Environment Canada Environnement Canada

Methods for the Estimation of Hydrometric Data

First Edition

INLAND WATERS DIRECTORATE
WATER RESOURCES BRANCH
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Canada

(Disponible en français sur demande)

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1. INTRODUCTION

This manual was prepared by D.W. Kirk, Ottawa, and L.H. Heinze, Regina, in consultation with the Regional Offices and approved by R.G. Boals, Head of the Data Control Section, Ottawa. It deals specifically with procedures for the estimation of daily water levels and daily discharges for relatively short periods under open-water conditions when basic field data are missing. Estimation of maximum instantaneous values is also covered, but not monthly or annual mean data. There is some overlap with other procedures, e.g. winter computations (especially during freezeup or breakup) or interpretation of the stage-discharge relation during unstable conditions such as backwater from weeds, beaver activity or shifting during floods (silting and scouring).

The value of complete, reliable water level and discharge records is readily apparent to those engaged in the field of hydrology. Discussions with data users have indicated the need for a concerted effort by the Water Resources Branch (WRB) to estimate data to prevent gaps in the records. The users stated that the Branch personnel collecting and compiling the data are the most qualified to carry out this task because of their intimate knowledge of the many factors that influence the records.

This is the first edition of this manual on "Methods for the Estimation of Hydrometric Data." Experience in the use of this manual may result in suggestions for revision or modification of some of the procedures. Comments will be considered carefully and addendum sheets issued to cover any suggestions that are adopted. Revised editions of the manual will be issued when extensive addenda or changes make this necessary.

This is one of a series of manuals which contain instructions and guidelines for the computation of streamflow and water level data to ensure that national standards and uniformity are maintained throughout the Water Resources Branch. Although these manuals are intended for internal use only, they are available to other agencies for general information on the understanding that the instructions therein are subject to change without notice.

2. BACKGROUND

Water levels are collected on a continuous basis at most gauging stations for a specific period of operation, e.g. year-round, standard period, irrigation period, low-water period, high-water period, etc. and for a specific purpose or purposes. For streamflow stations, discharge measurements are obtained at various water levels to define the stage-discharge relation and/or backwater or shift corrections. Another usual requirement is the determination of the maximum instantaneous water level or discharge that occurred during the year.

Field programs are set up for each station before the year begins to achieve the objectives in accordance with the operation schedule. However, the actual basic field data that were collected are sometimes incomplete; record loss occurs and it becomes necessary to apply indirect methods of estimation to produce a continuous record suitable for publication in the regular series of Water Resources Branch (WRB) data publications.

Numerous methods and techniques are available to extend or synthesize water level and streamflow records for periods of more than one year. However, such record extension or generation of large blocks of data by stochastic methods is beyond the scope of this manual.

2.1 Causes of Record Loss

Record loss usually occurs (1) because of missing or invalid water level records or (2) during periods when the stage-discharge relation is very unstable or indeterminate. Probably the most common and most serious causes of record loss are clock stoppage, malfunction of servomanometer or gas purge systems, and stilling well problems. Other losses are due to damage to the gauge or its overtopping by floods or ice jams or by vandalism.

It is not the purpose of this manual to offer suggestions for the solution of these problems.

2.1.1 Water Level Record Loss

The following are some causes of water level record loss:

(a) Missing or invalid gauge readings for stations not equipped with a recording gauge.
(b) Recorder malfunction for various reasons such as clock stoppage, pen left up, mechanism jammed, pressure leaks, orifice silted.
(c) Stilling well problems owing to freezing or silting of the intake, entangled float, dry well (stream still flowing), etc.

2.1.2 Unstable Stage-Discharge Relation

Record loss may occur even when complete water level records are available, but insufficient discharge measurements were obtained to define the stage-discharge relation accurately. However, some discretion is required whether it is appropriate to assign the symbol "E" even if shift or backwater corrections are applied. This may occur during shifting conditions (silting or scouring) especially during flood events, channel improvement (construction), tidal effect, backwater from tributaries, or if there is a "significant" extension of the stage-discharge relation at either the low-water or high-water range.

A period of very unstable or indeterminate stage-discharge relation conditions occurs when a satisfactory water level record is available, but the stage-discharge relation cannot be defined, usually due to rapidly changing backwater or severe scouring or silting of the channel. Although the chart trace cannot be used directly to calculate discharges, it may provide valuable information and should not be disregarded.

Record loss may also occur during ice breakup or freezeup or during intermittent ice cover and therefore it may be difficult to determine whether the symbol "B" or "E" applies. The method of estimation may overlap with "winter flow computations." In any case, the symbol "B" is to be used instead of the symbol "E" during ice conditions.

2.2 When to Estimate

In general, the missing data should be estimated to produce a complete record in accordance with the operational intent of the gauging station. This also applies to historical data where it is desirable to complete a block of data. There must, of course, be reasonable confidence in the results.

In essence, before a period of data is estimated, the following points pertinent to the station should be considered:

(a) Length of period to be estimated.
(b) Operation schedule for the year in question and for the period of record.
(c) Manual or recording gauge.
(d) The primary purpose of the records.
(e) The degree of daily fluctuation.
(f) Are flows regulated, if so, how much? during low flows? peaks?
(g) The usual shape of the hydrograph for the missing period in question.
(h) Availability of data for other stations on the same stream or nearby or adjacent basins.
(i) Are historical data required and relevant.
(j) The physical characteristics of the basins, e.g. urban, agricultural, forested, slope.
(k) Availibility of supplementary information, e.g. meteorological data, high-water marks, observer's notes, antecedent conditions, records from other agencies, real time data, satellite images, etc.
(l) If this is a "Water Level Only" station, what is the extent of wind effect? Are evaporation records available? reservoir? inflow? outflow? seiche?

After consideration of these items it may become apparent that a reasonable estimate can be made using one or more of the methods mentioned herein.

2.3 Documentation

The symbol "E" for "Estimated" is used only during open-water periods and indicates that a particular record is not as reliable as the other data for this period. A footnote of up to 120 characters can be used in data publications to explain the extent or nature of estimation.

The symbol "E" should be employed whenever data are computed by means of any of the estimation methods. The symbol "A" for "Manual Gauge" is used when a complete daily water level record is not available from a recording gauge. That is, if the water level trace is valid for only part of a day, the symbol "A" should be used even if the trace is estimated for the rest of the day. However, if the estimated portion is believed to be less reliable, then the symbol "E" should be employed. Perhaps the symbol "E" is warranted for the daily discharge when it is the maximum and a substantial extension has been required in the high-water range.

In any case, whether or not the symbol "E" is used, all interpretations must be explained in the Station Analysis for that year or in the Revisions File for historical data. Use a separate sheet, if necessary, to explain the basis for the estimate.

3. METHOD SELECTION GUIDE

The various factors that should be considered when selecting the appropriate method of estimation are summarized in this section. Supplementary information improves estimates. More detailed explanations and procedures are given in other sections.

3.1 Method Comparison Chart

Method	Merits	Limitations
Interpolation	Requires recorded data only at beginning and end of period.	Suitable only for short periods of not more than 10 days; should not be used for fluctuating data.
Chart interpretation	Can be used for various types of recorder malfunction.	Should be used with caution for fluctuating data.
Hydrograph comparison	Can be used for any portion of the hydrograph; graphical estimates easy to carry out.	Requires data from one or more stations with similar characteristics.
Recession constant	Reliable for "natural flow" streams during recession periods; useful for stations in "northern" areas or those with large component of lake storage.	Requires historical data to establish shape of recession.
Curve-fitting	Can describe recession in mathematical terms; useful for stations exhibiting well-defined predictable hydrographs.	Requires historical data; should be carried out by computer.
Mathematical models	Useful for dense networks and as a check on data estimated by other methods.	Computer model must usually be developed for each individual basin.

