QUALITY MANAGEMENT FRAMEWORK

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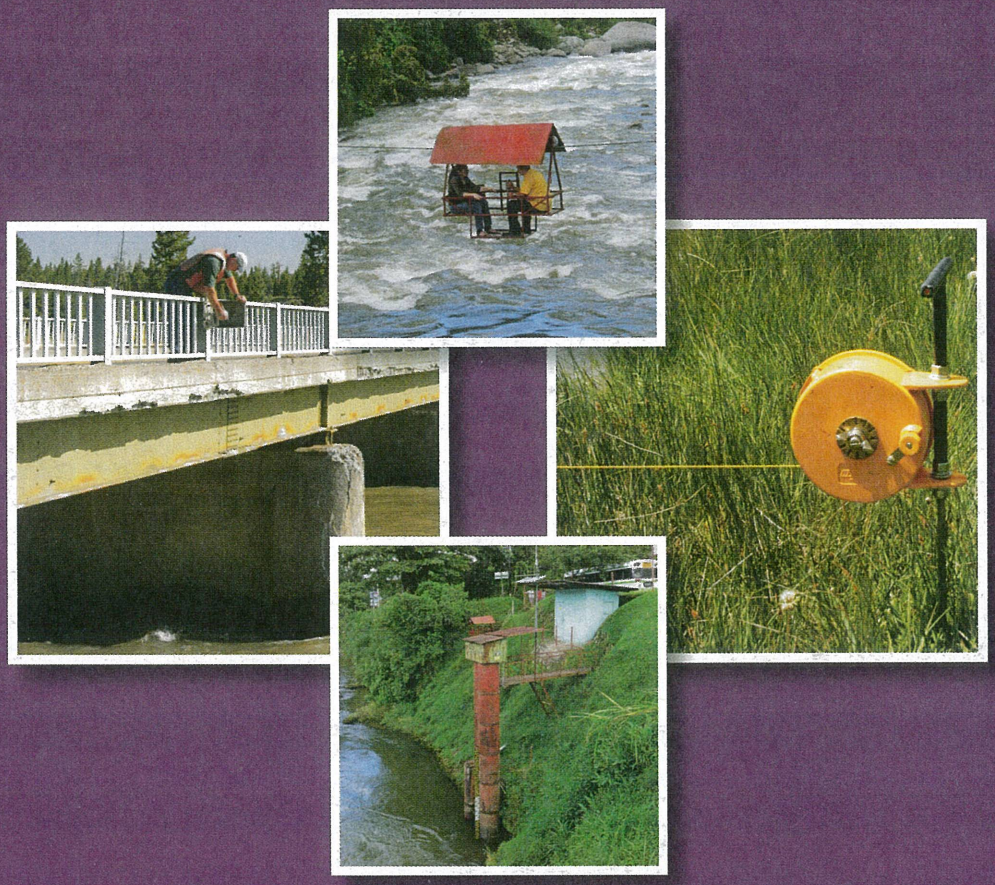

MANUAL ON STREAM GAUGING

VOLUME II – COMPUTATION OF DISCHARGE

World Meteorological Organization
Weather • Climate • Water

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Shift information for a basic rating is described in the following paragraphs. A basic rating includes a single rating of stage and cross-section area, a single rating of velocity-index and mean velocity and in some cases an optional rating of stage and a velocity correction factor. The rating discharge, Q_r, is computed by multiplying the cross-section area, A_r, from the area rating, times the mean velocity, V_r, from the velocity rating, and times the velocity correction factor, K_r, from the stage-factor rating. If the velocity correction factor is not used it is set to a default value of 1.00. The basic equation for discharge is:

$$Q_r = A_r V_r K_r \tag{6.20}$$

Shifts are allowed only for computation of V_r from the velocity rating. The stage-area and stage-factor ratings should not be adjusted through the use of shifts. If either the stage-area or the stage-factor ratings change, then new ratings should be prepared.

It also should be noted that a standard cross section must be used for the ratings and for computing shifts. That is, a specific cross section in the stream channel should be designated as the rating section. This cross section may be the same section as used for making discharge measurements or it may be a different section. All computations should be related to and based on the standard cross section. For instance, the mean stream velocity, as used for rating purposes, should be computed by dividing the measured discharge by the cross-section area determined from the stage-area rating of the standard cross section. This mean stream velocity is the velocity that should be used to check or define the velocity rating and the one to be used for plotting purposes on the velocity rating for those sites where a stage-factor rating is not used. If a stage-factor rating is used then this velocity should be adjusted by dividing it by the applicable factor before using it to check or define the velocity rating.

