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A decision support system for the analysis and use of stage–discharge rating curves

Mark P.J. DeGagne[a], Glen G. Douglas[a], Henry R. Hudson[b], Slobodan P. Simonovic[a,*]

[a]*Department of Civil and Geological Engineering, University of Manitoba, Winnipeg, Man. R3T 2N2, Canada*
[b]*Environment Canada, 500–269 Main Street, Winnipeg, Man. R3C 1B2, Canada*

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Abstract

A decision support system for fitting stage–discharge relations is being developed by the University of Manitoba, Facility for Intelligent Decision Support, for Environment Canada's hydrometric program. The process of developing and applying stage–discharge relationships has been documented, the decision support system framework established, and a number of expert 'rules' developed and evaluated for stable and non-stable channels. The system categorizes stage–discharge rating curves as stable if they deviate within a predetermined accuracy (e.g. ± 5% of discharge), or if one of a suite of curves can be applied within the predetermined accuracy specifications for given changes in the energy slope caused by weed growth, channel ice and other conditions affecting backwater. Non-stable channels are defined as channels that experience evolution or abrupt changes in stage–discharge relationships resulting from changes in channel form. Rating curve stability is determined based on deviations in the stage–discharge relationship, utilizing specific gauge, absolute differences between sequential streamflow measurements and an analysis of residuals. Periods of instability, such as a meander cut-off changing the hydraulic control, are often repetitive in hydraulic response, such that a pattern of instability is recognizable as events occur. In addition, periods of instability are interspersed with periods of stability. The repetition in pattern allows knowledge of correctly identified historic events to be applied to contemporary hydraulic conditions. A suite of rating curves can be developed for specific periods (e.g. summer weed growth) and stages. These curves can be automatically applied based on changing streamflow conditions such that streamflow estimates can be generated in a rigorous and accurate manner with minimal hydrographer intervention.

* Corresponding author.

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1. Introduction

Discharges in rivers are typically estimated by combining water level records with a functional relation, or suite of relations, describing variations in measured discharges with changing water levels. The functional relation between water level (or stage) and discharge is known as a stage–discharge curve, stage–discharge rating or rating curve. Procedures for measuring both stage and discharge, as well as the development of stage–discharge relations, have been established through a series of national and international standards (ISO, 1981, 1982, 1983). However, the actual practice of developing and applying rating curves varies between agencies (Mosley and McKerchar, 1993).

Many of the steps involved in estimating streamflow have been computerized by various agencies. Environment Canada (unpublished data, 1992) undertook an extensive review of hydrometric software identified by the World Meteorological Organization and other sources. In terms of rating curves, the degree of computerization ranges from digitizing hand-drawn curves in the Canadian hydrometric program to developing and applying a range of mathematically fitted and hydraulically derived curves, with error bounds, that are segmented by time and/or stage, in the Australian hydrologic data analysis system HYDSYS/TS (HYDSYS, 1991).

In the systems reviewed, verification of the appropriateness of rating curves is left to the hydrographer. In many systems, selection of curves is visual either in terms of apparent fit to the data (Institute of Hydrology, 1992), or in terms of the inflections in the rating relation (Rogers and Thompson, 1992). In HYDATA individual discharge measurements can be weighted in proportion to the square of the flow to better describe sparse high flow discharge measurements (Institute of Hydrology, 1992). In HYDSYS/TS the rating functions are displayed against the cross-section of the hydraulic controls, and the integrity of rating curves can be evaluated with measures of goodness of fit and by visual comparison. Comparisons can be made of the scatter in the stage–discharge relation and against a range of derived hydraulic parameters, such as variations in roughness (Manning's n) as stage changes, and hydraulic geometry relations. Discontinuities in these parameters should correspond to changes in hydraulic control (HYDSYS, 1991).

Rating curves may have to be extended beyond measured discharges. In practice, new streamflow measurements are made to develop or verify a rating relation. In the case of new curve development, several data points are normally collected over a range of flows before streamflows are estimated with the rating curve. This may result in the lack of flow estimates for a long period while the streamflow measurements are made. This is especially the case for extreme flow events where measurements are not available for curve development. As an alternative, theoretical curves can be developed based on hydraulic geometry of the reach and they may also be extended based on the same principles. Therefore, a logical extension of a system is the inclusion of rating curve extension procedures.

Considerable expertise and experience are required in locating gauging stations, recording water levels, measuring streamflow and observing site conditions, so that stage–discharge relations can be developed and applied to provide accurate estimates of streamflow. Data analysis and curve fitting involve repeated subjective decision-making based on human judgment, experience and rules-of-thumb. In addition, site conditions

often vary with time so that the relationships must be continuously updated to ensure the relationship is accurately represented. Rating curves are continually being redefined and reestablished, often without rigorous pattern recognition from the history of stage–discharge measurements and hydraulic, hydrologic and geomorphic conditions.

Decision support systems have been infrequently used to this point in hydrologic and hydraulic applications (Loucks and daCosta, 1991). Given the 'semi-structured' nature of the stage–discharge ratings process, it was thought that current practice could be enhanced by the development of a decision support system that could rigorously apply past experiences, and provide supporting hydraulic, hydrologic, and geomorphic analysis (Simonovic, 1989). The objectives of this research were: (1) to identify causes of rating curve variations; (2) to examine the applicability of decision support system concepts for the development and application of stage–discharge relationships by developing a decision support system framework to model the processes of stage–discharge curve development, use, and extension; (3) to evaluate the effectiveness and implementation implications for fielding the decision support system in an operational organization.

The decision support system is being developed as a joint effort of Environment Canada's hydrometric program and the University of Manitoba (Facility for Intelligent Decision Support at the Department of Civil and Geological Engineering). In the first phase of the project, presented in this paper, the decision support system framework was developed for stable and non-stable river channels in the Unix environment. In the second phase the system has been transferred into the personal computer environment. The evaluation and use of the stage–discharge decision support system in Environment Canada's hydrometric program is in progress using stage–discharge relations for a wide range of conditions in the Province of Manitoba, Canada.