3.2 Streamflow Characteristics

Streamflow Characteristic	Interpolation	Chart interpretation	Hydrograph comparison	Recession constant	Curve-fitting	Mathematical models
Regulated		X	X			X
Natural flow	X	X	X	X	X	X
High daily fluctuation			X			X
Low daily fluctuation	X	X	X	X	X	X
Rising limb	X	X	X			
Peak segment		X	X			
Recession limb	X	X	X	X	X	X

3.3 Basin Characteristics

Basin characteristic	Interpolation	Chart interpretation	Hydrograph comparison	Recession constant	Curve-fitting	Mathematical models
Small basin	X	X	X			
Large basin	X	X	X	X	X	X
Sparse network	X	X	X	X	X	
Dense network	X	X	X	X	X	X

3.4 Data Considerations

Data consideration	Inter-polation	Chart interpretation	Hydrograph comparison	Recession constant	Curve-fitting	Mathematical models
Manual gauge readings missing	X		X	X		X
Recorder malfunction		X	X			
Backwater during open water			X			
Stage-discharge problem		X	X			X
Short period 10 days or less	X	X	X	X		X
Long Period > 10 days			X	X	X	X
Data available for other stations	X		X	X		X
Maximum instantaneous missing		X	X			
Water level only to be estimated	X	X	X			X
Historical data missing			X	X		X

4. INTERPOLATION METHOD

A simple method of estimating data is by "straight-line interpolation." This method can be used reliably for short periods of not more than 10 days where the water level (or discharge) has remained relatively uniform or has increased or decreased at a steady rate - as evidenced by meteorological data, comparison with nearby streams or observer's notes. This method is usually more applicable under natural flow conditions or where the regulation pattern is known (such as a good record of reservoir water levels).

Generally, missing daily discharges should be estimated from the known discharge values. In some cases, however, water levels can be estimated on recorder charts or from graphs of observed gauge readings.

Missing data are computed by determining the difference between the known daily values before and after the missing period, dividing this value by the increment in days, and adding this value as a constant to each day, as shown in the following examples:

Example 1 - June 25 - 501.238 m (water level)
June 26 and 27 are missing
June 28 - 501.250

June 25-28 - difference = 501.250 - 501.238 = +0.012
Increment = 28 - 25 = 3
Difference ÷ increment = +0.004

June 25 = 501.238
June 26 = 501.238 + 0.004 = 501.242E
June 27 = 501.242 + 0.004 = 501.246E
June 28 = 501.246 + 0.004 = 501.250

Example 2 - May 3 = 5.23 m^3/s (discharge)
May 4, 5 and 6 are missing
May 7 = 5.05

May 3-7 difference = 5.05 - 5.23 = -0.18
Increment = 7 - 3 = 4 days
Difference ÷ increment = -0.045

May 3 = 5.23
May 4 = 5.230 - 0.045 = 5.185 = 5.19E
May 5 = 5.185 - 0.045 = 5.140 = 5.14E
May 6 = 5.140 - 0.045 = 5.095 = 5.10E
May 7 = 5.095 - 0.045 = 5.05

Note 1: During calculations use unrounded discharges until the final data are obtained.

Note 2: Although either water levels or discharge may be estimated by the straight-line interpolation method, interpolation during rising and falling periods is most natural if it is made to the water levels and the discharges are then computed. The reverse procedure may produce distorted water level and discharge hydrographs.

5. CHART INTERPRETATION METHOD

Water level record loss usually occurs because of missing gauge readings, recorder malfunction, or stilling well problems. Additional information such as high-water marks, meteorological data or observations by local residents improves estimates.

5.1 Missing or Invalid Gauge Readings

The observer may have read the gauge irregularly or incorrectly. A "one-metre" error or errors of several decimetres will result in a "spike" which cannot be substantiated by rainfall records or by comparison with other stations and therefore should be discredited. In some cases, more reliable daily water level records can be obtained from a graph of observed readings, especially during flood events when even a maximum instantaneous water level can be estimated.

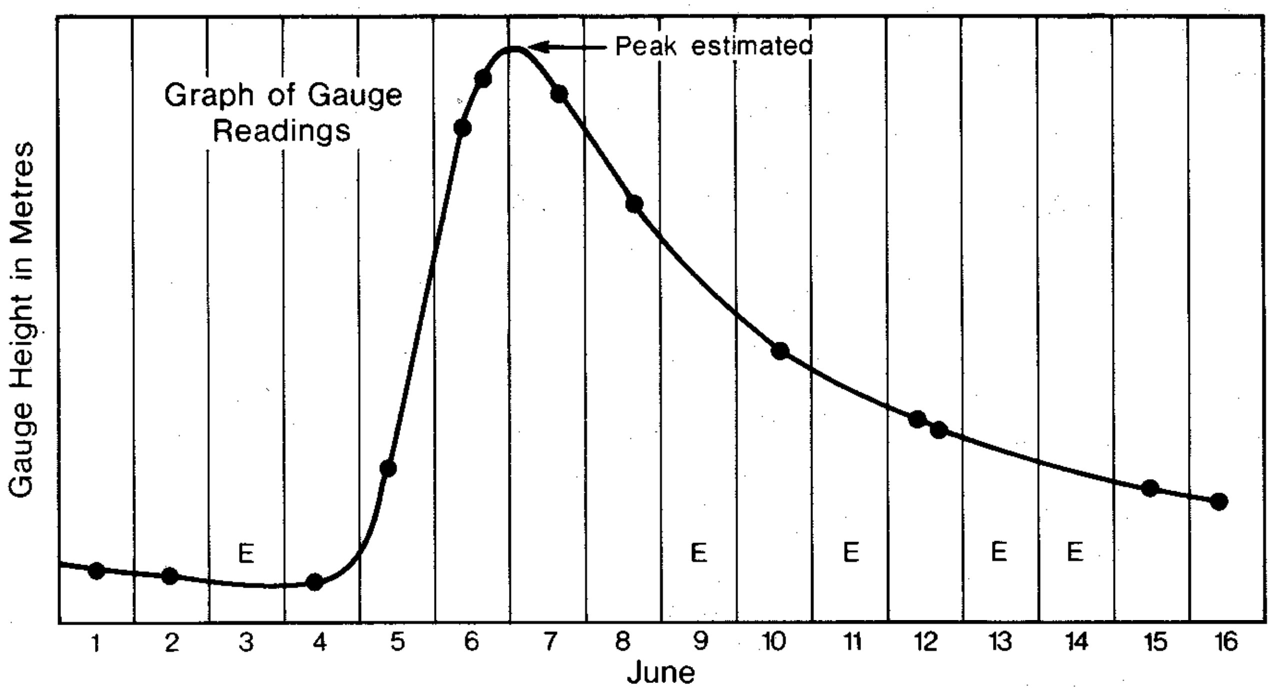

Figure 1. Estimating missing daily water levels.

5.2 Maximum Instantaneous Water Level

The maximum instantaneous water level can sometimes be estimated from a graph of observed readings or from a recorder chart trace if the float has become entangled.