The order of computations for shift determinations is important because two, and in some cases three, ratings are involved. The following step-by-step procedure should be used:

(a) Standard cross-section area, A_r – Determine the cross-sectional area, A_r, of the standard cross section from the stage-area rating, using the mean gauge height, G_m, of the discharge measurement;

(b) Velocity correction factor, K_r – Determine the velocity correction factor, K_r, from the rating of stage and velocity correction factor, using the mean gauge height, G_m, of the discharge measurement. If this rating is not used, then set the velocity correction factor to a default value of 1.00;

(c) Adjusted mean stream velocity, V_m – Compute the mean stream velocity, adjusted for the velocity correction factor, for the standard cross section using:

$$V_m = \frac{Q_m}{A_r K_r} \tag{6.21}$$

where Q_m is the measured discharge, and the other variables are as previously defined;

(d) Rating velocity-index, V_{ir} – Determine the rating velocity-index from the rating of velocity-index and mean stream velocity, by entering the rating with the adjusted mean stream velocity, V_m, as computed in equation 6.21;

(e) Velocity-index shift, S_v – Compute the velocity-index shift as the difference between the rating velocity-index, V_{ir}, and the mean measured velocity-index, V_{im}, for the discharge measurement. The shift, S_v, is defined by:

$$S_v = V_{ir} - V_{im} \tag{6.22}$$

S_v should retain the resulting algebraic sign (+ or –) for application purposes. When the computed shift is applied to the measured velocity-index, V_{im}, it will yield a corrected velocity-index to use for entry to the velocity rating when determining the rating mean velocity, V_r;

(f) Measurement percent difference, D – The measurement percent difference is the percentage of error between the measured discharge, Q_m, and the unshifted discharge, Q_r. To compute the unshifted rating discharge, Q_r, use equation 6.20 as described in previous paragraphs. The measurement percent difference is computed as:

$$D = 100(Q_m - Q_r)/Q_r \tag{6.23}$$

6.11 APPLICATION OF SHIFT ADJUSTMENTS

Shifts are gauge-height adjustments used to account for temporary changes to rating curves without having to re-define the rating curve. The methods for computing shift information for the various types of discharge measurements are described in the previous section, Discharge measurement shift adjustments. For surface-water computations, shift adjustments are added to unit values of the input parameter to yield temporary unit values that are applied to the rating curve for computation of the

output dependent variable. The algebraic sign of the shift must be maintained correctly. When measurements plot above a rating curve, that is, when the actual gauge height for a given discharge is higher than indicated by the rating curve, the sign of the shift is negative. When measurements plot below a rating curve the sign of the shift is positive. Also, it is important to note that a shift is a temporary correction, used only for computational purposes. It does not permanently alter the input unit value.

Although most shifts will apply to stage-discharge ratings they also may be defined and applied to the velocity-index versus mean velocity rating for velocity-index stations. Shifts should not be allowed for any other types of rating curves except stage-discharge ratings and velocity-index and mean velocity ratings. Because shifts are predominantly used for stage-discharge ratings, the shift discussions in this section will relate to that type of rating. Much of the following discussion regarding application of shifts is based on Kennedy (1983).

Shifts usually are applied only when discharge measurements deviate from a rating curve by more than a specified percentage. The specified percentage frequently is based on the accuracy of discharge measurements that can be made at the gauging station. For instance, if discharge measurements can be made with 5 per cent or better accuracy then shifts will be used only when measurements deviate more than 5 per cent from the rating. Otherwise, if more than two or three consecutive discharge measurements consistently plot on one side of the rating a shift curve may be used for these measurements even though they are within the specified shift percentage.

The shift adjustments that apply during the periods between discharge measurements must be interpolated by an appropriate method before the unit and daily discharge records can be computed. The method used will depend on the hydrographer's judgment considering the nature of the shifting, the frequency of measurements and the type of channel and control.

Small shifts that change gradually may be distributed satisfactorily by inspection using mental interpolation. Larger shifts, whose variations are adequately defined by discharge measurements, warrant a more rigorous analysis with some form of graphic shift-adjustment-variation diagram. The accuracy of discharge records computed from a rating with large and erratic shifts depends to a great extent on the frequency of discharge measurements, and particularly unstable streams may need weekly or even daily measurements to define the day-to-day shift-adjustment variation.

