle and upper reaches of the basin; and the greater opportunity for infiltration, evaporation, surface detention and interception during the initial periods of the storm.

6.6.2 Crest Segment

The crest segment includes that part of the hydrograph from the inflection point on the rising limb to a corresponding point on the recession limb. The peak of the hydrograph, or the maximum instantaneous discharge rate, occurs within this time interval.

6.6.3 Recession Limb

The recession limb includes the remaining part of the hydrograph, which may or may not decrease to zero discharge depending on the amount of base flow or groundwater flow. It represents the withdrawal of water from storage after excess rainfall has ceased. Consequently, it may be considered as the natural decrease in the rate of discharge resulting from the draining-off process. The shape of the curve is independent of time variations in rainfall or infiltration, and is essentially dependent upon the physical features of the channel alone. The general mathematical form of the equation often used to define this segment of the hydrograph is:

$$Q_2 = Q_1 K^{-\Delta t} \qquad 1$$

where Q_2 = instantaneous discharge rate at time, t_2,
W_1 = instantaneous discharge rate at time, t_1,
K = recession constant, and
Δt = elapsed time interval, $(t_2 - t_1)$.

This equation produces a straight line when plotted on semilogarithmic paper. The value of the recession constant, K, is generally not constant throughout all discharge rates. Frequently, the recession curve is broken into a series of line segments to obtain several values of K, with each value applicable within a given range of flows.

It is as yet impossible to accurately quantify the contribution of baseflow to total streamflow when the shape of the discharge hydrograph results from a single, short-duration storm, or possesses more complex shapes. Figure 4 shows several possible baseflow conditions in which the measured hydrograph is ABCDE. Line BGF is an extension of line AB, which represents the groundwater contribution if rainfall had not occurred. If no increase in groundwater occurs through infiltration, the hydrograph should return to this line when runoff stops. This is not the case in this example. Line DE is the baseflow occurring after the end of the runoff, and it has been displaced vertically upward from the baseflow prior to the storm. This is another baseflow recession curve but should have the same shape as ABGF if, as is usually assumed, the baseflow curve has a constant shape.

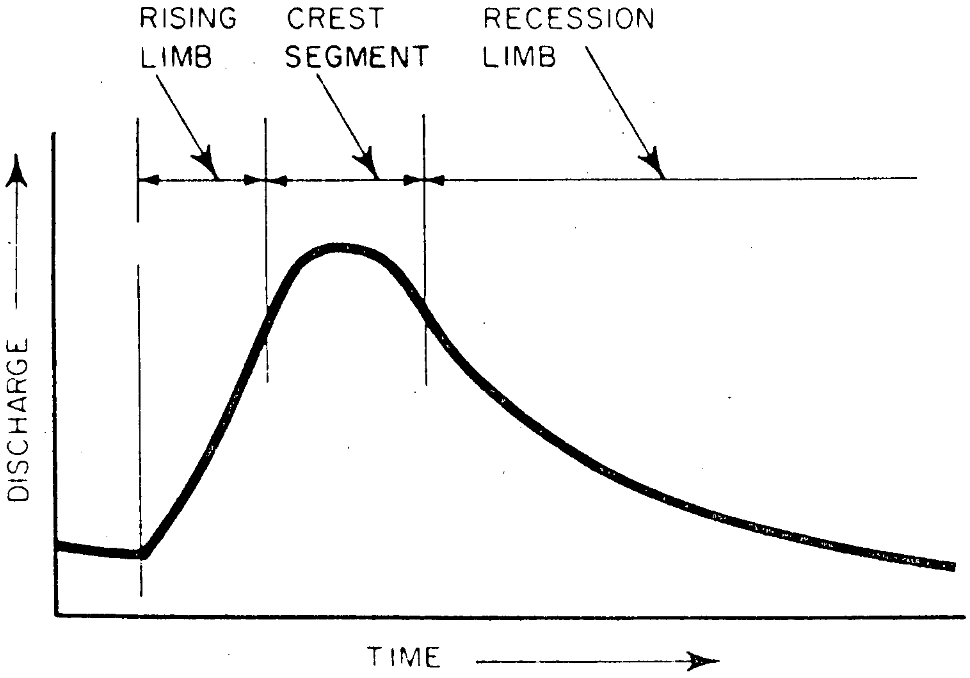


Fig. 3 Components of Hydrograph

In Figure 4, the later recession curve has been extrapolated backward to point K. Points B and D, where the baseflow curves deviate from the hydrograph, indicate respectively the beginning and ending of runoff. How do these two points connect? It is instructive to consider what happens to the baseflow during a storm. Figure 5 represents a cross section of a stream and adjoining land area. Stream water surface I represents a baseflow condition during which groundwater flows from the bank to the stream. Consider now a storm occurring so that the stage of the stream rises to level II. The hydrostatic pressure on the bank due to streamflow is now greater thant that in the water table, and groundwater flow actually reverses, with water flowing from the stream into the bank. In Figure 4 this condition is actually a negative discharge since the process subtracts from streamflow. The water entering the bank is called bank storage. In rivers where the hydrograph rises slowly and recedes slowly, bank storage can be significant.

Line BID in Figure 4 qualitatively represents the manner in which groundwater flow should behave during a period of rise in the stream. As the stage rises, the flow of groundwater decreases and eventually goes negative. If the soil in the drainage basin is highly permeable so that the groundwater table rises more rapidly than the stream stage, the baseflow may be represented by a curve such as BJD. Often a straight line from B to D or from G (a point under the hydrograph peak) to D is drawn and is assumed to represent the division between groundwater flow and surface runoff. The area below this assumed curve and the area between the baseflow curve and the hydrograph represent groundwater contribution and surface runoff respectively.

No matter which of the assumed baseflow curves shown in Figure 4 is used, the total surface runoff volume (area above the baseflow curve) is approximately the same. The time distribution is different, however, in each case. The difference between the ordinates of the baseflow curve and the hydrograph is the flow rate of surface runoff; therefore, curve BID indicates that the surface runoff peak occurs earlier than indicated by BJD, BD, or BGD.

In order to estimate the baseflow, curves AB and DE must be extended to G and K respectively. The baseflow curve is frequently assumed to be a decreasing function as defined by equation 1.

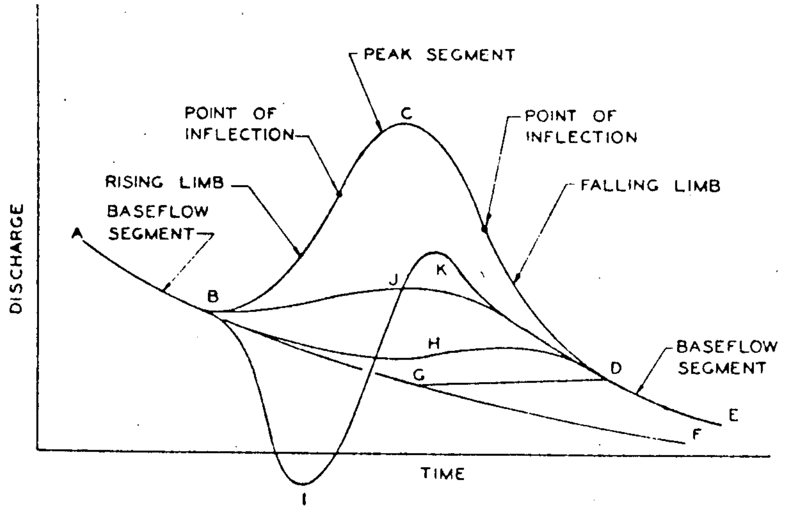


Fig. 4 Baseflow separation

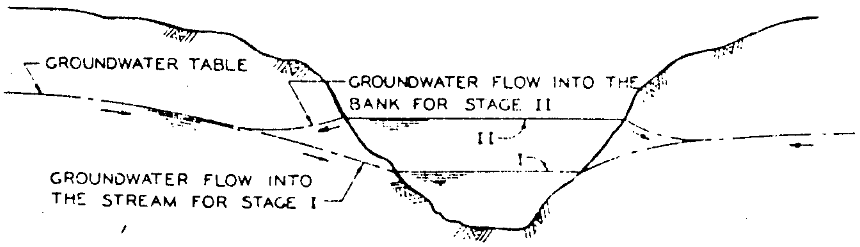


Fig. 5 Groundwater behavior during baseflow (I) and during flooding (II)

6.7 Factors Affecting Hydrograph Shape

The time distribution of runoff (the shape of the hydrograph) is influenced by climatic factors, and by the topographic and geologic features of the basin; thus the final hydrograph is affected by all three factors. However, it may be stated that climatic factors predominate in producing the rising limb, while the recession limb is largely independent of the storm characteristics producing the runoff.

6.7.1 Climatic Factors

The climatic factors which influence the hydrograph shape, and of course, the volume of runoff are:

(1) rainfall intensity and duration;
(2) distribution of rainfall on the basin;
(3) direction of storm movement; and
(4) type of precipitation and type of storm.

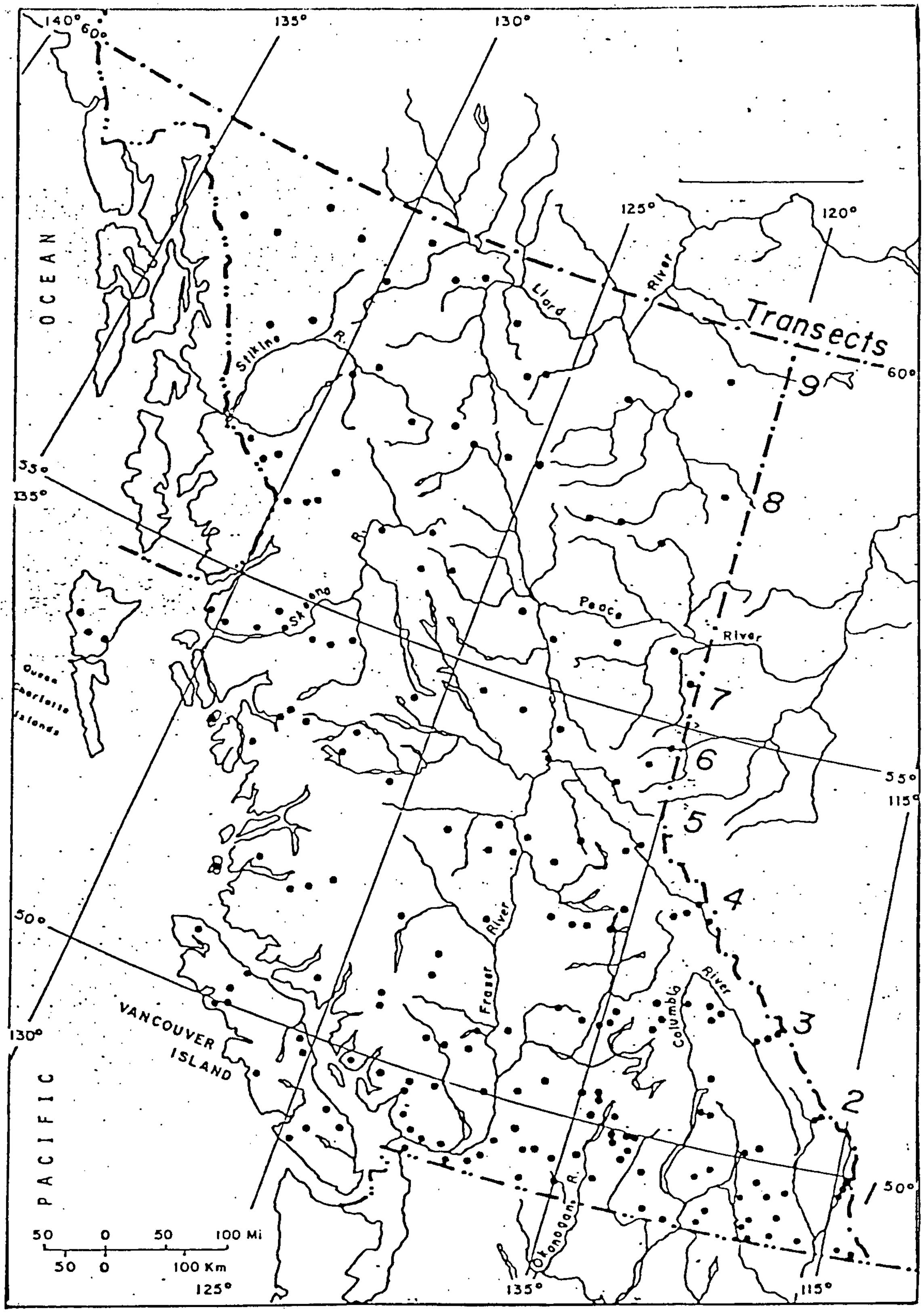
6.7.2 Topographic Factors and the Hydrograph

The surface-runoff hydrograph for a watershed represents the integrated effect of all physical characteristics of the basin and their modifying influence on the translation and storage of a rainfall-excess volume. The factors involved are numerous, some having a major bearing on the phenomena and others being of negligible consequence. Some suggested dominant factors include:

(1) Drainage-area size and shape;
(2) Distribution of the watercourses;
(3) Slope of the valley sides or general land slope;
(4) Slope of the main stream;
(5) Pondage resulting from surface of channel obstructions forming natural detention reservoirs.

6.7.3 Geological Factors

The geological factors, which affect the shape of the runoff hydrograph, are primarily those which govern the flow of groundwater and interflow to a stream. For example, an impervious formation of layer close to the surface would affect the amount of interflow (flow through the surface soil layers), hence the resulting hydrograph. The hydraulic conductivity of the surface layers affects the infiltration to lower levels, and thus determines the groundwater and interflow contributions to runoff. It should be mentioned that subsurface formations can make the groundwater drainage area to a stream much larger or much smaller than the surface drainage area. That is, the phreatic divide need not correspond and in many cases does not conform, to the topographic divide; hence a stream may show a proportionately high or low groundwater contribution depending on the subsurface formations. It is also possible that the groundwater table is normally at such a level that the stream continually supplies water (influent stream) to subsurface aquifers; or the stream may be effluent, receiving a continuous supply of groundwater; or influent at high stages and effluent at low.



NETWORKS

DK Krendler

Definition of a Network:

Number of stations established for a common purpose for gathering streamflow data in order to provide information.

Information required for:

1. Current Use
2. Planning and Design

Current Use Networks:

- Flood Forecasting
- Reservoir Operation
- Water Quality Control
- Legal Requirements
- International Commitments

Examples of Current Use Networks:

<u>Flood Warning</u> required during spring freshet to be supplied on a daily basis usually beginning in the middle of April.