This paper provides the discussion of channel stability followed by the formalization of the stage–discharge analysis framework. At the end, some of the decision support system implementation issues are addressed.

2. Channel stability

Ideally, hydrometric gauging stations are located such that a stable stage–discharge relationship is achieved and measurable changes in stage produce measurable changes in discharge. In practice, such sites may not exist, or use of such sites is prevented by the locational requirements for the hydrometric data, or logistical and other difficulties. As a result, gauging stations are frequently located in less than ideal river reaches and suffer a range of problems, which make the development and application of a stage–discharge relation problematic.

ISO standard 1100/2 (ISO, 1982) states: 'a stable channel is one wherein the physical form and frictional properties of the bed and sides remain constant with respect to time. Conversely therefore, an unstable channel is one wherein the physical form and frictional properties vary with respect to time; that is the channel itself is mobile.' The ISO definition goes on to define frictional changes induced by weeds, ice effects, tributary inflows and downstream regulation as constituting unstable conditions. This definition of channel stability is somewhat contradictory given the nature of instabilities and the statement in

ISO standard 1100/2 (ISO, 1982): 'In all circumstances of variable backwater at a given discharge, a stable channel will provide a stable stage–discharge relation when the energy slope of the water in the reach concerned can be included as a parameter in the discharge relation.'

Channel stability is time dependent. All channels evolve. The issue is the rate of evolution and the degree of change. For practical purposes, at an engineering time scale, and from a hydraulic perspective, some channels can be considered stable in terms of channel form and processes. However, these channels almost invariably have shifts in rating relations resultant from backwater effects such as weeds and debris.

As an operational definition, a stable channel means a channel in which the rating relation is essentially constant over time, or one where variances in the rating curve are attributable to a change in the energy slope of the gauging reach, rather than to an evolution of the channel itself. Departure from the ISO definition occurs in that backwater effects resulting from frictional changes (e.g. weeds and ice), local impoundment (e.g. beaver and debris dams), and upstream and downstream effects (e.g. changes in approach velocities owing to changing conditions upstream of the stable reach) are considered part of the stable regime. The rationale for inclusion of these effects in the stable category is that there is a strong tendency towards a repetition of fairly stable stage–discharge relations within these regimes from event to event.

Unstable channels are defined as those in which unstable rating relations result from channel evolution (e.g. scour and fill, and instability in the hydraulic control). Although some channels may appear relatively stable, most natural channels are subject to morphological and/or hydraulic change over their history. Unstable channels are also subject to variable backwater effects.

A central point of a stage–discharge decision support system (SDDSS) is the ability to recognize patterns of channel stability and to apply prior knowledge of river channel behavior to contemporary stage–discharge relationships.

3. Formalization of the stage–discharge analysis framework

3.1. Rating curve development

3.1.1. Identification of stability and data selection

Five process knowledge elements for modeling a rating relation for a non-stable channel were identified: identification of channel types; classification of stable and non-stable stage–discharge regimes; stratification of stage–discharge measurements into appropriate stability regimes; modeling and evaluation of stage–discharge relations; curve extension (Fig. 1). Logically, the first step in the process should be to evaluate all the data available for developing a stage–discharge relationship. If the data (i.e. observed vs. computed) plot monotonically, and within the prescribed accuracy for the site, for a weir for example, then no further stage–discharge analysis would be required. However, because the development of this system was staged (stable channel first, followed by unstable channel analysis), a stability classification is undertaken before evaluation of the rating relation (Douglas and Simonovic, 1992).

