

THE UNIVERSITY OF MANITOBA

**DECISION SUPPORT FOR RATING CURVE ANALYSIS
OF NON-STABLE CHANNELS**

by

Mark P. J. DeGagné

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree of Master of Science

DEPARTMENT OF CIVIL ENGINEERING

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ABSTRACT

The rating curve is constructed from physical measurements of gauge height and discharge. It is then used to convert records of water level into flow rates. This work illustrates theory and application of rating curve analysis for non-stable channels within the framework of decision support systems. The objectives are realized in three computer systems that perform rigorous, standardized procedures through a logical implementation of process. The research is justified by the need for greater accuracy and reliability from a non-subjective and standardized rating curve analysis.

The Stage-Discharge Decision Support System provides a means for classifying a gauging station, its respective hydraulic control(s) and the overall reach in question. The procedures of developing curves, and modifying, using and extrapolating beyond established curves are implemented for stable and non-stable classifications. The consultation is fully supported by an on-line help manual system.

The Multi-Objective Stage-Discharge Evaluator system tries to fit a proper curve, or curves, to any data set. Compromise Programming evaluates the improvement or deterioration of regression models recursively as one SD point is added at each iteration. The objective is to identify key transition points in the relation.

The Hysteresis Error Analysis System quantitatively assesses error to each SD data point due to the affect of hysteresis. The magnitude of error is based on the statistical distribution and position of the points with respect to a normal curve. The system uses the assessed error in a weighted regression routine to more accurately represent the rating, and provide confidence in future prediction of discharge based on stage.

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LIST OF ABBREVIATIONS

ADP	- Absolute Difference Plot
Bmod	- Best Model
CD	- Curve Development
DOE	- Department of Environment (Canada)
DSS	- Decision Support System
EC	- Environment Canada
ES	- Expert System
EV	- Explained Variance
FIDS	- Facility for Intelligent Decision Support
GIS	- Geographical Information System
GUI	- Graphical User Interface
HEAS	- Hysteresis Error Analysis System
ISO	- International Organization of Standardization
KB	- Knowledge Base
MOSDE	- Multi-Objective Stage-Discharge Evaluator
NSA	- Non-Stable Analysis
OUT	- Number of Outliers
RAE	- Relative Absolute Error
RDBMS	- Relational Database Management System
SC	- Stream Classification

LIST OF ABBREVIATIONS

SD	-	Stage-Discharge
S-D	-	Stage-Discharge
SDDSS	-	Stage-Discharge Decision Support System
SEE	-	Standard Error of Estimate
SGP	-	Specific Gauge Plot
USGS	-	United States Geological Survey
VBS	-	Variation by Stage
WBE	-	Water Balance Error
ZFS	-	Zero Flow Stage

The Rating Curve is used by hydrometric data collection agencies world wide, and "a thorough understanding of the relationship between stage and discharge is essential, since one of the basic responsibilities of a hydrometric technician is to collect and compute daily discharge data for publication purposes" (Anderson, 1988). Routine field measurements of stage (water surface elevation from an arbitrary datum) and discharge (amount of flow) are taken to establish a rating relation. Then the curve is used to make estimations of discharge based on continuous gauging records.

There is no standard method for establishing the curve which describes the Stage-Discharge (SD) relation for a particular river reach. Many agencies plot the stage-discharge data points by hand and use manual curve fitting techniques to establish the relationship (Anderson, 1988; and Rantz et al., 1983). Although an effective means of analysis these methods are time consuming, and subject to the technician's experience and knowledge of the behaviour of the particular river or stream. As hydrometric agencies begin to operate under stricter constraints, alternatives are sought for improved solutions to Stage-Discharge rating curve analysis.

An alternative to manual curve fitting is the use of more rigorous methods based on statistical and mathematical relations. As a start to a more comprehensive conceptual framework for water quantity data management (Simonovic, 1989), a prototype *decision support system* was developed by Douglas (1992) to develop, maintain and utilize stage-discharge curves within a computer framework. The purpose of this work was to set the initial framework for rigorous and standardized stage-discharge analysis. Because the

topic of SD analysis is broadly based, the research was limited to analysis development for stable channels only.

Although many factors affect the relationship between stage and discharge, the dynamics of the problem are very rarely addressed in analysis. Often times it is necessary to distinguish between channels that exhibit relatively stable SD relations and those whose relations change or shift over time and/or stage, so-called non-stable channels. The changing SD relations will result in multiple SD curves to be used for different time periods, and/or curves representing different ranges of stage. It is these types of complex relations that demand more complex analysis.

1.1 Problem Statement

The process of developing satisfactory stage-discharge relations for computation of discharge is very complex due to the nature of natural channels. The myriad of situations encountered by technicians when gathering SD data for establishing the rating are almost overwhelming. When natural channels change in shape, pattern and/or slope, a direct reflection is almost always seen in the SD relation. In channels that are relatively stable this change is a slow and gradual process. The variation is not always noticeable in the corresponding relationship for stage and discharge. However, fluvial channels with erodible beds and/or banks often experience more dramatic and sometimes relatively instantaneous changes that greatly affect the SD curve. Instabilities include frictional changes induced by the evolution of bedforms, and changes in the hydraulic geometry affecting the measurement reach. The consequence is an ever changing relation with a

multitude of manually generated curves over the history of the gauging record. The rating curves are continually being redefined and re-established, often without rigorous pattern recognition from the history of stage-discharge measurements and supporting reasoning (DeGagné et al., 1993).

Initial research in this field has seen the development of a prototype computer system to handle analysis for relatively stable channels (Douglas, 1992), where any change in the relation is temporary or due to a change in the energy slope. The initial framework presented comprehensive methods for curve development, and the application and maintenance of those developed curves. Continued research is meant to build on this research, taking into account the need for the recognition of major hydraulic and/or hydrologic phenomena that influence the channel control, geometry and corresponding relationship. The fundamental tasks should continue from the established decision support framework, and enhance the analysis to include the dynamic analysis required for channels that are continually evolving through time and space.

The *main objective* of this research is to develop and implement the procedure and initial criteria for Stage-Discharge analysis of non-stable channels. The current work is to be integrated with an existing stage-discharge decision support system (SDDSS) for analysis of stable channels (Douglas, 1992), and include the addition of a new user mode, which would enable the analysis to extrapolate from existing relations.

The inclusion of relevant hydraulic and hydrologic parameters that can assist in proper decision making is of primary importance. The framework for analysis captures the current capabilities of the already extensively developed database of Environment

Canada (EC). The development of the **process knowledge** takes greater priority in the early stages in order to accomplish a rigorous, logical and more standardized method of analysis within a computer framework. At the same time future requirements are identified and acknowledged as key aspects for the enhancement of better decision making.

To reflect the needs of increasing demands for understanding a growing computerized system for SD analysis, a fully functional and comprehensive help system becomes an important objective. The design of the help manual will reflect the need for instantaneous explanations that users may need as they work with a fully developed system in the future. Thus, a real-time on-line full description of process, background theory and interpretation is necessary.

The research was directed at looking at possibilities for enhancing the evaluation and understanding of the development of SD ratings from measurements that pose complex situations, and the inclusion of possible error. Presented as separate entities, the related studies illustrate possibilities for new approaches to analysis that go beyond current analysis. The modular design of all systems is considered necessary for future integration. The effect of enhanced computer analysis for SD data, using complex mathematical techniques, is viewed as a step towards a fully operational decision support system that will allow users at all levels of interest to more rigorously apply their knowledge.

At no time is it expected that the development of computer driven techniques will replace the need for technical expertise. However, enhancing the technicians ability to

diagnose complex situations for accurate representation of the rating relationship for natural channels is essential. It provides a means of encompassing new technology for efficient and standardized analysis, freeing time for much needed, continuing quality assurance. Also, with improved tools and help manuals an encompassing system for developing, using, maintaining and extending stage-discharge relations provides an excellent training tool.

1.2 Scope of Research

The scope of this research has dealt with the development of a *logical framework of procedure* to analyze and represent SD relationships for non-stable regimes within a computer environment. Because the analysis distinguishes between stable and non-stable channels, it is necessary to include a means for identifying channels as stable or non-stable within the development procedures. Based on developing a framework which recognizes patterns of variation, the criteria have been set to distinguish between significant variation and more stable regimes. The classification of a river channel is essential to providing adequate analysis.

Next, a logical framework pertaining to the hydraulic and/or hydrologic parameters affecting the stage-discharge relation was developed and implemented, in order to provide effective methods for more accurately defining the relation for non-stable channels. Consequently, the development of complex relations required the need to connect the development methods to new methods for using, modifying and extrapolating the curves. Finally, a comprehensive on-line help manual was developed that features support text

information based on a keyword look-up scenario.

The main contribution of this research is the implementation of stage-discharge analysis for non-stable channels within an existing decision support framework (Douglas, 1992; Gawne and Simonovic, 1992). The system has been titled Stage-Discharge Decision Support System (SDDSS), and the contribution of this research is directed towards the analysis of non-stable channels. Also, illustrated is the new mode for extrapolating information from existing curves, and the development of a complete on-line help manual system.

The system provides a flexible environment for decision support and user interaction for diagnostics and analysis of available data. At the same time the system has requirements for a broader base of information and database requirements, which should be generalized as part of a hydrometric program.

Related to this framework, two special techniques were independently developed to handle specific situations. Namely, the evaluation of SD measurements for possible error influenced by hysteresis phenomena, and the evaluation of SD models using a systems analysis approach in an iterative, continual manner to identify possible transitions in the SD relation with increasing stage.

The research demonstrates the increased capabilities that decision support systems are achieving in water resources today. This and other programs are bringing the technicians and analysts closer to the data in a highly interactive manner. Having said all this, a brief outline for the following thesis is presented.

The second chapter presents a brief overview of relevant research and background

literature in combination with the required background theory of necessary process elements for analysis. It provides background information, and a basis for evaluation for the current research. The background knowledge is necessary to set the framework for the analysis, and determine the initial criteria for the analysis of non-stable channels.

The implementation of non-stable channel analysis within the SDDSS, is illustrated in Chapter 3. Each mode is outlined, and the procedural framework is discussed. A case study follows, providing illustrative results of analysis for each mode. This is followed by the discussion of the implementation of the on-line help manual.

Chapter 4 deals with the implementation of a multi-objective compromise programming routine that evaluates the stage-discharge data one point at a time, in order to find transitions in the relation that may be expected with a complex geometric hydraulic control. The Multi-Objective Stage-Discharge Evaluator is designed to eventually be part of the SDDSS.

Another externally developed sub-system, HEAS (Hysteresis Error Analysis System), is presented in Chapter 5. The design of this system enables a user to evaluate quantitative error for each measurement as it is effected by hysteresis. The error is then used in a weighted regression scheme to determine an accurate representative mathematical equation for the SD relation. Accompanying the model is a confidence factor, which can be used in the predictions from the model.

The last chapter concludes the research with a discussion which evaluates the prototype systems, and provides suggestions for future research requirements. It is important to continue the development of such a system to accomplish a fully functional

and operational tool, which can be used rigorously to more accurately represent the SD rating in a standardized procedural format and enhancing the decision making process. In addition, its implementation could reap benefits as an excellent training tool.

2. PROCESS KNOWLEDGE REQUIREMENTS

2.1 Introduction

Although the use of the Stage-Discharge rating curve is a world wide accepted practice, the research behind the development process has not been extensive. Instead, the practice has developed through time as experience has been gained through knowledge of control behaviour. Standardized practice exists in the form of literature, but hydrometric agencies around the world still show differing practice. This is especially true for non-stable channels, where dynamic situations are not fully recognized and documented during development process.

This chapter outlines the basis and reasoning behind the formalization of procedure - the "process knowledge". The knowledge extends from the experience gained and understanding of the physical processes. Thus, it is the basis for the make up of the expert system component of the overall proposed decision support system. The theory integrates the review of pertinent literature which provides background knowledge and basis for the evaluation of implemented strategies.

2.2 Definition of Non-Stable Controls

Because this research pertains specifically to non-stable channels, it is necessary to define this term, and relate it to the development of the SD relation. Many published standards provide excellent definitions of a non-stable channel. For example, the International Organization for Standardization (ISO) defines non-stable or unstable

channels as:

"In unstable channels the channel geometry and friction properties and hence the control characteristics vary continuously as a function of time and so also does the stage-discharge relation at any given point in the channel" (ISO, 1983).

The standard also includes the term **shifting control**, which defines an unsteady control changing in time and with stage.

The United States Geological Survey (USGS, Rantz et al., 1982) also publishes a standard for the *Measurement and Computation of Streamflow* (**Geological Survey Water-Supply Paper 2175**). This standard supports the definitions provided by the ISO, and extends them specifically to sand-channel streams (Chapter 10). Explanations of rating shifts in these channel types are provided by theory of bedform evolution during a flood. The shifts are dependent upon the lag of the bedform as it evolves during the passing of a flood wave. Thus, a physical change in the hydraulic control is evident in certain flow regimes of sand-channels.

Shifting controls also apply to the obstruction of flow due to river ice, and other naturally occurring phenomena (eg., inundation of weeds on the hydraulic control). These phenomena can cause a decrease of flow through the channel, and back up the water (ie., backwater) raising the water level for the same discharge. However, these instabilities cause a change in the energy slope of the water surface profile, not a physical change in the hydraulic control. These types of rating shifts were addressed by Douglas (1992) in the previous decision support system for rating curves of stable channels or channels of relatively fixed geometry.

Both of the above mentioned standards provide definitions for unstable channels,

and the effect of shifting controls on the SD relation. But, they do not incorporate this directly into the analysis for rating curve development. Instead, when a shift is recognized remedial measures are provided to "correct the discharges" or new curves are drawn and utilized. The result is a number of hand drawn rating curves that exclude any recognition of channel evolution or established rating curve pattern. By building on the fundamental structure the original SDDSS (Douglas et al., 1993) and expanding the analysis to incorporate non-stable channels, it is possible to determine and record a gauging station's rating relation throughout its history. This facilitates learning from past experiences, and provides for revisions of previous flow estimates and applies confidence limits to flow estimates (DeGagne et al., 1993).

Five process knowledge elements for modelling a rating relation for a non-stable channel were identified: (i) the identification of stable and non-stable S-D regimes; (iii) the classification of these regimes; (iii) the segmentation of S-D measurements to appropriate stability regimes; and (iv) the modelling and evaluation of S-D relations. The final process knowledge element encompasses the extrapolation of the rating curve.

The conceptual view of the approach taken towards establishing possible SD ratings for non-stable channels is shown in Figure 2.1. It illustrates the present needs for non-stable channel analysis (exclusive of analysis for stable channels), which include: utilization of the database, defining the necessary parameters affecting the relation, and lastly, developing the knowledge base and formalizing procedures. The figure also illustrates the need to categorize a particular gauging station as stable or non-stable before a separate analysis can be made. The key to distinguishing between the two is the

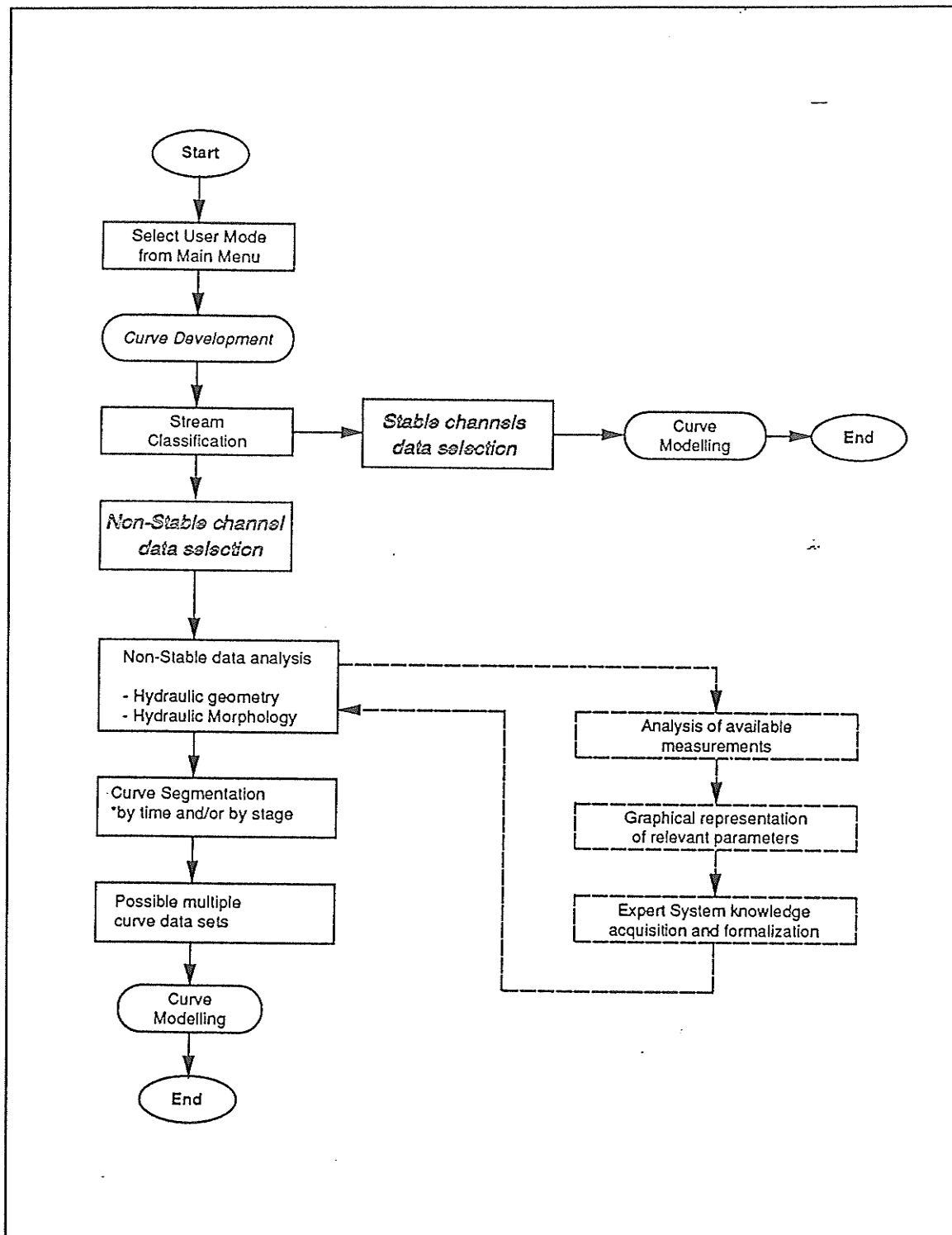


Figure 2.1: Conceptualization of Non-stable Analysis

variation of the channel, and its corresponding SD relation in time. The next section describes the background to the approach used within a decision support framework for classifying a channel. Following that, the formalization and knowledge background is defined for the SD data analysis of non-stable channels.

2.3 Stream Classification

Suitable methods for classifying the stream according to its relative stability were not available for implementation before this research. The HYDSYS (Hydsys Pty Limited, 1991) program provides the user with a graphical facility for selecting a data subset. It is based on a dual section plot of the "gauged discharge against time", and the "deviation of the gauged plot from the rated discharge against time". The facility allows the user to define the data set more clearly based on the observations from these plots, but no decision structure is in place to make recommendations for the proper selection based on the history of the control, and the flow regimes it is subjected to.

It is the intention of this work to provide a complete supporting routine with a defined decision rule structure which indicates appreciable change in the relation. The detection of appreciable change will then be linked to instability. The classification of a channel as stable or non-stable is a most important step when dealing with SD analysis. Because the dynamics of the two types are quite different it is necessary to analyze streams differently according to a given classification. Problems in developing stable channel rating curves described by Douglas et al., (1993) are magnified in unstable channel situations. The opportunities for application of a decision support system for

learning from experience and applying supporting hydraulic, hydrologic and morphologic expertise are great (DeGagné et al., 1993). In addition, the same reasoning allows for the establishment of the stream classification based on the channels previous behaviour in time.

Because a channels SD rating is a function of the channel's morphology, the framework of the classification analysis includes two additional classification categories; *Sediment Type and Channel Pattern*. Each classification has three options: sediment type is distinguished by **sand, sand-gravel and gravel**, and **braided, meandering and straight** are possible options for channel pattern. These options reflect the need for general classification of these parameters as part of the overall stream classification framework. The use of these parameters can be further realized as experience of analysis is broadened.

2.3.1 Detecting Variation of Channel Morphology in Time

All natural channels experience some form of variation in their morphology and flow regimes through time. However, it is suggested to study the evolution of channels in time in order to evaluate the amount of variation the channel has experienced. Recently, Simon (in print) has illustrated the importance of recognizing spatial and temporal trends of aggradation and degradation in order to provide an "energy-based rationale of the interdependency between processes and forms during channel evolution." Tools used for this analysis included the analysis of bed and bank movement of the streams over the period of study. The analysis showed key movements in the morphology

corresponding well with flood events.

Channels that vary significantly over time will be determined as non-stable channels. These channels will reflect trends of aggradation, degradation or abrupt perturbations in the morphology of the control reach which ultimately affect the SD relation. It becomes necessary to identify periods of significant hydraulic or hydrologic events in time, and relate them to the change in the stage-discharge relation. The analysis must provide a reasonable approach to identifying major altering events in a channel's history, and provide a measure of the degree of morphological change between major events. These events are usually periods of high flow, flood events or, opposingly, low flow (aggradation) periods. Other hydraulic phenomena, such as meander cut-offs, can significantly alter a stream's characteristics. The analysis incorporated should also be sensitive to human influence by possessing the ability to detect human induced change such as channelization and channel straightening. The following section deals with the implementation of the stability classification of a channel based on the analysis of the specific gauge plots for the channel.

Environment Canada often incorporates the use of the specific gauge plot (Spitzer, 1988) to show how the river environment is changing in time. Changes in the specific gauge plot are directly related to, or supported by, some hydraulic phenomena or hydrologic event which has altered the control and in turn the SD relation. Thus a similar approach can be taken with respect to developing some measure of variation a stream exhibits throughout its history. Then it becomes a matter of establishing tolerable limits for variation in order to distinguish between stable and non-stable channels.

2.3.2 Channel Stability Classification Using Specific Gauge

Classifying a stream with respect to its stability is a three step process. It includes the generation of the specific gauge record that will represent low, middle and high flows for a particular station. Then, an analysis of the specific gauge is performed to find any points in time where a major event has altered the S-D relation. After establishing the major altering events, an iterative analysis is performed on each time period between such events. The purpose of the last analysis is to determine the activity within each time period. A non-stable channel will show much activity in the gauge readings.

The **specific gauge plot (SGP)** represents the activity or behaviour of the gauging record with time (Figure 2.2). It is a plot of stage versus time, but the stage is plotted with respect to a specific (constant) discharge. To represent a range of flows the two, five and ten year floods are used as the specific discharges. These flow values are chosen to represent low, mid and high flow regimes within the channel. Stages are calculated by interpolation from the R56 measurement files for each discharge, and plotted with respect to the date of measurement. The R56 files are standard forms that represent the database of physical measurements taken at each station. They record the date, time, temperature, width, area, velocity, stage, discharge, as well as, any corrections made and remarks.