Fraser Basin:

7	stations	Fraser River
3	"	Quesnel River
1	"	Nechako River

Thompson Basin:

5	stations	North, South, Thompson R.
3	"	tributaries

Columbia Basin:

6	stations	Columbia River

Okanagan Basin:

6 stations

Reservoir Operation

Williston Lake Reservoir

Drainage Area = 27,800 sq. miles
72,000 square Km

Water Surface Area = 438,000 acres

Normal Range of
Controlled Water Levels = 2,100 - 2,205'

Usable Storage = 32,000,000 acrefeet
16,800,000 cfs-day

Gauges on Major Tributaries:

Finlay River	22% of Dr. Area
Nation River	10% " "
Parsnip River	7% " "
Omineca River	8% " "

Ingenika, Osilinka, Ospika, Pack and Mesilinka Rivers

4 gauges on Williston Lake

International Commitments

Int'l Gauging Stations:

Operated by USA	14 stations
Operated by Canada	5 stations

Int'l Boards of Control:

Columbia River Treaty Perm. Eng. Board	11 stations
Kootenay Lake Board	5 stations
Osoyoos Lake Board	6 stations
Skagit River Board	2 stations

Provincial Requirements For Current Use Data:

- municipal water supply
- bridge and culvert design
- fisheries habitat
- flood protection
- pollution control
- small hydro projects
- irrigation requirements

In 1983

101 stations (all-year)

plus 75 stations (irrigation)

Data for Planning and Design

Regional Network

Collect data for the study of hydrologic response for a geographic area

Hydrologic responses:

- Peak Flows
- Low Flows
- Long Term Runoff

Regional Network cont'd

Considerations for design:

1. Location :- homogeneous area
   - natural flow

2. Drainage Area Size:

mountains = 1500 Km^2 or less
flat = up to 3000 Km^2

3. Physiographic Features:
   - elevation
   - basin slope, channel slope
   - glaciers, snow field
   - shield effect, dist. to sea
   - windward slopes

Inventory Networks

1. Major Streams

size - greater than 1500 Km^2
in mountains
- greater than 3000 Km^2

volume of flow
- 50 to 100% greater

2. National Inventory
- large rivers flowing to the oceans : M.A.F. > 400 m^3/sec
- for water quantity trend determination : rivers flowing to the oceans : M.A.F. > 85 m^3/sec

SITE-SPECIFIC NETWORK

OPERATED FOR

PROVINCIAL WATER

MANAGEMENT NEEDS

INTERNATIONAL GAUGING NETWORK

INT'L GAUGING STATIONS

OPERATED BY USA	14 STATIONS
OPERATED BY CANADA	5 STATIONS

INT'L BOARDS

CRTPEB	11 STATIONS
KOOTENAY LAKE B	5 STATIONS
OSOYOOS LAKE B	6 STATIONS

FLOOD WARNING NETWORK

REQUIRED BY PROVINCIAL WATER MGMNT TO PROVIDE WATER LEVEL & STREAMFLOW DATA ON A DAILY BASIS DURING FRESHET

FRASER BASIN	11 STATIONS
THOMPSON BASIN	8 STATIONS
COLUMBIA BASIN	6 STATIONS
KOOTENAY BASIN	4 STATIONS
OKANAGAN, KETTLE & SIMILKAMEEN	10 STATIONS
NORTHERN REGION	3 STATIONS

2. Introduction to the Hydrologic Cycle - P.J. Pilon

The early natural philosophers considered water to be one of the four basic elements. The other three were earth, air, and fire. These early philosophers seemed puzzled more by the source and ultimate fate of the water than by the relentless flow of rivers and streams from mountain to sea. They pondered how the water got up into the mountains, and why the level of the seas did not rise continually.

Prior to the seventeenth century, people thought that the rainfall was inadequate to supply the rivers and that the earth was too impervious to permit storage and delay outflows. Many early Greek philosophers, such as Thales (sixth century B.C.), envisioned the earth to be comprised of mysterious underground reservoirs replenished from the sea. It was believed streams and rivers were extruded by a variety of forces (capillary action, vacuum, rock pressure). The disappearance of salinity was explained by the hypothesis of filtration.

Aristotle in the fourth century B.C. published ("Meteorologica") on the sun's observed evaporative powers and the known phenomenon of condensation of vapours by cooling. However, the process was confined at that time only to the underground chambers which supplied the streams.

Vitruvius, a noted first-century A.D. Roman philosopher, proposed a radical departure from the accepted subterranean concept. He stated that the precipitation which the mountain receives percolates through the rock strata to the foot of the mountains, where it comes out as streams.

Through to the fifteenth century little new enlightenment followed. However, in the 15th century da Vinci set down perhaps the earliest essentially true picture of the hydrologic cycle. In the sixteenth century, Bernard Palissy elaborated and refined da Vinci's ideas. These ideas were ridiculed and contradicted for another 250 years. It was not until well into the nineteenth century that the true nature of the evaporation-condensation-precipitation-percolation cycle was fully accepted.

The advent of what might be called the "modern" science of hydrology is sometimes considered to have begun with the quantitative expression of some of the ideas of the "new" cycle. In the seventeenth and eighteenth century, noted English and French physicists - among these were Perrault, Mariotté, and Halley - began the measurement of rainfall, streamflow, evaporation, and capillarity. Perrault obtained measurements of rainfall in the Seine River drainage basin over a period of three years. Using these and measurements of runoff, and knowing the drainage area size, he showed that rainfall was adequate in quantity to account for river flows. Measurements such as these, although crude, permitted reliable conclusions to be drawn regarding the hydrologic phenomena being studied.

During the nineteenth century experimental hydrology flourished. Population growth and industrialization made it necessary to have quantitative answers to the philosophical questions of centuries past. This need, coupled with a recognition of the probabilistic nature of the natural phenomena concerned, prompted the establishment of data-collection agencies (NWS 1870, USGS 1879, WSC 1908).

Although the basis for modern hydrology was well established in the nineteenth century, much of the effort was empirical in nature. In the early years of the twentieth century, the inadequacies of many empirical formulations became well known. From about 1930 to 1950, rational analysis began to replace empiricism. The 1950's saw the introduction of digital computers, which allowed extensive mathematical manipulations that would have been overwhelming in the past.

We have briefly traced the development of hydrology through the millennia, and can appreciate that the domain of hydrology embraces the full history of water on the earth.

However, it still may not be clear what in fact is "hydrology". Several modern texts devoted to the subject of hydrology define hydrology as:

> "the science that treats of the waters of the Earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with the environment, including their relation to living things."

This incredibly complex subject has been subdivided into various parts. Some of these branches include:

a) hydrometeorology - the study of problems intermediate between the fields of hydrology and meteorology;
b) limnology - the study of lakes;
c) cryology - studies dealing with snow and ice;
d) geohydrology - studies related to subsurface water; and
e) potamology - the study of surface streams.

However, very few hydrologic problems can be limited to any one branch. It is evident that hydrology is an extremely broad science and therefore borrows heavily from other branches of science and integrates them for its own interpretation and use. A few supporting sciences which may be used in hydrologic investigations include: physics, chemistry, geography, geology, mathematics, fluid mechanics, economics, sociology, agriculture, and wildlife management. From this, it is clear, if nothing else is, that hydrology is not entirely a pure science, and that the object of study is usually directed to a practical application.

2.1 The Hydrologic Cycle

The hydrologic cycle is a concept which considers the processes of motion, loss, and recharge of the earth's waters. It is remarkable to realize that the true nature of this cycle was not fully accepted until well into the nineteenth century.

Various components comprising the hydrologic cycle are shown in Figure 1. Precipitation in the form of rain, snow, hail, and so forth, comes from atmospheric water vapour and constitutes the primary input to the cycle. A portion of the rainfall may be intercepted by trees, grass, other vegetation, and structural objects, and will eventually return to the atmosphere by evaporation. Once precipitation reaches the ground, some of it may fill depressions (become depression storage), part may penetrate the ground (infiltrate) to replenish soil moisture and ground water reservoirs, and some may become surface runoff - that is, flow over the earth's surface to a defined channel such as a stream.

Water entering the ground may take several paths. Some may be directly evaporated if adequate transfer from the soil to the surface is maintained. Vegetation using soil moisture or ground water directly can also transmit infiltrated water to the atmosphere by a process known as transpiration. Infiltrated water may likewise replenish soil moisture deficiencies and enter storage provided in groundwater reservoirs which in turn maintain dry weather streamflow (baseflow). Bodies of groundwater are usually flowing so that infiltrated water reaching the saturated zone may be transported for considerable distances before it is discharged. Groundwater movement is subject to physical and geological constraints.

Water stored in depressions will eventually evaporate or infiltrate the ground surface. Once the water has found its way into the soil mass, its movement through the soil to the water table is referred to as percolation. Surface runoff ultimately reaches minor channels, flows to major streams and rivers, and finally reaches an ocean. Along the course of a stream, evaporation and infiltration can also occur.

The hydrologic cycle is a continuous process by which water is transported from the oceans to the atmosphere to the land and back to the sea. However, many subcycles exist. The driving force for the global water transport system is provided by the sun, which furnishes the energy required for evaporation. Note that the water quality also changes during passage through the cycle; for example, sea water is converted to fresh water through evaporation.

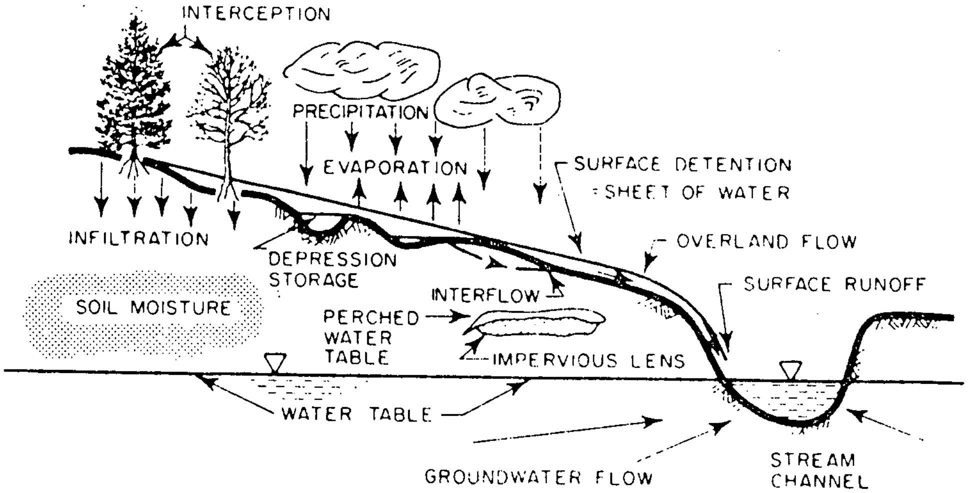


Fig. 1 Simple Representation of the Runoff Cycle

2.2 Scope of Hydrology

Some prominent hydrologists have suggested that there are three broad problems in hydrology:

(a) the measurement, recording and publication of basic data;

(b) the analysis of these data to develop and expand the fundamental theories;

(c) the application of these theories and data to a multitude of practical problems.

These three categories embody the programs and activities of Environment Canada which are all directed towards a common purpose:

> to foster harmony between society and the environment for the benefit of present and future generations of Canadians.

In all water resources projects, the estimation of the quantity of water, and its distribution with respect to time and space, is of prime importance. This is evident and basic to the planning, design, and operation of water resources systems. These systems may vary in size from a culvert on a country road to an integrated development of reservoirs, levees, and canals in a large river basin. Though the scope of consideration varies, we continue to be dealing with Canada's most valuable natural resource - water.

The complexity of the analysis may vary, dependent on the considerations and importance given the project, and our state of knowledge and expertise in hydrology. A multipurpose project may include:

i) water supply for municipalities and industries;
ii) flood plain management and flood damage reduction;
iii) hydropower for electric energy production, to include forecasting and reservoir optimization;
iv) navigation;
v) irrigation and drainage;
vi) watershed management for agricultural crop uses, including soil and water conservation and erosion control;
vii) water quality improvement for pollution control;
viii) water-oriented outdoor recreation; and
ix) fish and wildlife propagation.

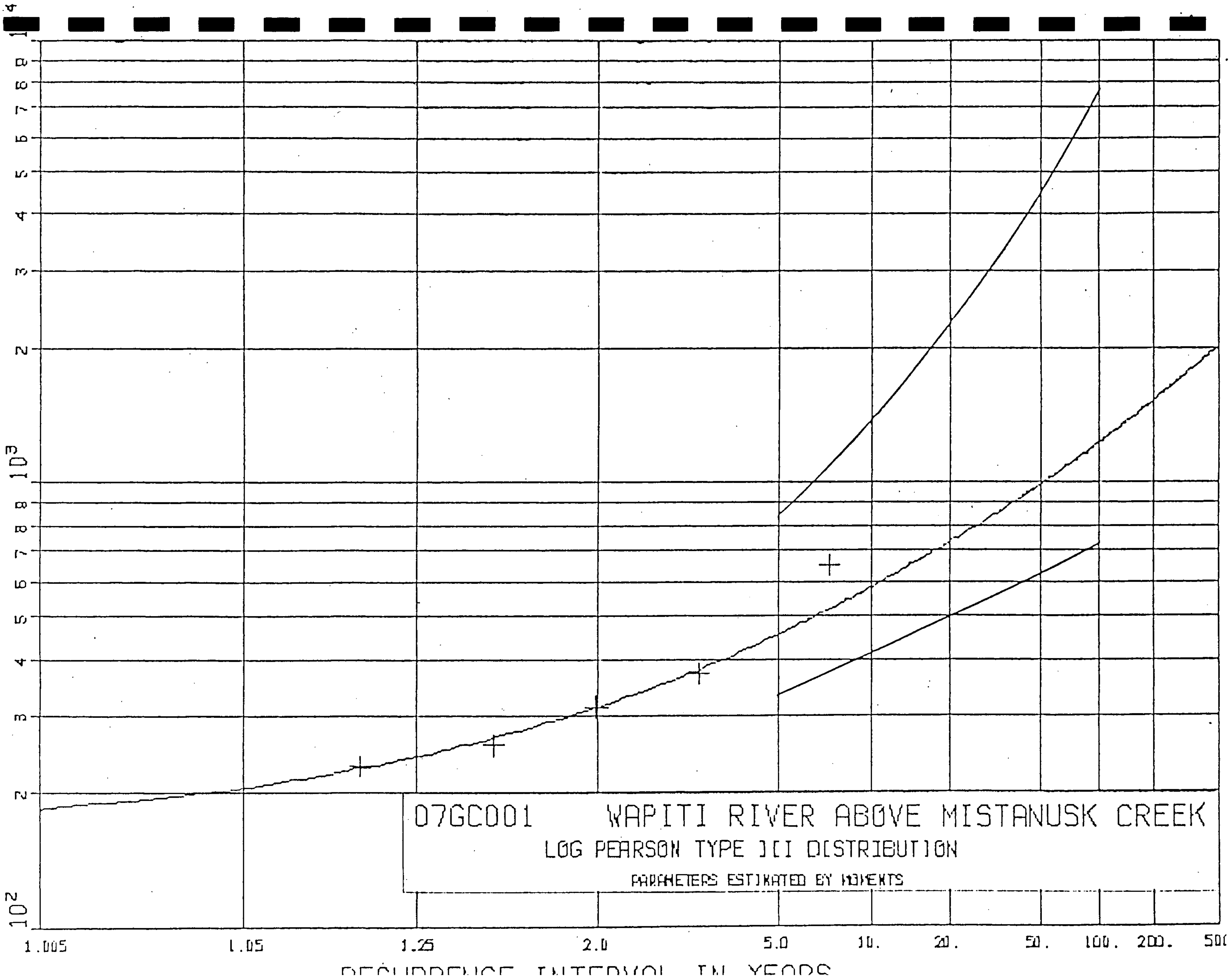
Each of the aforementioned points requires various approaches and considerations. Each may involve various aspects in the estimation of water quantity. For example, flood control primarily involves peak rates of discharge, whereas supply for most other uses involves analysis of the period of lowest flow.