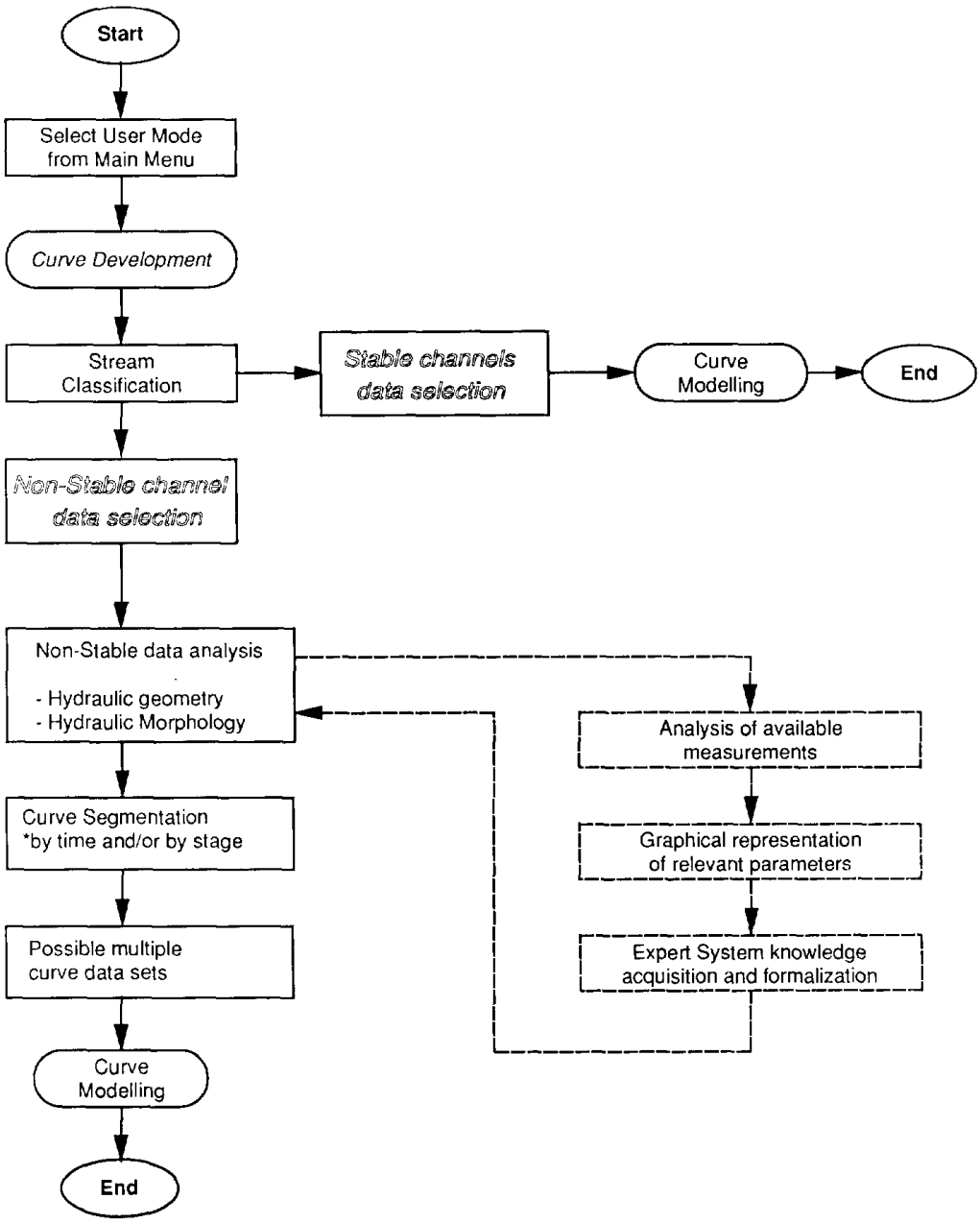

Fig. 1. Curve development framework.

A simple identification of channel types based on bed and bank material type (sand, gravel, mixed sand–gravel, armored and bedrock) and channel pattern (sinuosity, braided and non-braided) has been developed. At the moment, the classification is only a shell that is used to help indicate the types of channel instability to be expected (e.g. the evolution of a sand bed with changing shear stress, rating curve shifts owing to effects other than bed evolution in a bedrock channel, etc.). The objective in the future is to be able to use the hydraulic geometry and bed material characteristics to predict channel stability and

automatically select an appropriate rating curve from a family of curves. For example, in a sand bed stream the evolution from ripples to dunes, to anti-dunes to plane bed can be determined based on shear stress. Each of these conditions is characterized by a different rating curve. Given the antecedent flow conditions, and current streamflow, an appropriate rating curve can be automatically selected and applied to estimate real-time discharge.

ISO standard 1100/2-1982 clause 7.1 provides standards for the stage–discharge rating curve required to derive discharge from stage data, but there are no ISO standards for streamflow data themselves (Mosley and McKerchar, 1993). To comply with the ISO 9000 series of quality assurance standards, hydrometric stations in New Zealand have an accuracy specified for the station (e.g. 95% of all flow estimates from a gauge record with a rating applied shall be within ± 8% of the actual value) (Mosley and McKerchar, 1993). The same approach was employed in the SDDSS—stability of the stage–discharge relationship is determined relative to the required accuracy for a site. Specific gauge analysis (a plot of stage over time for a given discharge) is used to classify channel stability with respect to the stage–discharge relation over time. The stage associated with three specific discharges, the 2, 5 and 10 year floods, are used to represent low, mid and high flow regimes. The specific gauge chart is widely used in hydrometric analysis, but it takes on a new role in the stage–discharge analysis. The SDDSS uses the specific gauge to identify trends in the data, link them to the stability of the channel, and incorporate the knowledge of stability into the stage–discharge analysis procedure. The stages for a specified discharge are plotted against time. Periods of stage–discharge stability are illustrated by a relatively constant specific gauge, whereas non-stable channels have discontinuities or trends in the specific gauge with time (Fig. 2). Discontinuities are used to visually segment the specific gauge record into periods of transition and periods of relatively stable conditions. The significance of these discontinuities is quantified in subsequent analysis.

Absolute difference plots quantify differences between consecutive specific gauge values for segments of record identified in the specific gauge analysis (Fig. 2). The values are interpolated from stage–discharge measurements and represent the low, mid and high flow regimes. Transitions between periods of instability are illustrated by significant differences in sequential values. Periods tending to zero difference in sequential values signify periods of stability in the stage–discharge relationship. A tolerance of ± 5%, expressed in terms of discharge, is the default value to define significant shifts, hence instability (Rantz et al., 1982a,b). However, trends of small sequential change are not identified in the absolute difference plot analysis. Therefore, an analysis of residuals is also employed.

Trends of small sequential change in specific gauge measurements can be identified in an analysis of departures from the average value for a segment of record. Sequential stage–discharge measurement departures from the average illustrate changing conditions. These specific gauge residuals (Fig. 2) can also be used to identify individual stage–discharge measurement errors or short-term anomalies. A tolerance of ± 5%, expressed in terms of discharge, is the default value to define significant shifts, hence instability. If 10% of the residuals are out of bounds, the flow regime for the selected segment is considered unstable. At this point, instability in any one flow regime for a given segment classifies the period as unstable for all flow regimes.