The specific gauge becomes a record of the behaviour of the control throughout time. A stable river will show a specific gauge that is fairly constant through time. Non-stable channels will show discontinuities or trends in the gauge with time (Figure 2.2). The significance of these discontinuities is quantified in subsequent analysis.

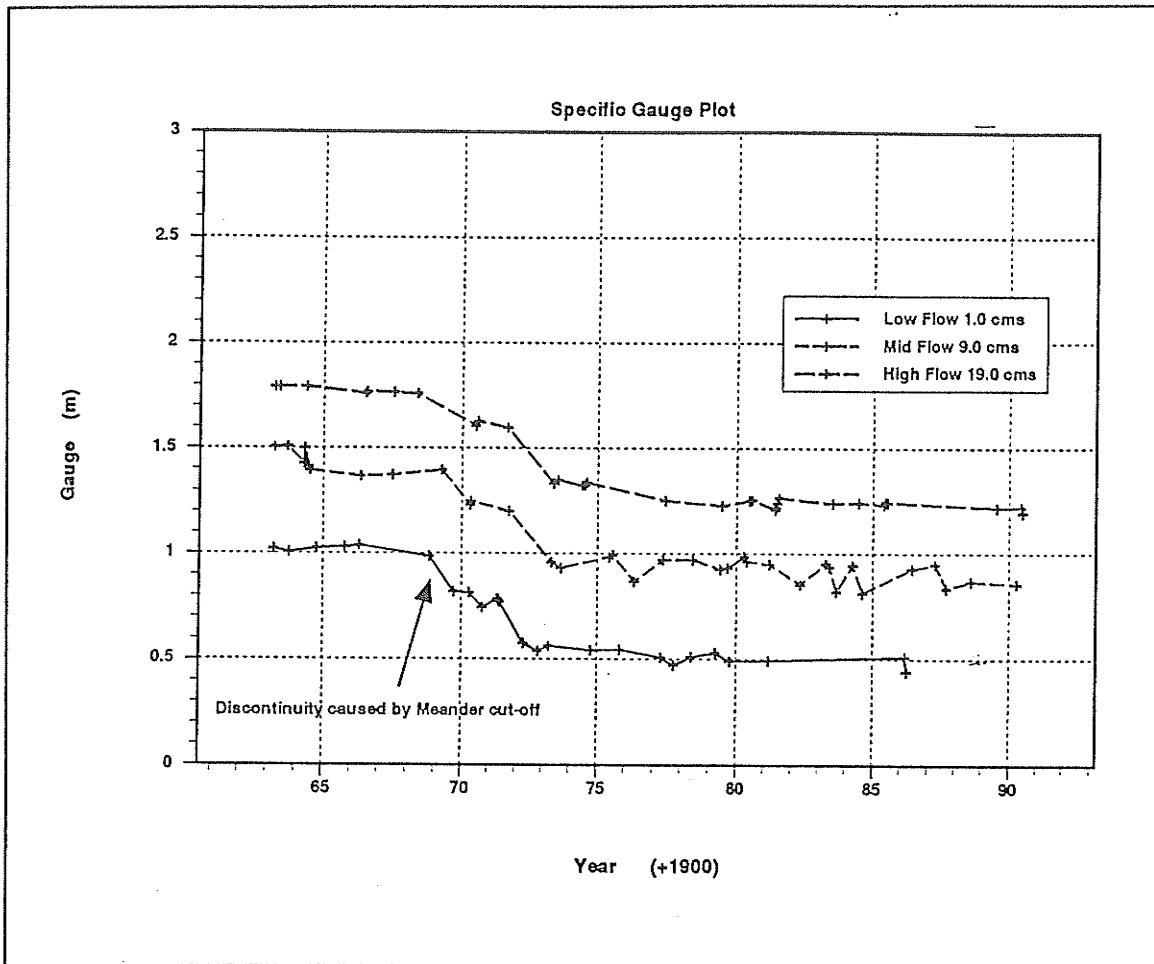


Figure 2.2: Specific Gauge Record

Absolute difference plots (ADP) - shown in Figure 2.3 - quantify differences between consecutive specific gauge values for segments of record identified in the specific gauge analysis. The values are interpolated from S-D 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 S-D relationship. A tolerance of ± 5 percent, expressed in terms of discharge, is the default value to define

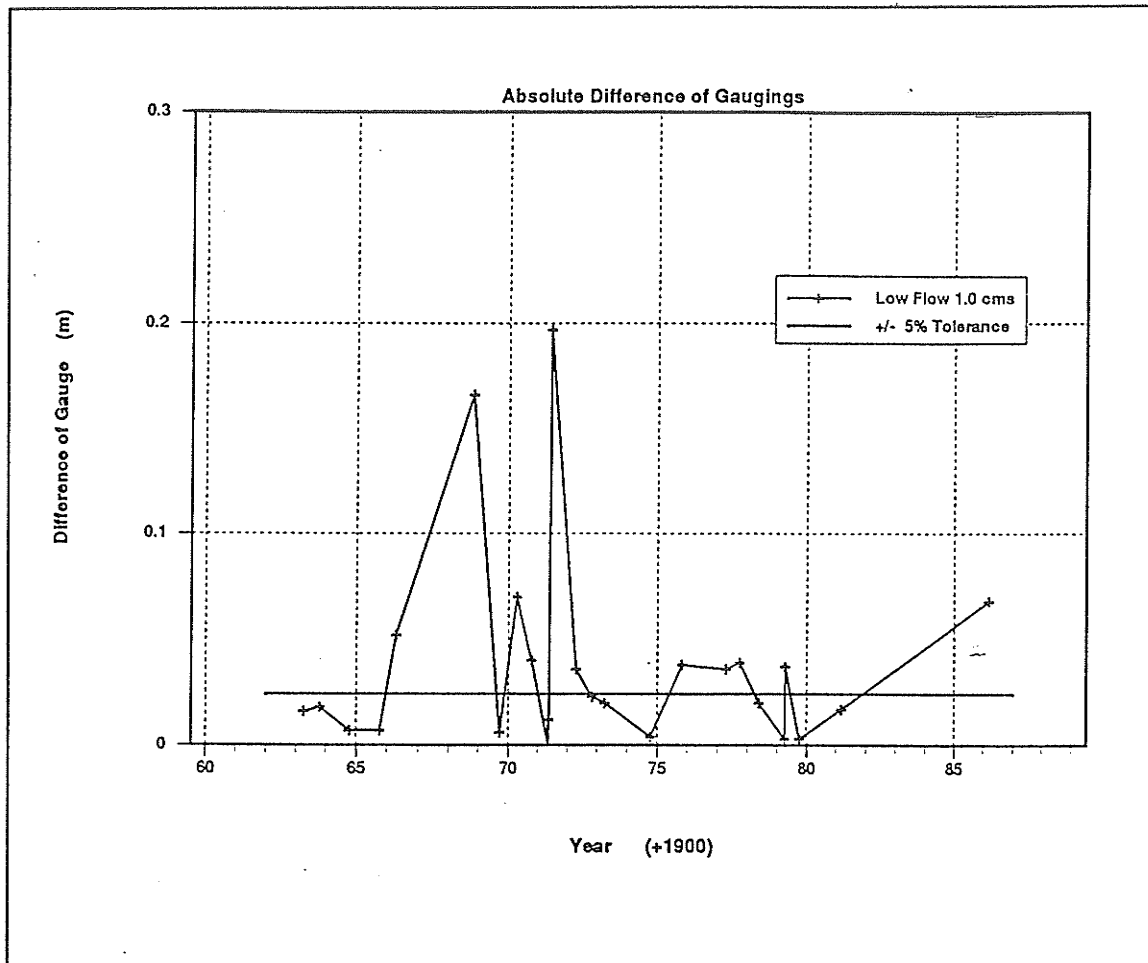


Figure 2.3: Absolute Difference of Gaugings

significant shifts, hence instability (Rantz and others, 1982). However, trends of small sequential change are not identified in the analysis. Therefore, an analysis of residuals is also employed (DeGagné et al., 1993).

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 S-D measurement departures from the average illustrate changing conditions. These specific gauge residuals (Figure 2.4) can also be used to identify individual S-D

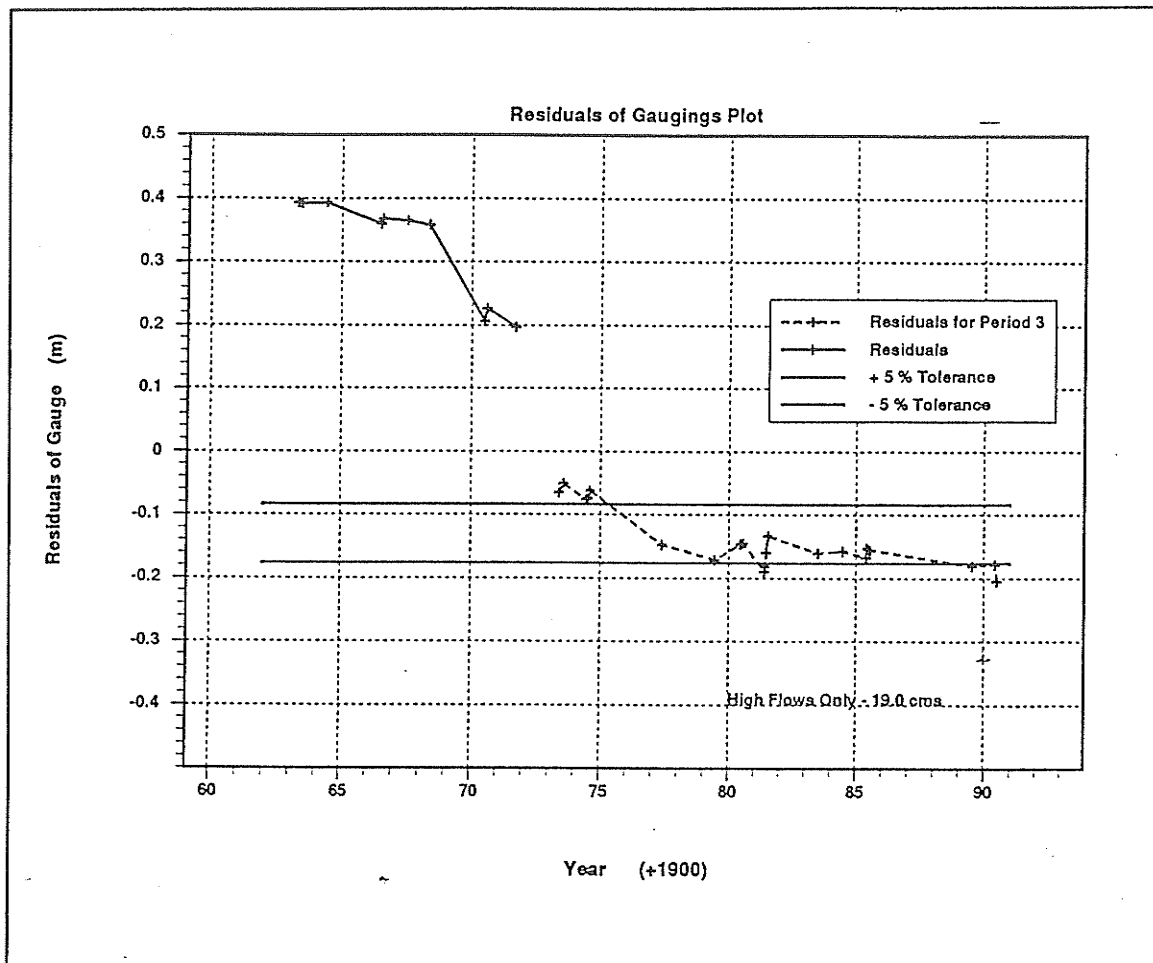


Figure 2.4: Residuals of Specific Gauge

measurement errors or short term anomalies. A tolerance of ± 5 percent, expressed in terms of discharge, is the default value to define significant shifts, hence instability. If ten percent 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 unstable for all flow regimes.

The specific gauge may be stable or unstable, or of mixed stability, for the low, mid and high flow regimes. In the current SDDSS instability in any regime for a

specified segment of record classifies the period as unstable for all flow regimes. This sets the current framework of the stability analysis, and provides an effective means for determining stream stability, however in the future, individual flow regime classifications of stability for given periods of record should be provided based on flows experienced in that particular time frame. That is, if only the 10 year events create instability but no such events have been recorded in the period of interest, the channel is effectively in a stable state.

When analyzing the ADP's and the residual plots, the data points are tested with respect to a ± 5 percent tolerance level. It is important to define this level. Stage or gauge is measured with reference to an arbitrary datum, and setting tolerance levels according to a ± 5 percent change in mean stage is often erroneous. For example, the mean gauge is 24 meters above datum, and the depth of flow is only 2.8 meters. A five percent change in gauge is 1.2 meters, which is unrealistic in terms of detecting a change over an actual depth of 2.8 meters.

The tolerance levels are defined with respect to discharge. However, it is not possible to do this without a S-D rating to evaluate discharge; a rating not yet established. It becomes necessary to create a "Preliminary Curve". For the ADP's this is based on the *last five years of open flow data*, and the residual plot levels are based on *open flow data for the time period in question*. Preliminary curves are used by calculating the discharge (D_{mean}) corresponding to the average gauge reading. Then, two discharges are calculated at the distance of plus and minus 5 percent of D_{mean} . The two new discharges are then translated to stages using the preliminary model established. These stages represent the

± 5 percent tolerance limits.

Using the gauging station's specific gauge record as a means of quantifying the channel's stability realizes many benefits. The time of occurrence of major events is identified, and periods between major events are categorized before being subjected to further analysis. Defining the SD relation more accurately as it evolves through time provides a means of pattern and trend recognition in the rating relation, or recognition of reoccurring regimes. This in turn displays the current state of the hydraulic control, and relates the current SD relation to the evolution of the channel (ie., the past is the key to the present).

The lack of the ability to identify the cause of the major events is not set within the framework of the specific gauge analysis. Failure to deal with those periods (years) when the SD relation changes (ie., identified shifts in the specific gauge) is a deficiency within the analysis. Future developments should try to incorporate tools to deal specifically with the identification and specification of developing SD rating relations for those years identified as shifts or "jumps" by the specific gauge analysis. For example, incorporating the sediment and channel pattern classification in the analysis to make recommendations for cause of transitions. That is, a sand channel stream which meanders significantly, and is subject to large floods is invariably going to experience large amounts of scour, bank erosion and/or meander cut-offs. The incorporation of sediment size and transport theory will determine the threshold flood value which initiates scour or fill.

2.4 Behaviour of the Stage-Discharge Relation

After defining and classifying non-stable channels, it is important to discuss their behaviour with respect to other physical hydraulic and hydrologic phenomena, and the impact that the processes have on the stage-discharge relations. More importantly, it is necessary to tie the background theory to the development of the decision support systems discussed in later sections. Three levels (Figure 2.5) of data analysis for stage-discharge development will be discussed each being subsequent to, but independent of, the previous, both in development and theory. The discussion deals with the development of rating curves that are affected by seasonal change, hysteresis, and/or complex geometric channel controls. A channel can be affected by any or all these conditions at a given time. The problem arises in the identification and determination of the effects, and how to incorporate the knowledge of their existence into the rating curve development.

2.4.1 Detecting Seasonal Variation of Discharge

River ice conditions are a normal occurrence at higher latitudes and altitudes. Their effect on the stage-discharge relation has been well documented (ISO, 1983, Rantz et al., 1982). Remedial measures for shifts in the curve are based on methods of correcting the computed ice condition discharges from open water curves by direct ratios (Discharge-Ratio method) or by variable percentages based on hydrographic and climatic comparison. Other methods provide a means for reducing recorded gauge heights by a variable backwater value to obtain estimated true daily discharges. All methods subject actual recorded measurements to an analysis which alters them from their measured

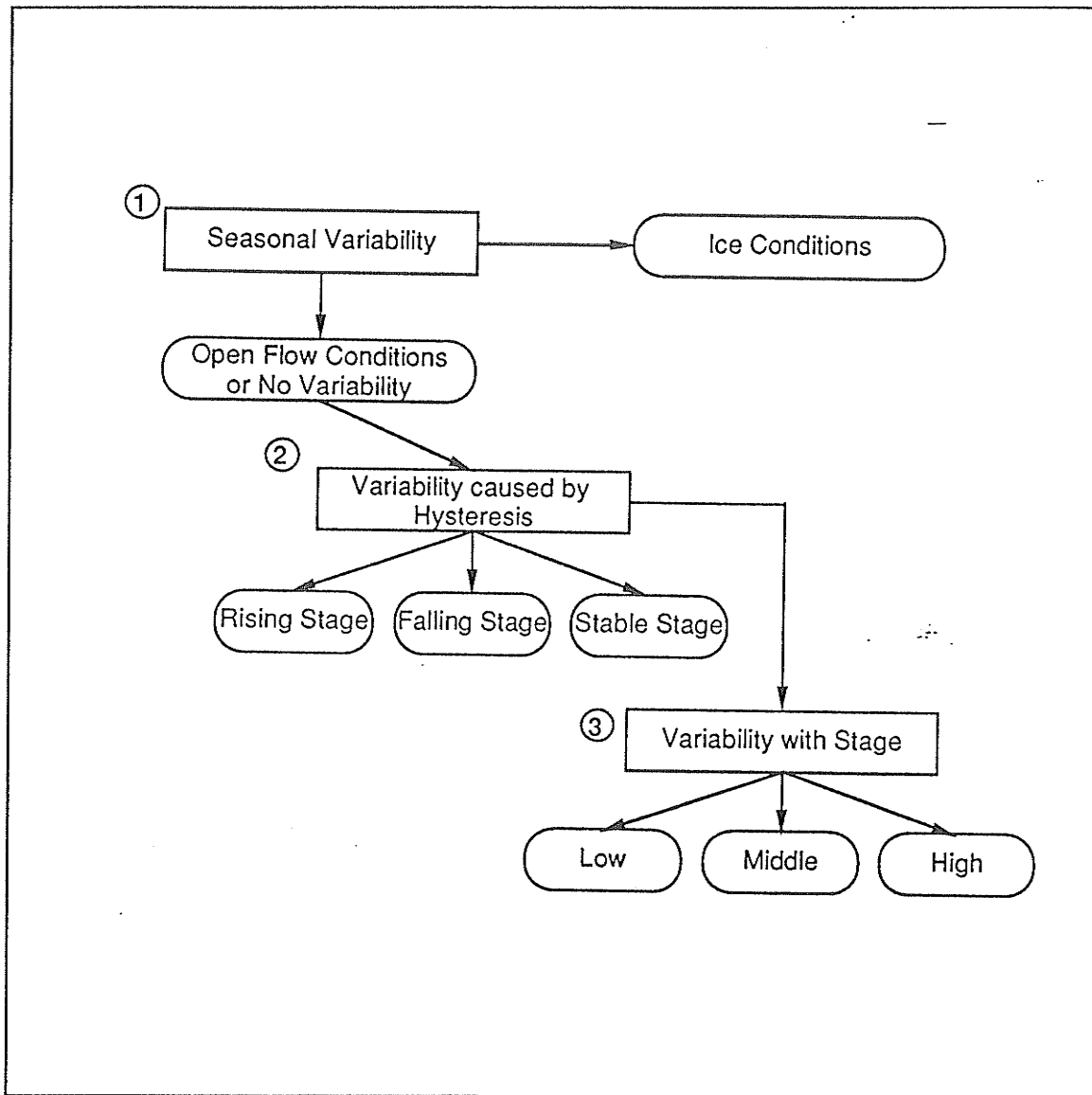


Figure 2.5: Hierarchy of Data Selection

values. The analyses are often subjective and erroneous, without sufficient quantification of the induced error, because these methods are based on graphical techniques open to subjectivity, and they are not often backed by adequate measurement or supported hydraulic reasoning.

It is rarely considered to create distinct rating relations for ice and open flow data.

It is proposed to try to achieve the logical separation of the data according to its seasonal variation. As a first step within a data filtering scheme, this separation is practical because further analysis is different for the two types of data. The problem is in identifying the two groups, and allowing for their distinction and unique curve development. Consideration must be given to the existing capabilities of the current EC database, and the use of relative physical parameters that clearly define the relationship between ice condition and open flow measurements. Currently a stage-discharge measurement is accompanied by measurements of width, area and velocity. Experience shows that the differences are significant when relating seasonal differences to these physical measurements, especially depth (related to stage), width and area.

The decision to split the S-D data seasonally is assisted by three plots that represent the relationship of the hydraulic control and the rating relation. The three plots are displayed simultaneously, and consist of a plot of stage versus discharge measurements, stage versus width measurements and stage versus area measurements. On each plot (see Figure 2.6) data influenced by *ice conditions* is distinguished from *open flow* data by a different colour. 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.

At this point, open flow data will be subject to further analysis, but ice conditions represent a more complex set of influences on the S-D relation. The 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 at this point. Thus, the following two sub-

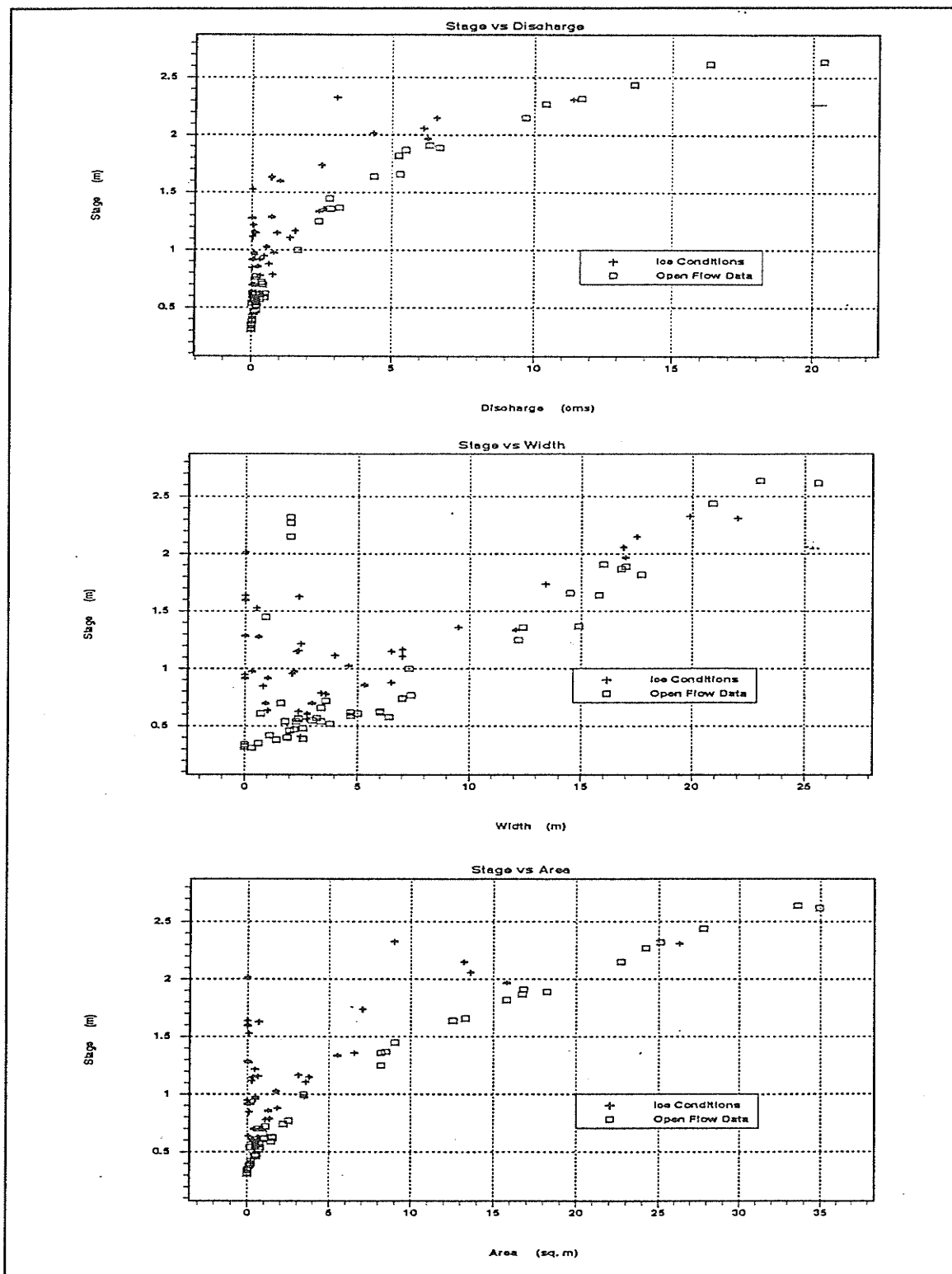


Figure 2.6: Parameters for Seasonal Variation

sections pertain only to the further analysis of the distinguished open flow measurements.