From the preceding discussions, it is obvious that the hydrologic cycle is subject to the various complicated processes of precipitation, evaporation, transpiration, interception, infiltration, percolation, storage, and runoff. The material to be presented in the following presentations will attempt to detail some of the important aspects of these processes and to outline some standard and innovative procedures used in their estimation and analysis.

FLOODS

AND THEIR ANALYSIS

A.G. Smith

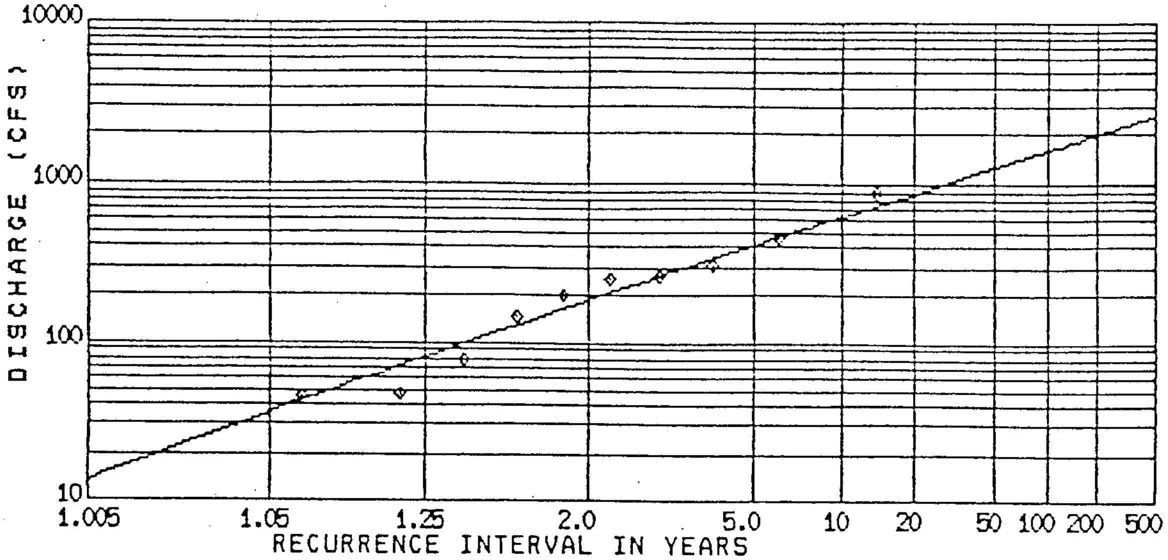


07GC001 WAPITI RIVER ABOVE MISTANUSK CREEK

LOG PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

08MG005R   LILLOOET RIVER NEAR PEMBERTON 10YR



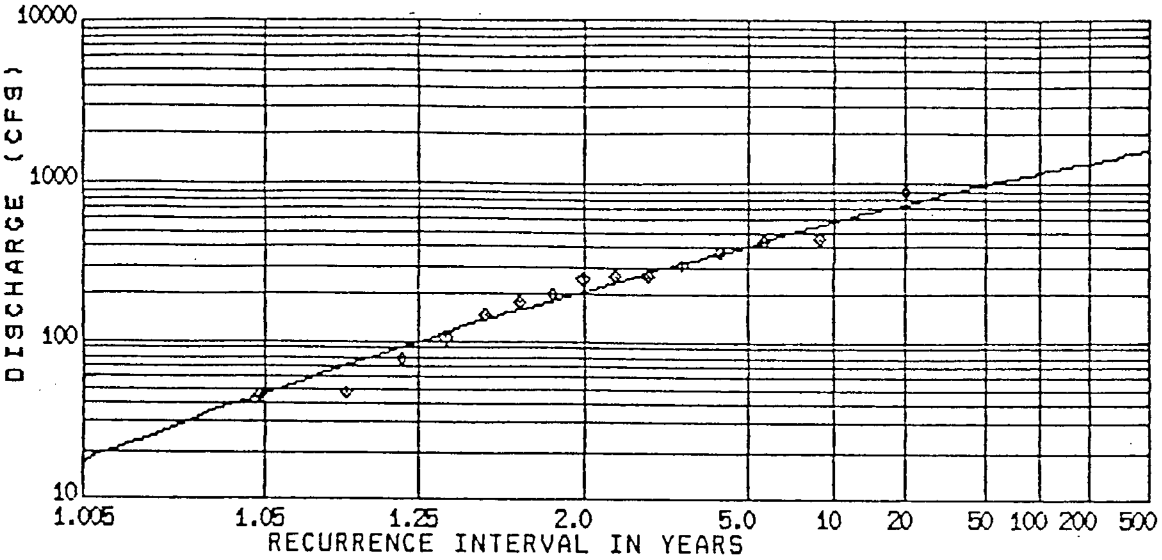
LOG PEARSON III BY MOMENTS

10 YEARS OF RECORDS

100 YEAR FLOOD ESTIMATE   1590 M^3/S

10 YEAR FLOOD ESTIMATE   620 M^3/S

08MG005R - LILLOOET RIVER NEAR PEMBERTON



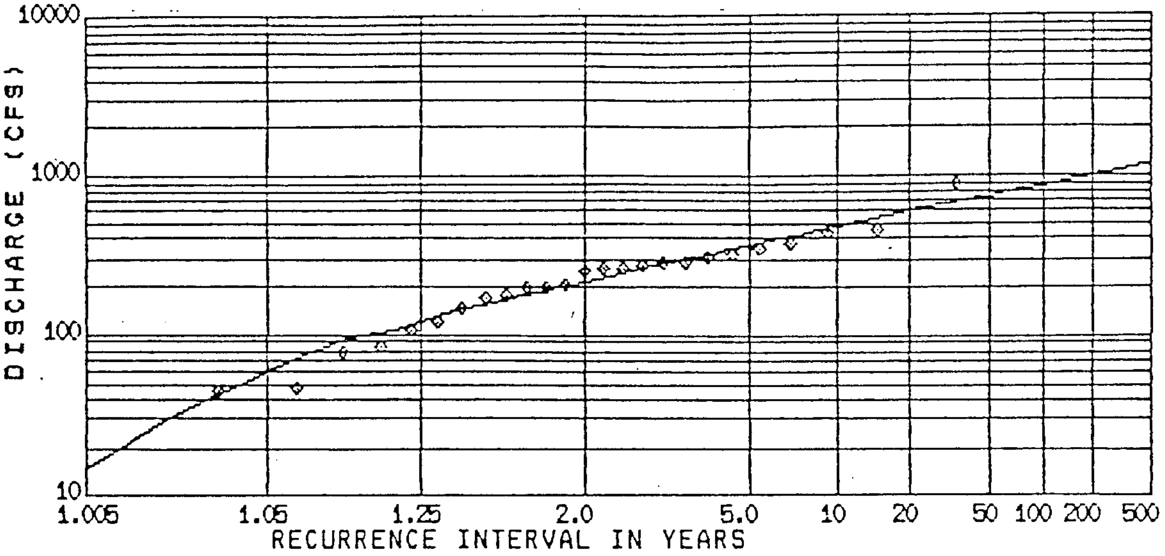
LOG PEARSON III BY MOMENTS

15 YEARS OF RECORDS

100 YEAR FLOOD ESTIMATE 1150 M^3/S

10 YEAR FLOOD ESTIMATE 570 M^3/S

08MG005R LILLOOET RIVER NEAR PEMBERTON 25YR



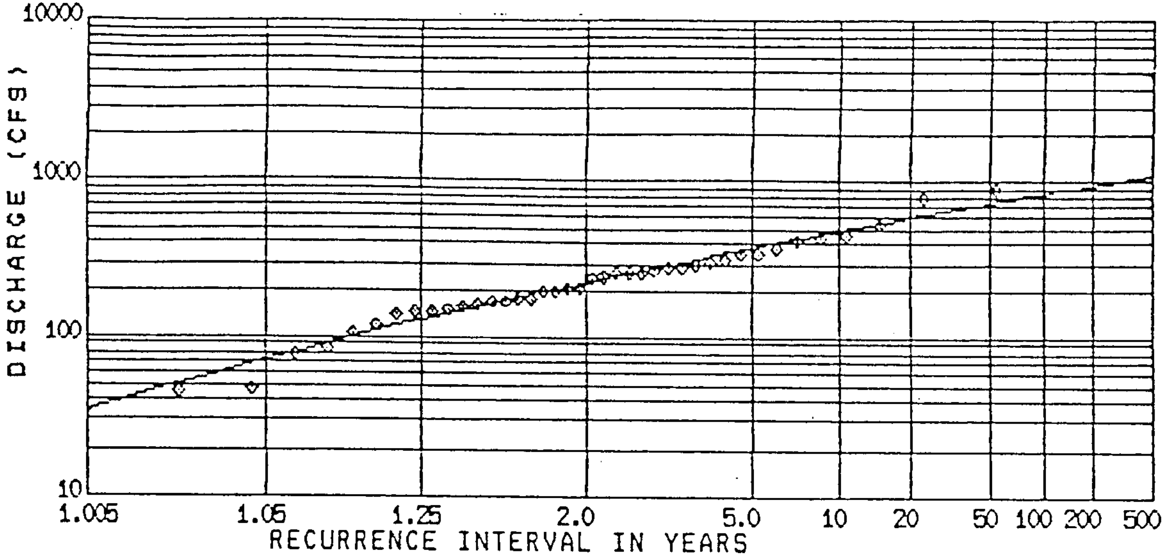
LOG PEARSON III BY MOMENTS

25 YEARS OF RECORDS

100 YEAR FLOOD ESTIMATE 816 M^3/S

10 YEAR FLOOD ESTIMATE 482 M^3/S

08MG005R LILLOOET RIVER NEAR PEMBERTON 40YR



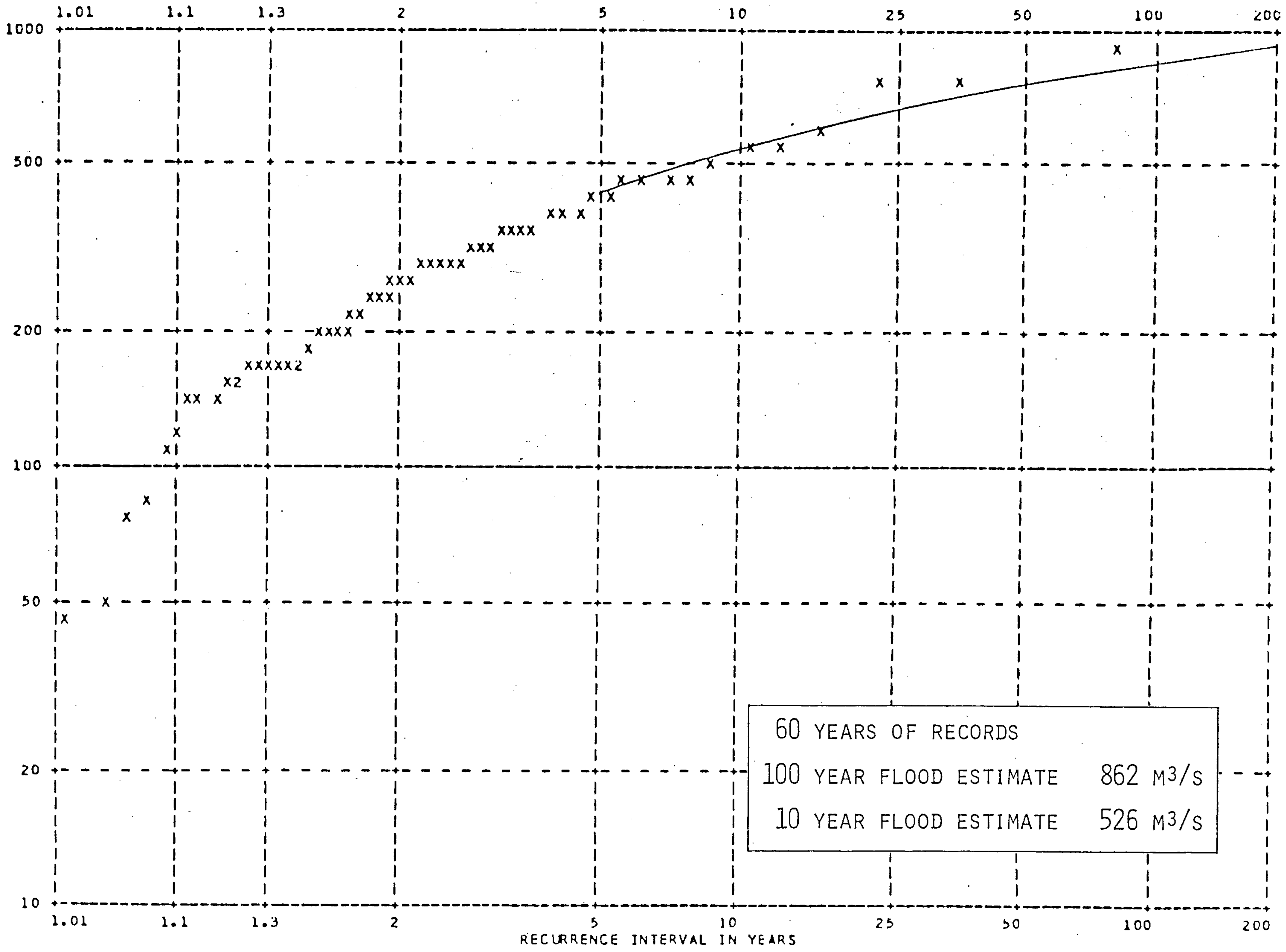
LOG PEARSON III BY MOMENTS

40 YEARS OF RECORDS

100 YEAR FLOOD ESTIMATE 830 M^3/S

10 YEAR FLOOD ESTIMATE 483 M^3/S

[redacted] LLO[redacted]RIV[redacted]EAR[redacted]BERT[redacted]- ST[redacted]ON N[redacted]8MG[redacted]