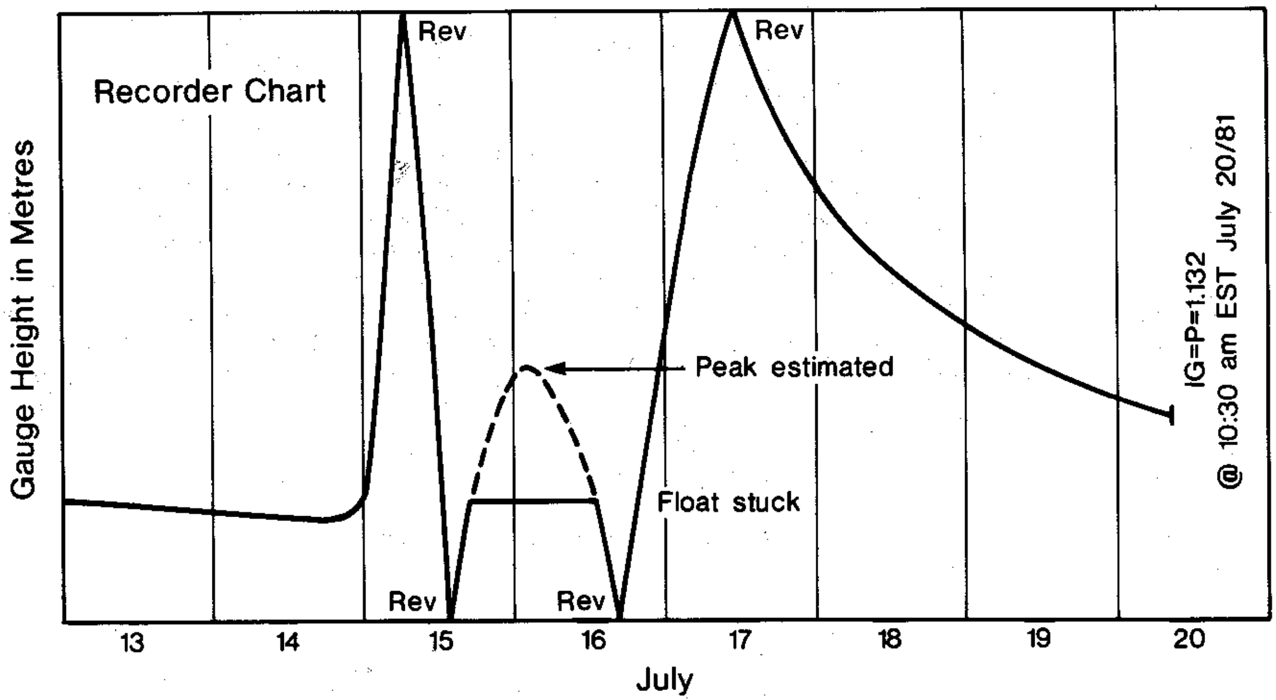

Figure 2. Float entangled.

5.3 <u>Recorder Malfunction</u>

Probably the most common cause of recorder malfunction is clock stoppage for a variety of reasons. Other causes are (a) paper supply exhausted, (b) pen left up, (c) recorder mechanism jammed (pen carriage, reversal) and (d) too much ink or not enough ink.

In most cases, the water level trace cannot be reconstructed and the daily discharges must be estimated by some other method such as hydrograph comparison.

If the range of stage during the period of missing data is known, e.g. clock stoppage, the estimated daily discharges should not exceed these limits.

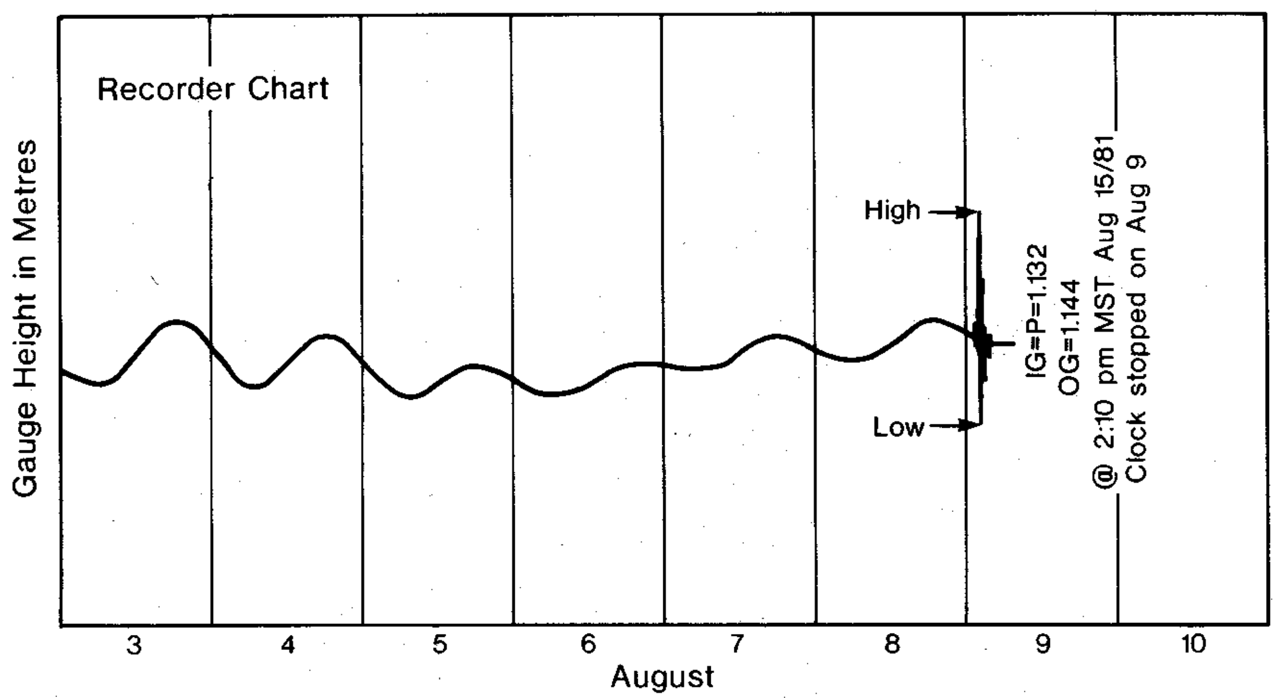

Figure 3. Clock stoppage.

5.3.1 Manometer and Pressure Gauge Problems

About one third of the recording gauges used by WRB are of this type. Problems associated with these recorders are probably the most serious because it often is not obvious that the water level trace is invalid, e.g. during slow gas leakage. Also during intermittent malfunctioning, it is not clear which specific portion of the chart trace does indeed represent the true water level. The symbol "A" should be used where the water level trace is estimated, and in fact in some cases, it would be more appropriate to use the symbol "E". Many of these problems are identified in the internal WRB "Servo-Manometer Gauge Troubleshooting Handbook" dated July 1981, prepared by K.D. Loeppky (Calgary). Missing, incomplete or questionable water level records can be estimated or confirmed by the hydrograph comparison method.

5.4 Stilling Well Problems

The most common stilling well problems are frozen or silted intakes. Other causes or problems are (a) well not deep enough, (b) float entangled (or frozen in), (c) beads out of pulley (wire slippage may not be uniform), (d) high humidity (paper problems), (e) intake not dampened (causes "painting") and (f) drawdown (velocity too high at intake).

Chart traces can sometimes be estimated by comparison with hydrographs for upstream or downstream stations on the same stream. However, time lags and hydrograph shapes should be substantiated by previously recorded data under similar flow conditions.