2.4.2 Discharge Variation Due to Hysteresis

Hysteresis, or looped, rating relationships may occur in both stable and non-stable channels where channel control is effective (ie. 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 and others , 1982). 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.

The ISO standard (Chapter **ISO 1100/2-1982 (E)**, "Liquid flow measurement in open channels - Part 2: Determination of the stage-discharge relation", Annex B, ISO, 1983) recommends developing a "normal" curve, if an adequate number of measurements are taken on both the rising and falling limbs of the flood wave passing the control. However, often the rising limb measurements are avoided due to the rapid change in stage or debris in the channel. In this case, the standard suggests making separate curves for rising and falling limbs (or just falling limbs and applying a correction for discharge on the rising limb). The decision to separate the curves, and produce multiple hysteresis rating curves is left to the technician, no guide lines or rules are given.

The SD points can vary from the curve quite significantly, and there are no means

of assessing the error of the points being considered. Rantz et al., (1983) describes methods for correcting points to a normal curve (discharge adjustment), but the methods are based on subjective, tedious graphical techniques.

This research has taken two approaches to providing remedial measures when considering the hysteresis phenomenon, and its effect on the stage-discharge relation. Firstly, a comprehensive utility is provided for establishing the differences between rising, falling and relatively stable stage measurements. Distinct curves (a hysteresis curve set) can then be made for each scenario. The smaller *Hysteresis Error Analysis System* (HEAS) tries to establish confidence of error in a *normal* curve. The future combination of systems will allow technicians to use either approach depending on their particular experience of a given station.

The framework has been set with the proper diagnostics in order to distinguish between established populations of rising and falling stage measurements. The distinguishing parameters are based on the relation between the discharges for steady and unsteady conditions at the same stage (Rouse, 1950). Equation 2.1 illustrates the relevant parameters. General experience indicates that the wave velocity in natural channels can be related to mean velocity by a ratio of 1.3. Since mean velocity is the only consistently measured quantity at this time it is the key parameter in the diagnostic scheme. Coupling mean velocity with $\pm dh/dt$ (positive indicates rising stage and negative falling stage) allows for determination of the occurrence of hysteresis effects.

$$\frac{Q_m}{Q_c} = \sqrt{1 + \frac{1}{S_c v_w} \frac{dh}{dt}} \quad (2.1)$$

where

Q_m = discharge for unsteady flow

Q_c = discharge for steady flow at same stage as Q_m

S_c = energy slope - steady flow at same stage as Q_m

v_m = wave velocity

dh/dt = rate of change of stage

For clarity, only rising limb and falling limb measurements are identified by colour or symbol, and are plotted on three diagnostic graphs: stage-discharge, stage-mean velocity and discharge-mean velocity (Figure 2.7). If there is hysteresis, the rising and falling limb measurements are readily discernible. The stable population fall in 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 (DeGagné et al., 1993).

The Hysteresis Error Analysis System approaches the analysis of error induced by hysteresis effects in a different manner. Instead of correcting measured discharges or establishing separate curves for rising and falling stage measurements, it tries to associate a quantitative error to each SD measurement. A total error of 20 percent may be assigned to a particular measurement depending on its position with respect to a preliminary "normal" curve, and its rate of change of stage. The production of the preliminary curve is to represent the normal curve, or the curve of zero rate or expected average. A comparison of the expected average, and the actual distribution of the data about it reveals the relative error.

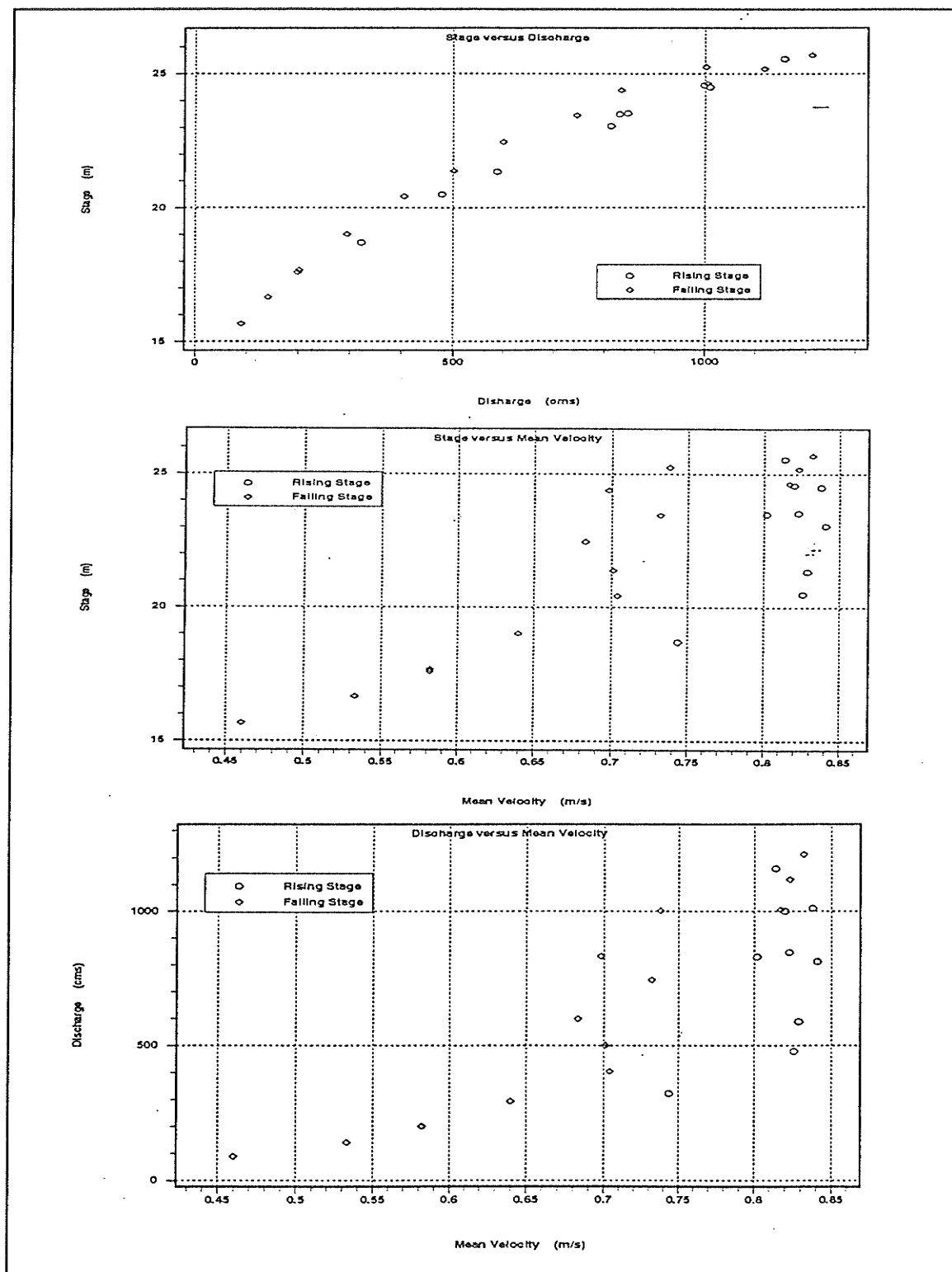


Figure 2.7: Variation Caused by Hysteresis

The error analysis is inclusive and iterative for flexibility. Weights, directly proportional to the assigned error, are given to the measurement before they are included in a weighted regression routine. The optimal curve from this routine - the "corrected" curve - is the final result of the analysis. Although similar to the preliminary curve this curve has different parameters and an associated confidence factor (based on average error). The confidence factor can then be used in defining a plus-minus range of discharges predicted from the curve (ie., 300 ± 4.2 cms). This method presents the advantage of providing statistical meaning to predictions made from a normal curve, which current practice (Anderson, 1988) ignores. Chapter 5 clearly illustrates the framework for the analysis.

2.4.3 Variation of the Rating with Stage

The final level of the hierarchy explores the possibility of an S-D relation that changes with stage. Many channels exhibit smooth changes with respect to the slope of the rating relation over the entire range of measured stage. Others show abrupt changes in the slope of the relation. This is a function of the hydraulic control, and its effect on the flow. If the control changes physically or geometrically with stage, abrupt changes in the S-D curve can be detected with the appropriate diagnostic tools.

J. Anderson (1988) of Environment Canada (Hydrometric Technicians Manual) indicates the possibility of a dramatic change in the rating due to the differing roughness factors of in-bank and greater than bank-full (flood plain) stages of a hydraulic control. The suggestion is to create separate hand drawn curves for in-bank and bank-full stages,

or in other words, a low and high water curve set.

This research intends to provide an automated facility for diagnosing and creating such curves. The approach taken is similar to that of the HYDSYS/TS program (Hydsys Pty Limited, 1991), where a user can develop as much as five curves from the cease to flow stage to the highest stage of the control. The system also provides a rubber banding routine for smoothing between created curves. The approach taken will expand on this method by creating a module with a decision support framework to provide diagnostic tools for assessing the appropriate stages to define low and high water curves.

Developing the diagnostics stems from the knowledge of the control and behaviour of relevant parameters as they change with stage. The relevant parameters are often derived from Manning's formula:

$$Q = A\bar{v} = \frac{AR_h^{2/3}S^{1/2}}{n} \quad (2.2)$$

where

- Q = discharge (m^3/s)
- $\bar{v}$ = mean velocity (m/s)
- A = cross-sectional area of flow (m^2)
- R_h = hydraulic radius (m)
- S = slope (m/m)
- n = Manning's coefficient of roughness

Any major variations in any of these parameters can greatly affect the stage-discharge relation. However, Manning's n and slope are not often measured or estimated by technicians. Figure 2.8 illustrates how the hydraulic radius, area and estimated mean

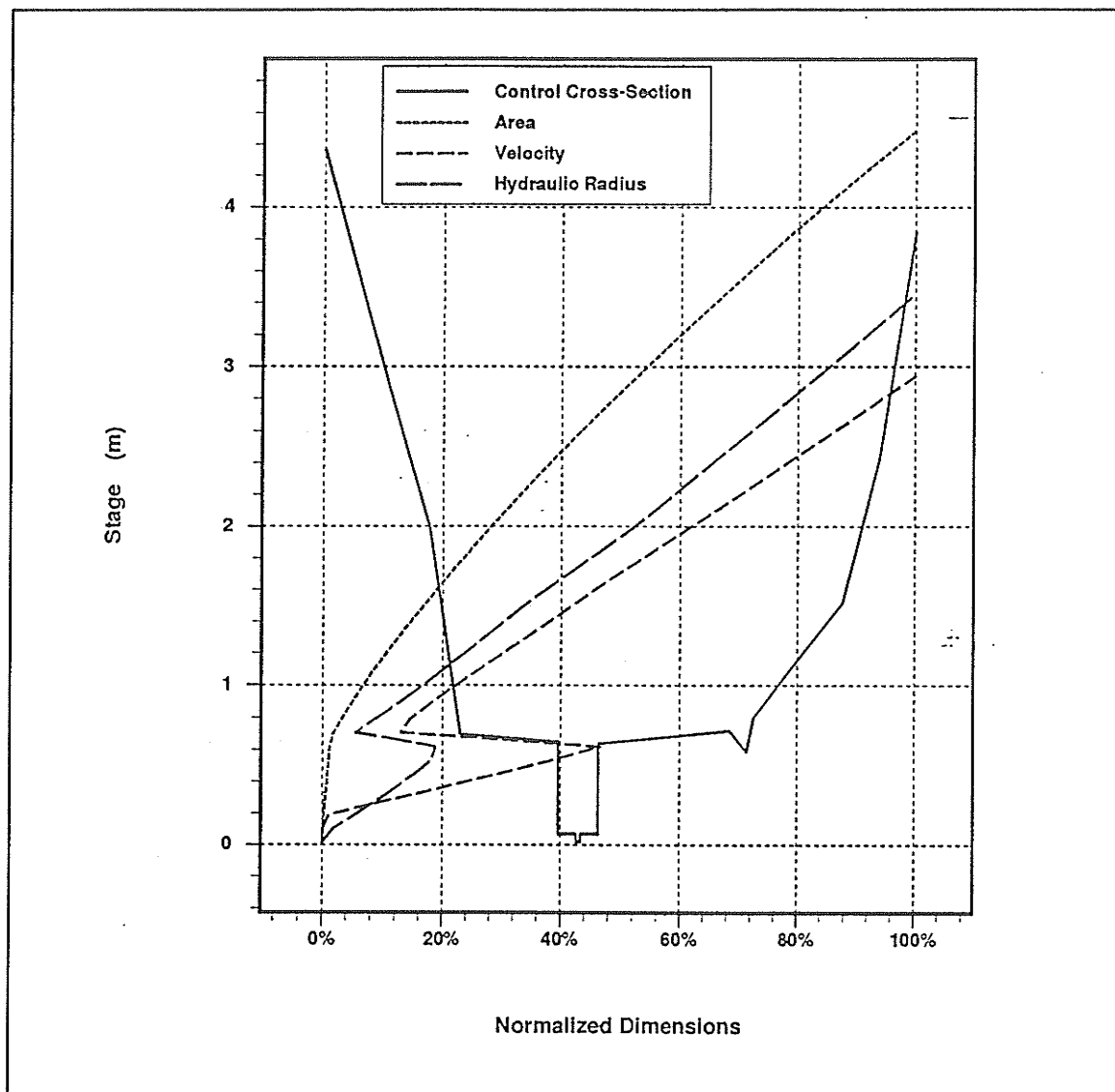


Figure 2.8: Variation with Increasing Stage (adapted from HYDSYS, 1991)

velocity can vary with stage. Here a slight decrease in roughness is evident until the bank-full stage. An immediate increase in roughness at bank-full stage is indicated in the behaviour of the parameters. Thus, the parameters are indicative of the effect of the physical geometry of the control, which then can be related to its influence on the SD rating.

The framework for analysis deals with the geometric constraints on the control. For example, the slope of the relation is often very different for measurements taken below bank-full stage from those that are taken above bank-full stage or on the flood plain. For this reason, it is necessary to gain knowledge from information provided by the cross-sectional geometry of the hydraulic control.

A diagnostic plot of the available cross-sectional geometry and the S-D data is used to detect any "variation by stage" (VBS). The two data sets appear on the same plot. This plot becomes the tool used to determine if there are any distinguishable points on the graph where the relation is discontinuous or fragmented. Knowledge of the hydraulic control provides physical meaning to the choice made. By entering the appropriate stage where the relation changes abruptly, separate S-D curves can be made (and later joined) between transitional points (the entered stages). The analysis is visual at this point. The crude graphical tools do not allow multi-dimensional complex geometric plotting of simultaneous parameters (as HYDSYS does, Hydsys Pty Limited, 1991), but future developments hope to employ such a facility. Future developments include plots of SD with hydraulic controls, as well as stage-area, stage-velocity, stage-hydraulic radius and stage-roughness. These parameters are either measured or can be derived in the current HYDSYS framework, but the power of this facility will be enhanced by decision rule set for recommending the stage points where a change in the relation occurs. That is, tolerance limits will be developed for these graphical representations as diagnostic tools.

The MOSDE (Multi-Objective Stage Discharge Evaluator) has been created to

achieve the same results by an analysis independent of the knowledge of the hydraulic control. A computer based approach MOSDE (see Chapter 4) employs the method of systems analysis on derived regression statistics for the development of stage-discharge rating curves. The regression is done recursively as the program steps through the data set, by adding one point at each iteration. The multi-objective technique called Compromise Programming evaluates the improvement or deterioration of the model using a set of statistical criteria. The overall task is to fit a proper curve, or curves, to any given SD data set. Also, the key transition points in the SD relation are identified. This process is designed to eliminate ambiguity or subjectivity associated with current methods used for the development of SD relationships that behave dynamically due to the complex geometry of the control.

2.4.4 Modelling the Relation between Stage and Discharge

Representing the rating relation with a mathematical model has proven very successful in the past. Phase 1 of the SDDSS project (Douglas et al., 1993) implemented a straight forward strategy for model development based on the power transformation of stage. Then Gawne and Simonovic (1992) expanded this approach by incorporating the automatic development of 62 models (41 transformations of stage, and 21 BOX/COX transformations of discharge). This approach included four statistical tests (skewness, kurtosis, uniform variance of residuals, and straight line probability plots) and multi-objective analysis to improve the assessment and narrow the evaluation of the models produced. Both of these approaches were directly adapted into this research, and now

taken one step further based on the approach taken in the HYDSYS/TS system.

HYDSYS/TS (Hydsys Pty Limited, 1991) has a subroutine called HYRATBLD, which allows the user to create models based on seven different methods. The theoretical foundation for the methods employed is based on work by Brian Chester (1986). One particular method produces one model from a power^{2/5} transformation of discharge. Hydraulically derived, this transformation effectively linearized data of Western Australian streams before fitting a regression model to it. The optimal model for the other methods was established when HYRATBLD minimized the window error for the selected measurements. The method for quantifying error was not given.

This research builds on the first two approaches (already incorporated in the SDDSS) by adapting techniques from the HYDSYS/TS program. The addition of the power^{2/5} algorithm into the automatic generation of now 63 models before evaluation. Then an optimizing routine (see chapter 4) produces the **best model** of the 63 based on several different measures of error. This approach eliminates ambiguity and bias in the evaluation of the rating curve models produced.

2.5 Rating Curve Extrapolation

Peak discharges are very difficult to measure, and often the gauge record indicates a stage value that is outside the defined range of the current SD curve. Therefore, a comprehensive decision support system must be able to extrapolate from currently established rating relations.

In 1987, A. G. Smith described seven methods, including the use of the current

curve, for making estimations of stage or discharge beyond the applicable range of the current relation. Case studies provided in the paper illustrated the effectiveness of the use of the current curve method where it was applicable. The decision must be based on explicit knowledge of the control, and its behaviour with stage. This is a key aspect incorporated in this research. The other methods proved equally adequate, but the author recommends testing methods on similar channels where data is known before implementation.

Although numerous techniques exist for making predictions beyond the measured range of stage, three approaches taken from ISO (Chapter **ISO 1100/2-1982 (E)**, "Liquid flow measurement in open channels - Part 2: Determination of the stage-discharge relation", Annex D, ISO, 1983) are utilized in the SDDSS. It seems logical to extrapolate based on the velocity area method due to the fact that current measurements are made on the same concept. Therefore, all three extrapolation methods use the knowledge of the cross-sectional area of the control. The methods are: (a) Extrapolation of the established S-D mathematical model; (b) extrapolation of mean velocity using the relationship between mean velocity and hydraulic radius; and (c) extrapolation using a modified Manning's equation.

The first method is the direct application of a developed mathematical model to a known stage or discharge that is greater than that applicable in the model's original development. The mathematical model makes it easy to translate a discharge to stage, or a stage to discharge. However, extending a mathematical model beyond the range of data that it is applicable to is often very erroneous. One must expect that the data will

continue in the same way as you extend the curve, but the relationship can change drastically with increasing stage. With knowledge of the hydraulic control it can be determined if the current relation is appropriate above the maximum measured stage. If the control does not display any dramatic geometric changes as stage increases, the current model should be applicable.

Of the two remaining methods, the first utilizes the logarithmic relationship between mean velocity and hydraulic radius, which usually plots as a straight line. This relation can be extended to extrapolate mean velocity, and the cross sectional area for the prediction of discharge or stage.

The last method of extrapolation is based on a key assumption, that when extrapolating beyond the maximum measured stage, the mean velocity is relatively constant. Using this assumption and the equation for velocity according to Manning (see Equation 2.2), it is possible to estimate a discharge or stage. Using the above assumption and the knowledge of the control cross-section to determine A and R_h , leaves:

$$\frac{S^{1/2}}{n} = \text{constant} = k \quad (2.3)$$

The above relationship often holds true for higher stages, but knowledge of slope and Manning's n give more accurate results. Therefore, overriding the assumption and input the slope and Manning's n parameters are allowed. Otherwise, the illustrated equations are used to predict discharge or stage from knowledge of the relationship of cross-sectional area with stage, and k is held constant.

It is important to reveal the fact that none of these methods work without explicit knowledge of the cross-sectional geometry of the hydraulic control. This knowledge has been implemented so that future database requirements reflect the need to include the control in the analysis. This is a key step towards defining the accuracy and reliability of the SD curves, and the information derived from them.

3.

SDDSS STRUCTURE AND APPLICATION

3.1 Introduction

Decision Support Systems combine engineering expertise, systems approach, computer graphics and Expert System (ES) technology to assist water resources planning, decisions and operations. Several definitions apply to the term Expert System, but the following is particular to water resources (Simonovic, 1992):

"A water resources expert system is a computer application that assists in solving complicated water resources problems by incorporating the multi-disciplinary engineering knowledge, principles of systems analysis, experience, intuition, and engineering judgement in the solution procedure"

A decision support system integrates expert systems with databases, external subroutines, and graphical user interfaces and displays. The expert system component is the brain stem of the DSS holding the decision rule base, inference engine and system control. It is linked to a data base, retrieving data and storing data derived during analysis. The expert system also relies on importing data to external routines for data manipulation such as systems analysis techniques. The whole system is interactive with the user through graphical user interface (GUI), where data can be seen, (graphical display) assessed, and system queries can be answered. Option menus are also displayed allowing the user to control the course of action at given times.