LOG PEARSON III BY MOMENTS

COMPARISON OF FLOOD ESTIMATES FOR SELECTED LENGTHS OF RECORD

60 YEARS OF RECORDS

100 year flood estimate	862 m3/s
10 year flood estimate	526 m3/s

40 YEARS OF RECORDS

100 year flood estimate	830 m3/s
10 year flood estimate	483 m3/s

25 YEARS OF RECORDS

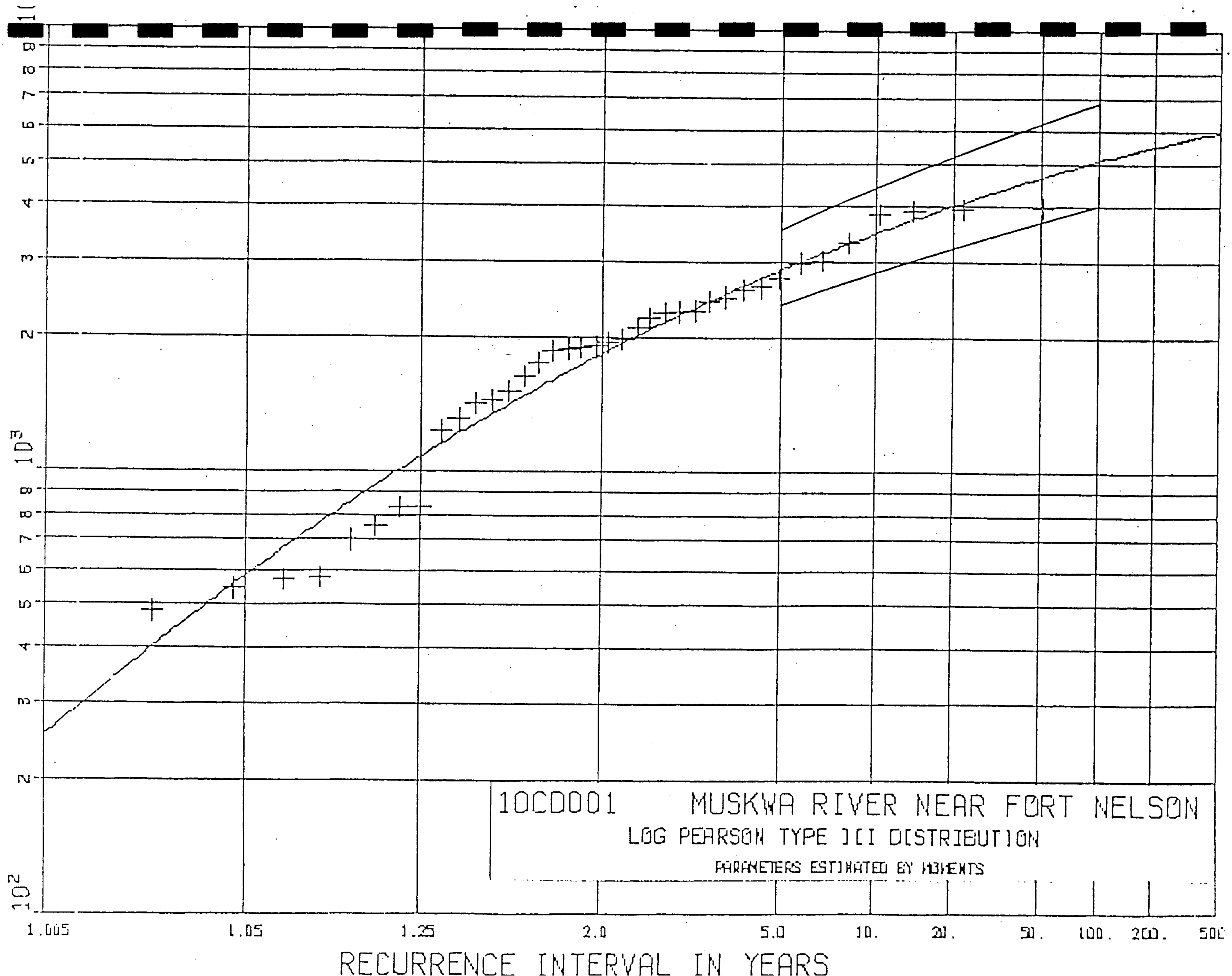
100 year flood estimate	816 m3/s
10 year flood estimate	482 m3/s

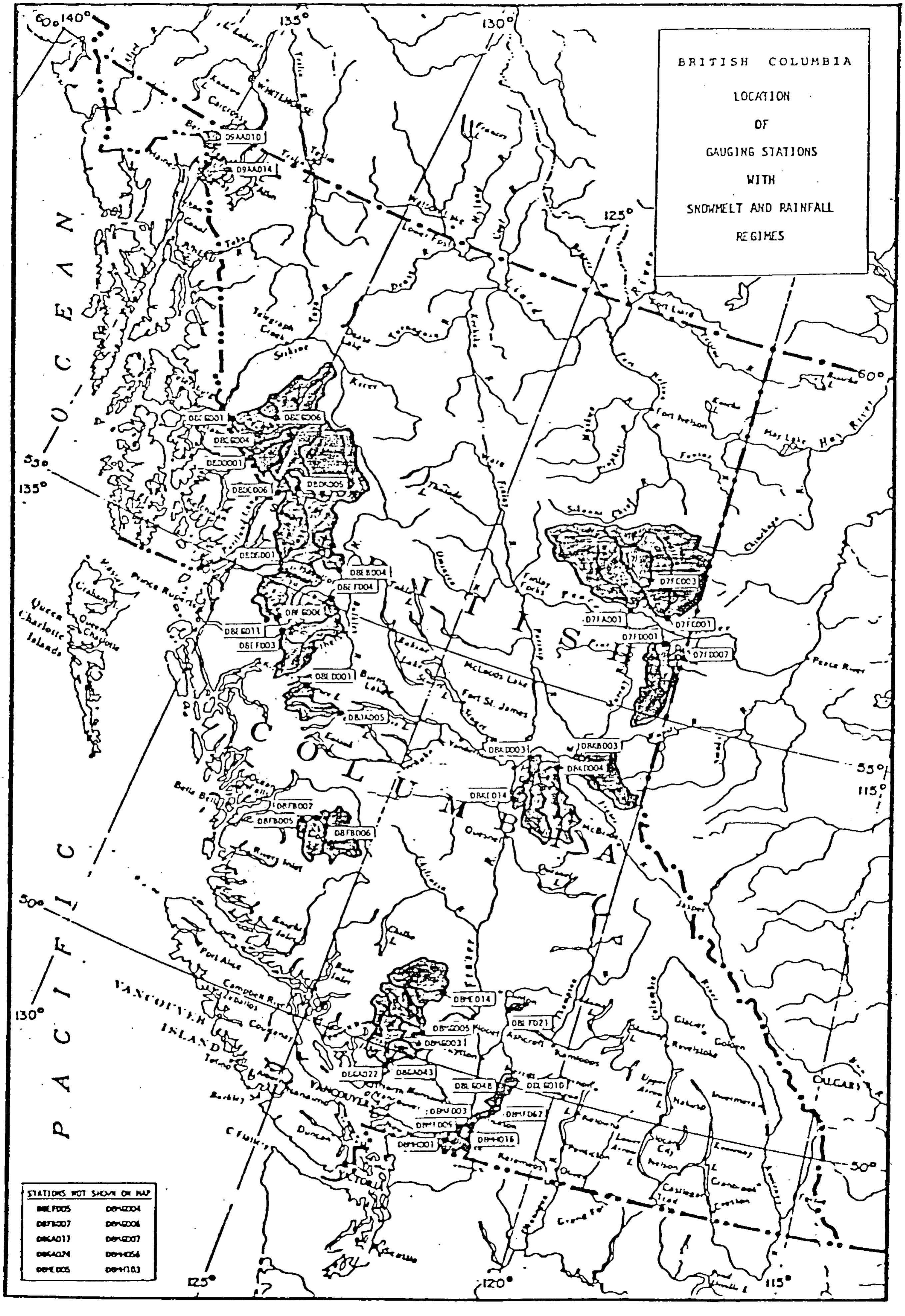
15 YEARS OF RECORDS

100 year flood estimate	1150 m3/s
10 year flood estimate	570 m3/s

10 YEARS OF RECORDS

100 year flood estimate	1590 m3/s
10 year flood estimate	620 m3/s


10CD001 MUSKWA RIVER NEAR FORT NELSON
LOG PEARSON TYPE III DISTRIBUTION
PARAMETERS ESTIMATED BY MOMENTS
RECURRENCE INTERVAL IN YEARS
1.005
1.05
1.25
2.0
5.0
10.
20.
50.
100.
200.
500
10²
2
3
4
5
6
7
8
9
10³
2
3
4
5
6
7
8
9