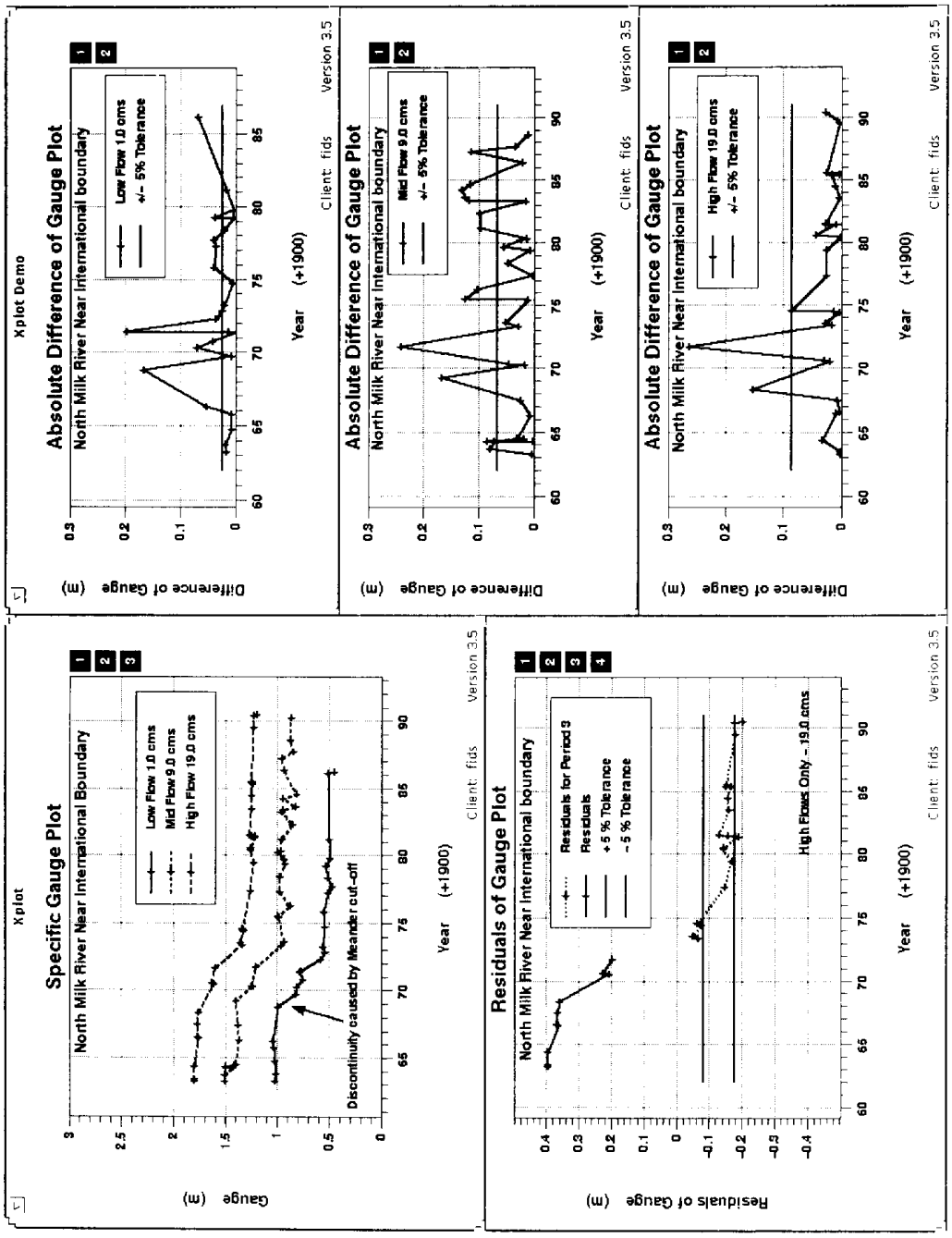

Fig. 2. Components of stream classification process.

The specific gauge may be stable or unstable, or of mixed stability, for the low, mid, and high flow regimes. In the current version of SDDSS, instability in any regime for a specified segment of record classifies the period as unstable for all flow regimes. In the future, individual flow regime classifications of stability for given periods of record will be provided based on flows experienced in that particular time frame.

Discontinuities may be caused by events such as floods, which cause scour or fill, and channel evolution (e.g. a meander cut-off, or channel degradation over time, which may produce abrupt rating changes and longer-term trends, respectively). River ice is a special case that is discussed below. Ideally, the causes of rating curve shifts are documented in site observations, but this is frequently not the case. Thus, an approach to segment hydrometric records by time has been developed. In the future, channel evolution may be interpreted from an analysis of the flow history, hydraulics, and channel description within the SDDSS.

Once the stream gauging record has been classified into periods of stability, the stage–discharge measurements are stratified into appropriate stability classes. The curve fitting and evaluation process is similar for both stable and unstable channels.

Curve development and evaluation is undertaken in a hierarchical fashion. As mentioned above, if the data plot monotonically, and within the prescribed accuracy for the site, for a weir for example, then no further stage–discharge analysis would be required. Frequently, however, the data have distinct populations that are stratified by time and/or stage.

For many Canadian rivers the initial stratification is by season, with a split into open water conditions and ice conditions. The decision to segment the stage–discharge data seasonally is assisted by simultaneously plotting three graphs of stage–discharge measurements, stage–width measurements, and stage–area measurements (Fig. 3). Normally the open water and ice condition data form distinct populations and are analyzed separately. If there is no seasonal distinction, the data are treated as a single population.

Segmentation by time may be further refined to identify particular conditions in a stream within the seasonal split. For example, weed growth has maximum effect in mid to late summer, and river ice conditions can be subdivided into periods of freeze-up, stable ice cover, and break-up. Modules for freeze-up, development of a stable ice cover, and break-up have been defined, but the rules for implementation have not been developed. However, the same principles of data segmentation and curve fitting and use can be applied to the ice period as used in the open water analysis. In the future, a modeling component will be developed to incorporate ice evolution in the river channel based on meteorological and hydraulic parameters.

The need for further stratification is based on an outlier analysis. Rating curves are fitted to the stage–discharge subset and values deviating beyond an acceptable accuracy bound are isolated for further scrutiny to determine the potential cause(s) of the deviant measurements. Each outlier is isolated from the data set and information regarding the conditions under which the measurement was observed is referenced from the database. If no information is available, the system prompts the user with a series of questions, trying to establish the cause of the deviation (e.g. the system identifies measurements affected by beaver activity, wind, debris, weeds, tributaries and unexplained backwater conditions).