6.11.1 Shift-adjustment variation diagrams

A shift-adjustment variation diagram (sometimes called a V-diagram), a graph of the relation between shift adjustment and either time or stage, is commonly used to interpolate shift adjustments between measurement-defined values. The V-diagram shifts can be graduated with time, stage or time and stage simultaneously either manually or as part of an electronic processing system.

When a low-water control is scoured or filled or affected by backwater from leaves, debris or aqueous growth, the corresponding rating shift is greatest at low water and normally tapers to zero at some higher stage. This is called a stage-variable shift. If the channel is alluvial and its bed is raised and lowered by sediment being picked up or deposited, the shift variation with stage may be negligible compared to its variation with time, and the shifts are called time variable. Most streams have shifts that must be graduated with stage while the stage graduation is changing with time.

Time-variable-shift distribution can be made manually or by an electronic processing system using interpolation between discharge measurement-defined shifts. The hydrographer may introduce arbitrary data points based on judgment and knowledge of stream conditions.

Stage-variable-shift distribution can be made by using V-diagrams similar to those in Figure II.6.3. Each diagram involves a base-rating curve (the numbered rating in effect at the time) a shift-rating curve (a rating curve drawn to fit the measurements that define the shift, usually only on the rating work-curve sheet) and the V-diagram (the gauge-height differences between the base curve and shift curve, plotted against stage). The shift curve should normally be drawn first with the same consideration given to its shape as would be given to a numbered rating. The V-diagram is best defined by drawing its corresponding shift curve first. The V-diagrams of the type in Figure II.6.3(a), for relatively small shifts, may be defined directly from measurement-defined shifts without drawing a shift curve. This process is not recommended with other V-diagram types or for large shifts where it could lead to grossly misshapen equivalent ratings and dubious discharge records.

The use of a stage-varied-shift adjustment is equivalent to drawing a new numbered rating curve and may be preferable for temporary rating changes. The principal use for stage-shift diagrams is one step in the process used for varying shifts with both stage and time as explained in subsequent paragraphs of this section.

Figure II.6.3 illustrates typical stage-shift V-diagrams and the relations between their corresponding base rating curves and shift curves. The V-diagrams for manual application are usually curved and shifts are determined by direct readings from the curve. The V-diagram must be approximated by two or more straight lines for application by an electronic processing system. Selected coordinates that define the V-diagram are entered to the electronic processing system and applied by interpolation between the entered points.

Shift adjustments varied by time only

The simplest way to vary shift adjustments between discharge measurements is by time interpolation. Time-varied shifts are usually used for periods when stage does not change very much, and the shifting control is affected by a gradual change due to scour or fill. For example, such a condition might be caused by gradual accumulation of falling leaves on a section control. Time interpolation of shifts is sometimes more convenient when computing discharge records by hand methods. For automatic data processing, time interpolation of shifts can be accomplished through the use of two or more constant (vertical) shift-variation diagrams with linear interpolation between successive diagrams.

Shift adjustments varied by stage only

The use of a stage-varied-shift adjustment is equivalent to drawing a new numbered rating curve and may be preferable for temporary rating changes. The shift-variation diagrams shown in Figure II.6.3 are typical stage-only diagrams, as described in a previous section. They are applied over a period of time by manually or automatically determining the shift for each stage value for which discharge is computed during the specified time period. Stage-only shift-variation diagrams are an integral part of the more typical situation, where shift application is varied by both stage and time, as described in the following section.

Shift adjustments varied by time and stage

Two or more shift curves can be used in combination to apply shifts to unit values so that the shifts are varied either by time only, or both stage and time. Varying the shift in this way is accomplished by defining a shift curve and assigning it a starting date and time, but no ending date and time. A second shift curve is defined with a subsequent starting date and time. If the two shift curves are defined so that each one has a different constant shift (not varied with stage), then the electronic processing system will interpolate between these two shifts based on time only. This procedure commonly is referred to as time interpolation of shifts as described previously. If two consecutive shift curves are entered so that one or both of them have shifts that vary by stage, then the electronic processing system will interpolate shifts based on both stage and time for all unit values between the two assigned shift curves.

Shift curves should be defined and numbered as a means of describing and tracking specific shifting characteristics at specific points in time. Each shift curve usually is based on one or more discharge measurement and other field observations that define a change in the position of the rating curve, and this change usually is considered a temporary change. To estimate shifts at other times, intermediate to the defined shift curves, a linear-interpolation procedure is used.