BRITISH COLUMBIA

LOCATION

OF

GAUGING STATIONS

WITH

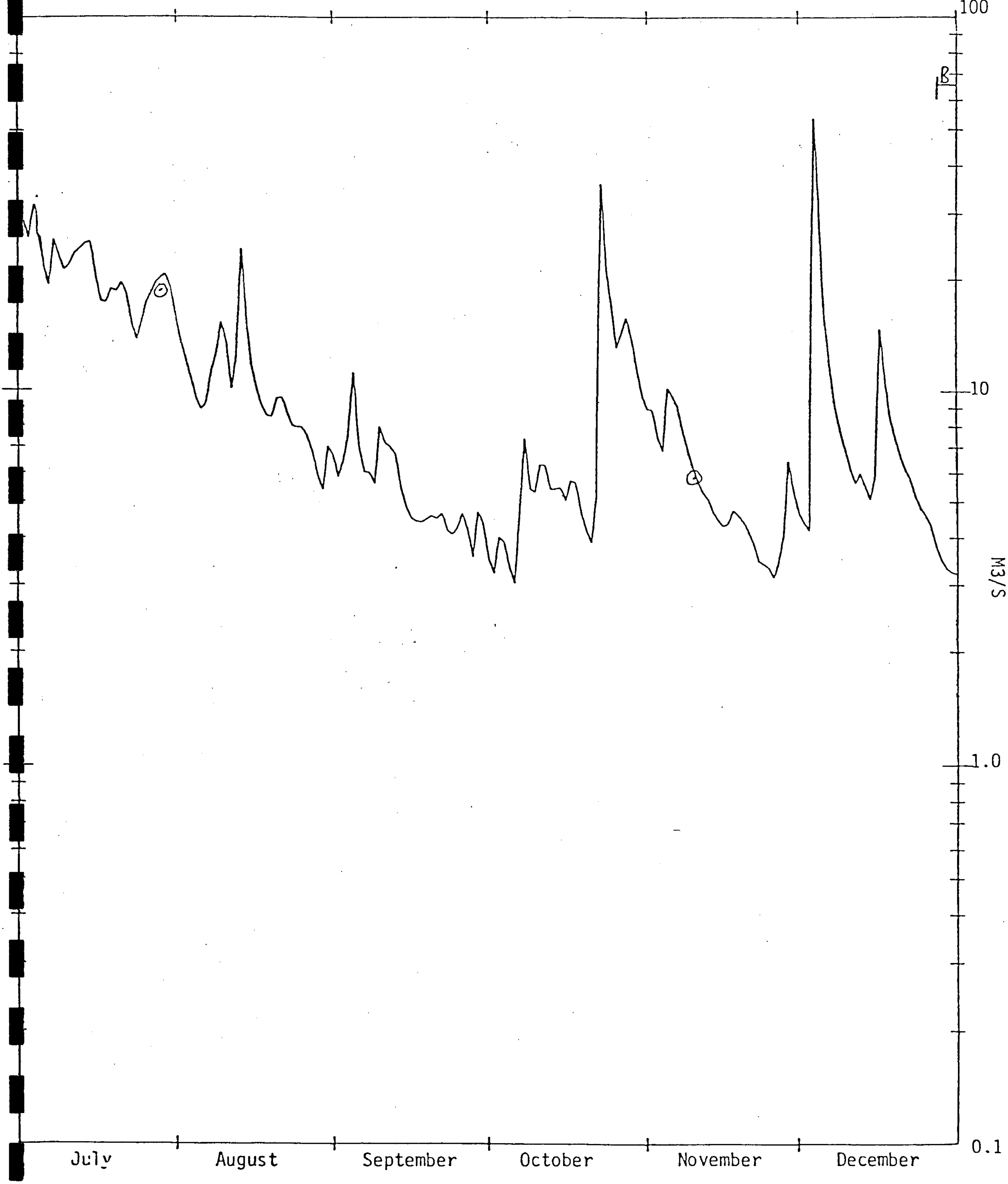
SNOWMELT AND RAINFALL

REGIMES

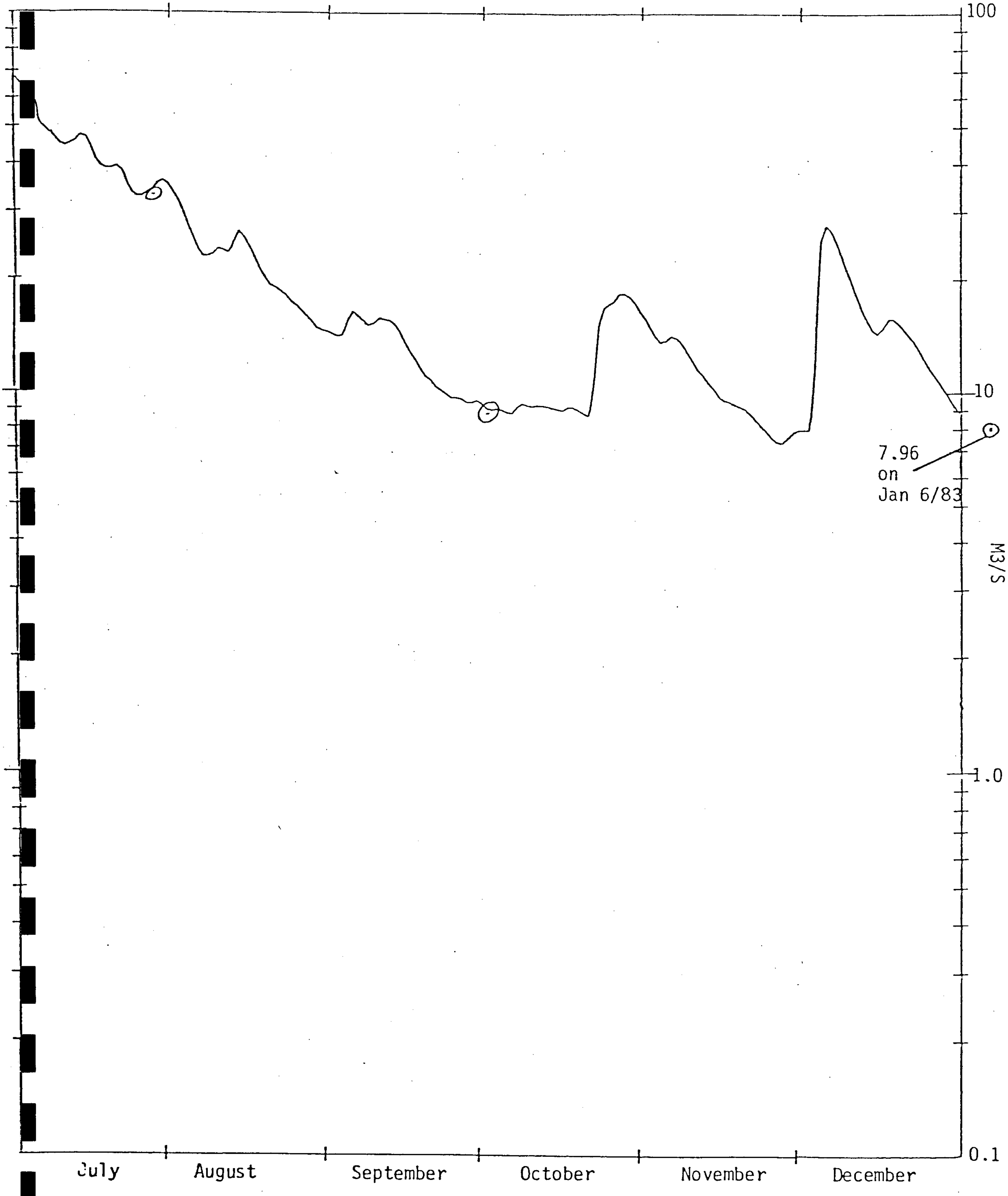
STATIONS NOT SHOWN ON MAP

08EF005	08MG004
08FB007	08MG006
08GA017	08MG007
08GA024	08MH056
08ME005	08MH103

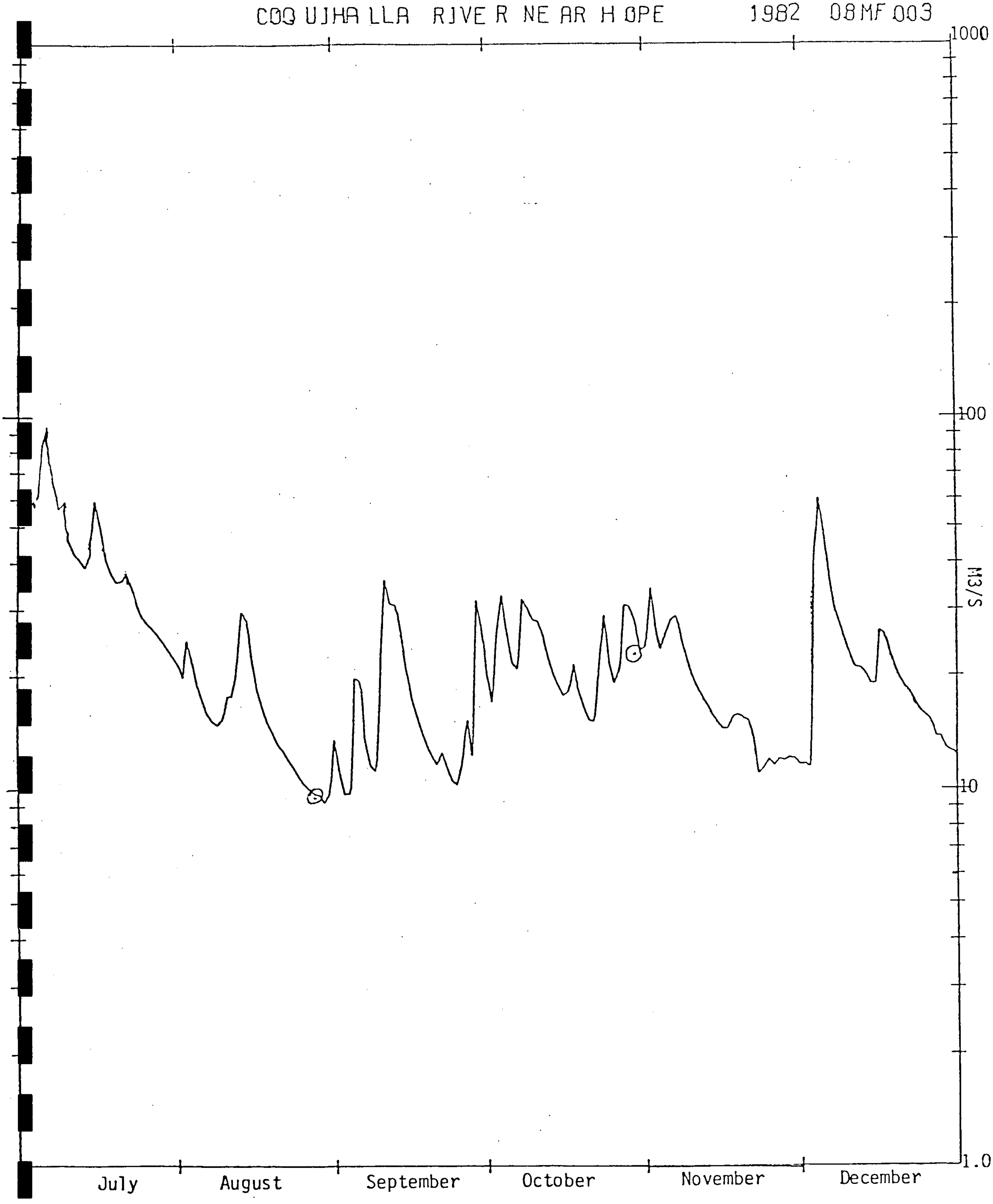
SLESSE CREEK NEAR VEDDER CROSSING 1982 08MH056



CHILLIWACK RIVER AT OUTLET OF CHILLIWACK LAKE 1982 08MH016



7.96
on
Jan 6/83

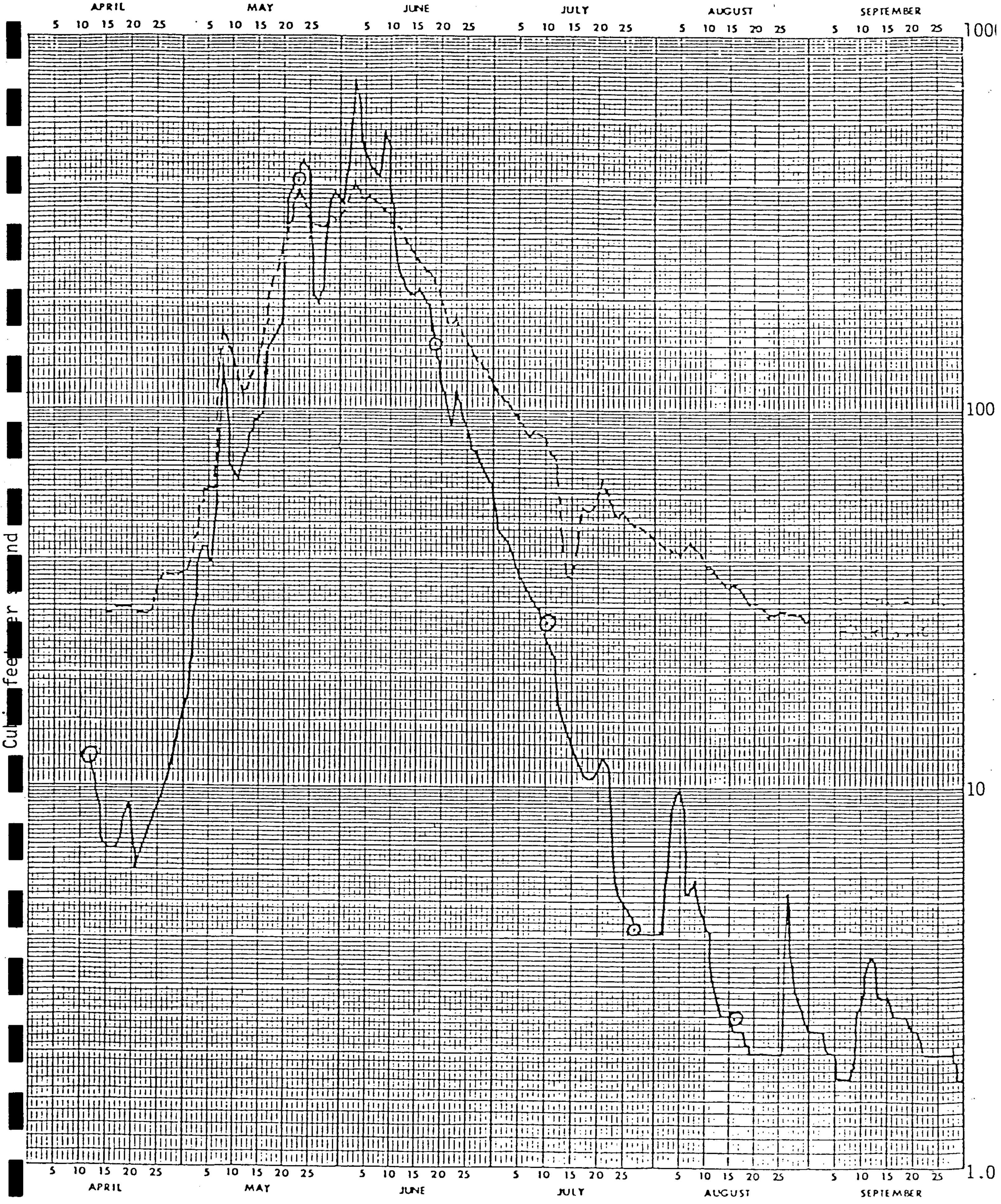

COQUIHALLA RIVER NEAR HOPE
1982
08MF003
1000
100
10
1.0
M3/S
July
August
September
October
November
December