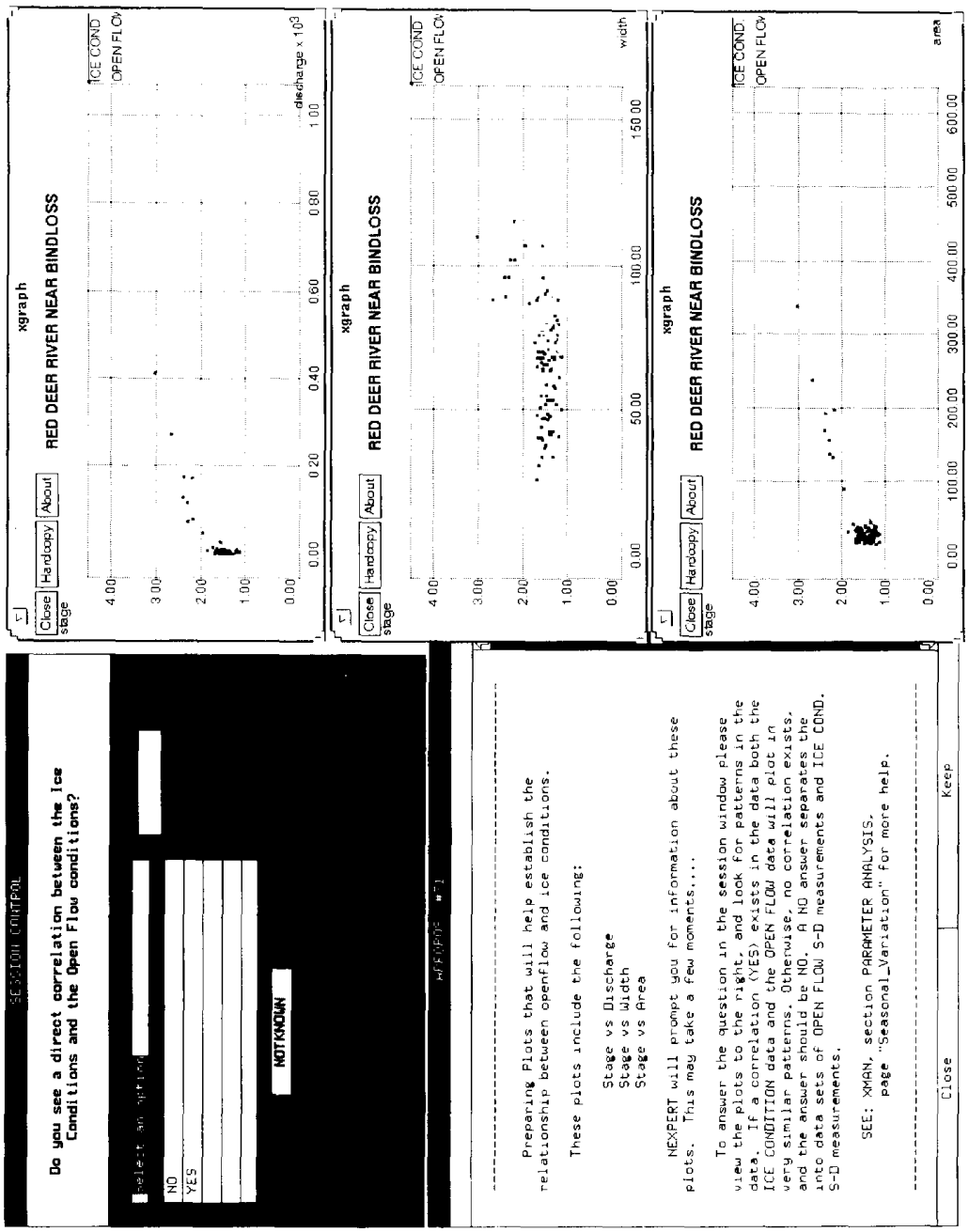

Fig. 3. Seasonal variation analysis.

Once all outliers have been identified and processed, the system allows the outliers to be separated from the original data set and remodeling may commence.

Hysteresis is treated as a further refinement of time segmentation. Hysteresis, or looped, rating relationships may occur in both stable and non-stable channels where channel control is effective (i.e. the friction from the natural roughness of the river channel controls the velocity and the depth of flow) and the rate of change of discharge is rapid. Discharges for a given stage are generally greater on the rising limb than the falling limb of the hydrograph because the wave front is steeper on the rising limb (Rantz et al., 1982a,b). An additional complexity in the non-stable channel case concerns the evolution of the channel, particularly in sand bed streams. Because of the bedform lag in response to changing flows, hysteresis effects may occur whereby rising limb discharges are greater or smaller than falling limb discharges for similar stages. For clarity, only rising limb and falling limb measurements are identified by color or symbol, and are plotted on three diagnostic graphs: stage–discharge, stage–mean velocity and discharge–mean velocity. If there is hysteresis, the rising and falling limb measurements are readily discernible. The stable population falls between these groups. The end result is the stratification of these populations for further analysis. This module will be developed further to include analysis of the rate of hydrograph rise, analysis of bedforms, and identification of hysteresis situations based on bed material, channel geometry, and flow conditions.

The final level of hierarchy explores the possibility of a stage–discharge relation that changes with stage. Abrupt changes in the stage–discharge relation and associated hydraulic geometry relationships are frequently attributable to the geometry of the hydraulic control. For example, discontinuities associated with overbank flow are readily apparent. The user is asked to input the stage where the relation changes abruptly, and then separate stage–discharge curves can be made (and later joined) between transitional points. The result is a set of curves that represent the rating relation more accurately over the entire range of measured stage. The analysis is visual at this point. Future developments include plots of stage–discharge with hydraulic controls, as well as stage–area, stage–velocity, stage–hydraulic radius, and roughness.

3.1.2. Modeling and evaluation

Once the stage–discharge measurements have been classified into appropriate time and stage ranges, the rating curve models are developed and evaluated (Gawne and Simonovic, 1994). Mathematically, fitted rating curves can be developed for any time- or stage-based segment of stage–discharge measurements. In addition to the advantages of speed and precision, a major advantage of using statistically based modeling over conventional graphical methods of curve fitting is the ability to specify levels of accuracy or confidence bounds to the curves, hence the discharge estimate. This approach is perceived by potential users in Environment Canada as an important improvement over current practice.