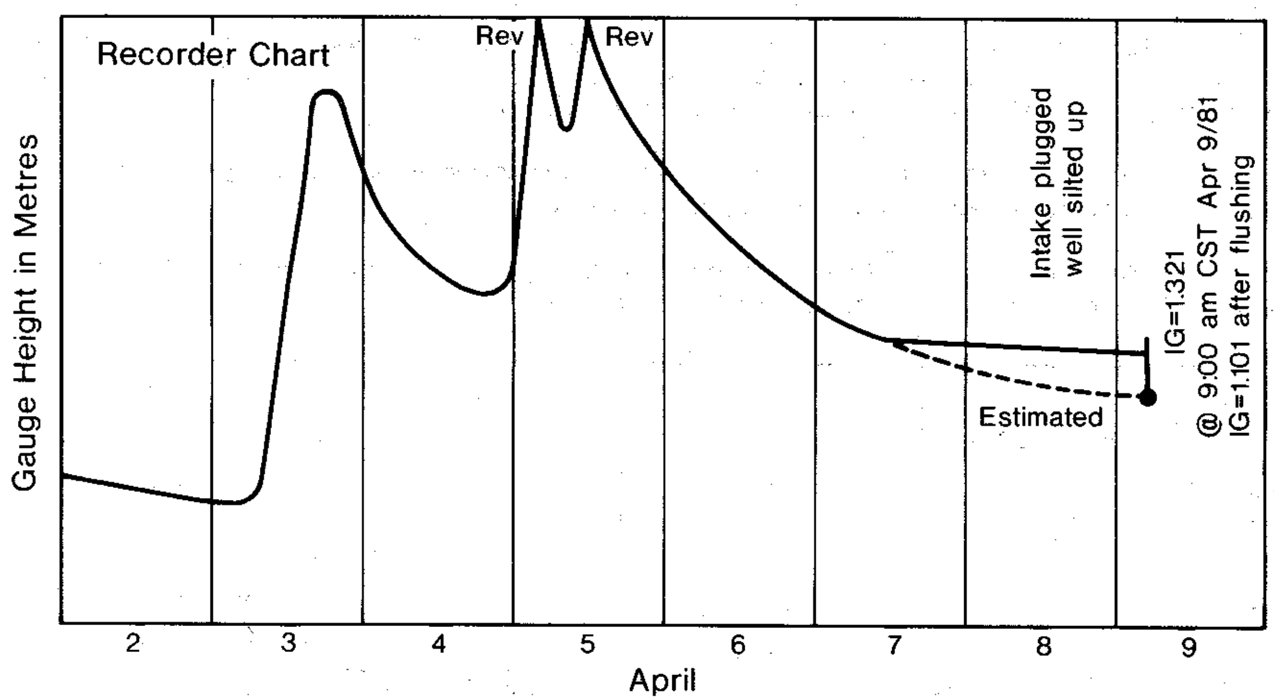

Figure 4. Intake silted.

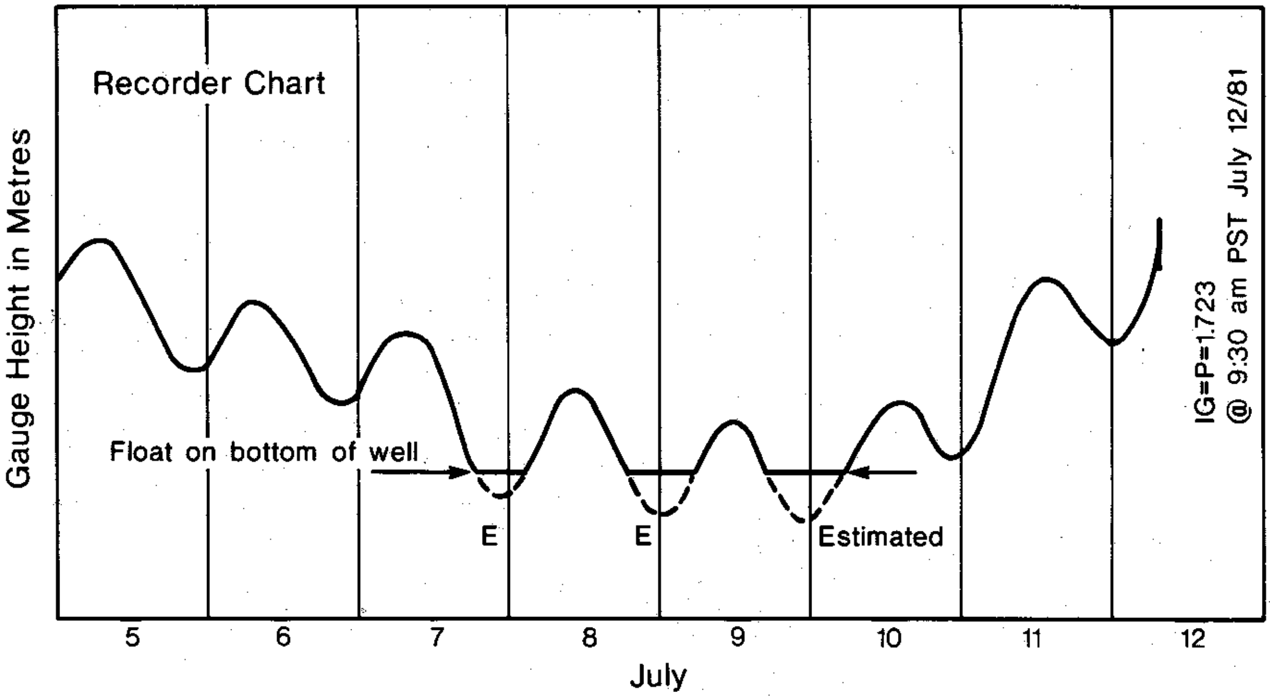

Figure 5. Well not deep enough.

6. HYDROGRAPH COMPARISON METHOD

This method involves estimating daily discharges or water levels from a graphical comparison of hydrographs. The hydrograph for the station with missing data is compared with the hydrographs for stations on the same stream and/or its tributaries, or with hydrographs for stations in adjacent hydrologically similar basins.

If a reference station is not available, hydrographs of previously recorded data can be used as a guide by choosing a flow event which approximates the magnitude of the missing period. The shape of these previously recorded hydrographs incorporates the effect of the various basin characteristics (e.g. slope, forestation, etc.), thereby defining the possible shape of the estimated hydrograph.

The duration, intensity and distribution of rainfall (as well as temperature records, e.g. during snowmelt periods) and the contribution of tributary flow must be considered. Other supplementary information is also useful, if available, e.g. high-water marks, "bucket" surveys, observer's notes, antecedent conditions, degree and type of regulation or storage. If the flow is regulated, any diversions to or from the system or the effect of storage must also be considered.

An understanding of the time lags at various stages for stations in the same basin is important. Knowledge of the regional and basin characteristics is also required when selecting stations which are comparable.