The promise of interactive computer software to readily define proper decision domains and proposed alternatives has given this branch of research a grand boost. Together with the increased accessibility of the micro-computer, highly portable software development tools, interactive graphic displays and graphical user interfaces (GUI), the

practicality of DSS is limitless. The book, *Decision Support Systems - Water Resources Engineering* (Loucks and da Costa editors, 1991) provides an excellent background of DSS development and theory prior to 1991. Others have incorporated geographical information systems (GIS) and complex modelling procedures in more recent literature (McKinney and others, 1993, Urbaniak, 1991 and Raman, 1992).

The current research emphasizes the development framework or the implementation of the process knowledge formulated in Chapter 2. The importance of setting standardized and logical procedures is placed higher than the methods of analysis. The benefits of the systematic methodology provide rigorous analysis which provides greater accuracy and reliability through an encompassing and operational computer environment.

The SDDSS was developed as a prototype, which could fully function operationally meeting the requirements set by hydrometric agencies such as Environment Canada (Douglas et al, 1993, DeGagne et al., 1993 and Hudson 1993). The database and analytical knowledge of the SDDSS should be expanded as future requirements for complex stage-discharge analysis are realized.

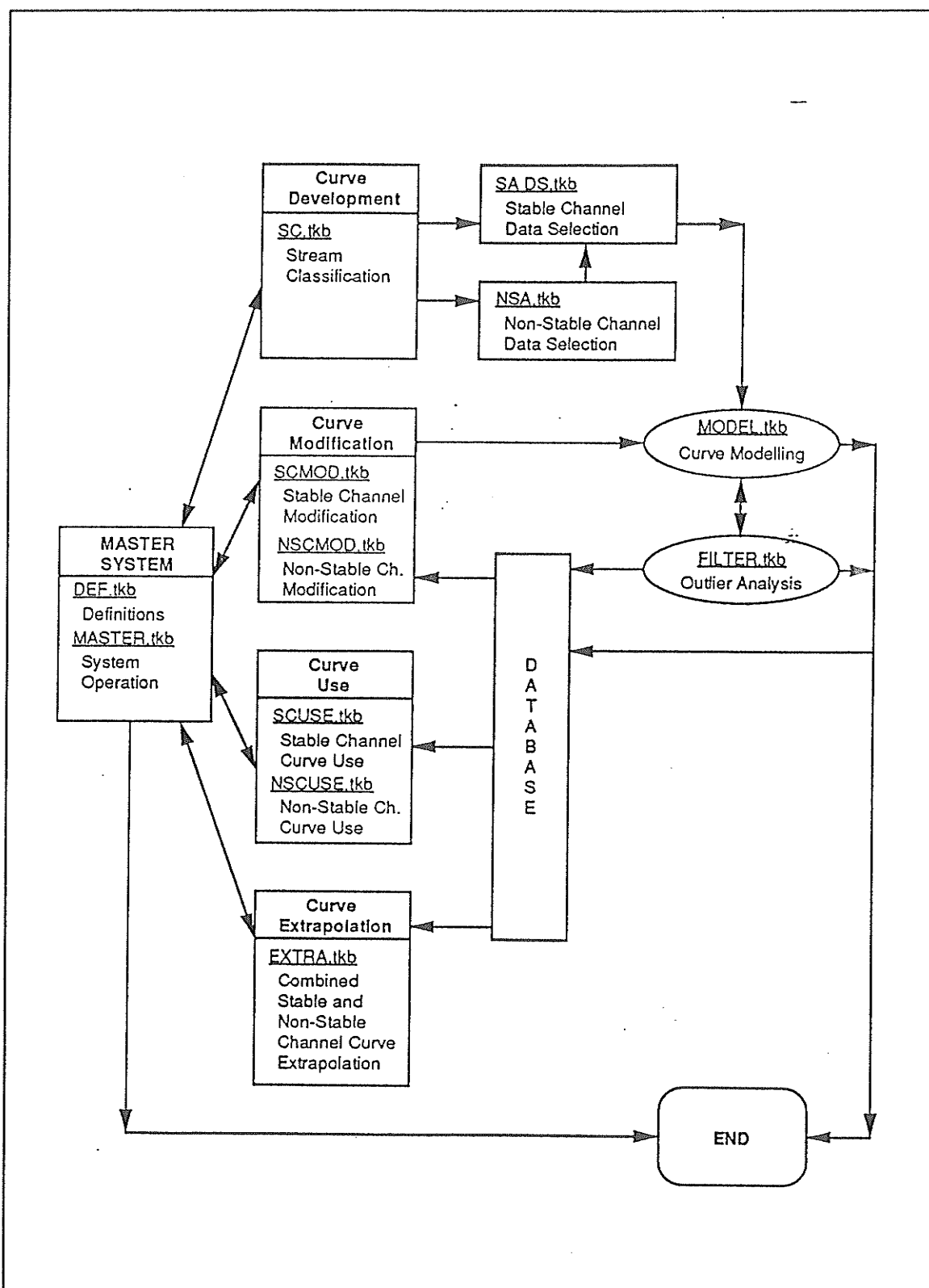
3.2 Prototype System

Following the success of the implementation of the SDDSS in phase 1, the Sun Sparc station running a Unix operating system provides the hardware platform. Maintaining and expanding the knowledge components was performed using the NEXPERT OBJECT 2.0 (Neuron Data, 1991) software. Success was also maintained

through the use of ORACLE (Moran, R., 1989) RDBMS, because of NEXPERT OBJECT's ease of communication and data retrieval with this software. NEXPERT OBJECT provided easy access and control over any FORTRAN (Sun Microsystems Inc., 1990) 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. New software development by Neuron Data will allow for future portability of the SDDSS on any hardware platform.

The system as a whole consists of several sub-systems. Each subsystem has a specific task, and they are linked to each other to allow an integrated cooperative environment. The user modes make up the subsystem components, and each user mode has developed knowledge bases that perform the necessary tasks. The knowledge bases (KBs) hold the syntax for the incorporated process and analytical knowledge. They are the corner stones of the program structure driving the processes, the database links and the necessary execution of external routines and graphic displays. Figure 3.1 illustrates the process elements and the flow of the system that links them together. The knowledge bases are organized as independent units, which cooperate with each other. This allows for efficient programming, easy integration and focused development. The current organization also allows for ready expansion as knowledge components are added.

The previous chapter described the process knowledge concepts for analyzing the SD relation for unstable channels. The basis for the analysis is forwarded through the development of rating curves, their use, modification and extrapolation. Each function represents a user mode which has been incorporated into the SDDSS system (Figure 3.1).



Each mode is available for application from the main menu. Control and procedure is interactive between the user and the SDDSS. The following section discusses the computer framework and process for each of the four modes: (i) **Curve Development**, (ii) **Compute Discharges**, (iii) **Curve Modification** and (iv) **Curve Extrapolation**.

3.2.1 Operational Framework of SDDSS

User interaction is demanded throughout the consultation process, and the technician's expertise and knowledge of the current station are very much required. The purpose of the SDDSS is to formalize the process of making and using SD relations, not to eliminate the technical expertise, which is always essential. However, the expansion realizes great improvements in the diagnostic procedures available to the technician. This section will detail the functional operation of the SDDSS, and special emphasis has been placed on new procedures pertaining to non-stable channels.

Main Menu

The main menu is within the SCUSE.tkb, and the curve extrapolation user mode has been added as an option to the main menu. Also, it is possible to change the setting of the current station by choosing the option "Select New Station". This becomes an important function because the main menu is activated before and after completion of all user modes. Therefore, the user is allowed to change the station they wish to work with at these times.

Curve Development

The Curve Development (CD) framework is comprised of 5 KBs (see Figure 3.1). The KBs work interactively and cooperatively to produce a curve or curves for stable and non-stable channels. Because the system handles both types, the first order of business is to classify the stream. This is handled by the SC.tkb knowledge base. One of two paths are then taken upon a successful classification. Data selection is handled by SA_DS.tkb (Stable channels Analysis Data Selection) and NSA.tkb (Non-Stable channels Analysis). The mathematical modelling component is contained in the MODEL.tkb, and the last procedure to analyze outliers is performed by the FILTER.tkb.

Stream Classification

Upon selection of "Make a New Curve" from the main menu, the CD mode is activated. The master system unloads the main menu and loads in the SC.tkb for stream classification. The current station is then ready for a complete investigation to determine its classification with respect to its stability, sediment type, and channel pattern. Figure 3.2 illustrates the flow schematic of the analysis. From this figure follows a detailed description of the framework, that has been programmed into the SDDSS to accomplish the classification process.

The first step in the stream classification deals with finding adequate values for representing the full regime of flow, and creating the specific gauge plot accordingly. At first attempt, the system tries to extract the two, five and ten year flood values from the current station's flood return table in the database. The specific gauge plot (SGP) is

produced when these values are used to interpolate stage from the open flow measurements in the database. The three flows are then shown on one graphics window (see Figure 3.2). The graphic plots run in the

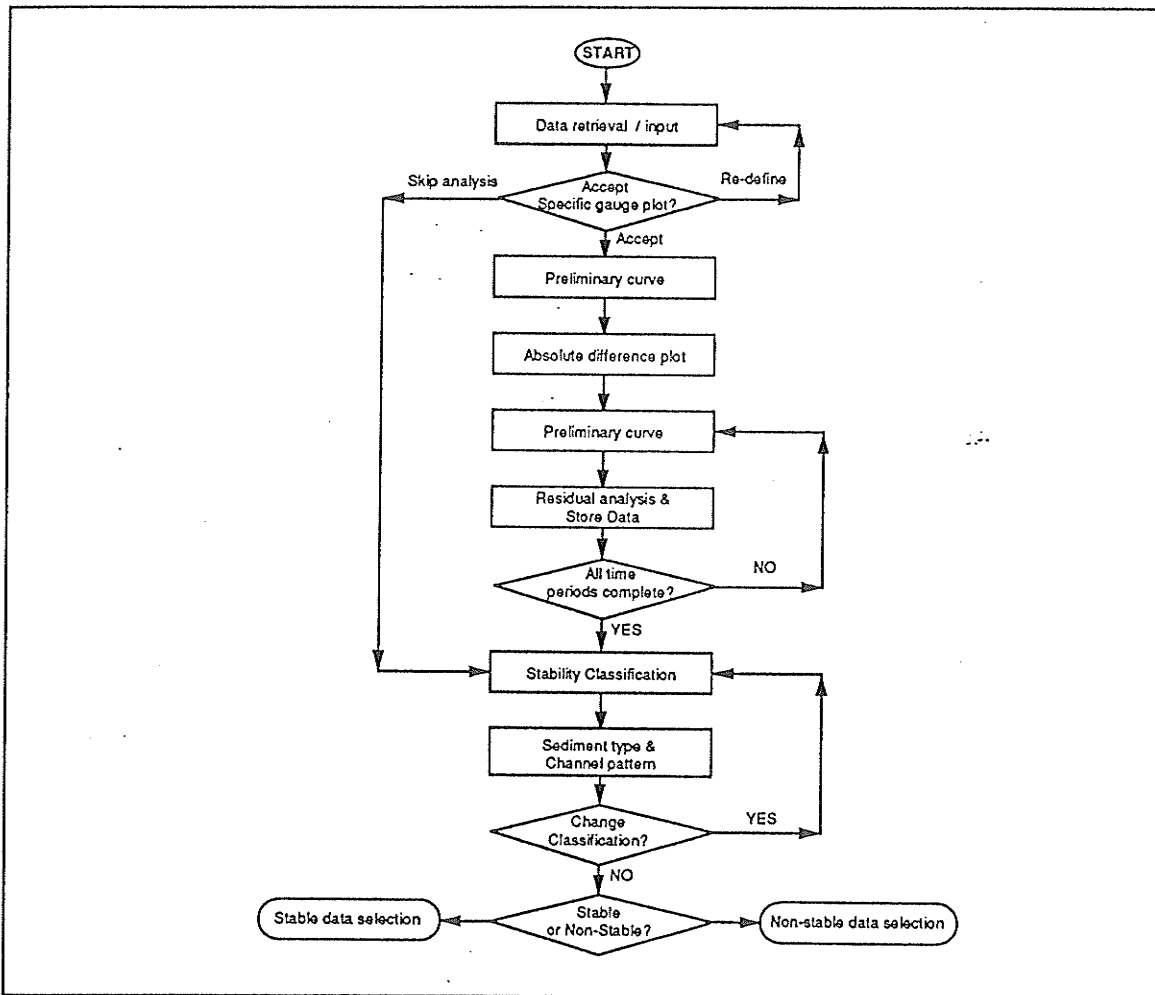


Figure 3.2: Framework of Stream Classification

"background" environment. This allows for the main program to continue to run while viewing the SGP. The plots are then cancelled automatically by the system when a new task is about to be performed and the plot is no longer needed. Figure 3.3 depicts the monitor display of a successful plot of a specific gauge record. Each flow is plotted in

SESSION CONTROL

What would you like to do now ???

Select an option

Continue to Analyze Specific Gauge
Reset Flood Frequencies
Skip Specific Gauge Analysis

NOTKNOWN

APPROPOS #10

The following values for flood return flows will be used:

- 1) 1.0 cms for the Two year flood
- 2) 9.0 cms for the Five year flood
- 3) 19.0 cms for the Ten year flood

Below the SPECIFIC GUAGE PLOT is shown. It is your decision to choose whether or not you would like to use these DEFAULT Flood Frequency values or provide alternatives. You MUST have values displayed for all three Flood frequencies or the analysis will not work

Please answer the question in the session window now!

Close Keep

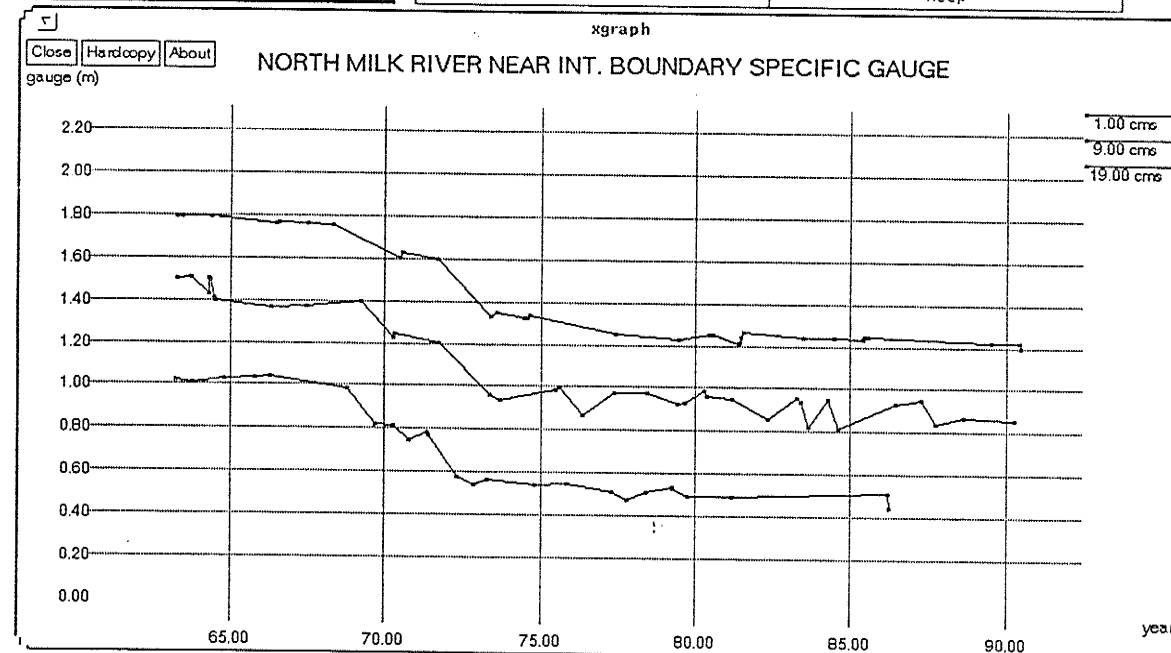


Figure 3.3: Specific Gauge Plot

a different colour. If no information on the flood return periods exists, the user is prompted to input the two, five and ten year floods, and the SGP is re-plotted. At this point, the SGP can be visually inspected. If sufficient data points do not appear on the SGP, the system has the ability to reset and re-submit new flow values to represent the low, mid and high flow values, or "skip" the specific gauge analysis altogether. Conversely, a SGP that fully represents the flow regime can then be further subjected to analysis. The interpretation of the SGP is left to the user. If the specific gauge analysis is skipped, the **default classification becomes stable**. Otherwise, the analysis is continued.

Upon continuation with the stability analysis (ie., specific gauge analysis), the system displays a message screen on the monitor explaining that a preliminary curve has to be made using the last five years of the open flow SD measurements. This is necessary for establishing the tolerance limits in terms of discharge used in the analysis of the absolute difference plot (ADP). At the end of the message, the user is asked to close the message window, and the system links the user to the mathematical modelling section.

The query string used for retrieving the SD measurements is automatically set before entrance to the modelling section. Thus, the selection is made automatically and the user is shown the SD data that is to be modelled. At this point, a model should be made as outlined later in the *Mathematical Modelling* section. Because the system only requires a best estimate of the relationship between SD, it is not necessary to specify and force-fit through the zero flow stage (ZFS). Also known as the cease to flow stage, the

ZFS is the highest gauge when there is no longer any flow in the channel. It is also not necessary to complete an outlier analysis at this time. After completing the modelling process and arriving at an appropriate relation, the user has to store the model for immediate use in the specific gauge analysis.

Storing the preliminary curve ends the modelling process and the respective KBs are unloaded and the system returns to the stability analysis. The preliminary curve is used to establish the ± 5 percent tolerance levels displayed in the absolute difference plots, which are created and plotted upon return to the stream classification process. An external program examines the data from the ADPs and any detected "jumps" are then displayed to the user via a message window. The detected jumps indicate extreme events that have altered the rating relation. Figure 3.4 shows the monitor display of the three absolute difference plots. The years in which a jump occurs are then singled out as being highly unstable. The years between jumps become the segments in time that an SD relation is to be made. But first, these time segments are subject to the residual of gauge analysis to determine the stability of each time segment. Those years in which a jump occurs are excluded from further analysis due to the unknown nature of the instability causing the jump.

As seen in Figure 3.2, the residuals analysis is an iterative process. Each time segment is subject to the analysis. The analysis begins when the system links to the modelling section and automatically selects the open flow SD measurements data for the time period to be analyzed. The user makes the preliminary curve and stores it for use in the residuals of gauge analysis. The modelling section is then exited and control is

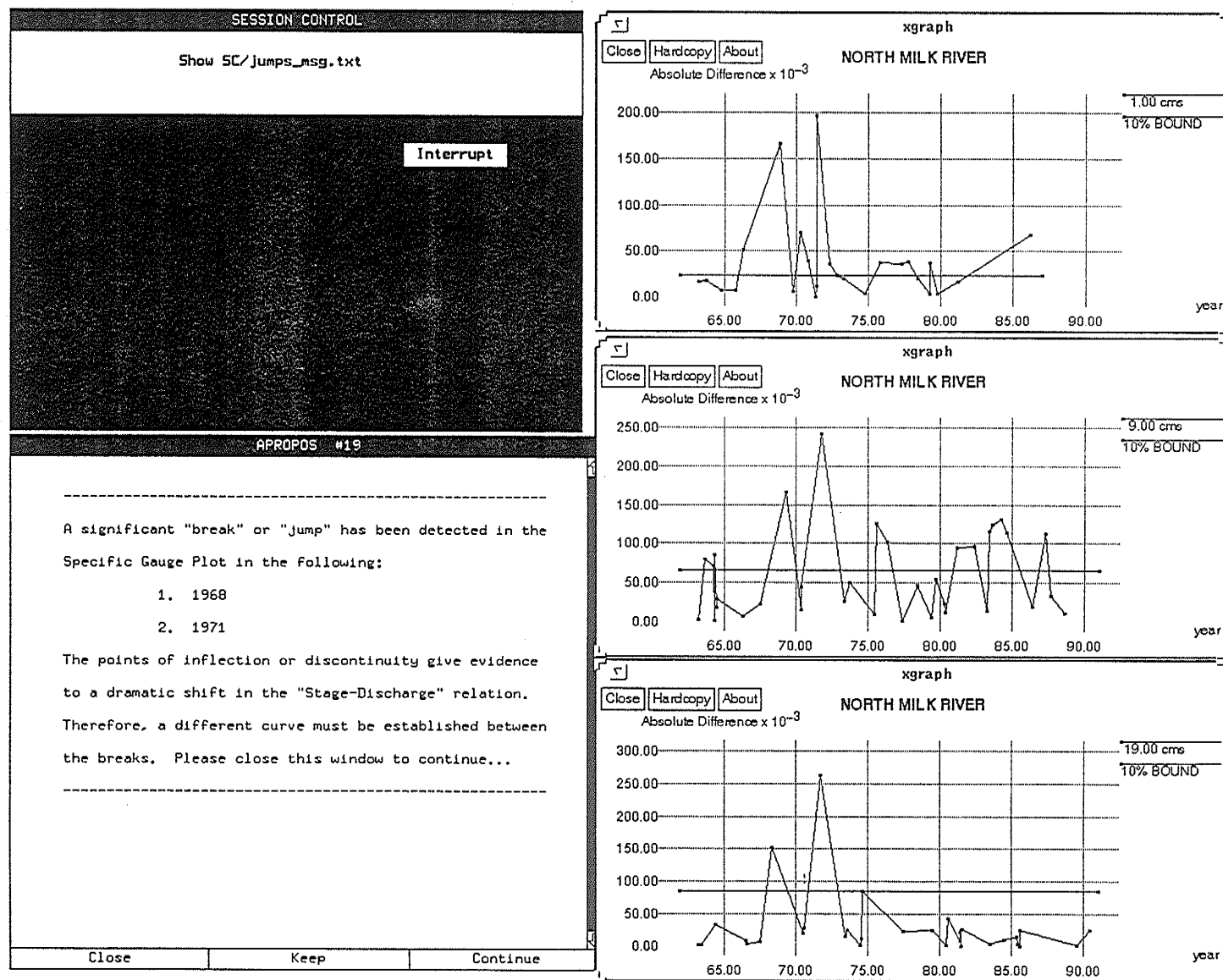


Figure 3.4: Absolute Difference Plots

returned to the SC KB where the residual plots are created and plotted one at a time. Along with each plot, a message display is provided with information on the time segment, flow regime, stability classification and other parameters of the residual plot (Figure 3.5). This information is then stored in a separate table in the database. After all three residual plots are displayed for one time segment, the residuals of gauge analysis is re-iterated for the following time segment until each segment has been analyzed and stored in the database. The system continues by providing the user with the overall stability classification, and then prompts the user for information regarding sediment type and channel pattern. The user inputs the information from the available choices and then the information is stored in the database. The user has the choice of changing any of the classification parameters. If the user decides not to change the classification, the process is complete. The system then moves to further develop the rating relation according to the classification.