A linear regression analysis is the modeling technique used to create the stage–discharge relationship. The analysis requires a linear relationship between the data, thus the system includes a procedure to transform the data in an attempt to achieve linearity of the data before modeling. The power and Box–Cox transformations are used, stepping through predetermined ranges of transformation parameters to generate

a number of modeling data sets. For example, with power transformation the exponent two is a default, and a range is set that describes hydraulic limits. The default value of two is based on a rating function for a parabolic channel with frictional control ($Q = C(h+a)^2$). A linear regression analysis is then performed on each of the data sets. The mathematical modeling module includes a thorough statistical analysis of each model produced, screening out all linear regression models that are statistically incorrect. That is, all stage–discharge models that do not follow the requirements of a linear regression are discarded. The linear regression requires that criteria be met regarding the residuals, which are simply the difference between the model predicted discharges and the measured discharges. The residuals must be independent, of uniform variance, and follow a normal distribution. The analysis includes both automated and user interactive testing procedures.

Finally, modeling includes a procedure that determines the most representative stage–discharge relationship from the remaining set of models following the residual analysis screening process. The objectives used in the analysis are the values of three calculated statistics, the standard error of estimate (SEE), the sample coefficient of determination (r^2), and the number of outliers. Graphically, the number of outliers is defined as the number of data points which lie outside allowable error limits defined for the model. A default value of $\pm$ 20% is provided on the basis of experience with several 'problem' stations in Manitoba, Canada. Data points are then identified as outliers if the per cent error between the measured discharge and the model estimation of discharge exceeds the allowable error limit. It is possible that different models will be deemed optimal on the basis of different statistics. For this reason, a multi-objective programming technique, Compromise Programming, is incorporated into the system to combine all three objectives so as to select the most representative stage–discharge model.

3.1.3. Curve extension

When the systematic gauge record shows a period of stage beyond the measured range of discharge, it becomes necessary to predict discharges for the recorded water levels. This is the function of the curve extension mode. Structured much like the curve development and curve modification modes, the first task is to allow the user to choose a curve or particular set of curves to use in the following extension processes.

Three methods—extension of the established stage–discharge mathematical model, extension of mean velocity using relationship between mean velocity and hydraulic radius, and extension using a modified Manning's equation—are implemented to predict discharges (from user-specified stage) or stages (from user-specified discharge). The choice and value to be extrapolated are designated by the user. Then, external routines are accessed to produce the desired results. Multiple iterations can be performed where results can differ depending on the method chosen. The three relationships have been used in standard practice, and referenced from the ISO (1983), Section ISO 1100/2-1982 (E), Annex D. It seems logical to extrapolate based on the velocity area method, as current measurements are made on the same concept. Therefore, all three extension methods use the knowledge of the cross-sectional area of the control. Each of these methods is readily applied using information provided by current hydrometric practices.

3.2. Using and modifying developed rating curves

Two additional procedures have been developed within the SDDSS to make it a more complete operational tool. The use of developed rating curves (mathematical models) to produce discharges from systematic stage records, and the updating (modification) of those models to handle new data as they are incorporated into the database have been developed as additional tools at the user's disposal.

Curve use allows the user to produce average daily discharges from continuous records of water level. When choosing the curve use mode, the SDDSS takes one of two paths depending on the stability classification of the station in question. Although similar objectives are apparent for stable and non-stable channels, knowledge components have been implemented in separate knowledge bases owing to difference in analysis and the sequential approach taken in prototype development. Computations are made by applying the appropriate stage–discharge model or models to the systematic gauging record.

The procedure begins after a curve or curves are selected for use. The used curves depend on the conditions set when they were developed (i.e. open or ice, hysteresis and/or variation with stage). The SDDSS instructs and aids the user when selecting appropriate curves for use, and on-line help is always available. An external program automatically applies the curves to the gauging record for computation of daily discharges. The discharges are then presented on screen, or for printing, as daily average discharges, by month. From the statistical analysis of discharge data it is possible to compute confidence intervals for 80, 90 and 95% confidence levels.

Curve modification is concerned with updating curves as additional stage–discharge data become available. The processes for modifying developed curves from stable and non-stable regimes are currently separate, but future development will amalgamate the procedures into one user mode. Owing to the cyclic nature of non-stable channels, the added ability to compare new data with a historical curve in the database is built into the non-stable channel modification.

Regardless of the stability type, the modification process begins when a curve or curves are selected (aided by the inference of the SDDSS). The program continues by retrieving 'OLD' measurements (those used in the initial creation of the curve), new measurements and any other 'modifying' data. The 'modifying data' consist of those measurements that were observed during six possible 'backwater events'. These measurements are distinguished in the main data table by a 'remark' system currently used by Environment Canada. They are: (1) measurements affected by beaver activity; (2) measurements affected by wind activity; (3) measurements affected by debris on the control; (4) measurements affected by weeds on the control; (5) measurements affected by a nearby tributary; (6) measurements affected by unexplained backwater conditions. The user is asked to select which modifying set or sets of data they wish to use in the modification process.