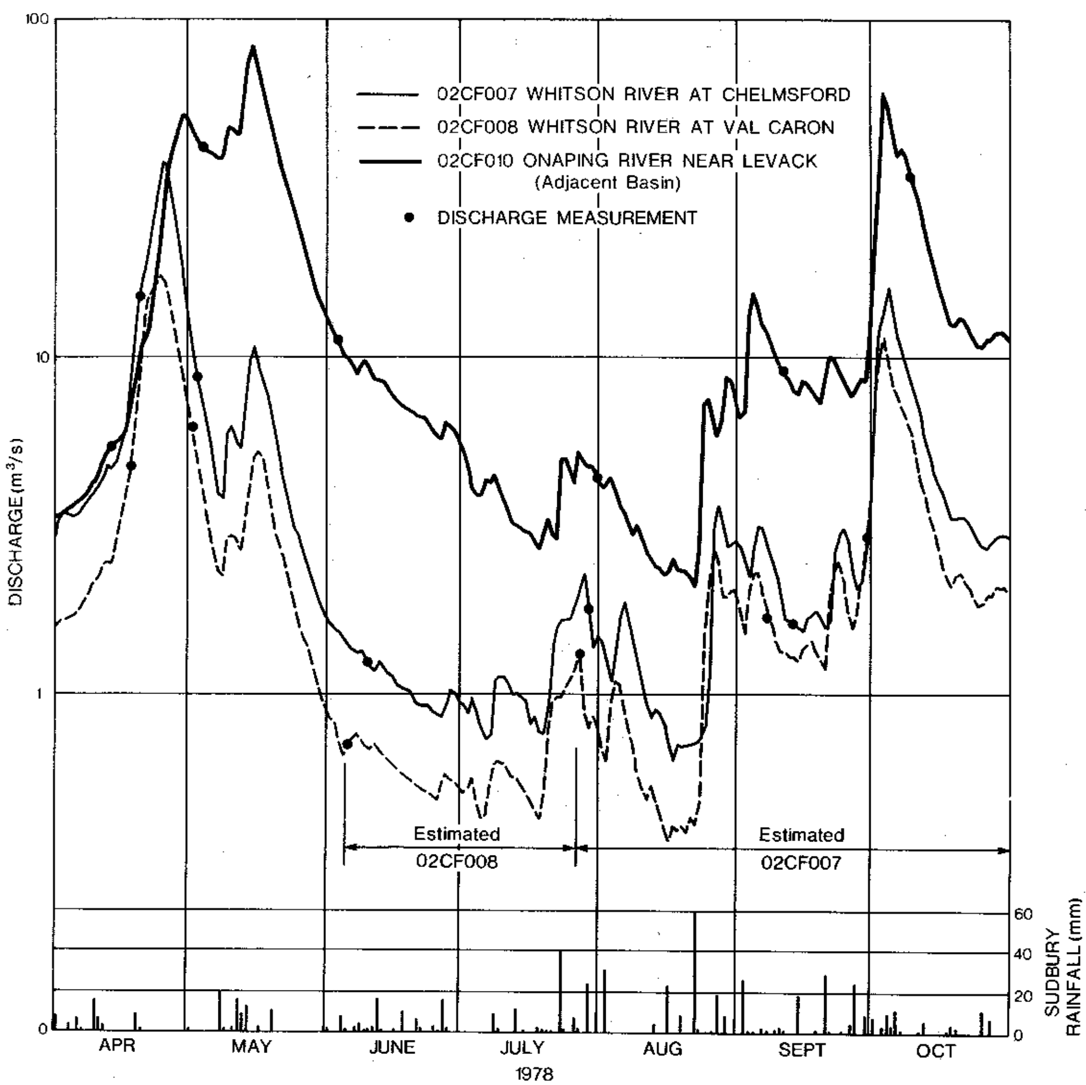

Figure 6. Hydrograph comparison method.

Hydrograph comparison also provides a means of comparing the runoff yield for river basins. To make this comparison, a horizontal line representing the drainage area is marked on the logarithmic ordinate of each hydrograph. For example, if the drainage area is 9720 km^2, mark the line at the discharge equivalent of 97.2 m^3/s (Figure 7). Slide one hydrograph sheet vertically until the drainage area lines match, and if the discharges then also match, the two basins have equal unit yield (the station with the higher discharge hydrograph has the greater unit yield). Upstream stations usually have greater unit yield. A problem may be encountered in using unit yield as an estimation tool because it is often difficult to determine the effective or contributing drainage area, especially for those basins with large flat areas which contribute sporadically depending on antecedent storage conditions.

The hydrograph comparison method should be used to check chart interpretations or the application of shift/B.W. corrections during periods of unstable stage-discharge relationships. It should also be used for verification or confirmation of all final computations, even those not "estimated."

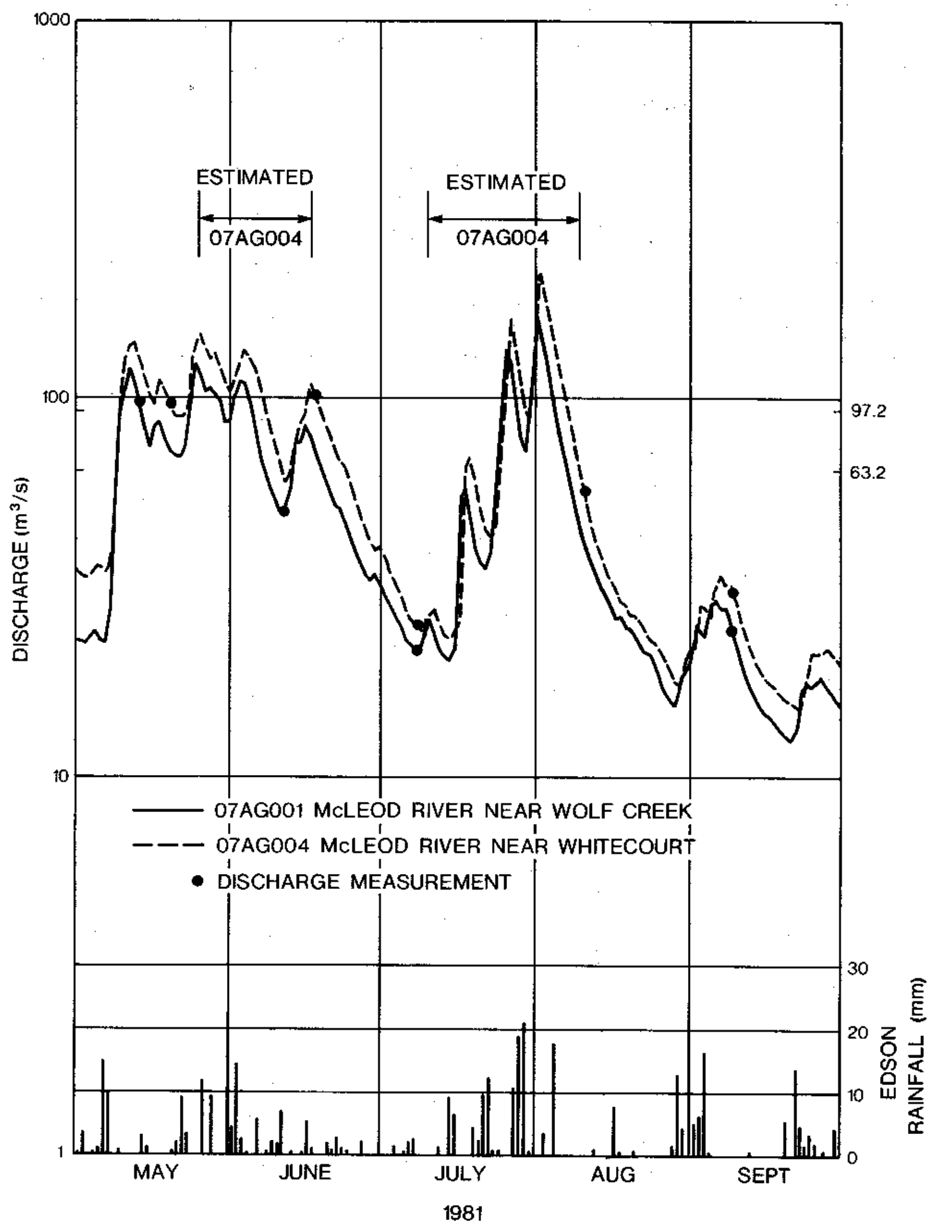

Figure 7. Hydrograph comparison method.

6.1 General Procedure

A general procedure for estimating daily discharges using this method follows:

(a) Obtain the annual hydrograph using the STREAM or MANUAL program, or plot shorter periods of say, May to September, on semilogarithmic paper.
(b) Plot the discharge measurement results.
(c) Assemble supplementary information. Plot the appropriate rainfall and/or temperature data.
(d) Examine historical hydrographs for other stations on the same stream, its tributaries or those from an adjacent basin. Plots of historical data are available from Ottawa from the FLOW file, using form 067-2087M (refer to Section 6.7 of the FLOW File Operations Manual, Fourth Edition, or Section 6.1 of the Manual of Hydrometric Data Review Procedures, Fifth Edition, for the procedure for requesting these historical hydrographs).
(e) Decide which station(s) should provide the most reliable estimates. The discharge measurement results for the year being estimated should have already been plotted for the reference station(s).
(f) Place the reference hydrograph and the hydrograph to be estimated on a light table and shift one until they match. Sketch the missing record by tracing the reference hydrograph. The hydrographs often will not match at both the low and high ranges; in this case, the high-water portion should be matched first and estimated, and the hydrograph should then be shifted accordingly before estimating medium- or low-water discharges.
(g) Record the estimated daily discharges on a work sheet and enter them as Updating Corrections for the STREAM or MANUAL program. A mathematical check may be used to confirm the estimates using a drainage area or daily discharge ratio where applicable. However, it may be difficult or inappropriate to apply such ratios to daily values unless the time lags at the various stages are well defined by historical records under similar flow conditions.
(h) Explain the basis for the estimates in the Station Analysis. Use a separate sheet if necessary, and include the reference hydrographs that were used.