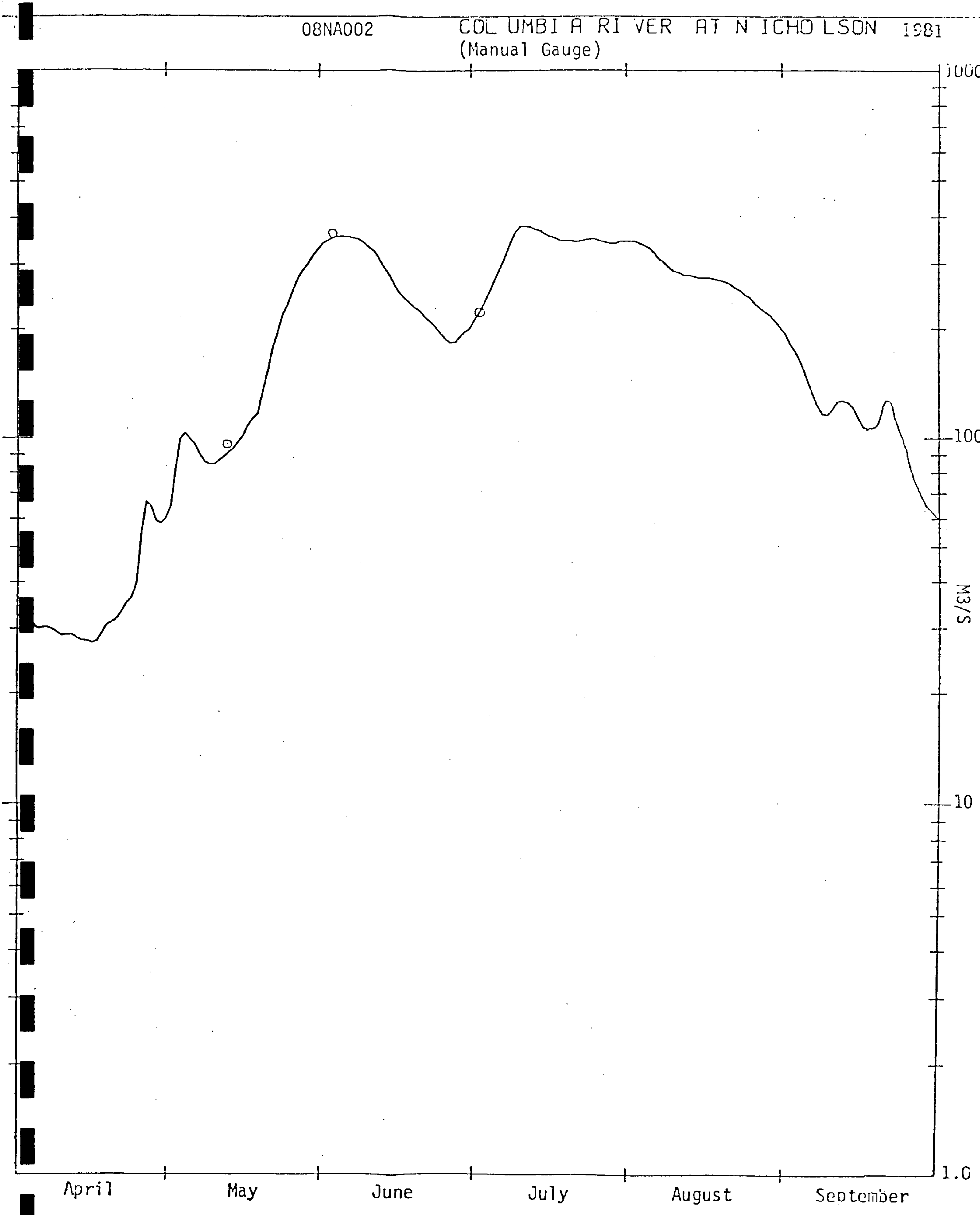
HYDROGRAPH FOR

--------- Salmon River at Falkland 08LE020

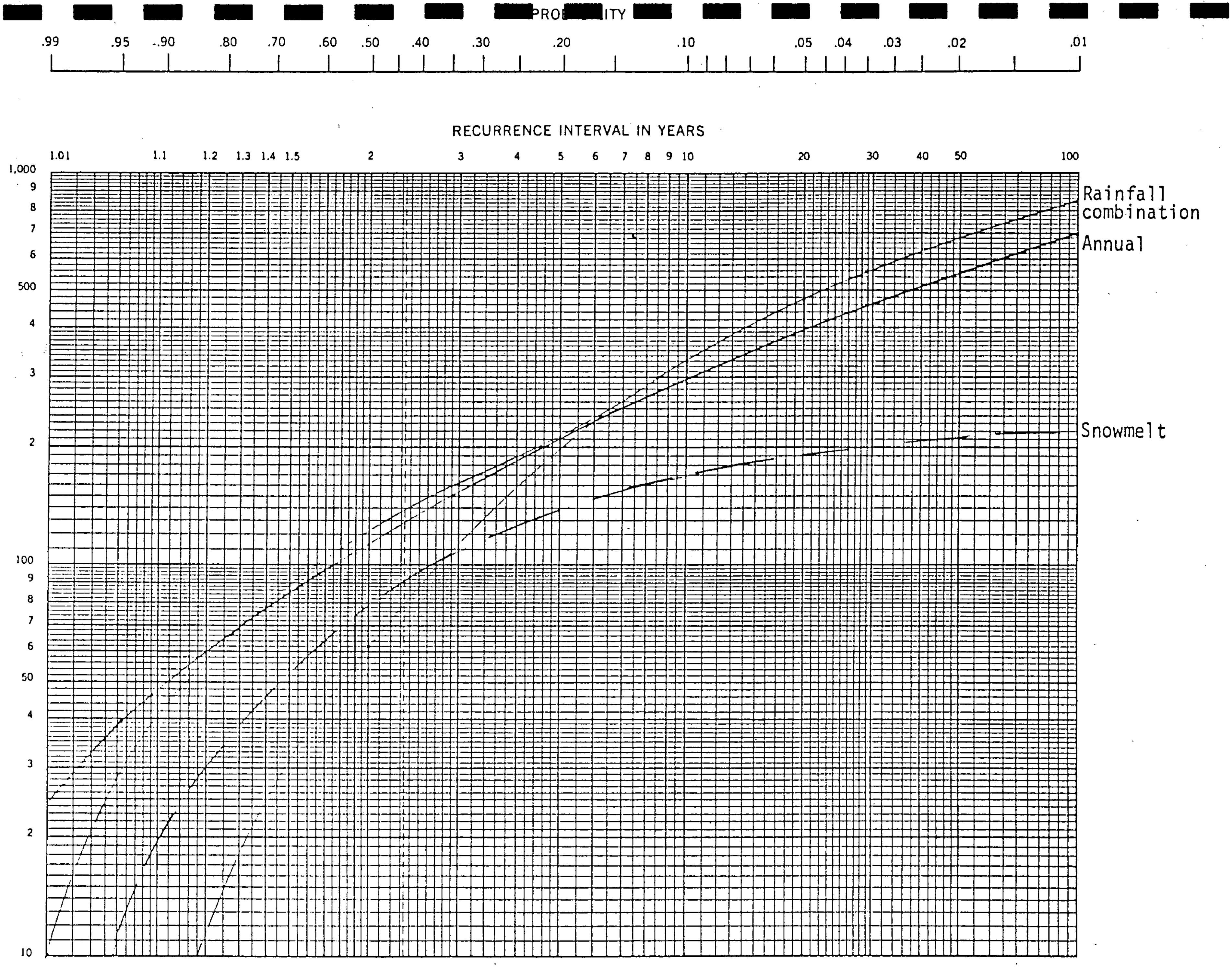
——— Salmon River above Adelphi Creek Station No. 08LE019

for year ending September 30, 19 67

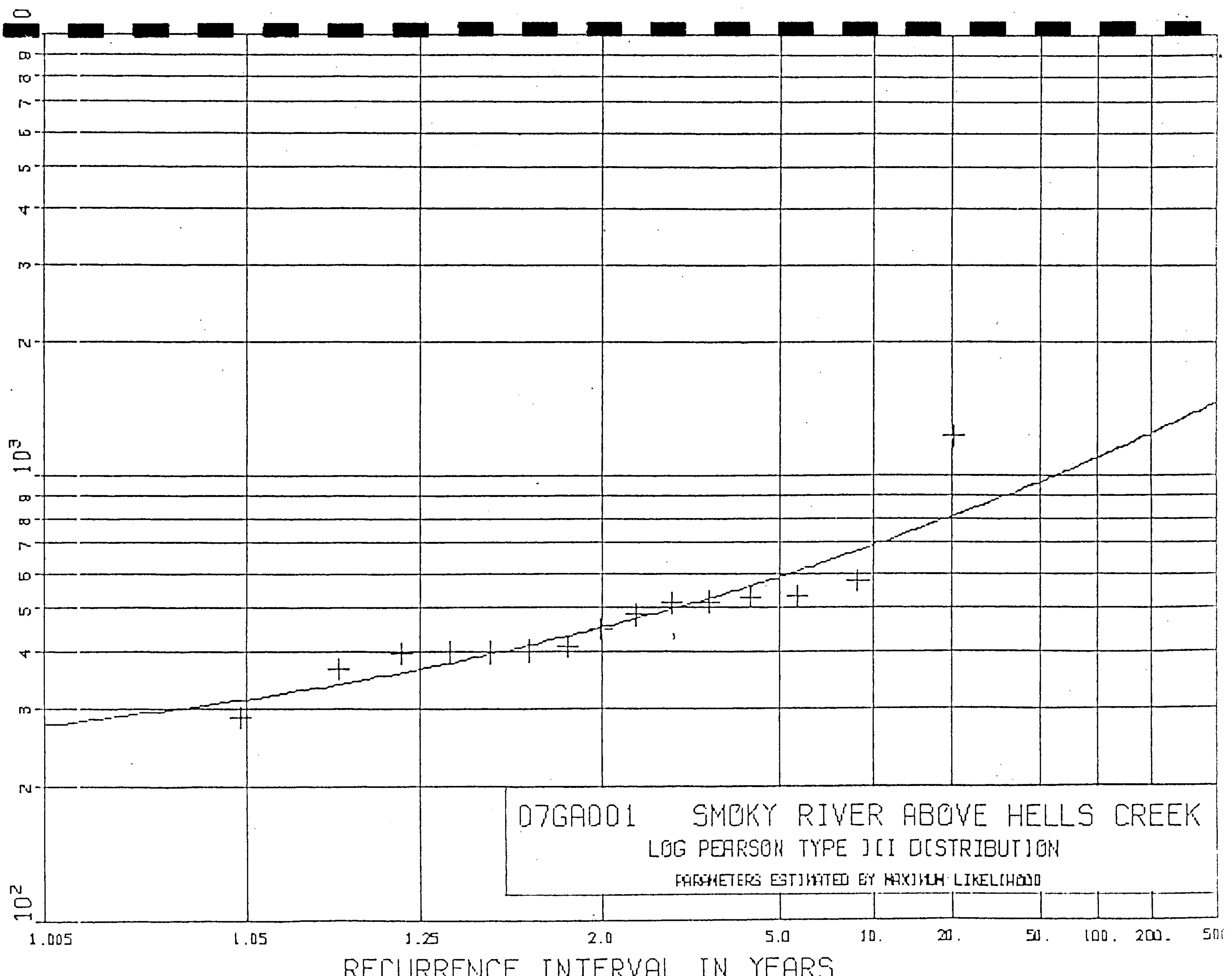


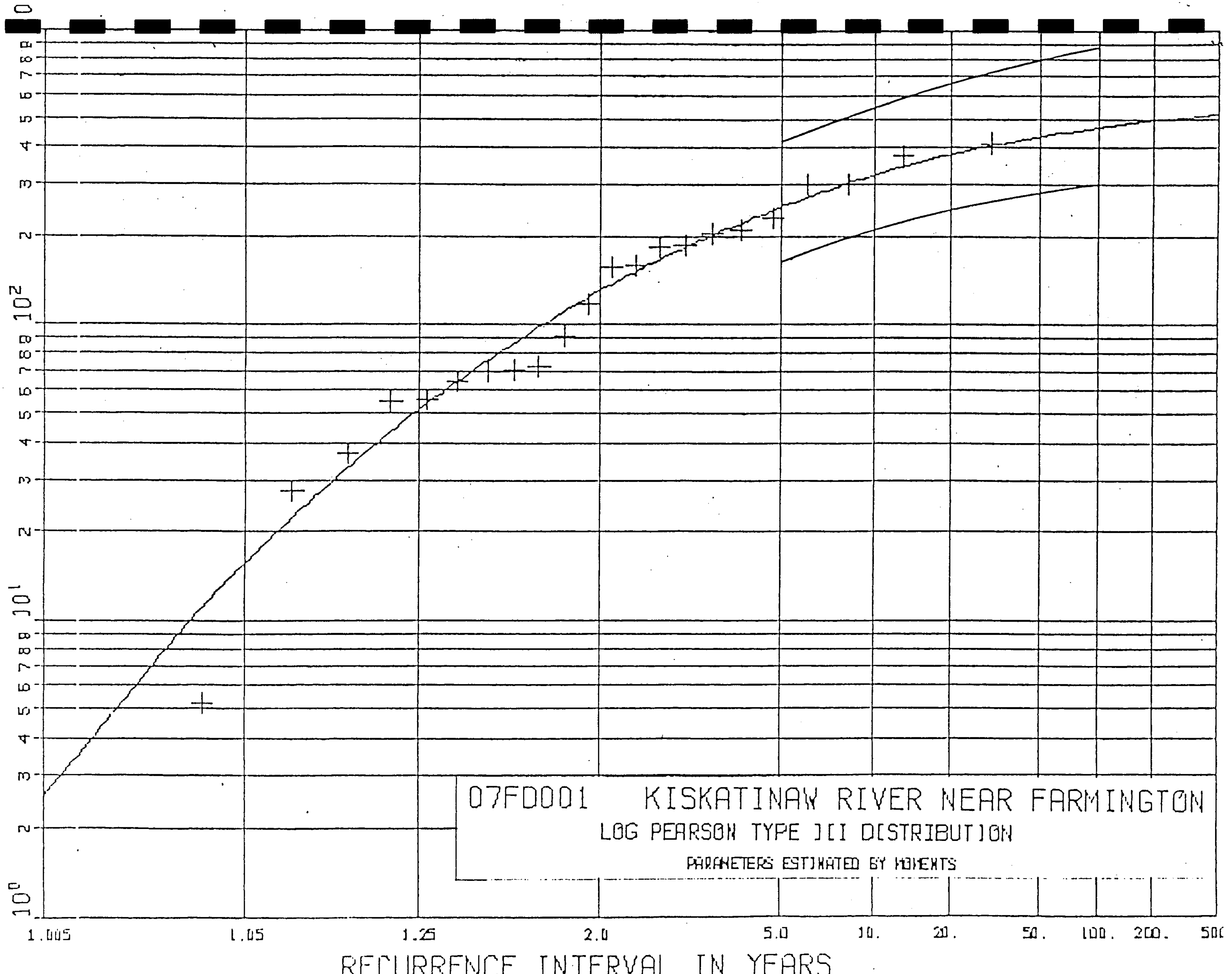


08NA002
COLUMBIA RIVER AT NICHOLSON
1981
(Manual Gauge)
1000
100
10
1.0
M3/S
April
May
June
July
August
September