If the stream was classified as stable, the SC.tkb is unloaded and the master system loads in the data selection KB (SA_DS.tkb) for stable channels. On the other hand, if the stream is classified as a non-stable channel the system automatically loads in the NSA.tkb. The focus of this research is non-stable channels, therefore, the framework and operation of data analysis and filtration for non-stable channels follows.

Non-Stable Channel Analysis

The data selection and modelling of SD measurements for non-stable channels is performed in a hierarchical structure of data filtering (Figure 3.6).

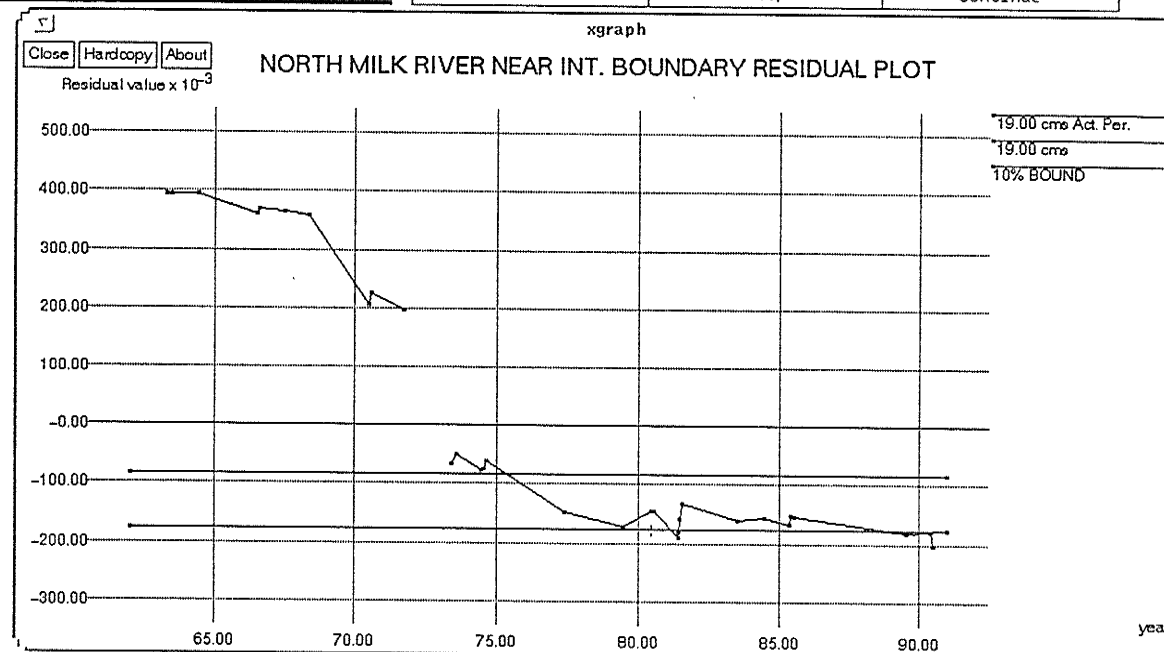
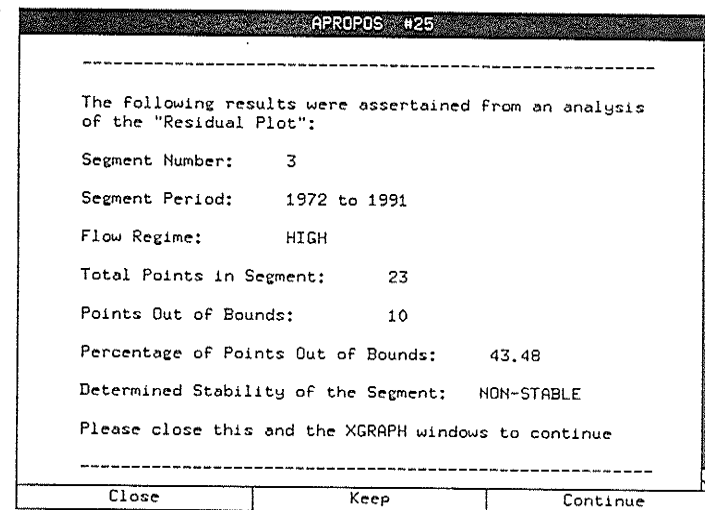
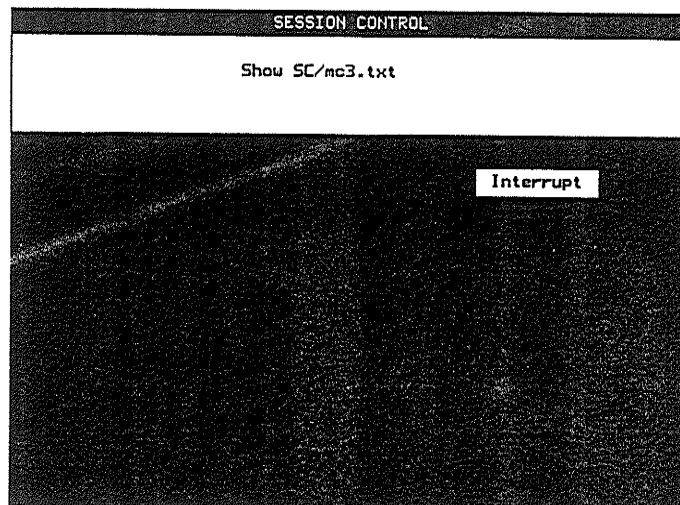


Figure 3.5: Residuals of Gauge Plot

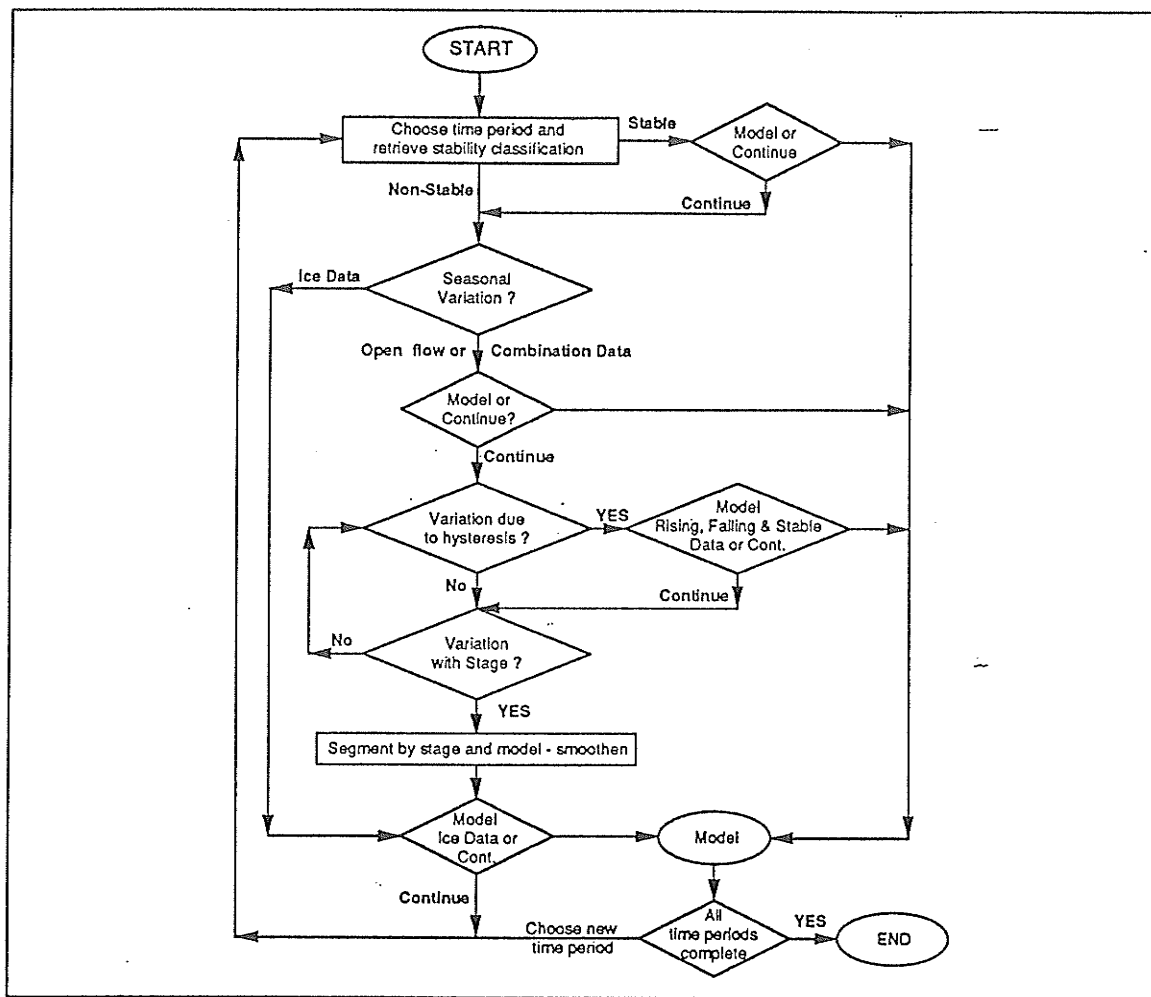


Figure 3.6: Framework for Non-Stable Data Selection and Filtration

All information about the current station is automatically transferred to the NSA.tkb. The opening message window displays the results of the stream classification analysis that has just been completed. The report tells the user the current station and its general classification, as well as each time period's respective classification for all flow types. The user is then prompted to choose a time period to work with. After choosing a time period, the information for the time period is shown to the user, and at this point the user has the opportunity to change the selected time period. If the user decides to

continue, the system enters the hierarchy of data filtration and selection at the first level.

One of two paths is taken according to the stability classification of the time period. If a time period is determined to be relatively stable, the user is shown (graphically) all SD measurements for the time period, and the user has the choice to mathematically model the data or continue through the hierarchy of the analysis. The user's decision is based on the stage versus discharge chart displayed. Alternatively, if the time segment chosen was determined to be non-stable, the system automatically defaults to seasonal variation level, the next level in the hierarchical structure of the analysis.

The user's decision to separate the data set seasonally is aided by three plots. Shown in Figure 3.7, the plots are stage versus discharge, stage versus measured width at water surface level and stage versus cross-sectional area of water in the channel. The figure also shows the text screen and the question presented in the session window. The data sets, ICE COND. and OPEN FLOW (see legend in graphs of Fig. 3.7), are presented in different colours. If the user observes that the data sets do not plot in similar patterns, they answer the question with "NO". This means that there is no correlation between the data and they should be separated seasonally. Otherwise, the choice should be "YES" if no distinction can be made between the data sets. The system continues to the next tier considering ice and open flow conditions as one data set. If the answer is NO, the system separates the data into the respective data sets and continues by first choosing the open flow data. The system will follow this branch of the data selection section until a satisfactory curve or set of curves is made. Then, it will automatically bring the user

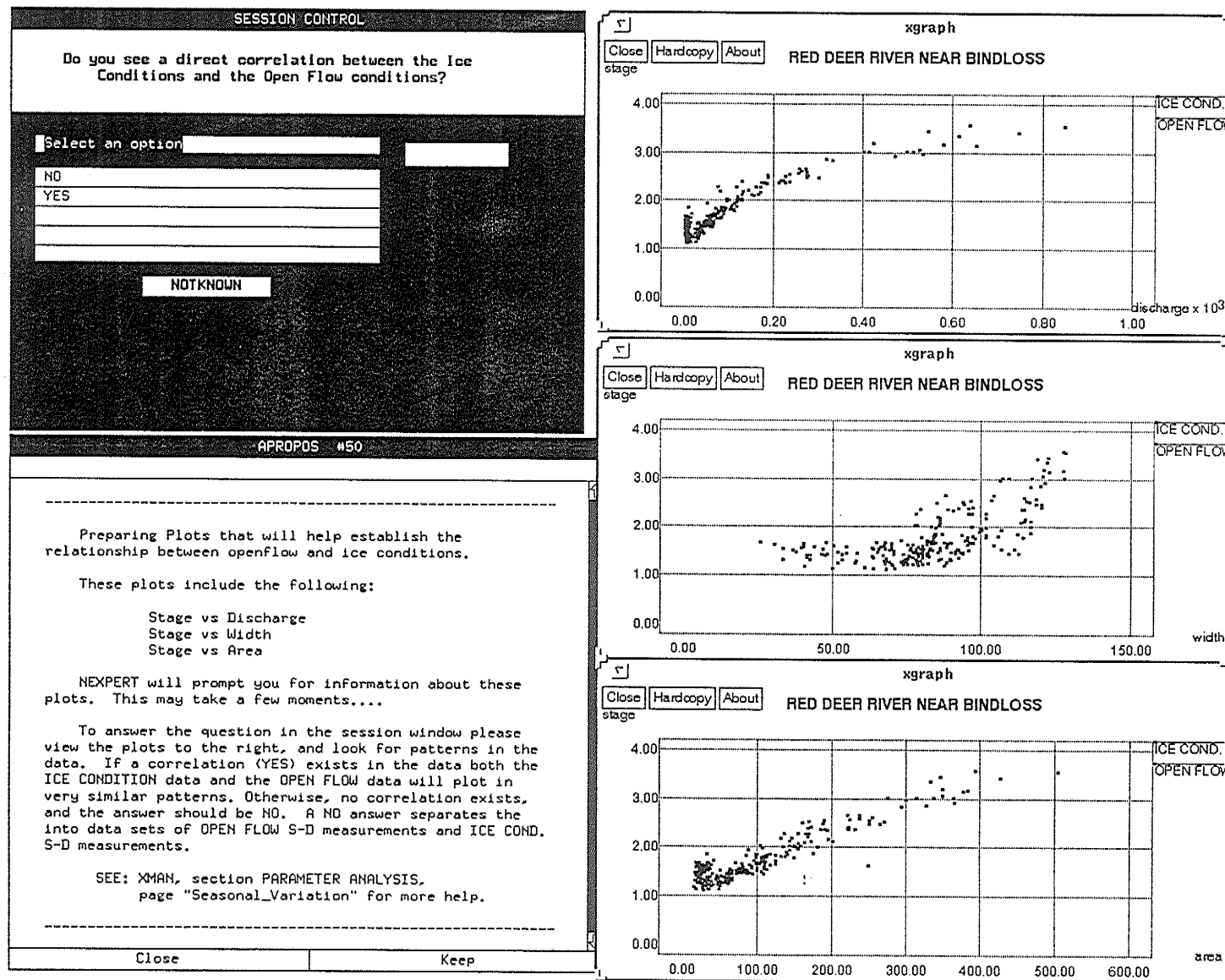


Figure 3.7: Diagnostics for Seasonal Variation

back to the seasonal level (tier 2) displaying the ice condition data for further manipulation. At this point, only the framework for manipulating the ice condition data is set, where the data should be looked at from three separate points of view. The ice data should be analyzed with respect to partial ice cover, complete ice cover that is buoyant, and complete ice cover that is suspended above the water surface. Currently, there is no means of filtering the data to identify these conditions and the framework has been set up but not completed at this time. Therefore, the consultation progresses towards the further attention paid to open flow data.

Considering the open flow or combination open/ice flow data, the system presents the user with a graph showing all respective SD measurements in the time period. The user then has the choice to continue or to model the presented data. Choosing to model the data, the system loads up the modelling KBs, and automatically selects the appropriate measurements (from a predefined query string) for modelling. Choosing to continue will bring the system to the third level in the hierarchy, the level that judges the relation with respect to hysteresis.

When trying to establish if the rating curve is subject to hysteresis, the data set from tier 2 is graphically represented with rising stage and falling stage measurements shown in different colours on three graphs. The work bench (user interface display consisting of the session window and text and/or graphic display) is set up identically to that of Figure 3.7. The graphs presented are stage versus discharge, stage versus mean velocity and discharge versus mean velocity. The question asks if there is any evidence that the data set is subject to hysteresis. A "NO" answer eliminates the need to separate

the data, and the system automatically continues to the fourth level in the filtration process. A "YES" answer signals for the data to be separated and considered for modelling by means of rising, falling and stable stage in order. Each data set is presented to the user with the choice to model or continue consecutively. Choosing to continue will bring the data set to the next level and the data set will be analyzed to see if there is any variation in the rating with stage.

The final level of the filtration and selection process determines if there is a transition in the rating curve with stage. The user is presented with the SD data set continued from level 3 along with the most recent cross-section of the hydraulic control (of time period). The work bench for tier 4 is featured in Figure 3.8. From this figure, the user defines any points in the total range of stage where it is evident that the SD relation changes. Then, the system automatically sets the query strings for stages between transition points for data selection and modelling.

The framework is set to handle a maximum of two transition points. This translates to three separate relations for the entire stage range (low, middle and high stage ranges). The data is segmented and modelled in order of ascending stage. The user is given notice of what stage range is about to be modelled.

After completing the models for the entire range, all models are shown to the user along with the respective SD data. The models are distinguished by colour, and then the user is asked if they would like to smooth the curves through the transition zone. Again, only the framework for this procedure has been set up. Due to the lack of a proper method for smoothing, this process is not implemented at this time. A message is given

SESSION CONTROL

How many TRANSITION POINTS are CLEARLY evident in this Stage-Discharge relationship?

Type a value

NOTKNOWN

APROPQS #52

To the right is the stage vs discharge data with the latest cross-section for this river reach. Use this plot to aid you in answering the following questions.

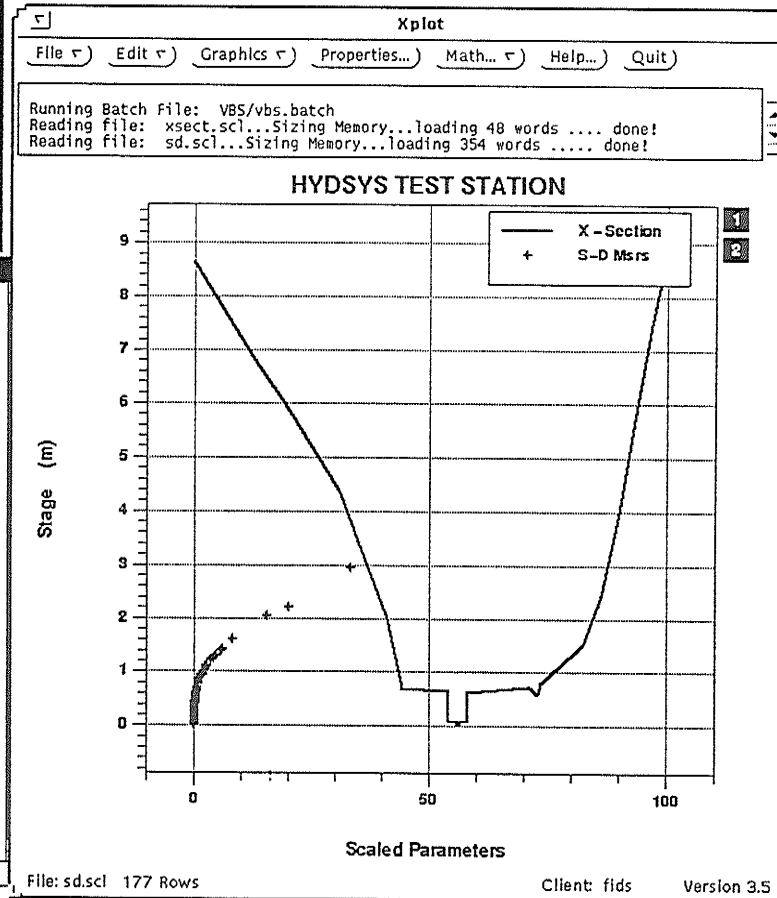
The first question allows you to decide how many partitions or stage segments are in the relationship. A transition zone will occur at a point in the cross-section where the geometry changes rapidly. Look for these changes and input the number of transition points first. Then NEXPERT will ask you to put in the stage value of each point.

NOTE: The horizontal axis has been normalized to a maximum value of 100. This is due to a limitation in the plotting tool used, but is not of serious consequence at this time.

Please answer the question in the session window now...

Close

Keep



to the user with the above explanation, and the system continues. The TIDEDA system (Rodgers and Thompson, 1991) provides an excellent utility for curve smoothing, and future development should include similar methods for rubber banding between end points of curve segments.

From the fourth level, the system returns the user to continue with the selection process according to the conditions in which the data set just modelled was received. For example, if the data set came from tier 3 as rising stage data, the system returns to tier 3 to consider falling stage data. The process is re-iterated until all appropriate curves are made which completely define the SD rating for the time period in question.

When a set of curves is completed to define one time period's rating, another time period can be selected for manipulation, data selection and filtration. However, before this is done all parameters that are relevant to the set of curves made are stored in the database for later use. The stored parameters reflect the conditions set before entering the curve modelling section. For example, if the set of curves are made for open flow conditions, and the channel is affected by hysteresis this information is stored in the database. The system exits this section only after all time periods have been successfully represented by a curve or set of curves. The end result is a suite of curves that fully and accurately represents the SD relation in time and space.

As mentioned above, when choosing to model the SD data the user is automatically linked to the mathematical modelling section of the system. The query strings that select the SD measures from the database for modelling are defined and built within the hierarchical structure of the filtration process. They are relayed to the

modelling section when the link is made, and the data is retrieved from the database automatically and shown graphically to the user as the data set to be modelled. The user is then ready to model the data.

A coding system has been put in place within the data selection environment. The purpose of this coding system is to provide a means of identifying curves as to their particular development and use. For example, a curve that is made for low stages of open flow has a specific code attached to it to define the type of data selection used when developing the curve, and to define the type of curve it is to be used for in the other three modes. This ensures that at all times the SDDSS knows exactly what type of scenario it is dealing with, and how it is applied to the data.

Mathematical Modelling

Before the modelling begins, the user is asked if the zero flow stage (ZFS) is to be set. Setting this parameter eliminates any measurements below the ZFS from the data set. If the user bypasses this stage, the ZFS becomes the highest zero flow stage. If there is no measured zero flow stage, the default is zero. The user can then enter the modelling procedure and choose one of two courses of action. The first is manual statistical modelling. It consists of user supplied transformation exponents, and evaluation based on statistical parameters. The procedure has been outlined by Douglas and Simonovic (1992). After choosing an exponent, the user is asked if they would like to force-fit the model through the ZFS. This simply tells the regression analysis that the intercept is the zero flow stage. This feature is very useful and meaningful when knowledge of the

control is known, and can be applied to the data set. The second method is that of automated statistical modelling (Gawne and Simonovic, 1992). The process creates 63 different models for several transformations of stage, and several BOX/COX transformations of discharge. Then, statistical tests are performed to arrive at the best possible fit. At this time the user does not have the opportunity to force-fit the models through the ZFS.