Individual shifts, and not entire shift curves, should be interpolated. That is, only those shifts needed to adjust unit values should be determined by interpolation, and not those outside the range of recorded unit values. Likewise, the interpolation process should be continuous in time, so that a shift interpolation is performed for each unit value to which shifts are to be applied.

The interpolation procedure is described in the following step-by-step example:

(a) Two shift curves, numbered 001 and 002 for example, are defined graphically for use at dates and times, t_1 and t_2, respectively;
(b) An interpolated shift, S_n, is required for unit value, G_n, at an intermediate date and time, t_n;
(c) The electronic processing system computes the shifts, S_1 and S_2, corresponding to the unit value, G_n, from each of the shift curves, 001 and 002, respectively;
(d) The electronic processing system performs an un-weighted, linear time interpolation of shifts S_1 at time t_1, and S_2 at time t_2, to obtain the shift, S_n, at time t_n;
(e) The same interpolation procedure is used to estimate shifts for all other unit values resulting between times, t_1 and t_2.

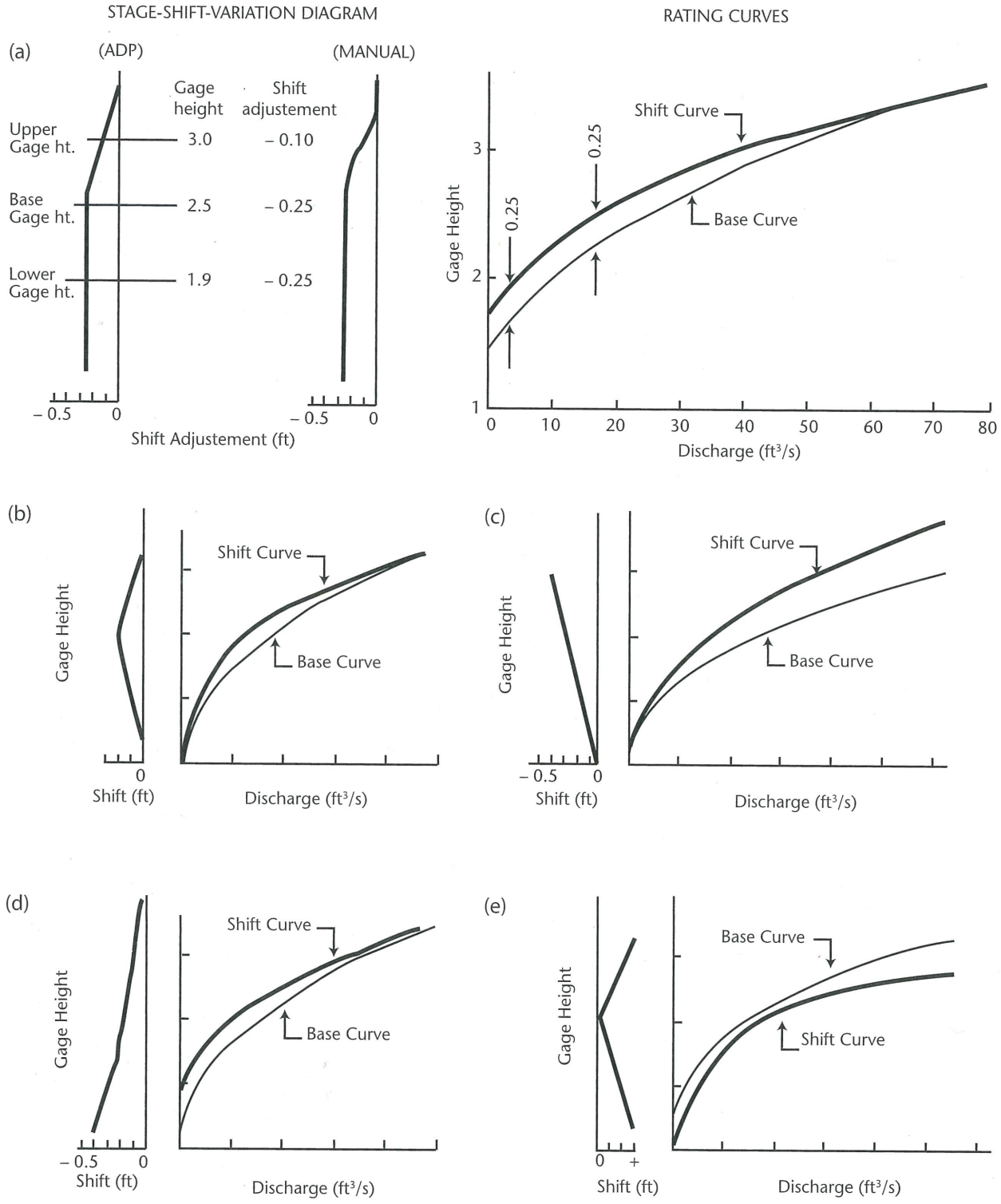

Figure II.6.3. Effect of various stage-shift-variation diagram shapes on shift-curve shape

All computed and interpolated shifts should be rounded to the same number of significant figures as used for the gauge height or other unit value to which the shift is to be applied. Rounding should be performed before any application process.