7. RECESSION CONSTANT METHOD

The shape of the falling (recession) limb of a hydrograph can be described mathematically by a simple equation with one constant. This recession constant is unique to a specific watershed under similar flow conditions and its value can be used either to gain an understanding of the flow processes (hydrograph separation into various components) or to estimate the falling hydrograph when the discharge along any point of the falling hydrograph is known. More detailed explanations of this principle are given in an internal draft paper on "The Use of Recession Constants" by Ian McLaurin (Winnipeg).

This method is applicable only to the recession limb of a hydrograph, during periods without significant precipitation. The recession constant can vary considerably, depending on the magnitude of the flow, and therefore should be used with caution. It should be substantiated by historical data under flow conditions similar to those for the period being estimated.

A general mathematical equation for the recession limb is:

$$Q_2 = Q_1 K^{\Delta t} \qquad (7\text{-}1)$$

where Q_2 = discharge at time t_2
Q_1 = discharge at time t_1
K = recession constant (<1)
Δt = elapsed time interval ($t_2 - t_1$)

Rearranging the equation, the recession constant can be obtained as follows:

$$K = \left\{\frac{Q_2}{Q_1}\right\}^{\frac{1}{\Delta t}} \qquad (7\text{-}2)$$

Equation 7-1 will produce a straight line on semilogarithmic paper, but because the recession constant is generally not consistent throughout the entire range of discharges or for all seasons the recession curve should be broken into short segments for various discharge ranges.

7.1 Short Periods

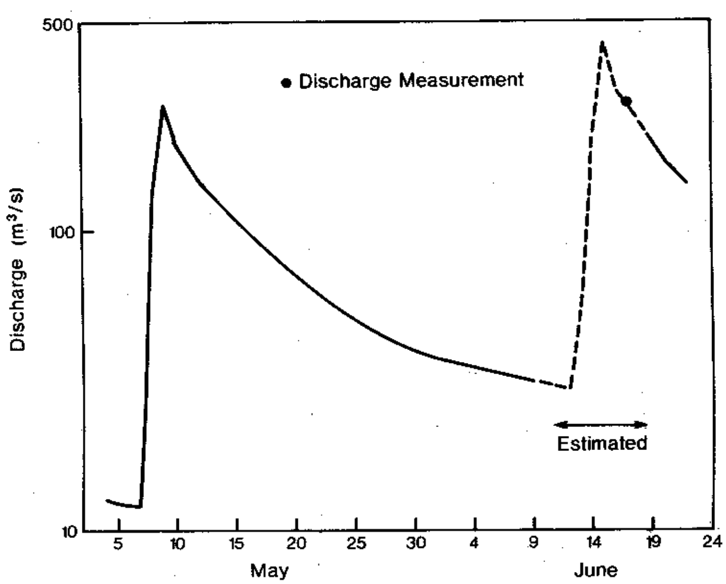

Figure 8. Recession constant method.

Estimated period June 10-19

June 10-12 estimated by average recession constant calculated June 1-9.

June 13-14 estimated by hydrograph comparison.

June 15-16 estimated by reverse recession constant calculated May 10-11.

June 18-19 estimated by recession constant calculated June 17-20.

The recession constant can be used to estimate short periods of missing records either forward or backward along a recession limb from a known discharge value. The "K" values are calculated from daily values just prior to or after the missing record, or from a complete hydrograph in another part of the record. The following example illustrates the method (also see Figure 8).

Date	Recorded (m^3/s)	Calculated K	K Used	Estimated (m^3/s)
June 1	36.8			
2	36.2	0.98(1)		
3	35.4	0.98		
4	34.5	0.97		
5	34.0	0.99		
6	33.4	0.98		
7	32.6	0.98		
8	32.0	0.98		
9	31.1	0.97		
10			0.98(2)	30.5E(3)
11			0.98	29.9E
12			0.98	29.3E
13	heavy rains		rising limb	55.0E(7)
14	heavy rains		rising limb	200 E(7)
15				428 E(6)
16			0.72(4)	308 E(5)
17	268 A		0.87	268 A
18		0.87(8)	0.87	233 E(9)
19		0.87	0.87	203 E
20	177	0.87	0.87	
21	157	0.89		
22	143	0.91		
May 4	12.9			
5	12.3	0.95		
6	12.1	0.98		
7	12.2	1.02		
8	131	>1 rain		
9	266	>1 rain		
10	191	0.72(4)		
11	168	0.88		
12	146	0.87		

Notes

(1) $K = \frac{36.2}{36.8} = 0.98$

(2) The average "K" calculated for the recession of June 1-9 is for the continuing recession to the start of rain on June 13

(3) 31.1 x 0.98 = 30.5 m^3/s

(4) The "K" values for the recession from the peak on June 15 come from another period of record (May 4-12) with similar flow conditions

(5) The June 16 flow is estimated "backwards" from the flow on June 17: 268 ÷ 0.87 = 308

(6) The June 15 flow is estimated "backwards" from the flow on June 16: 308 ÷ 0.72 = 428

(7) The discharges for the rising limb (June 13-14) cannot be defined by recession constants and must be defined by another method (e.g. hydrograph comparison)

(8) $K = \left\{\frac{177}{268}\right\}^{1/3} = 0.87$

(9) 268 x 0.87 = 233

A – Manual gauge
E – Estimated

7.2 Long Periods

The recession constant method is also useful when estimating a long period of record of several months that is void of significant rainfall and where two or three discharge measurements are available. In this case, the recession constant is calculated from other periods of historical records for the station.

A recession curve may also be developed by plotting values of Q_2 against Q_1 some fixed time "t" later. Normally, a curve indicating a gradual change in the value of "K" results. This curve approaches a 45° line as Q approaches zero. The recession curve for the Churchill River above Otter Rapids is illustrated in Figure 9. This method may be used to construct recessions for base flow or direct runoff. For base flow recession, data should be selected from periods several days after the peak of a flood so that it is reasonably certain that no direct runoff is included. After the base flow recession has been established, it can be projected back under the hydrograph immediately following a flood peak and the difference between projected base flow and the total hydrograph used to develop a direct runoff recession curve. The base flow curve should be drawn to envelop the plotted data on the right because such a curve represents the slowest recession (high K). Conversely, data for the direct runoff recession are enclosed on the left.