As mentioned in the above sections, the user is prompted to make several curves throughout the analysis. In the stream classification section, the user is asked to make preliminary curves to enhance the analysis. These curves should be fairly simplistic to make, considering that they are used as a best guess for allowable stage deviation. There is little need to apply the ZFS parameter to these curves, and they should be made by the first alternative manually. The user must remember to store these curves in the database for immediate use in the stream classification section.

When making curves from data selected in the non-stable channel analysis the user has to pay attention to the application and conditions that apply to the curve. For example, if the data set represents low flow stages only (ie., there is variation by stage in the relation), the user would most certainly define the ZFS. However, the following data set would represent high flow stages, and the user would most certainly not set the ZFS for this model. Otherwise, the modelling procedure can be as in-depth as the user specifies. The mathematical models that are made to represent the SD rating for a particular set of conditions, must be stored in the database. It is absolutely necessary when creating models of the SD relation which represent a subset of the overall rating,

that each "BEST" model of each subset relation is stored. This is to ensure that when the relations are used later that the overall rating relation is fully represented.

Outlier Analysis

The outlier analysis process has been outlined by Douglas (1992), and functions as a filtering system which tries to define the cause as to why certain measurements do not fall within a prescribed limit of tolerance to the curve. This analysis is used for both stable and non-stable channels. The outlier analysis concludes the procedure for the development of SD rating curves.

Compute Discharges

After selecting "Compute Discharges" from the main menu, the curve use mode is activated by the system. The first priority is to establish the correct path to take for computing daily discharges for the current station. If a channel was determined to be stable in the stream classification section the master system computes discharges as outlined by Douglas and Simonovic, (1992). Alternatively, a channel that has been classified as non-stable will take a slightly different course of action (Figure 4.9). The master system retrieves the classification out of the database and follows the path according to the predetermined stability classification. Retrieving a non-stable classification provokes the master system to load in the NSCUSE.tkb for handling the computation of average daily discharges for the current non-stable channel.

Upon entry into the non-stable curve use section, the user views a text window

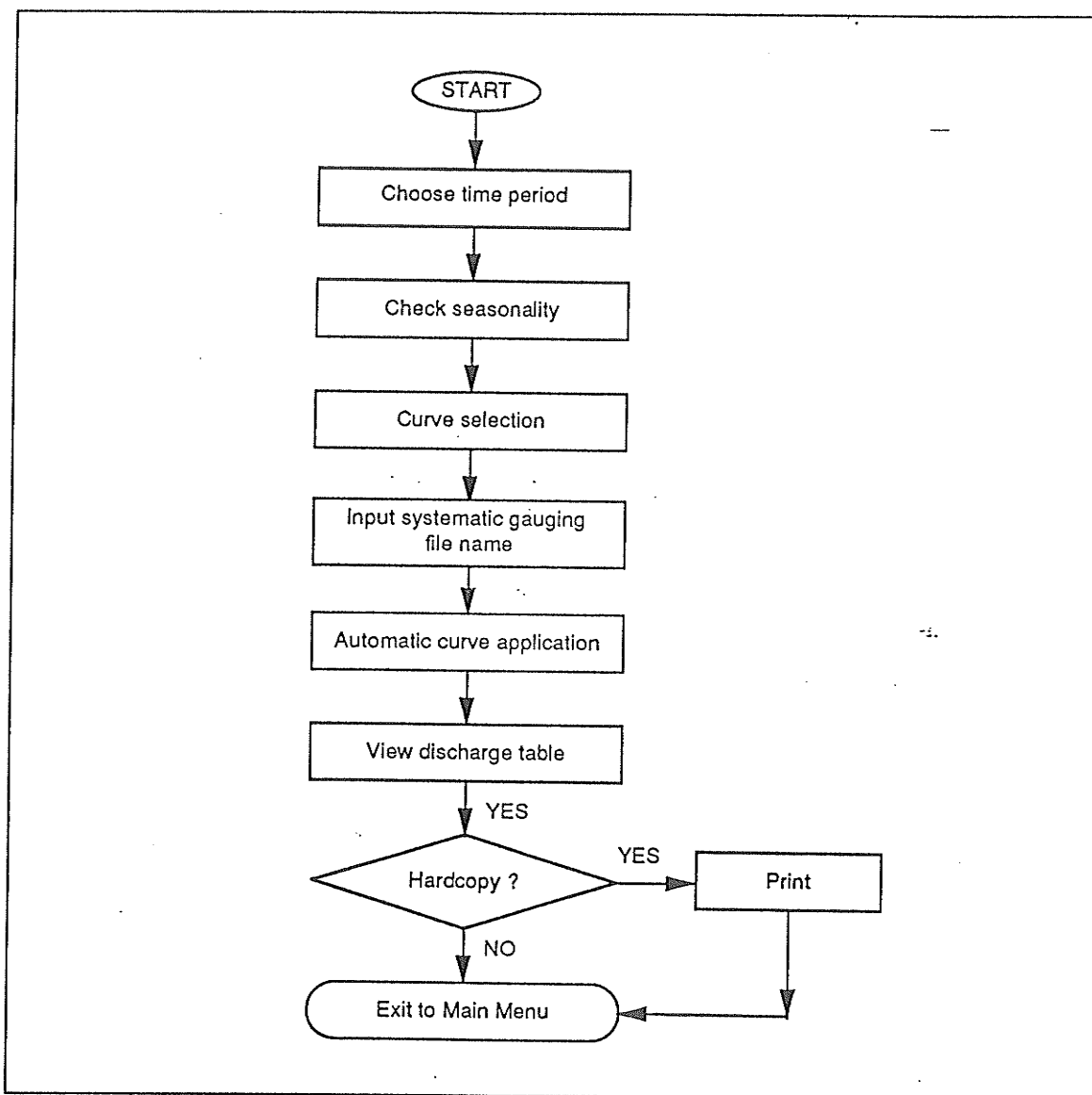


Figure 3.9: Framework for Compute Discharges (Non-Stable Channels)

that contains a summary report of the time segments in the station's period of record. When prompted, the user specifies the applicable time period and the system retrieves database information regarding the channel control and the type or types of conditions applicable to each curve made (seasonality, hysteresis effect, and/or variation effect with stage). If the current station is subject to seasonality, the user is prompted to tell the

system whether or not the gauging record applies to open water flow or ice condition flow. Otherwise, the curves apply to the gauging record throughout the year. Then, the system displays all active curves that apply to the current station. The curves are arranged in sets in chronological order. The sets apply to hysteresis, or variation with stage or both. Default curves are the first curves made for the station. The user has the power to override this setting, and select the set of curves he/she wishes. After inputting the complete path for the file that holds the gauging record information, the curve set is automatically applied to compute average daily discharge. For example, if the station is subject to hysteresis the curve set will contain three distinct models (rising, falling and stable stages). Taking these curves, the applied external program will analyze the gauging record for all three conditions and compute discharges using the appropriate model (ie., discharge for a gauging point on rising limb will be modelled with the rising stage curve). The computed daily discharges are then presented with or without confidence bounds in tabular form as determined by the user. The table is then available on an optional hardcopy. The presentation of the results and optional hardcopy represent the end of the section, and the system unloads the active KB and returns to the main menu.

Curve Modification

When the system retrieves a stable classification, the curves are modified as described in Douglas and Simonovic (1992). Otherwise, a non-stable retrieval commands the system to load in a newly developed KB called NSCMOD.tkb. This KB handles the process of modifying the mathematical relationships established for non-stable channels,

and the framework is illustrated in Figure 3.10.

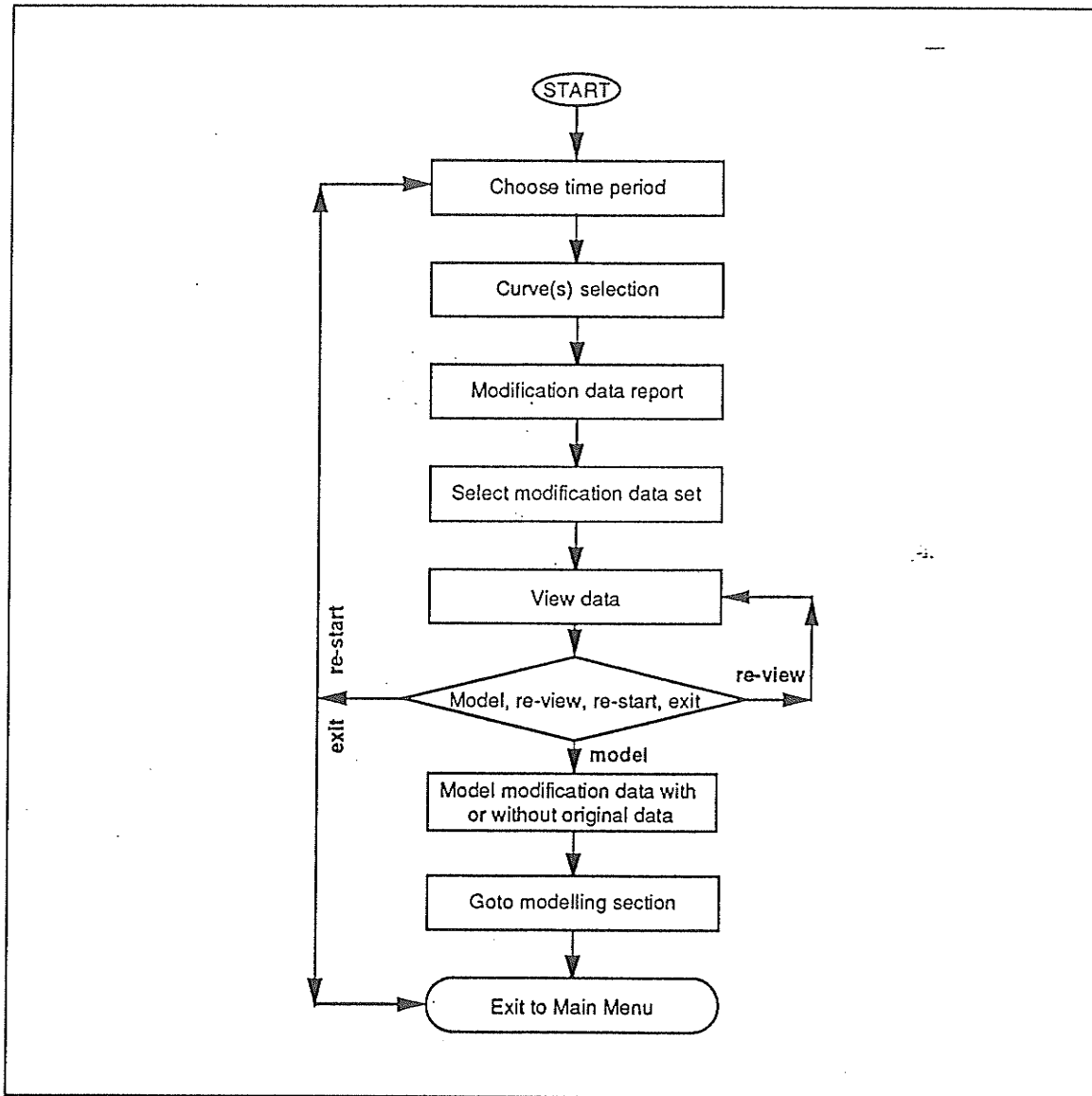


Figure 3.10: Framework for Curve Modification (Non-Stable Channels)

The system starts by prompting the user to select a time period presented on the initial message window. Again, the information from the database for the time period selected to be modified is retrieved from the database. This is followed by the report on all curves that pertain to this time period. The curve selection process is slightly different

for curve modification however. The user is solicited to input (no defaults) the curve number or numbers he/she wishes to work with. The number of curves entered is based on any variation by stage. If all curves were made without any variation with stage (ie., one curve represents the entire range of stage), the user selects only one curve to modify. Otherwise, the user selects a set of curves that represent the entire range of stage.

The program continues after selecting the appropriate curve(s) by retrieving data from the main data table regarding the original data and any other modifying data. The modifying data consists of those measurements that were observed during some "backwater" event, and any new measurements beyond the last time period. A report is produced which provides the user with the current station information, the end of the final time period and the number of original data points used to produce the curve to be modified. As well, the report displays the number of NEW measurements, and the number of measurements taken during six possible "backwater events". The measurements are distinguished in the main data table by a remark system currently used by Environment Canada. They are:

- 1) The number of measurements affected by Beaver Activity
- 2) The number of measurements affected by Wind Activity
- 3) The number of measurements affected by Debris on the Control
- 4) The number of measurements affected by Weeds on the Control
- 5) The number of measurements affected by a Near by Tributary
- 6) The number of measurements affected by Unexplained Backwater conditions.

From this report, the user is asked to select which modifying set 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 graph is produced and shown simultaneously with a plot of the original SD measurements against time contrasted with the modified SD measurements in time (termed pseudo hydrograph). 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. If the modified data plot in a random fashion about the original data, they should be modelled separately. Figure 3.11 shows the monitor display of the two graphs along with the options presented to the user in the session window.

Three of the options allow for back tracking. The first exits curve modification to the main menu. The last two allow the user to re-start the modification process or re-view the data shown respectively. However, the most important options deal with continuing the modification process, and ask the user if he/she would like to model 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 system sets in motion the process of building the query string for data selection and loading up the data selection KB for the user to model the data. The SD data is automatically selected according to the user's wishes and the user enters the data selection process at the point where the data is viewed and ready to be modelled. After completing the mathematical modelling process for the modified data set, the system returns to the NSCMOD.tkb, and immediately unloads this KB to return to the main menu.

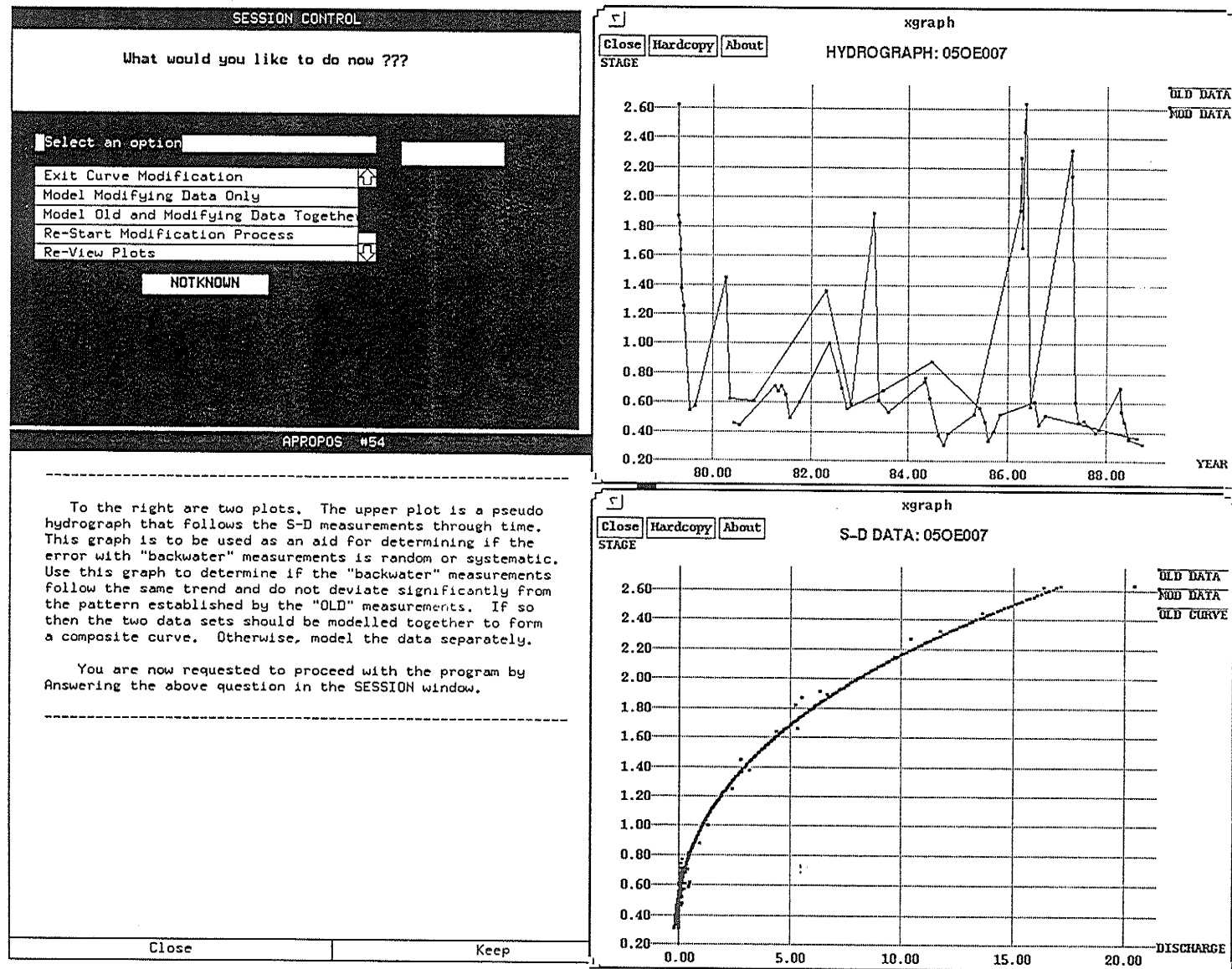


Figure 3.11: Curve Modification Diagnostics

Curve Extrapolation

To start the last module of the SDDSS the user selects "Extrapolate Data" from the main menu (Figure 3.12). This choice signals the master system to up load the EXTRA.tkb, and initiates the curve extrapolation process. This single KB handles the extrapolation for both stable and non-stable channels.

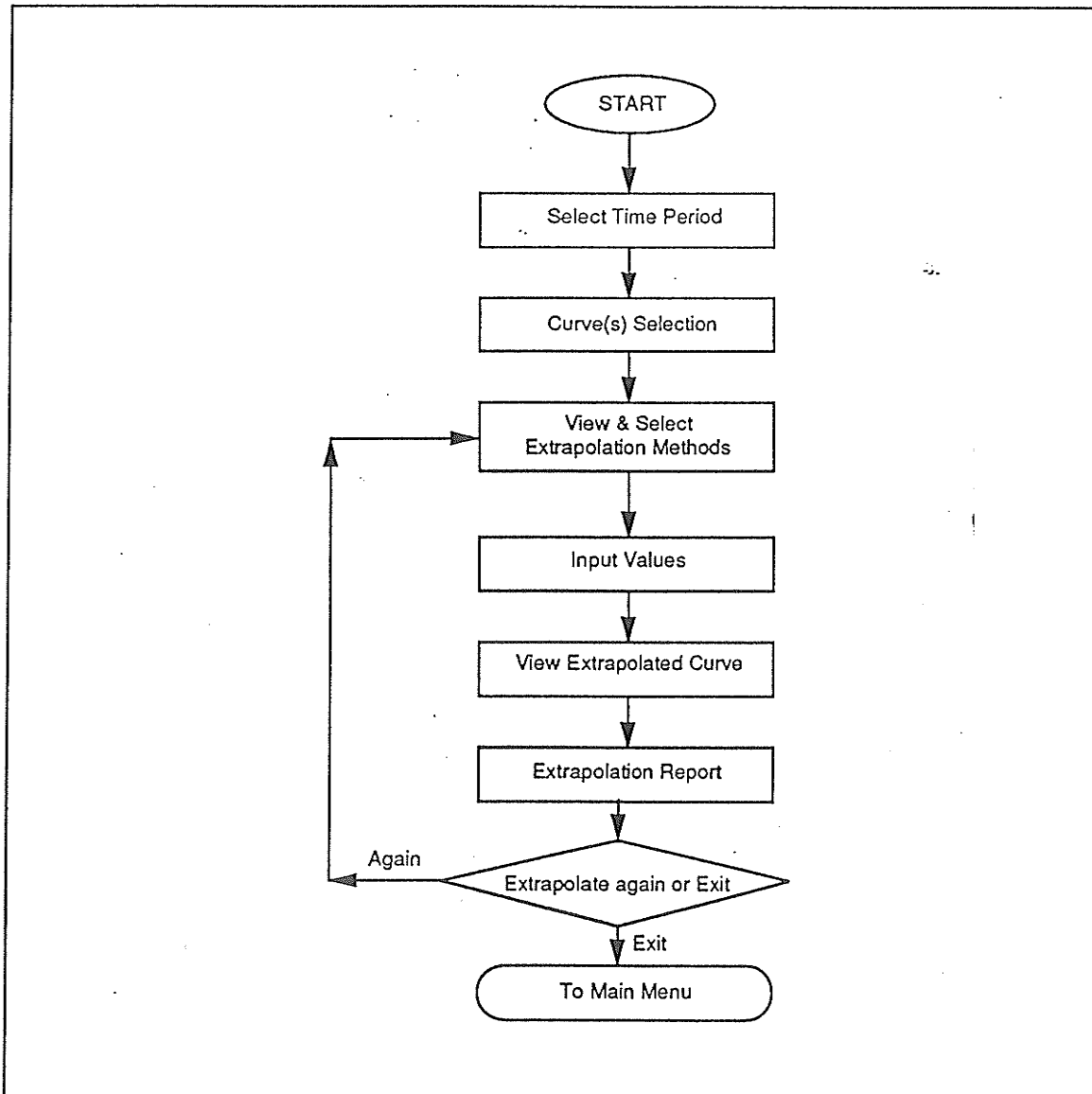


Figure 3.12: Framework for Curve Extrapolation

The process starts the same way as the curve modification process where the user selects a time period and a curve or curves to use in the extrapolation. Once this is complete, the system displays two graphs simultaneously (Figure 3.13). The upper graph displays the stage versus mean velocities of the current station. This graph illustrates the behaviour of mean velocity with stage. The mean velocity is derived from the current SD relation and its extrapolation, and also the extrapolation of the mean velocity by the remaining two methods. The graph is to be used as a diagnostic tool to aid the user in deciding the best method for extrapolation. The plot of the velocity can be used by the technician to compare to field notes, or the choice can be made based on an estimate of expected velocity at higher stages. The lower graph is simply a plot of the cross-section of the hydraulic control, and the stage area curve. It gives physical meaning to the shape of the above graph. A text message screen is also echoed at this time explaining the purpose of the two plots, and the choice of extrapolation methods available.