6.11.2 Unit value graphical comparison of shifts

Shifts that are applied to a time series of unit values should be displayed with the electronic processing

system in a graphical plot. The graphical comparison should show a time-series plot of the unit values of gauge height (or other independent variable) and a superimposed plot of the unit values of shifts. Scales for the two plots should be used so that each plot is easily discernible and readable. The hydrographer should have the option to change either or both of the scales. An example plot is shown in Figure II.6.4.

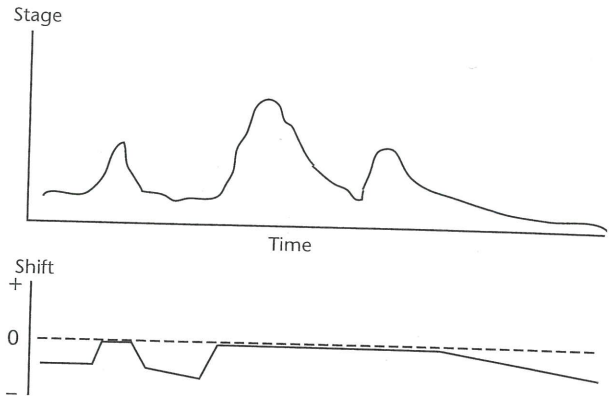

Figure II.6.4. Example plot of unit values of stage and shifts

6.12 PRIMARY COMPUTATIONS

Primary computations are the functions that convert input data, such as gauge height, velocity index and other auxiliary data into time series of unit values, daily values, monthly values and annual values of discharge, mean velocity, reservoir contents and other output parameters. In the past primary computations were generally performed by hand. Today, almost exclusively, primary computations are performed by automated data processing systems. Therefore, the subsequent discussions of primary computations are described in terms of automated data processing methods.

The primary computation process is dependent on the type of gauging station and, except for stage-only stations, always will require the use of at least one rating curve. To carry out the conversion process previously developed data and information will be required, such as time series of input variables, correction diagrams, shift curves and rating tables. The conversion should be carried out with minimal interaction from the hydrographer and should produce files of information that can be used to produce tables and graphs that commonly are referred to as primary output.

6.12.1 Unit value computations

Unit value files of uncorrected input parameters, such as gauge height and velocity index, are entered to the electronic processing system as described in previous sections of this chapter. Also, specific information such as parameter correction diagrams, shift curves and rating curves are entered as described previously. The primary computations should produce additional unit values files of specific output parameters, dependent on the station type. These unit values and their associated time tags are saved for the purpose of computing daily mean values, various statistics and for archiving. The unit values files that should be computed for each type of station are described in the following sections.

Stage-only stations

Stage-only stations are those stations where unit and daily mean values of gauge height and associated statistics are required. For this type of station only the unit values files of gauge-height data and the gauge- height correction information are needed. Primary computations should create the following unit values files. Unless otherwise noted, each unit value file should be saved for further use and for archiving:

(a) Gauge-height corrections – The electronic processing system should evaluate and compute the gauge- height correction that corresponds to each input value of gauge height. Gauge-height corrections include instrument errors, gauge datum errors and gauge datum conversions (for example, conversion to a mean sea level datum). The computations should use each correction and correction diagram as defined by the hydrographer. The corrections and correction diagrams should be interpolated by time and stage, as required. If two or more corrections or correction diagrams apply to the same time period, the gauge-height correction should be determined from each one independently for each time step, and summed to produce the cumulative correction for each time step. All gauge-height corrections should be rounded to standard gauge-height precision before using them in further calculations. The resulting time series of cumulative gauge-height correction values should be saved as a working file, and for later archiving;

(b) Corrected gauge heights – A unit values file of corrected gauge heights should be computed by adding the cumulative gauge-height correction (see above) to the input unit values of gauge height for each time step. This file of corrected