The data can then be viewed graphically with or without the original ('OLD') curve. The stage–discharge curve is produced and shown simultaneously with a hydrograph of the original and modified data. The hydrograph is used as a diagnostic tool. It is supposed to aid the user in distinguishing between the modified set of data and the original data. Fig. 4 shows the two graphs along with the options presented to the user in the session

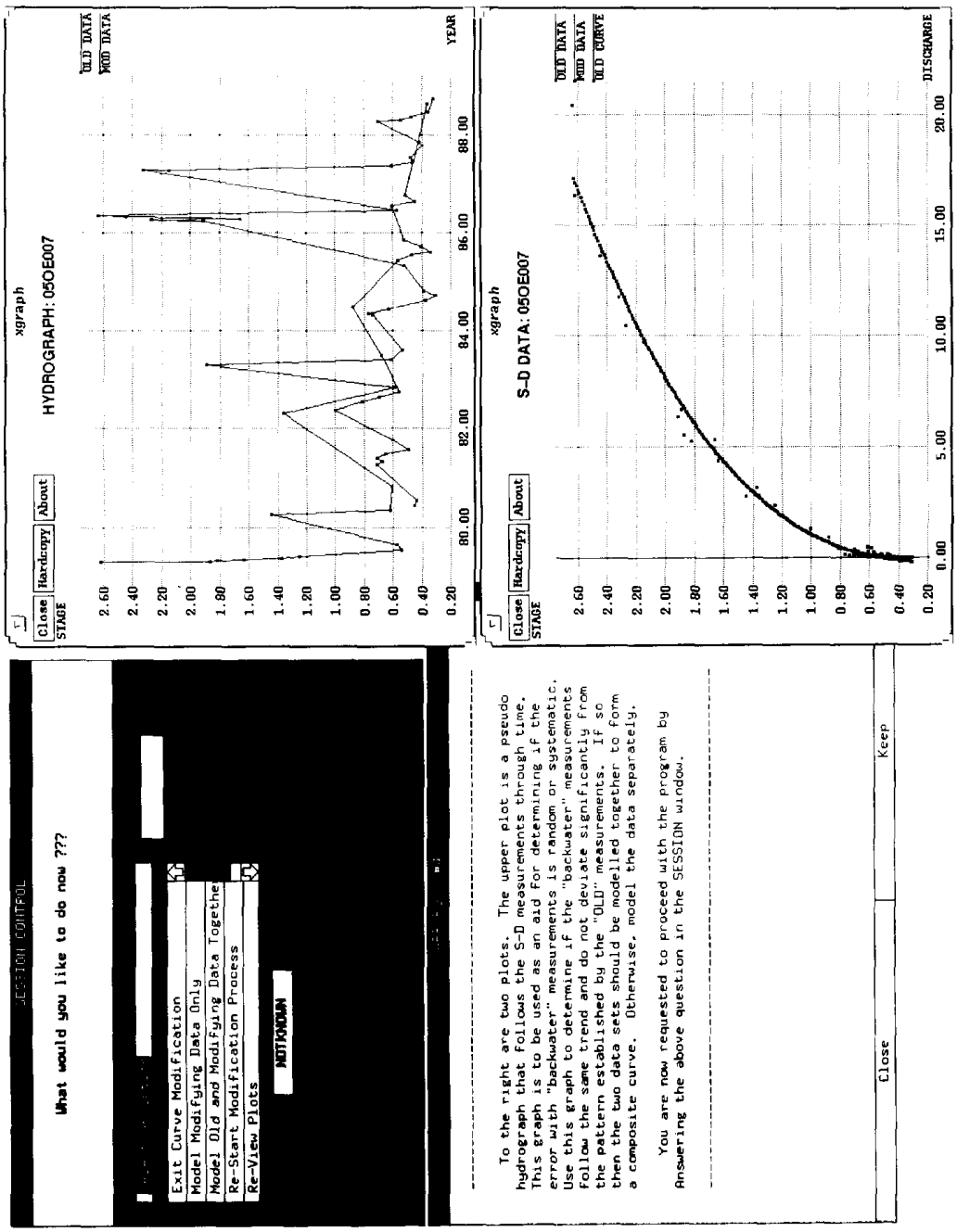

Fig. 4. Curve modification diagnostics.

window. Options are provided for modeling the modifying data set alone or with the old data set. This decision is based on the plots shown to the right of the session window. When selecting one of these options, the SDDSS links the user to the modeling components to create a modified stage–discharge curve or a curve which represents only NEW or 'backwater' data sets. As before, these curves can be stored in the database for later use.

4. Implementation issues for the SDDSS

4.1. Development environment

A Sun Sparc station running a Unix operating system provides the hardware platform. Maintaining and expanding the knowledge components was performed using the NEXPERT OBJECT (Neuron Data, Inc., 1991) software. Data manipulation was maintained through the use of the ORACLE (Moran, 1989) relational database management system. NEXPERT OBJECT also provided easy access and control over any FORTRAN or script routines that eased any computational burden, or provided any requisite data manipulation. Graphical presentation is provided by the public domain software XGRAPH and XPLOT by DUX software.

An on-line help manual has been developed using other public domain software. XMAN provides an excellent means to look up explanations for keywords highlighted by the SDDSS system. Keywords are stored within sections that correspond to the user modes of the system. Manual pages are accessed through this hierarchy of pull-down menus and look-up keywords.

4.2. User modes

Section 3 described the process knowledge concepts for analyzing the stage–discharge relation for stable and unstable channels. The basis for the analysis is provided through the development of rating curves, their use, modification, and extension. Each function represents a user mode which has been incorporated into the SDDSS system (Fig. 5). Each mode—curve development, curve use, curve modification, and curve extension—is available for application from the main menu. Control and procedure are interactive between the user and the SDDSS.

The system as a whole consists of several subsystems. Each subsystem has a specific task, and they are linked to each other when one subsystem demands cooperation from another. The user modes make up the subsystem components, and each user mode has developed knowledge bases (12 altogether) that perform the necessary tasks. Fig. 5 illustrates the process elements and the flow of the system that links them together. The curve development component of the system is composed of five knowledge bases (Fig. 5), with a large number of rules in each of them. Forward chaining is used mostly throughout the system, to capture the process type of knowledge appropriately. The knowledge bases work interactively and cooperatively to produce a curve or curves for stable and non-stable channels. Overall system operation is coordinated by two knowledge bases (DEF.tkb and MASTER.tkb). One knowledge base handles streamflow classification (SC.tkb). One of