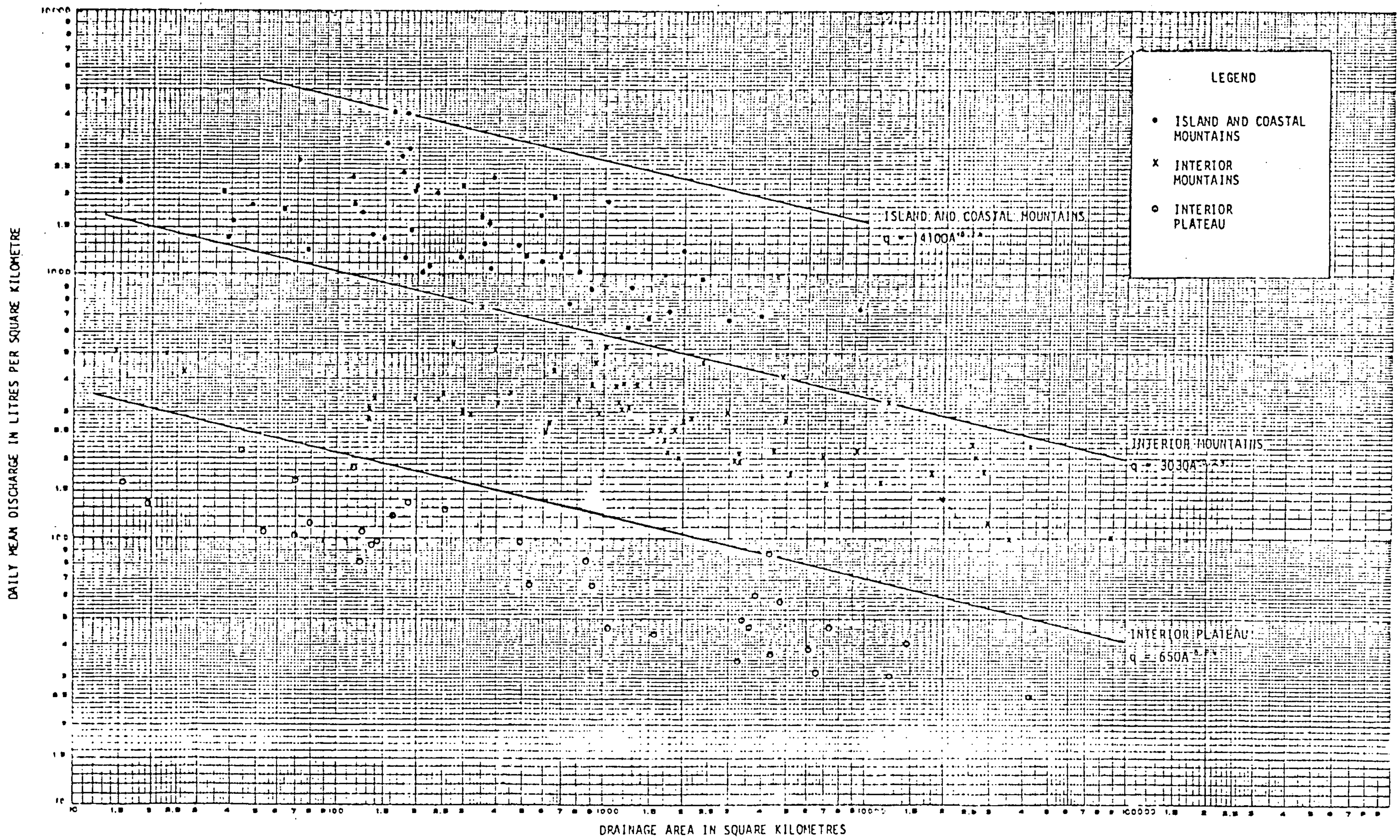


Log Pearson by Moments
BLUEBERRY RIVER BELOW AITKEN CREEK


07GA001 SMOKY RIVER ABOVE HELLS CREEK
LOG PEARSON TYPE III DISTRIBUTION
PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD
RECURRENCE INTERVAL IN YEARS
1.005
1.05
1.25
2.0
5.0
10.
20.
50.
100.
200.
10^2
2
3
4
5
6
7
8
9
10^3
2
3
4
5
6
7
8
9


07FD001 KISKATINAW RIVER NEAR FARMINGTON
LOG PEARSON TYPE III DISTRIBUTION
PARAMETERS ESTIMATED BY MOMENTS
0
8
7
6
5
4
3
2
10^2
8
7
6
5
4
3
2
10^1
8
7
6
5
4
3
2
10^0
1.005
1.05
1.25
2.0
5.0
10.
20.
50.
100.
200.
500
RECURRENCE INTERVAL IN YEARS

ENVELOPE CURVE OF EXTREME FLOODS IN BRITISH COLUMBIA



VARIABILITY OF RUNOFF

RUNOFF   HYDROLOGIC RESPONSE OF AN AREA

AREA   DRAINAGE BASIN

COMBINED SURFACE AND
SUBSURFACE DRAINAGE
SYSTEMS

R. M. Lutt

VARIATION OR VARIABILITY implies change

Change may be real or a mistaken observation

VARIATION OR VARIABILITY is of paramount importance in statistics (methods for studying variation).

HYDROLOGIC RESPONSE

IS COMPLICATED FUNCTION
OF INPUTS PRECIPITATION
SOLAR RADIATION

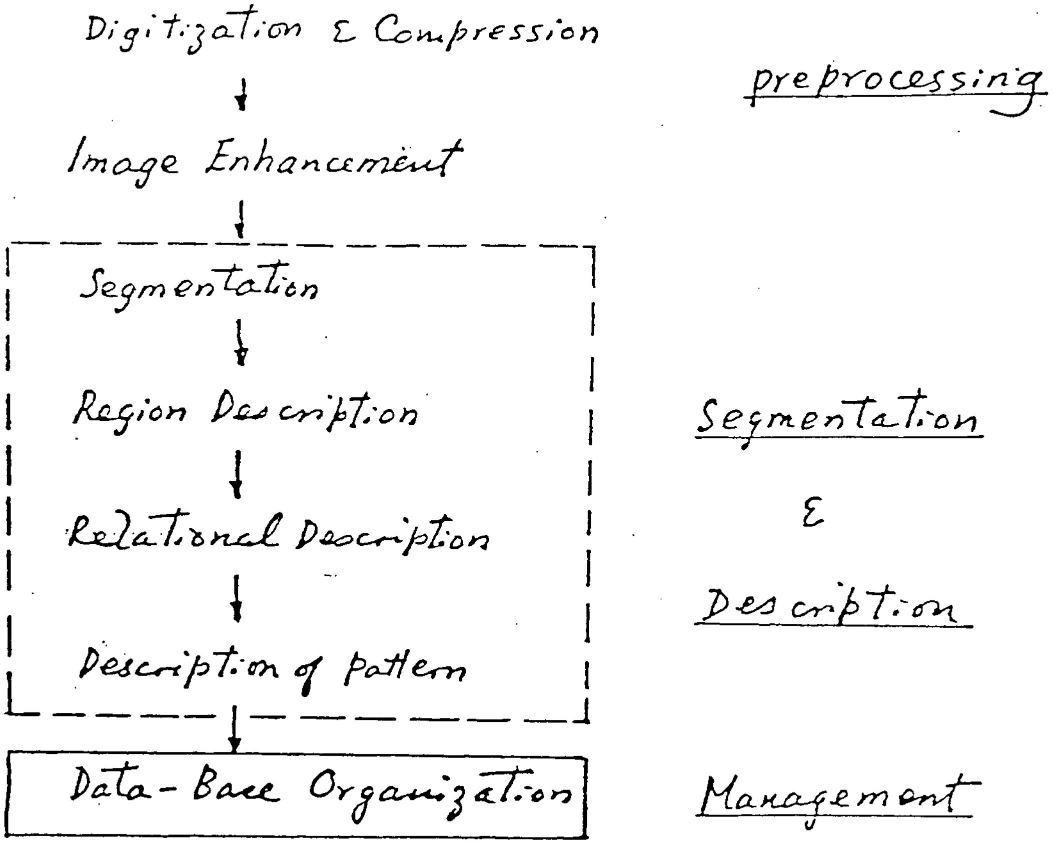
AND OF
THE STATE OF THE DRAINAGE BASIN
SOIL MOISTURE
VEGETATION
LAND SURFACE TOPOGRAPHY
AQUIFER DIMENSIONS

COMMON KNOWLEDGE THAT THERE ARE CHANGES
IN TIME AND SPACE IN THE INPUTS
AND STATE OF THE SYSTEM.

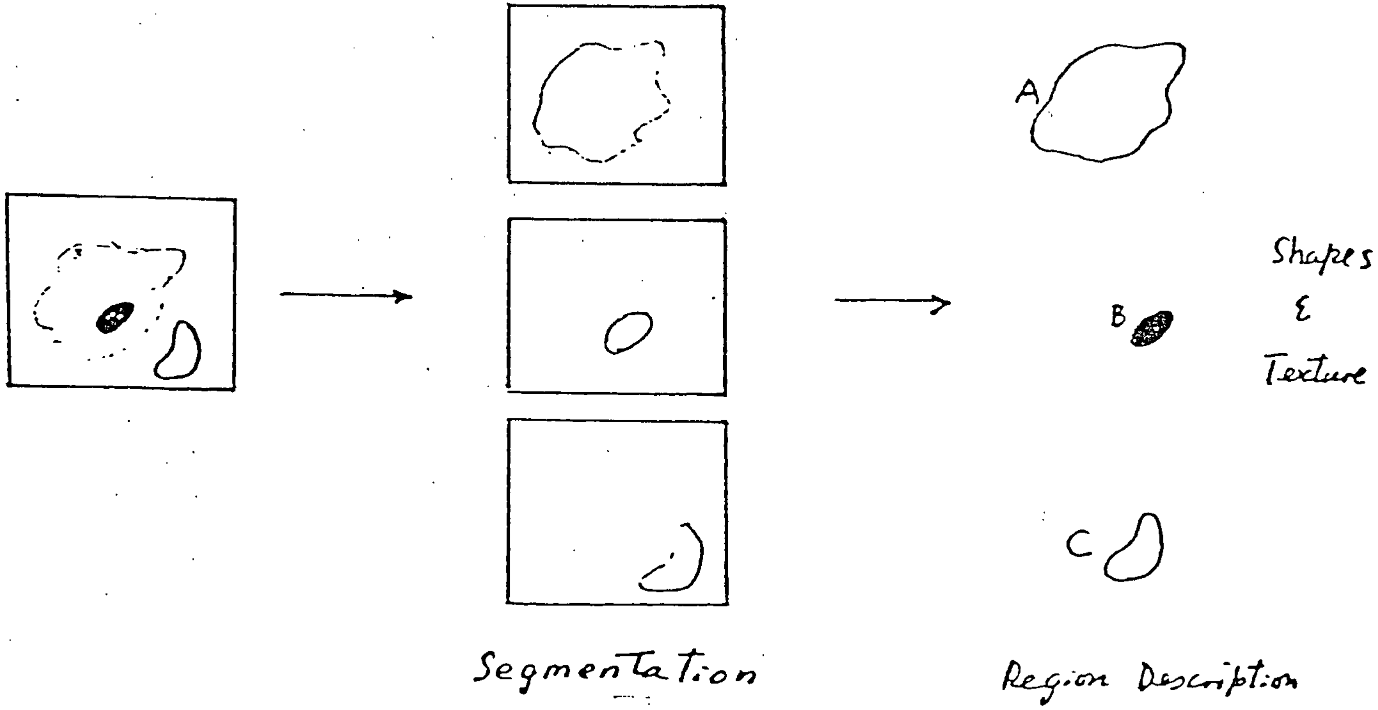
HYDROLOGIC RESPONSE IS A TIME AND SPACE
SERIES.

HYDROLOGY IS AN OBSERVATIONAL SCIENCE
ACCURATE COMPREHENSIVE OBSERVATIONS
ARE NECESSARY TO UNDERSTANDING OF
HYDROLOGIC RESPONSE