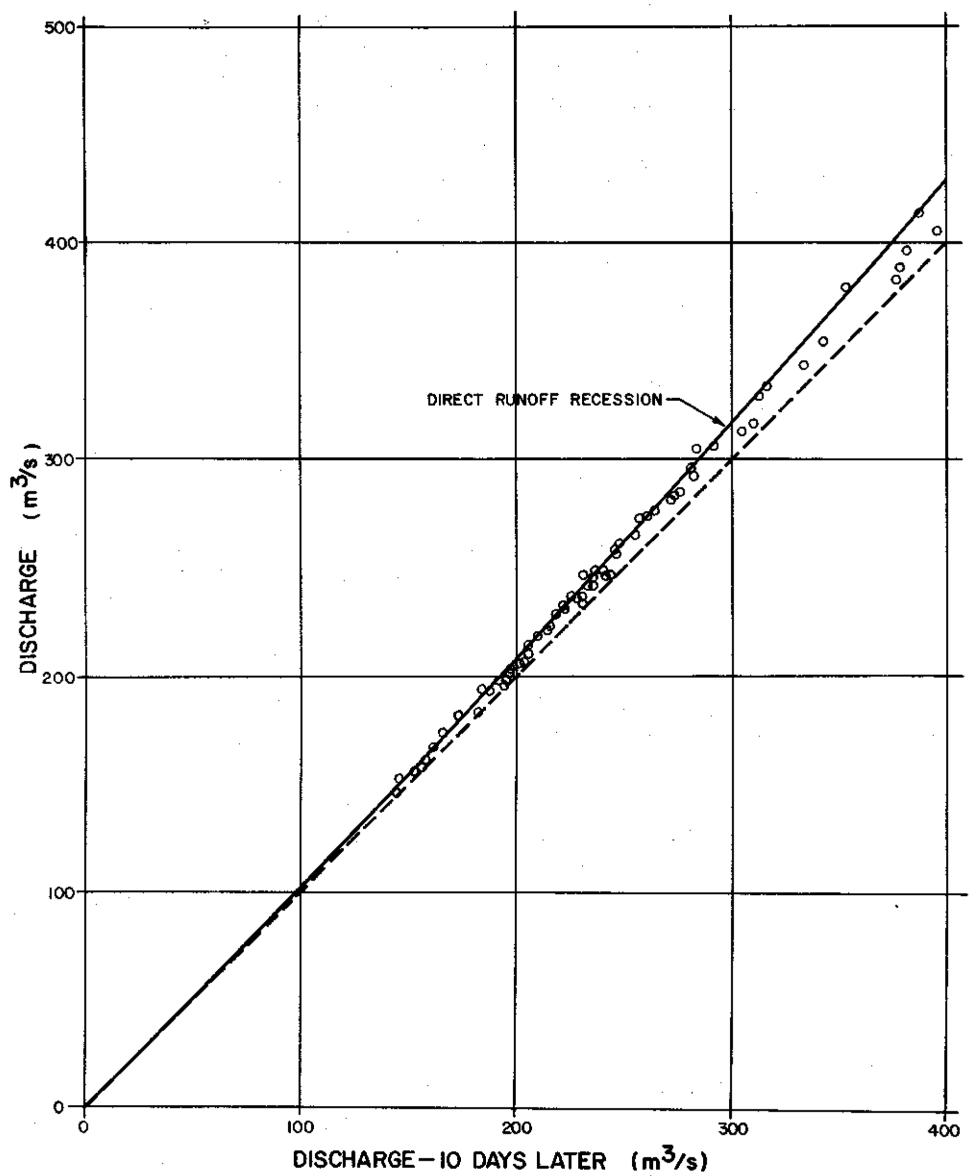

Figure 9. Recession curve for Churchill River above Otter Rapids.

8. OTHER METHODS

Several mathematical methods are being studied by the Water Resources Branch to determine their suitability for estimating missing data. These methods will probably require computer models based on historical data. They are usually unique to a specific river basin and are applicable only when calibrated. More detailed information will be provided by the Data Control Section (Ottawa) as these procedures are developed.

8.1 Curve-Fitting Method

An alternative method of estimating missing record for a recession is through the use of one of numerous curve-fitting programs available for computers or programmable calculators. However, the results must be evaluated against historical data to determine their suitability.

The programs transform a curvilinear relationship into a linear form, then produce a "best-fit" straight line using the least-squares method. Measures of goodness of fit of this line to the real data points can be obtained and can provide the user with a form of rating for each of a number of curve-fitting attempts on a data array.

With reference to hydrograph analysis, visual inspection of hydrographs of recorded data for a number of stations shows that the recession segment may be represented by one of the equations shown below:

(a) Linear regression $y = a + bx$
(b) Exponential curve $y = ae^{bx}$
(c) Logarithmic curve $y = a + b \ln(x)$
(d) Power curve $y = ax^b$

where y = value of the dependent variable (discharge)
x = value of the independent value (time)
a = constant
b = slope of the line.

8.2 Summation Program

A summation/statistical program was developed by the Water Resources Branch, Ontario Region, for use in a dense network of gauging stations within one river basin. The basin used in the test was the Saugeen River in southern Ontario.

The program output permits the comparison of:

(a) Total flows of the upstream stations against the downstream stations.
(b) Runoff coefficients of the streams against each other.
(c) The individual stream contributions relative to the total flow.
(d) Individual station data against historical information.

With this capability, data can be checked against historical and adjacent stream data, and the calculation of missing record be facilitated.

8.3 Flow-Routing Methods

Streamflow routing methods are used extensively in flood forecasting, in planning and design of water resources structures and in hydraulic and hydrologic modelling for a variety of other purposes.

Hydrologic mathematical routing models, including the Muskingum, modified Puls and SSARR routing methods are used in operational hydrology and can be made practicable for use in hydrometric surveys to fill in missing data under certain conditions. However, they are not yet part of the operational procedures of the Water Survey of Canada Division.

APPENDIX A. STREAMFLOW HYDROGRAPHS

The information given in this appendix was drawn from the "Handbook on the Principles of Hydrology" by D.M. Gray, University of Saskatchewan, published by the Secretariat Canadian National Committee for the International Hydrological Decade, 1970.

A streamflow hydrograph is a graphical presentation of discharge of a stream versus time. Since discharge can include contributions from surface runoff, interflow, groundwater flow, channel precipitation and natural or artificial regulation, the hydrograph may take on a multitude of shapes. An understanding of the many factors that influence the shape of the hydrograph is important when computing streamflow data.

A.1 Hydrograph Characteristics

A typical hydrograph for a single runoff event is shown in Figure A-1. It is characterized by a period of increasing discharge (rising limb) culminating in a peak or crest, and a period of decreasing discharge (recession limb).

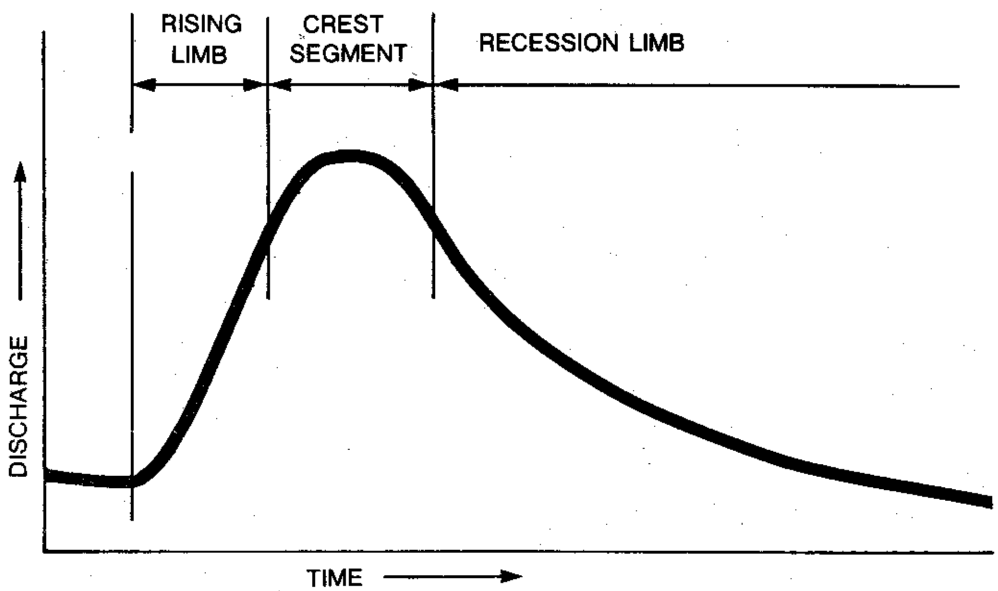

Figure A-1. Elements of a typical hydrograph.