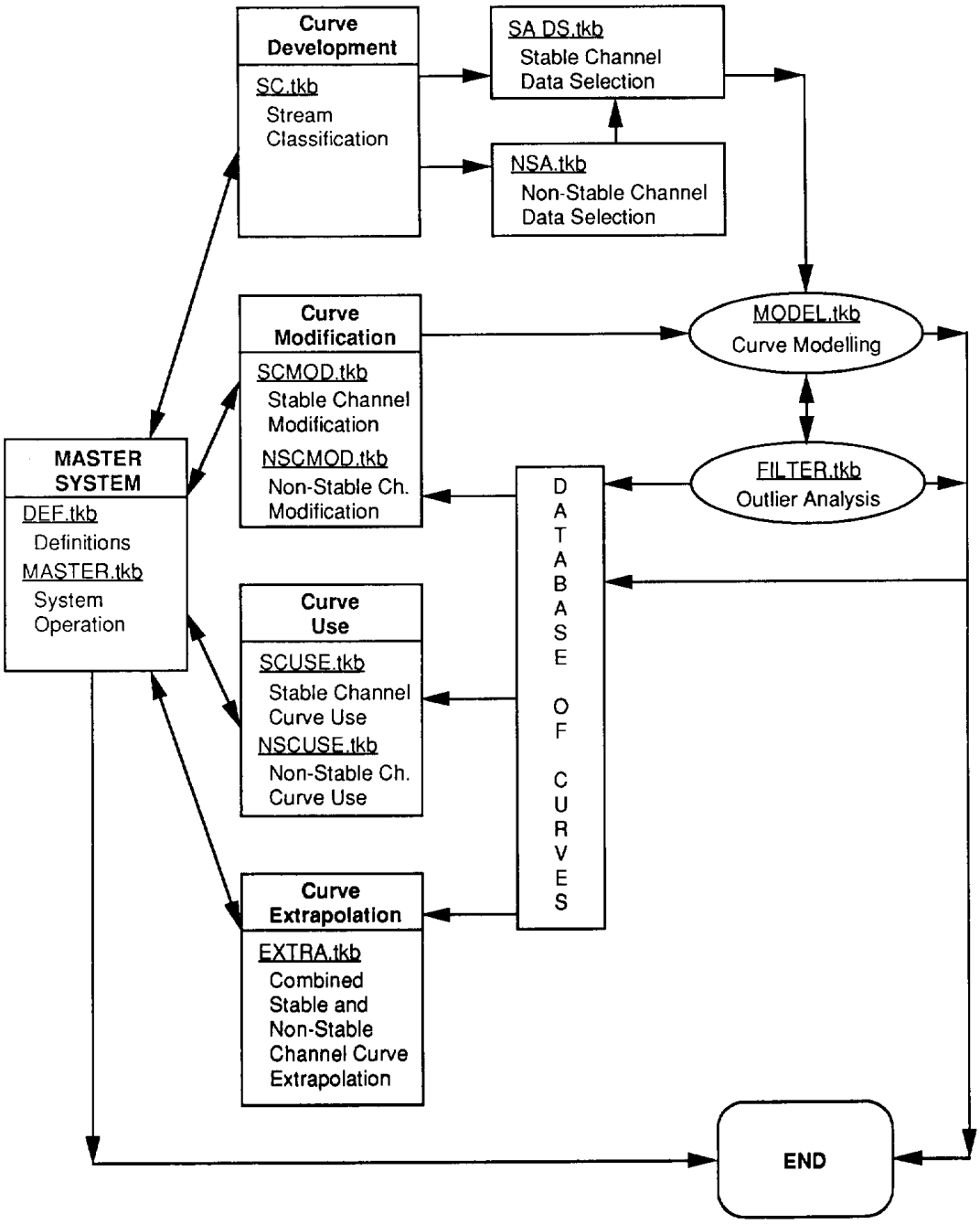

Fig. 5. SDDSS framework.

two paths is then taken upon a successful classification. Data selection is handled by two knowledge bases (stable SADS.tkb and non-stable channels analysis NA.tkb). The mathematical modeling and the last procedure of outliers analysis are done by two separate knowledge bases, MODEL.tkb and FILTER.tkb. Curve modification mode is dealt with in another two knowledge bases. These knowledge bases handle the process of modifying the

mathematical relationships established for stable (SCMOD.tkb) and non-stable channels (NSCMOD.tkb). The single knowledge base handles the extrapolation for both stable and non-stable channels (EXTRA.tkb). Curve use mode consists of two knowledge bases, SCUSE.tkb for stable and NSCUSE.tkb for non-stable channels.

4.3. User manual

The user manual provides a comprehensive library of explanations regarding the use of the SDDSS, as well as explanations for the methods, and background theory on the processes of the SDDSS. The XMAN icon is displayed as a window during the operation of the SDDSS. The operation and manual page selection are totally window and menu driven.

Accessing the manual pages for information requires a simple click of the mouse pointer on the manual page button and the opening manual page is displayed directly beneath the icon. Overall, the XMAN manual page browser provides a comprehensive on-line manual page look-up system, and a system that is easily documented and updated. In addition, the manual pages describe the functionality and ease of use of the system. The manual also provides documentation and standardization of procedure for stage–discharge analysis. It is a key function which adds to an all-encompassing system to rigorously provide standardized stage–discharge rating curve analysis.

5. Conclusions

The stage–discharge decision support system (SDDSS) described in this paper provides an alternative to Environment Canada's present approach of manually plotting and fitting curves for development of stage–discharge rating relations. Using statistical analysis techniques, the system considerably reduces the time required and the subjectivity of the manual hand-drawn curve fitting used in many hydrometric programs. Significant advantages are seen in the ability to rigorously and precisely fit curves and develop stage–discharge relations, and quantify confidence limits in the use of these curves. The present SDDSS research has developed a framework to capture the expertise of hydrographers in rating curve development and application and to employ the technology for training and for operational application. To fully exploit the capabilities of the SDDSS, additional observations of site conditions must be quantified, staff expertise enhanced, and operational procedures revised. A logical extension of the system is to include deterministic or empirical predictive ability regarding channel stability. For example, how much scour and fill will occur and how does roughness change with flow conditions?

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