MAJOR IMAGE & SCENE ANALYSIS PROCEDURES

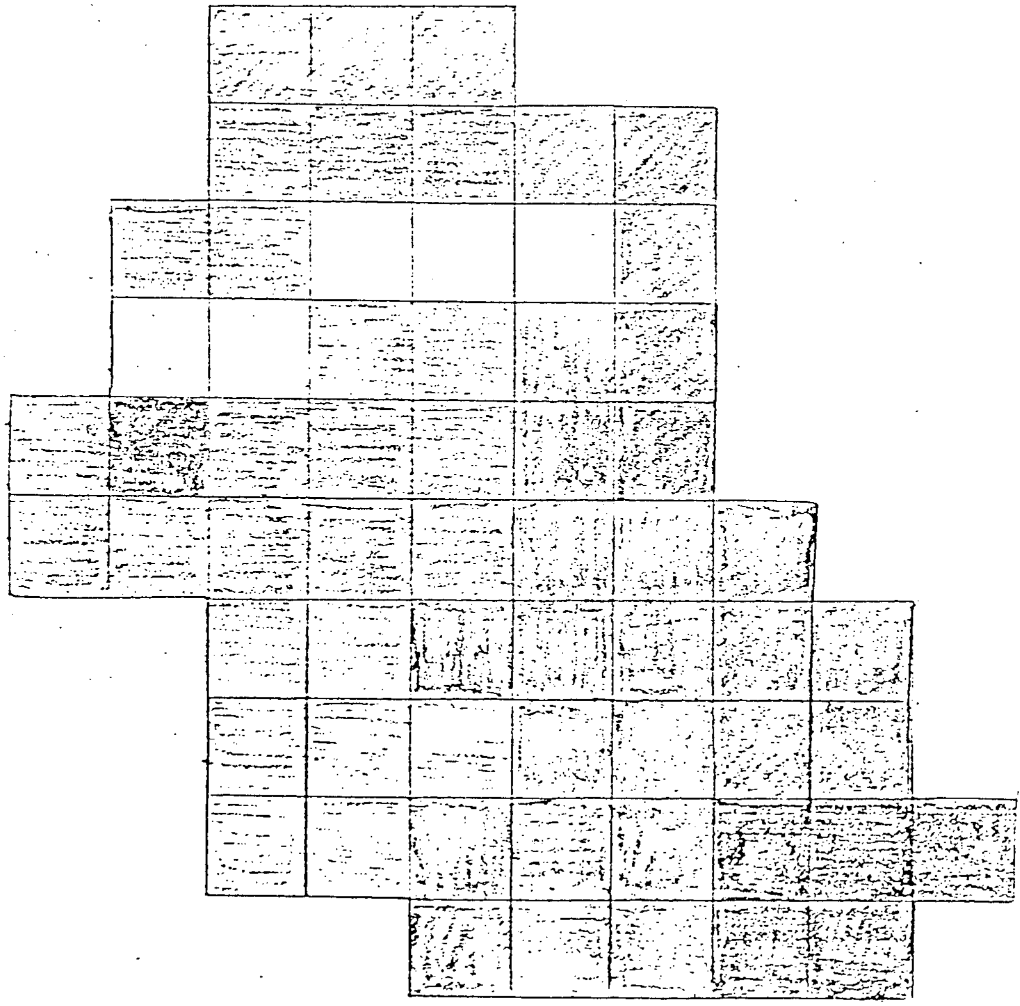


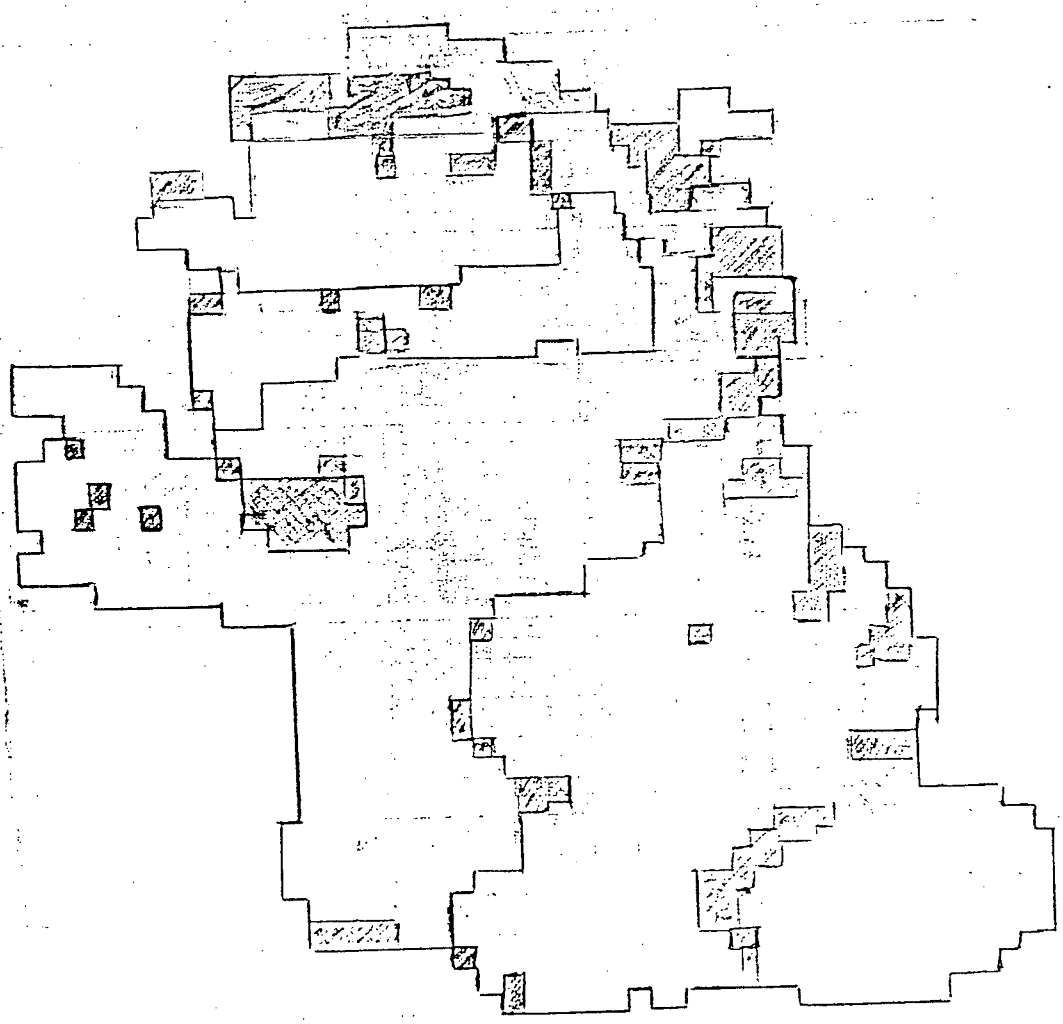
Ex.

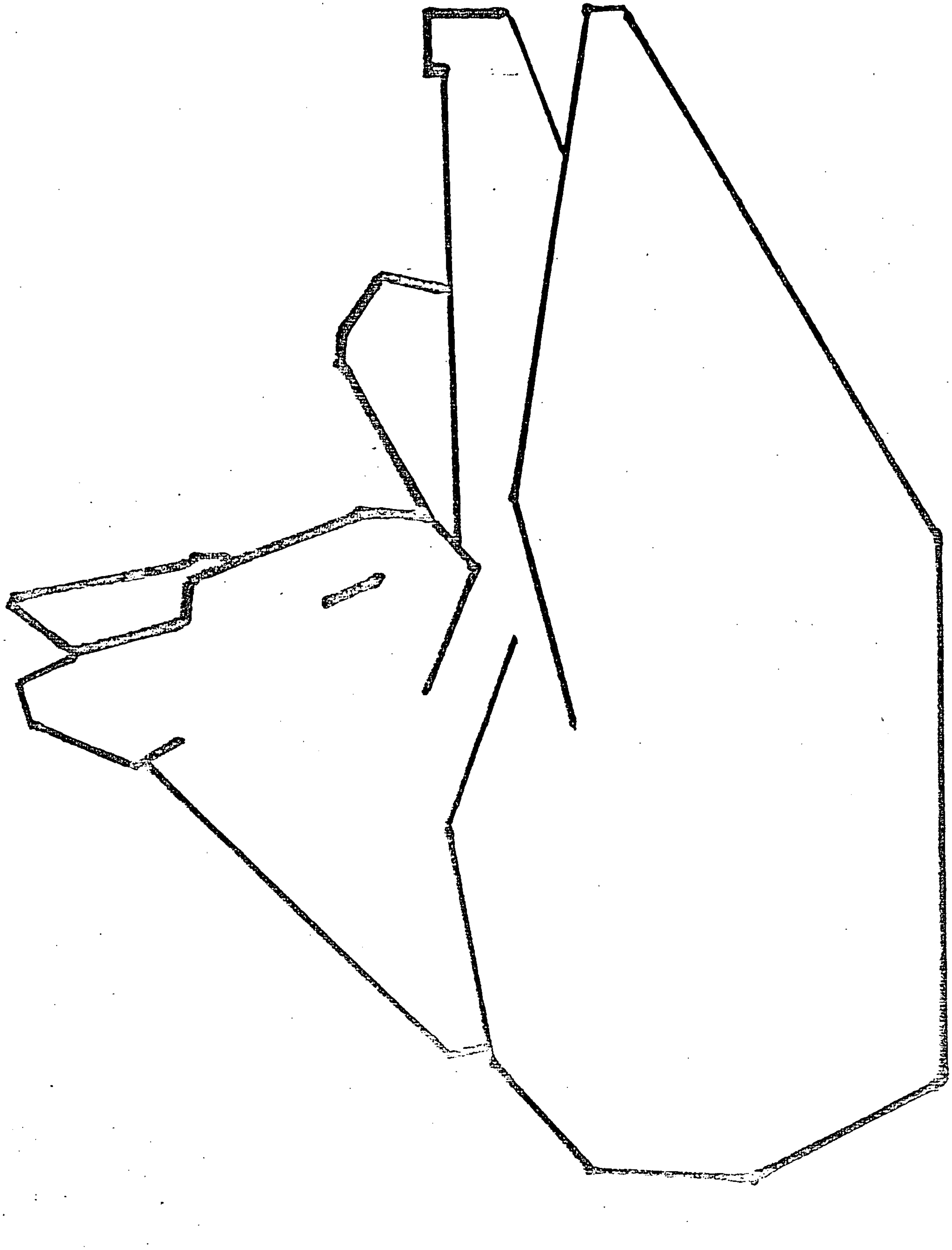


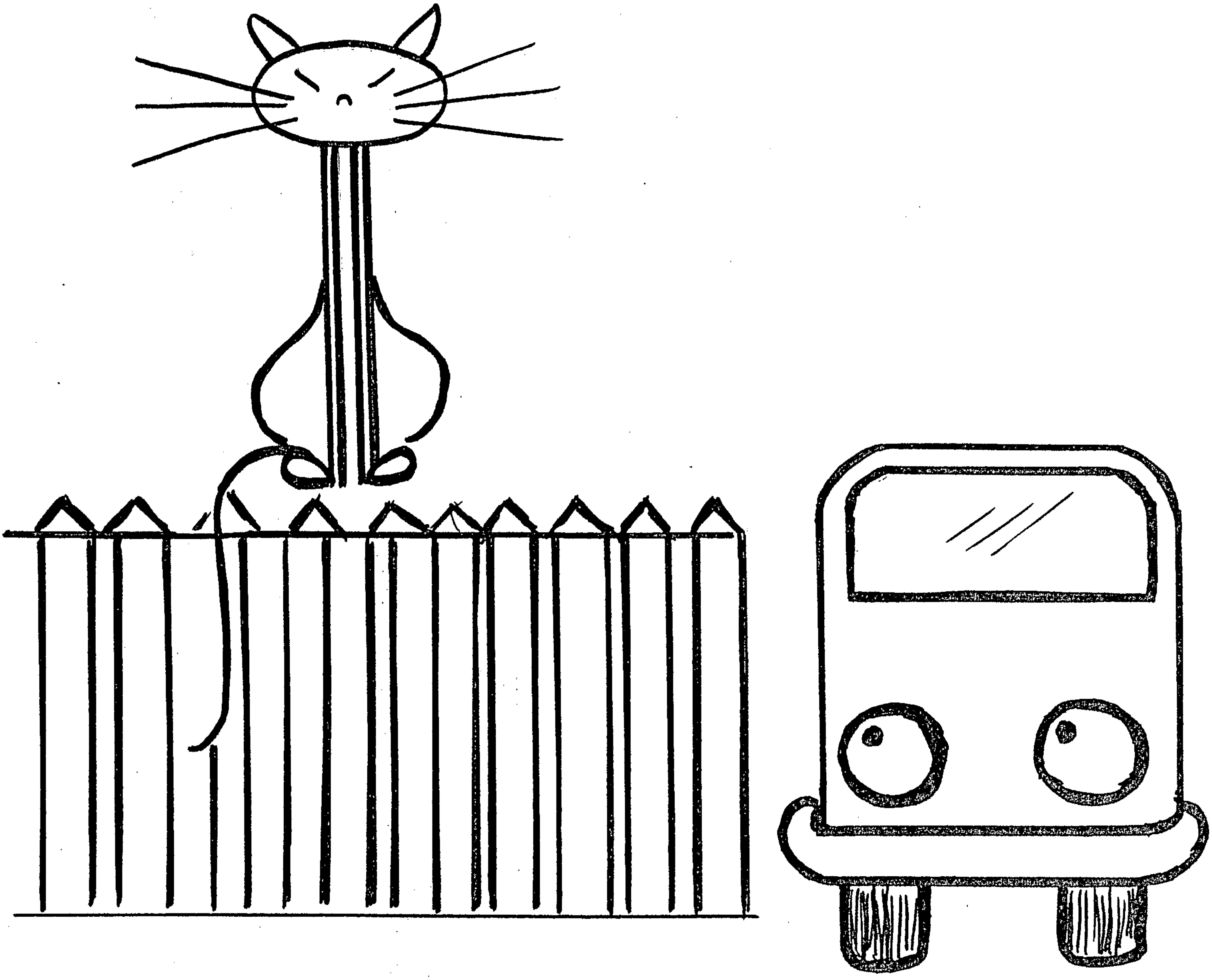
Segmentation

Region Description









HYDROLOGIC REGIONALIZATION

IDENTIFY ZONES OF HOMOGENEOUS
HYDROLOGIC RESPONSE

AIM - REDUCE OR QUANTIFY VARIATION
IN ESTIMATES OF RUNOFF

TEMPORAL VARIABILITY

TIME SERIES ANALYSIS OF MONTHLY STREAMFLOWS

STRUCTURE (PATTERNS)	SEASONALITY SERIAL DEPENDENCE DRIVING MECHANISM

AIMS OF STUDYING HYDROLOGIC SERIES

TIME AND SPACE VARIABILITY

LOOK FOR STRUCTURE (PATTERNS)

USE STRUCTURE:

- TO FILL IN MISSING RECORDS
- TO ASSESS GAUGING ACTIVITIES

OUTLINE BASINS

AND EXTRACT DIGITAL DATA FROM
PIXELS BELONGING TO BASINS FOR
EACH GOES SCENE

FOR EACH GOES IMAGE EXTRACT DIGITAL
VALUES BELONGING TO EACH BASIN

- MEAN BASIN RESPONSE FOR EACH IMAGE
- MEAN BASIN RESPONSE OVER ALL IMAGES

GOES DATA ASSEMBLY

STUDY PERIOD	48 MONTHS
SAMPLING RATE	1 IMAGE/MONTH
NAVIGATE	EACH IMAGE
NAVIGATION	RELATION BETWEEN PIXEL COORDINATES & LATITUDE & LONGITUDE
FOR LANDMARKS	

DEFINITION OF TERMS

GOES	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE
DIGITAL DATA	DIRECT FROM TAPES SUPPLIED BY NOAA
(HYDROLOGIC) REGIONALIZATION	SUBDIVIDE GEOGRAPHIC AREA INTO SUBAREAS OF HOMOGENEOUS RUNOFF

GOES DATA GATHERING

SPACECRAFT	ORBIT & ATTITUDE CHANGES IN TIME
VISSR	VISIBLE AND INFRARED SPIN SCAN RADIOMETER
PIXEL	PICTURE ELEMENT
COORDINATES	SCAN LINE SAMPLING ALONG LINE GIVES ELEMENT

SEEK ASSOCIATION AMONG 3 SETS OF DATA

1. FROM GOES-WEST
2. RUNOFF FROM A SET OF BASINS
3. PHYSIOGRAPHIC PARAMETERS

A SET OF 60 BASINS IN
SOUTHERN BRITISH COLUMBIA
BASINS NATURAL FLOW

PURPOSE OF RESEARCH

INVESTIGATE AND QUANTIFY THE
POSSIBLE CONTRIBUTION OF DATA
(IN DIGITAL FORMAT) FROM GOES TO
REGIONALIZATION OF RUNOFF
IN AN AREA WITH
COMPLEX RUNOFF GENERATION CONDITIONS

STANDARD ERROR

$$\mathrm{SQRT}\left(\frac{\mathrm{SUM\ SQUARE\ RESIDUALS}}{\mathrm{NOBS-NEP-1}}\right)$$

RESIDUAL=OBSERVED RO-ESTIMATED RO

RELATIVE STANDARD ERROR

$$\frac{\mathrm{STANDARD\ ERROR}}{\mathrm{MEAN\ OF\ OBSERVED}}$$

	STANDARD ERROR	
OVERALL SAMPLE	MM	RELATIVE(%
GOES + PHYSIOGRAPHIC (BEST EQN BY BMDP9R)	316	33
GOES VISIBLE	697	73
29 WET INTERIOR		
PHYSIOGRAPHIC	150	16
GOES VISIBLE	312	17
PHYSIOGRAPHIC + GOES	132	14
BEST BMDP9R EQN	312	32

PHYSIOGRAPHIC PARAMATERS

2 GRIDS

2 KM X 2 KM

10 KM X 10 KM

VARIABILITY OF RUNOFF

RUNOFF	HYDROLOGIC RESPONSE OF AN AREA	
	AREA	DRAINAGE BASIN
		COMBINED SURFACE AND SUBSURFACE DRAINAGE SYSTEMS

TEMPORAL VARIABILITY

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(PATTERNS)

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SERIAL DEPENDENCE
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PREPROCESSING	Digitization
	& Compression
	Enhancement
SEGMENTATION & DESCRIPTION	Segmentation
	Region Description
	Relational Description
	Description of Pattern
MANAGEMENT	

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- SOIL MOISTURE
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- AQUIFER DIMENSIONS