The rising limb extends from the beginning of surface runoff to the first inflection point and is generally concave upward. The shape of the rising limb is dependent upon the characteristics of the time-area histogram for the basin and the duration, intensity and uniformity of inflow (rainfall and/or snowmelt).

The crest segment extends from the inflection point on the rising limb through the peak to a corresponding inflection point on the recession limb.

The recession limb is a period of decreasing discharge extending from the inflection point on the falling limb to base flow. In general, most streams are subject to contribution from groundwater and interflow, resulting in a gradually decreasing slope for the recession because of the varying time lags associated with the different components of flow. The shape of the recession limb is essentially dependent upon the physical features of the basin.

A.2 Factors Affecting Hydrograph Shape

A.2.1 Climatic Factors

(a) Precipitation intensity and duration:

Precipitation has an effect on the volume, peak discharge and duration of runoff. An increase in rainfall intensity will generally increase the peak discharge and volume but will have little effect on the time base of the hydrograph. For a large basin, variation of rainfall intensity usually has an insignificant effect on hydrograph shape. An increase in rainfall duration often has the effect of increasing the contributing area of a drainage basin as surface storage is filled and will lengthen the time base of the hydrograph.

(b) Distribution of precipitation:

Precipitation near a gauging station will normally produce a more rapid rise, sharp peak and rapid recession. The same precipitation in the upper reaches of the basin will produce a lower, broader peak.

(c) Direction of storm movement:

A storm moving downstream over a basin will produce a higher, sharper peak than a storm moving upstream.

(d) Type of precipitation, type of storm, temperature:

A snowmelt hydrograph will generally produce a shape which has a broader time base than a rainfall hydrograph, often with diurnal fluctuation. The rate of runoff is lower from snowmelt because of lags due to the nature of the snowpack and its distribution as well as the attenuating effects of cool evening temperatures. Conversely, an extended period of warm temperatures, as a result of a large warm air mass settling over a basin, can generate unusually sharp peaks from snowmelt.

An increase in meltwater temperature because of increased solar absorption during a snowmelt period is significant in exposed areas such as south-facing valley slopes, urban areas and cultivated fields. This warmer water increases the rate of snowmelt and contributions from melting channel ice.

Runoff from snowmelt during periods of relatively low daytime temperatures and freezing nights will tend to be sporadic and unpredictable because the runoff period is extended and a greater opportunity for contribution to subsurface supplies is afforded. Under these melt conditions a cyclic effect will normally show up on the chart trace.

Snow dams and ice jams have the effect of altering the shape of the hydrograph to a larger degree for a small basin than for a larger basin.

(e) Antecedent conditions:

Antecedent conditions have an effect owing to a change in the groundwater component and the contributing area of a basin. High antecedent precipitation increases the groundwater component and may increase the contributing area as surface storage increases.

A.2.2 Topographical and Geological Factors

(a) Drainage area size and shape:

An increase in drainage area size will lengthen the time base of runoff generation. A compact drainage basin with short tributaries will exhibit a higher, sharper hydrograph than one which is long and narrow but of equal size.

(b) Distribution of the drainage system:

A well-defined system of drainage reduces the distance the overland flow must travel, resulting in a hydrograph which is short and concentrated.

The hydrograph shape is also affected by the runoff characteristics of river basins with urban, agricultural or forested areas.

(c) Slope of the main channel:

An increase in channel slope increases the slope of the recession limb and decreases the time base of the hydrograph.

(d) Slope of the effective drainage basin:

The slope of the effective drainage system has an effect on infiltration and travel time to the main channel. On large basins, overland flow time periods are small in comparison with flow in the main channel.

(e) Pondage:

Basin storage or pondage has the effect of decreasing the peak flow and increasing the time base of the hydrograph.

(f) Geological factors:

The geological construction of the drainage basin has an influence on the contribution to or depletion of groundwater and interflow. An impervious soil substructure may reduce considerably or eliminate completely the groundwater component, whereas a basin characterized by a porous soil may exhibit a relatively large groundwater component.

A.2.3 Streamflow Regulation

Reservoir regulation or withdrawals from the river such as irrigation or municipal pumpage may change the entire character of the hydrograph which existed prior to regulation. Backwater effects (e.g. beaver activity) in a stream can also be considered regulation because of changes to the natural flow, mostly during low-flow periods. The distance between the regulation source and the gauging station determines whether changes are abrupt or gradual. Changes due to reservoir regulation in particular may be so extensive that normal low-flow periods become high-flow periods and vice versa. These changes are particularly important when estimating data. Unless it is known that regulation did not occur during a period of missing record, the only reliable methods of estimating the data are hydrograph comparison using other stations on the same stream or flow routing.

A.2.4 Storage

Reservoirs, lakes, channels, banks adjacent to water bodies, and valleys can all provide storage of water. Storage can either absorb an upstream change of flow or attenuate the flow pattern downstream from the storage. Water losses also occur as a result of storage, by evaporation from the surface of the stored water, by increased infiltration due to ponding, or by evapo-transpiration along the banks of the water body. Water gains can also occur as a result of storage where 100 percent of the precipitation falling on a ponded surface becomes surface runoff. Lakes may also have large marshy areas and associated mud flats from which evapo-transpiration may take place.

Reservoirs have an effect on downstream flows which will be dependent on, among other things, the storage prior to the flow event and on the way in which the reservoir is operated. A small reservoir which is full prior to a large peak flow may have very little effect on the peak. However, if there is sufficient storage and the water is not immediately released, a peak flow upstream from the reservoir may not be seen downstream. Much of the flow entering a reservoir may be impounded or diverted and will result in major modifications to flow patterns below the reservoir.

The primary effect of natural lakes is generally to attentuate the outflows. When a large flow enters the lake, the water goes into storage, thereby raising the head only a relatively small amount in the lake. This small head elevation produces a relatively small increase in the outflow. The surface area of the lake and the discharge control characteristics of the lake are important in assessing the effect of lake storage on downstream flows. The greater the surface area, the greater the storage; the narrower the control, the greater will be the attenuating effects.

Storage in stream channels is a function of the bank material and the length and width of the stream. A stream having more storage capacity causes an upstream flow change to be more attenuated than one with a smaller amount of available channel storage.

Bank storage can occur along all types of bodies of surface water. The amount of storage available is a function of the length of shoreline, the type of bank material, and the effective volume of bank material. Groundwater gradients adjacent to the stream are a major factor with respect to how much of the water going into bank storage on a rise returns to the water body on a falling stage and how much goes into groundwater. Where the water body is bordered with fairly solid bedrock, there will be little or no significant bank storage. However, when there are broad areas of unconsolidated material adjacent to the water body, there may be considerable bank storage. If the bank material is fairly dense and changes of stage fairly rapid, then little effect may be expected from storage.

Valley storage usually occurs during high flows when a stream overflows onto the flood plain. The storage effect is a function of the area overflowed and the gradient of the valley. If the water can flow back into the channel quickly on the recession, the attenuating effect may not be very great. Water can be lost to the stream during high-flow events by being trapped in depressions, by recharge to the groundwater; by evapo-transpiration from the vegetation on the flood plain; and by water surface evaporation due to exposure to the sun and wind.

Water storage occurs when water is transformed into ice. Backwater is associated with ice formation. Ice storage occurs at times during initial freezeup when it often can be noted on the recorder chart as a sharp drop followed by a period of fluctuating water levels and, finally, a return to the usual chart trace after formation of a stable ice cover. This distinctive chart appearance is the most pronounced at stations located above ice-free controls and especially when the channel above the gauge is wide and shallow with a low slope. The sharp drop in stage is particularly evident if a severe cold snap occurs before an ice cover has been formed.

Wedge storage, or that water between an imaginary line drawn parallel to the channel bottom and the actual water surface, increases during the rising limb and decreases during the recession.