The user closes the text window and proceeds to choose an appropriate method of extrapolation. If the chosen method is "Extrapolation using Manning's Equation", the user is then presented the opportunity to input known values of slope and Manning's n , or continue the program with these as constants. Regardless of the user's input, the program continues and asks if the user would like to extrapolate stage from a designated discharge or discharge from a designated stage. The appropriate value is then entered, and the extrapolation is made by an external program. However, before the results are presented, the user first views two more graphs (Figure 3.14) in order to diagnose the relevance of the extrapolation made. The graphs shown simultaneously are: a graph of

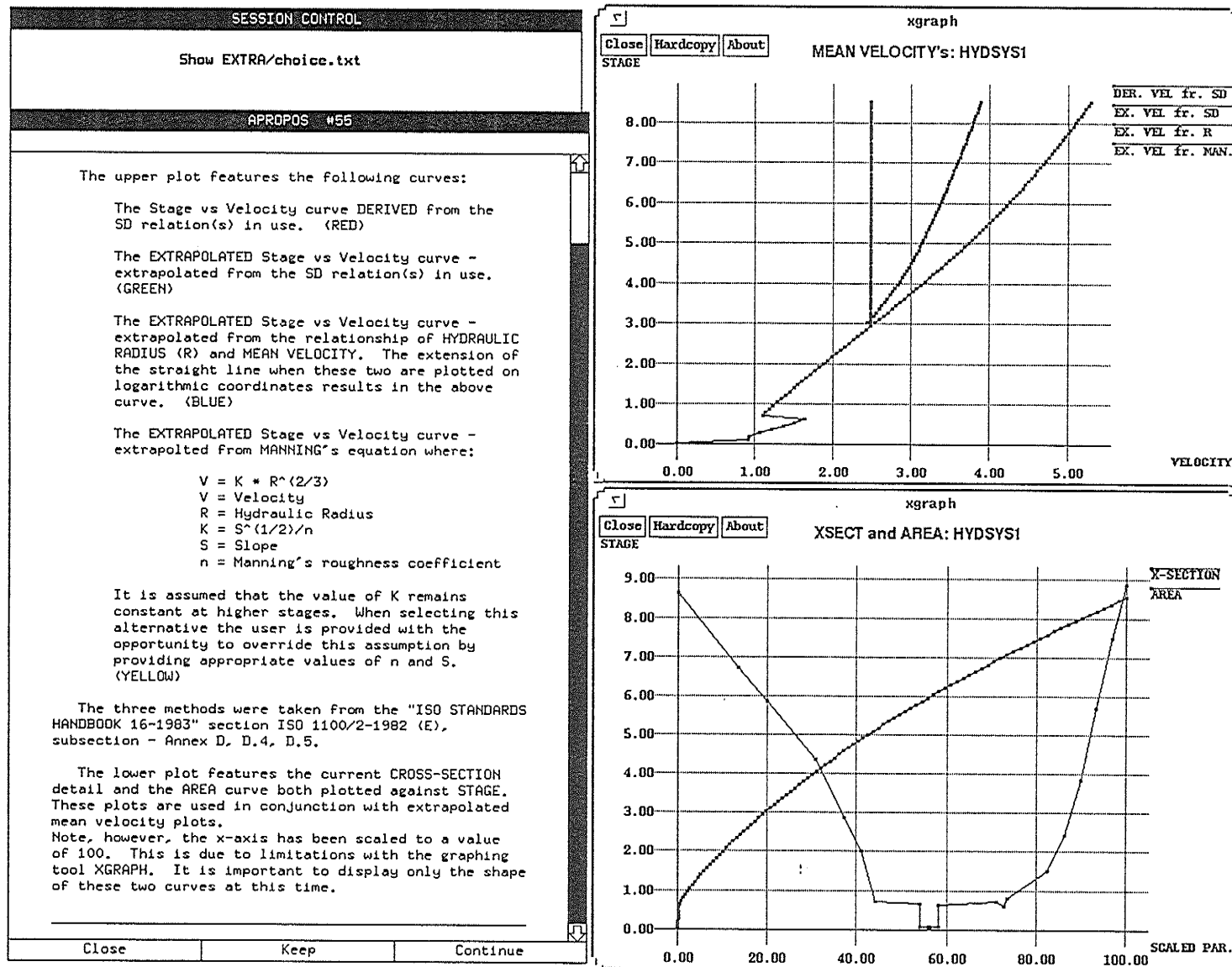


Figure 3.13: Extrapolation Method Diagnostics

SESSION CONTROL

Show EXTRA/valid.txt

Interrupt

APPROPOS #56

To the left are two graphical representations of the extrapolation process. The upper curve displays the measure of $K = S^{(1/2)/n}$ as a function of stage, while the lower curve displays the EXTRAPOLATED S-D relation.

Using these graphs to validate the extrapolation is an important step. By displaying any discontinuities in the SD relation one can determine that if they do not have any physical meaning the extrapolation is in error.

NOTE: IF the Manning's Equation method is used for extrapolation the upper plot is virtually useless because K is held constant in the EXTRAPOLATED STAGE RANGE.

SEE: The Section (5) - Curve Extrapolation, manual page #8 - evaluating the extrapolation for more information

The results of your choice of EXTRAPOLATION will follow please CLICK on the CLOSE button now...

Close

Keep

Continue

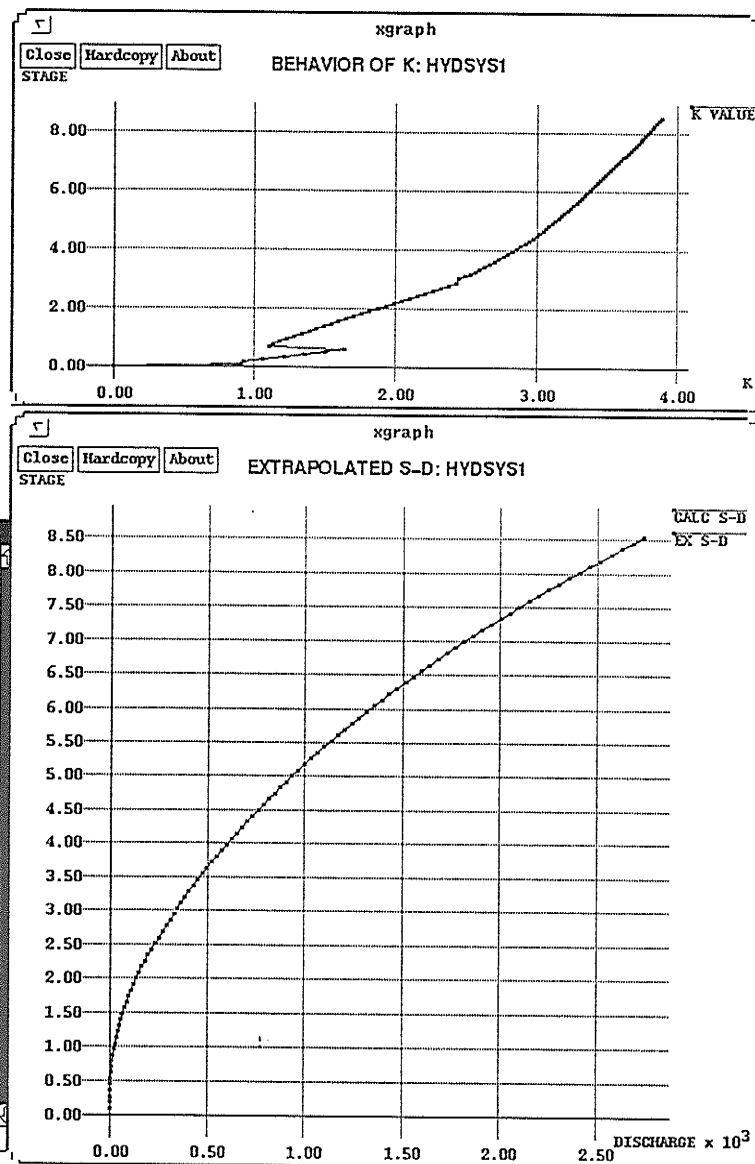


Figure 3.14: Extrapolation Evaluation Diagnostics

the behaviour of K (equal to $S^{1/2}/n$); and the extrapolated SD curve. These curves aid the user in defining the accuracy of the extrapolation value. If the relationships show a smooth and continuous transition between the current SD and the extrapolated SD, then the user can expect a respectable extrapolation value. After viewing the two curves, the extrapolation report is shown. The report provides the user with the input and results of the extrapolation made. The user is then asked if he/she would like to make another extrapolation. A "YES" answer reverts the system back to the point of the process where the user chooses a method for extrapolation. A "NO" answer exits the system to the main menu, but the user may acquire a hardcopy of the final extrapolation report before exiting.

3.3 Case Study

Three separate stations will be used in this case study to illustrate the analysis performed by the SDDSS on real data, because the database is not fully developed to handle all aspects of the SDDSS's data requirements. The data may be available, but has not been entered in the database. There are no appropriate hydraulic control cross-sections available from the hydrometric program. Some stations better illustrate some modes, because the cause of rating shift is known. Each user mode will be illustrated in this case study. The reasons for the station use will be presented as it occurs in the text.

Curve Development

Separate cases for stream classification and data selection will be presented for the curve development procedures.

Stream Classification

The North Milk River near the international border (station number 11AA001) is the station chosen for the stream classification, because it can be directly compared to previous studies: Spitzer, (1988) and McLean and Beckstead, (not dated). The Milk River's valley is generally wide and has walls composed of glacial till underlain by sandstone. The river meanders significantly through this glacial valley, with a large quantity of silt and sand sediment. The channel has experienced many changes throughout its history. Figure 3.15 depicts the SD relations developed since 1962.

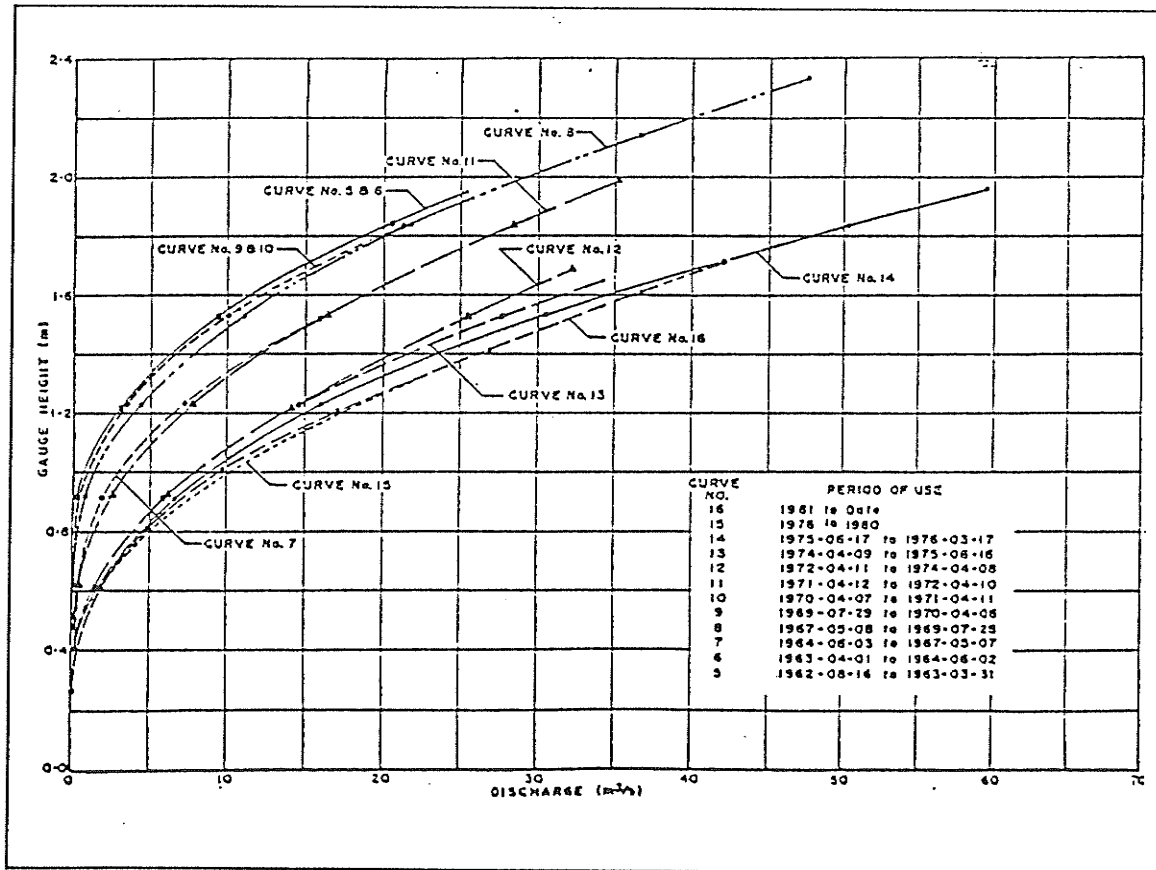


Figure 3.15: Stage-Discharge Relations: Since 1962 - North Milk River near International Boundary (Spitzer, 1988)

From the figure it is obvious that the relation is unstable, with the most dramatic shift occurring in 1972 (curve 11 to 12). The dramatic shift is concurrent a meander cut-off just below the gauging site. The specific gauge also illustrates the dramatic changes in the regime of the river (Figure 3.16). Spitzer attributes the "abrupt changes" to a partial cut-off in 1969, which completed between March 14 to 22, 1972. The following are the results of the SDDSS analysis for stability.

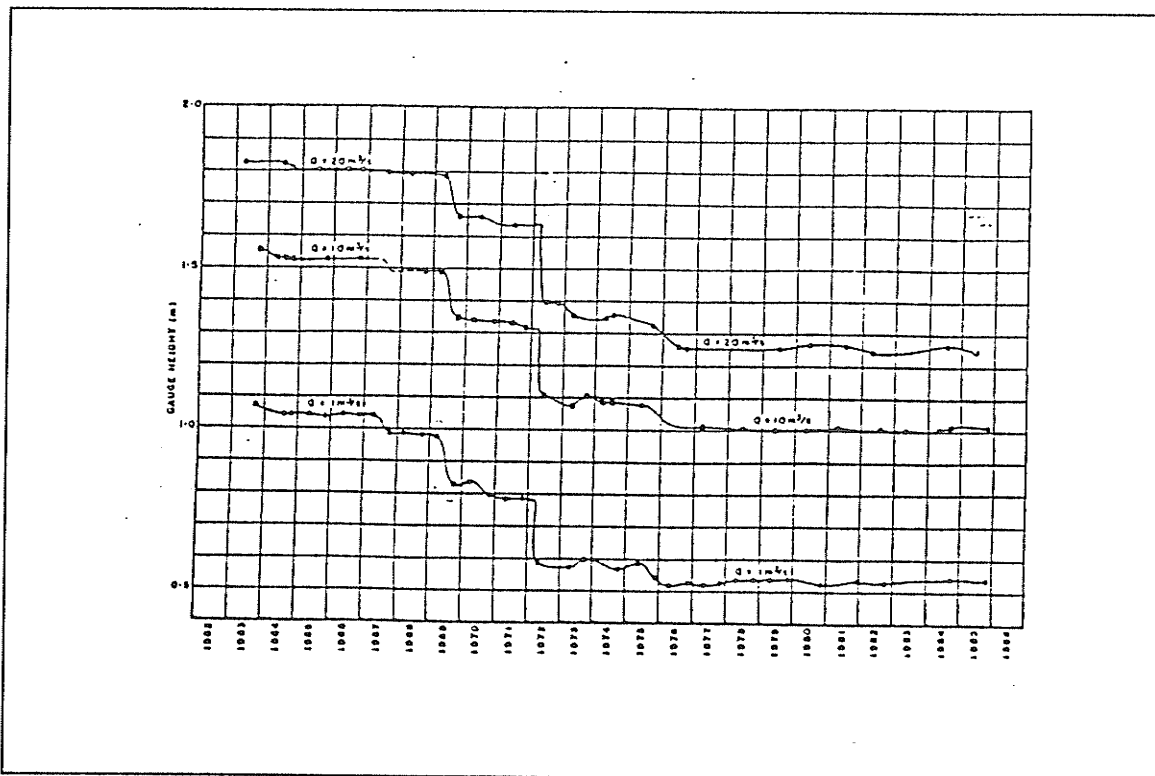


Figure 3.16: Specific Gauge for North Milk River (Spitzer, 1988)

Discharges of 1, 9 and 19 m³/s were used in the SDDSS analysis to represent the two, five and ten year floods (Figure 3.17). They are close to the flood frequency estimates used by Spitzer, namely 1, 10 and 20 m³/s (fig 3.16).

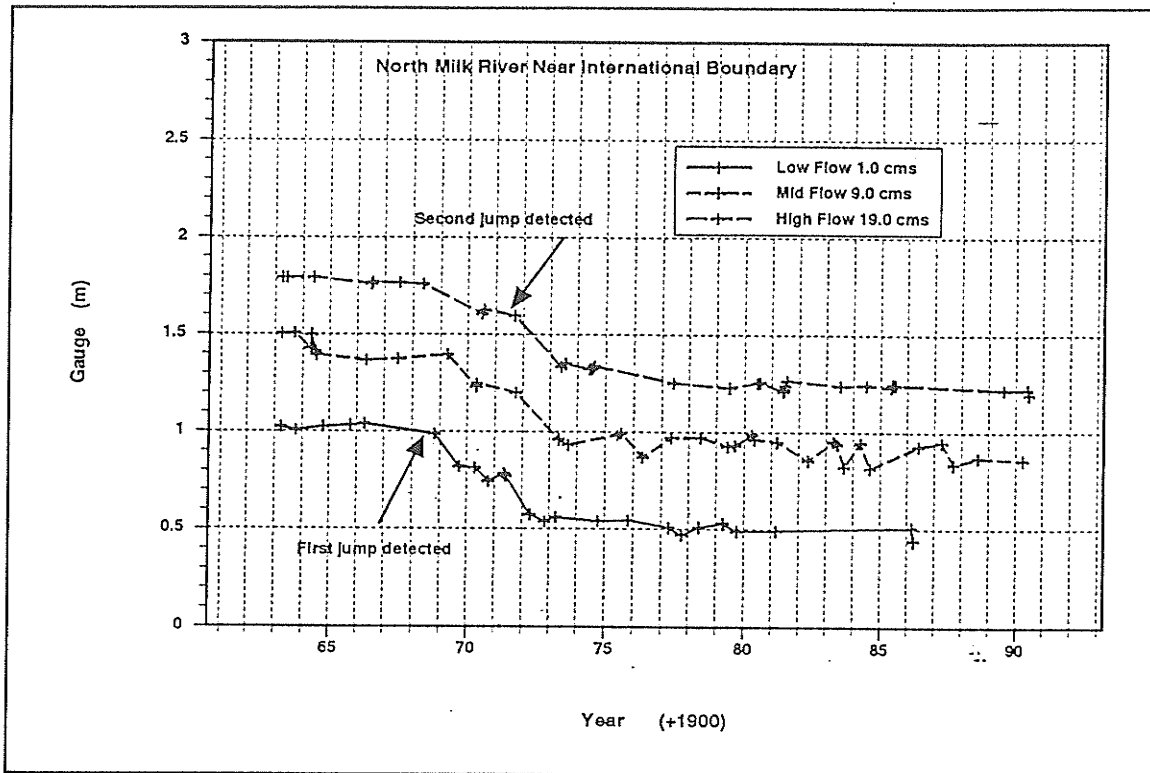


Figure 3.17: Resulting Specific Gauge Plot from SDDSS Analysis

The sequential specific gauge analysis - via absolute difference plot - reveals the detection of two significant "breaks" or "jumps": the first occurring in 1968, and the next in 1972. The results are very comparable, although the SDDSS indicates the partial cut-off starting in the latter part of 1968. This is a function of the interpretation of the SD measurements, which are interpolated to plot the specific gauge. The deficiency is also attributed to the dependence of the plot on the number of measurements in the data base. A significant number of measurements must exist over the entire regime (high, medium and low), in order to achieve effective analysis by this method. Thus, a review, and possible revision of the criteria may be necessary. Nevertheless, the current strategy and framework of analysis seems effective.

Following the identification of the jumps, the resulting classification analysis reveals the following summary:

STREAM CLASSIFICATION SUMMARY					
Station Name: NORTH MILK RIVER NEAR INT. BOUNDARY					
OVERALL STREAM CLASSIFICATION					
STABILITY CLASS		SEDIMENT TYPE		CHANNEL PATTERN	
-----		-----		-----	
NON-STABLE		SAND		MEANDERING	
CLASSIFICATION BY TIME SEGMENT					
SEGMENT NUMBER	TYPE OF FLOW	FIRST YEAR OF SEGMENT	LAST YEAR OF SEGMENT	NUM. OF POINTS	STABILITY CLASS.
-----	-----	-----	-----	-----	-----
1	LOW	62	67	5	NON-STABLE
1	MIDDLE	62	67	9	STABLE
1	HIGH	62	67	6	NON-STABLE
2	LOW	69	70	3	NON-STABLE
2	MIDDLE	69	70	3	NON-STABLE
2	HIGH	69	70	2	NON-STABLE
3	LOW	72	91	14	NON-STABLE
3	MIDDLE	72	91	23	NON-STABLE
3	HIGH	72	91	23	NON-STABLE
-----	-----	-----	-----	-----	-----

Note the number of points in the analysis for the second time segment. The lack of adequate data could have an effect on the programs ability to accurately define the stability of the stream in this time segment. However, by defining the time period as unstable the data is subjected to a more comprehensive data filtration analysis, which directly follows the classification. Future research should reflect the similarities between the data filtration schemes for stable and non-stable channels, and have a joint data selection procedure. The importance of the classification procedure would then be in the identification of major disturbances and critical periods which alter the SD relation.

Non-Stable Channel Analysis

The focus now turns to a stream that displays instability over the range of stage. Taken from HYDSYS (HYDSYS Pty, 1991), an Australian developed software package for time series data management, the data comes complete with a profile of the hydraulic control. Termed herein as the *Hydsys Test Station*, the extracted data spans the years between 1967 and 1991, and has a stage range of 0.002 to 2.95 meters. The hydraulic control is a complex cross-section, with the main channel below 0.65 meters, and a secondary channel whose profile extends to the 8 meter stage. Thus, a physical transition in the hydraulic control at approximately 0.65 meters can be associated with an expected transition in the SD relation at the same stage. At this time, results of the HYDSYS analysis were not available. However, this data is used as an illustration to see the analytical power of the SDDSS.

The stream was classified as a non-stable channel with no major perturbations occurring in the specific gauge diagram. Therefore, only one time period need be analyzed - from 1967 to 1987. There are no ice effects for this stream. Therefore, the curves pertain to assumed normal open flow conditions. Although the database was not adequately developed for the analysis of any hysteresis effects, the station is not known to be affected by this phenomenon. Thus, the analysis continued to the fourth level in the hierarchy; the variation by stage analysis, where the control's cross-section is required. Figure 3.18 illustrates the control and the point where a transition in the curve exists. Consequently, the data set was separated into two parts - 0 to 0.65 meters and 0.65 to 2.95 meters. Mathematical models were developed by the SDDSS, and the optimal

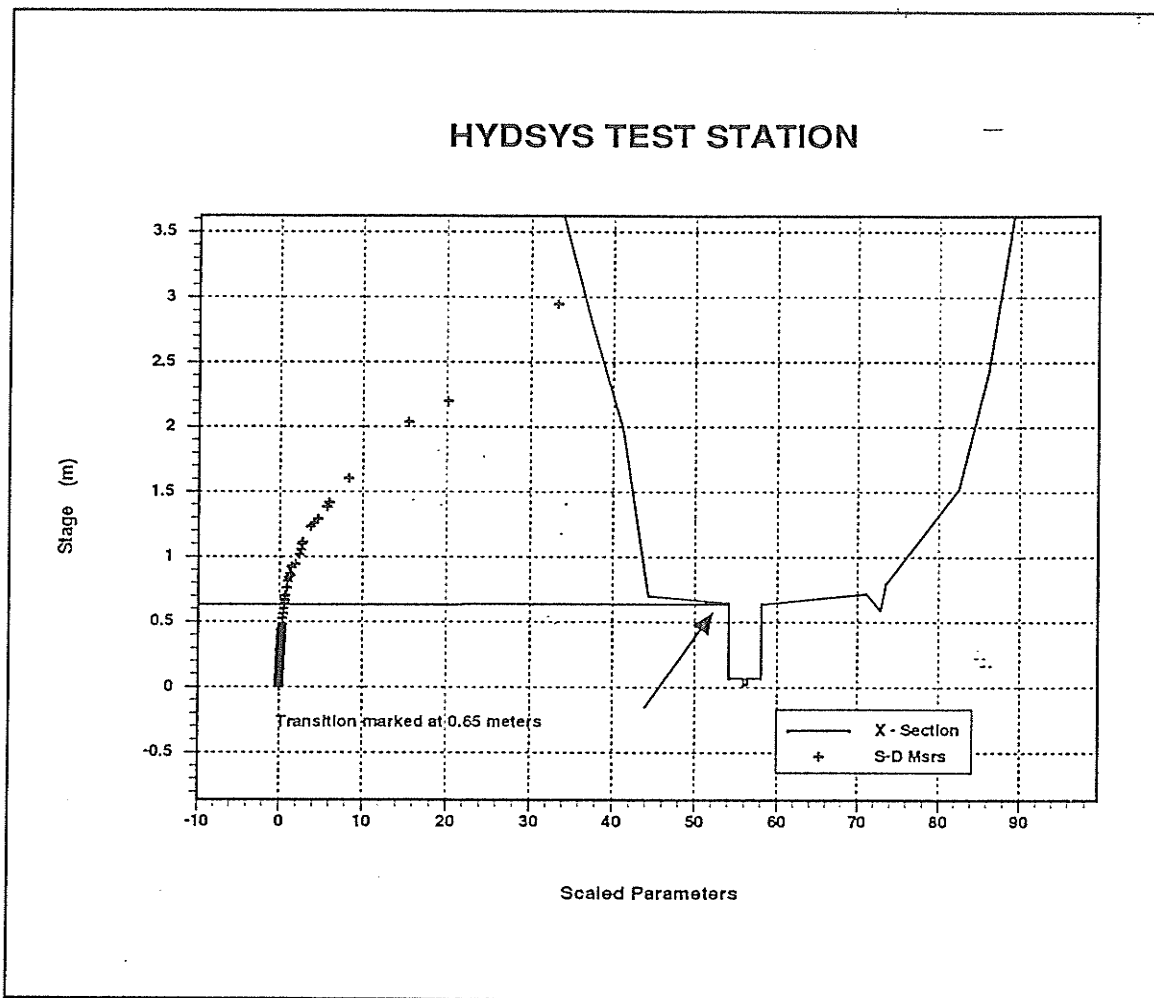


Figure 3.17: Cross-Section Used in Analysis of Hydsys Test Station Data

models chosen are shown in Table 3.1. Notice that in curve number 3 (Curve Id, column) that the Zero Flow Stage was set at 0.002 meters. This coincides with the channel bottom.

The statistics show excellent fits: Curve 3 - $SEE = 0.108$, $R^2 = 0.9885$ and the number of outliers $OUT = 35$, Curve 4 - $SEE = 7.085$, $R^2 = 0.9905$ and $OUT = 3$. The number of outliers was based on a 20 percent allowable error, and most outliers were found near the bottom of the curves. The shapes of the two curves are shown in

Table 3.1: Results of the Curve Development Analysis

Curv Id	Type Code	Date of First Meas.	Date of Last Meas.	Min Stage	Max Stage	No Flow Stage	Min Dis	Max Dis	Transform Type	B0	B1	Trans Exp.	#N of Points	Previous Curve Id.
3	ONHLW	05-Feb-80	23-Dec-86	0.009	0.640	0.002	0.000	5.015	POWER	-0.044	11.430	1.70	151	NA
4	ONHHI	14-Jul-80	21-Nov-86	0.664	2.950	NA	5.993	319.697	POWER	-5.456	36.911	2.35	26	NA

Figure 3.19, where it is evident the transition zone spans the range of stage between 0.640 and 0.664 meters. In this area no curve is truly applicable. These same two curves will be used to illustrate the Curve Use and Curve Extrapolation modes later in this section.

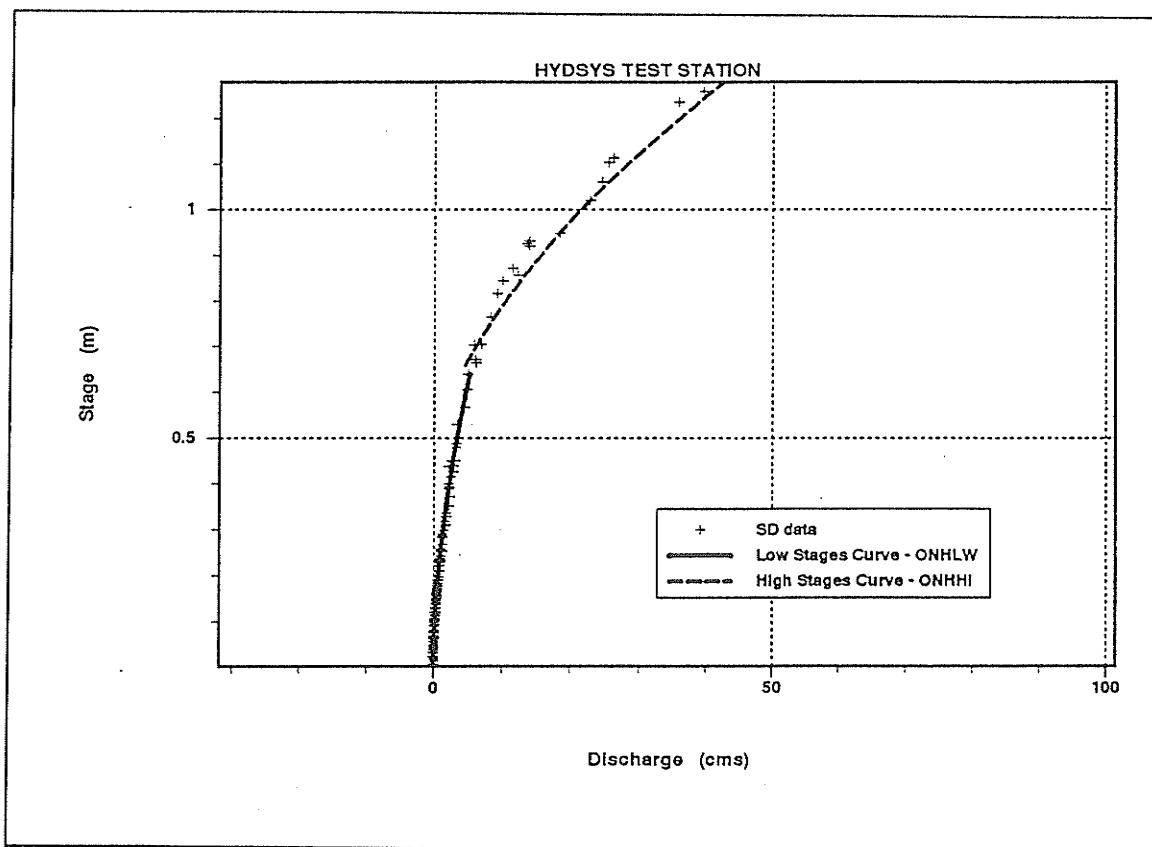


Figure 3.19: Results of Non-Stable Channel Analysis

Compute Discharges

The application of the above two curves to a record of hourly gaugings is performed automatically. An example gauge record for 1984 was used in this mode, spanning from May 7 to September 10. The gauging record is displayed in Figure 3.20. Note the position of transition zone. The external routine used to calculate the average daily discharge marks this zone, and applies the upper curve to it by default. Future research to apply smoothing algorithms to these zones will also be incorporated into the Curve Use mode for streams that vary by stage.

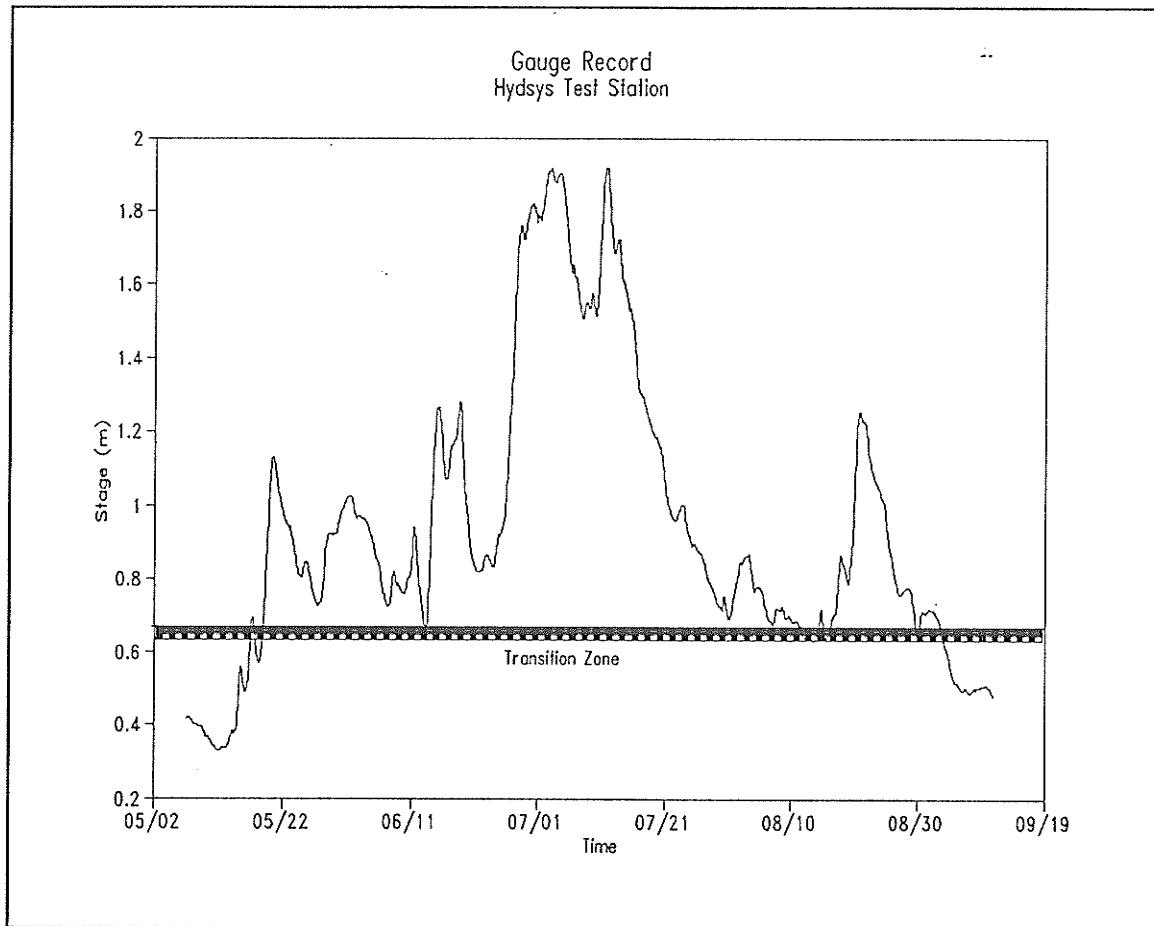


Figure 3.20: Hourly Gaugings for the Hydsys Test Station

The results of the application of the curves to the above record are posted by the SDDSS, and shown to the user as in Figure 3.21. The monthly maximum, minimum and mean are also calculated, along with the maximum and minimum daily flows. These curves could also have been used to produce a confidence interval associated with each average daily discharge.

Curve Modification

Joubert Creek at St. Pierre-Jolys (Station Identification Number 05OE007) is an excellent station for illustrating the power of the Curve Modification mode. A smaller stream in the Southeast corner of Manitoba, Joubert Creek often has backwater problems due to the inundation of the control with weeds. This effect is evident in the gaugings of the summer months, and the corresponding SD measurements. The SDDSS database has a record of measurements from 1979 to 1991. A normal open curve (ODAT code) was developed for this time period, and Table 3.2 illustrates the results. Accompanying the table is the stage-discharge graph (fig. 3.22) of the original model and its corresponding curve.

Table 3.2: SD models for Joubert Creek

Curv Id	Type Code	Date of First Meas.	Date of Last Meas.	Min Stage	Max Stage	No Flow Stage	Min Dis	Max Dis	Transform Type	B0	B1	Trans Exp.	#N of Points	Previous Curve Id
4	ODAT	20-Apr-79	22-Apr-91	0.310	2.637	0.350	0.001	20.400	POWER	-0.081	1.311	2.65	45	NA
5	WDS	12-Jun-80	31-Jul-90	0.336	1.130	0.350	0.001	1.580	POWER	-0.028	1.102	3.50	29	4

APROPOS #8												
DAILY DISCHARGE IN CUBIC METERS PER SECOND FOR 1984												
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1						134.635	297.851	103.446	89.360			
2						127.371	323.169	109.584	83.762			
3						125.833	320.019	105.679	75.819			
4						120.334	319.842	98.223	68.062			
5						110.393	285.887	94.641	64.716			
6							98.542	256.136	86.539	63.727		
7					55.547		93.447	236.720	88.739	63.514		
8					53.886	101.564	234.134	90.156	64.400			
9					52.749	97.062	237.555	87.624	65.053			
10					50.092	101.421	250.222	86.009	63.295			
11					47.896	114.855	318.724	83.268				
12					47.590	94.382	288.356	80.994				
13					48.837	91.735	272.268	79.824				
14					52.466	150.908	248.456	85.762				
15					66.152	170.386	230.580	81.845				
16					68.544	146.160	198.764	86.738				
17					82.741	159.589	182.272	102.771				
18					75.967	173.285	170.890	104.615				
19					115.028	139.501	162.954	114.682				
20					149.618	112.400	152.123	167.422				
21					134.857	104.849	132.555	169.387				
22					124.516	108.156	126.207	151.095				
23					115.437	108.389	130.560	140.656				
24					103.524	114.503	121.346	131.970				
25					106.890	124.192	114.946	113.471				
26					97.619	165.764	111.395	100.799				
27					92.869	245.383	104.028	96.755				
28					109.809	282.491	97.342	98.002				
29					119.587	296.213	91.829	87.124				
30					123.500	295.627	91.242	86.926				
31					132.316		91.011	89.740				
MAX					149.618	296.213	323.169	169.387	89.360			
MIN					47.590	91.735	91.011	79.824	63.295			
MEAN					89.122	143.646	199.980	103.371	70.171			
MAXIMUM Daily Flow = 323.169 cu.m/s												
MINIMUM Daily Flow = 47.590 cu.m/s												
Close												
Keep												

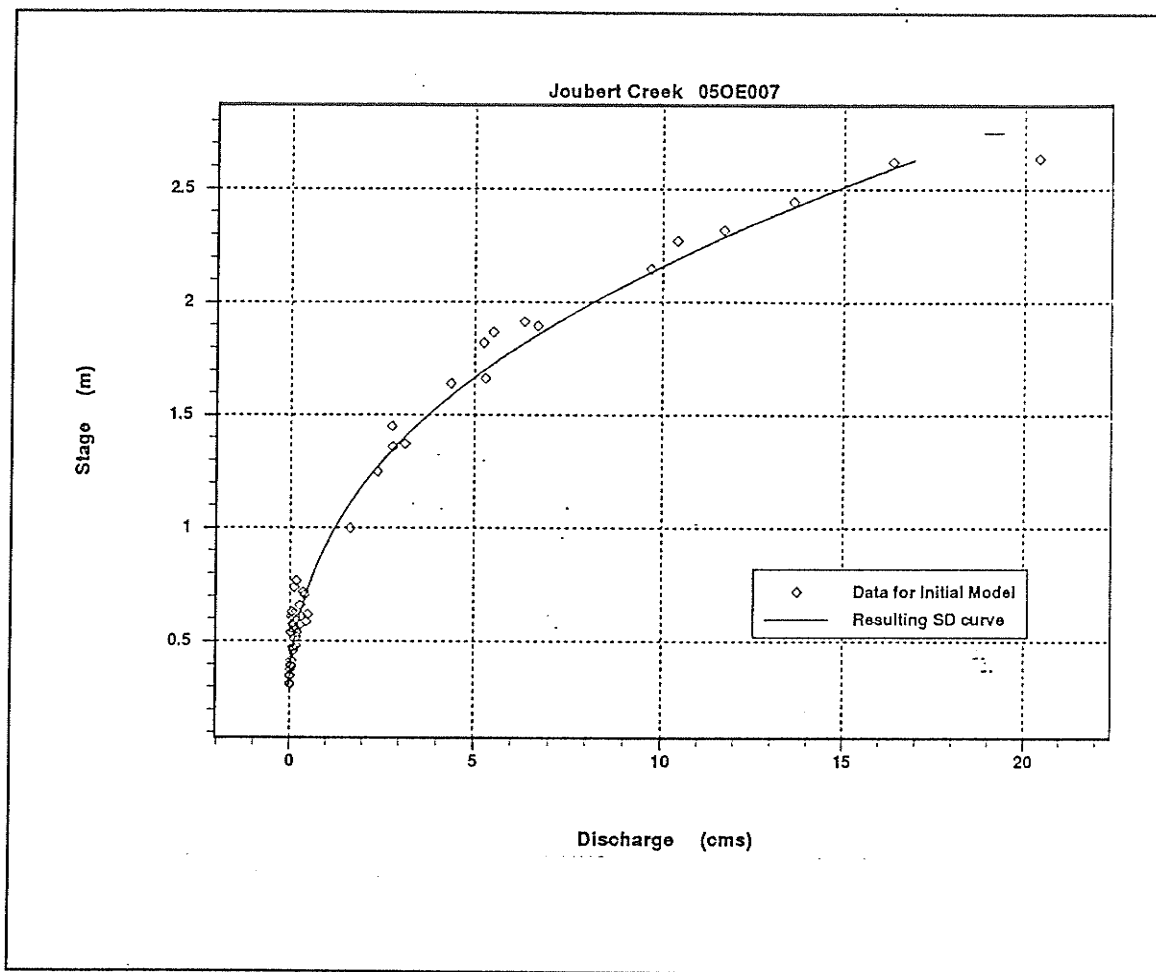


Figure 3.22: Initial Model Development for Joubert Creek

It is interesting to see the scatter of points near the bottom of the curve. This is an indication of an inadequate or infrequently used remark coding system used by Environment Canada, because it appears that under low flow conditions there are many influences on the SD relation at this site.

For non-stable channels it is easy to see differences in the data assumed to represent normal open flow, and those data points identified as backwater due to various phenomena. Figure 3.23 is a graphical comparison of the assumed normal flow, and the

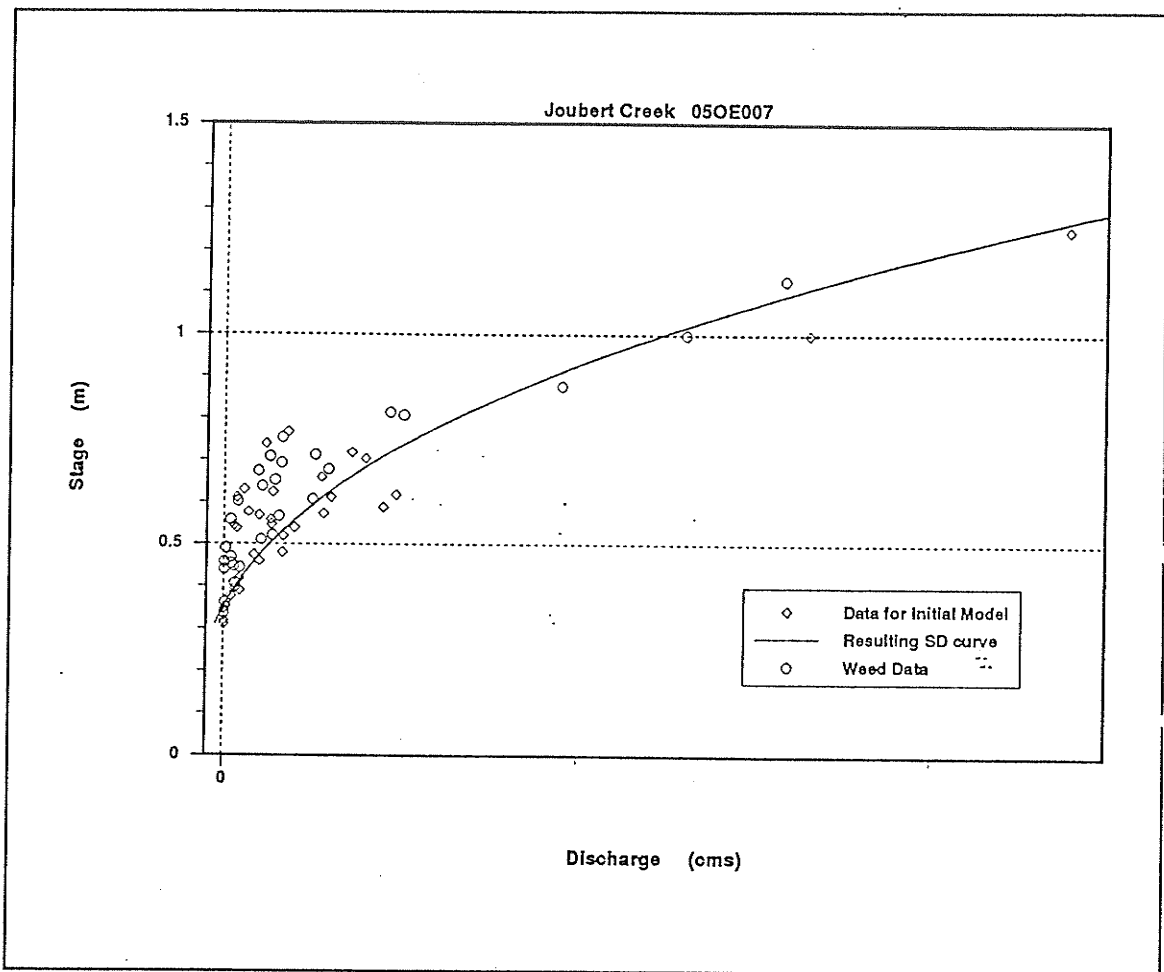


Figure 3.23: Comparison Diagram of Normal Flow and Weed Data

weed remarked measurements. Notice the dispersion of the original data among the rather coherently displaced weed data.

Through the SDDSS analysis it was decided to separate the modified data from the open flow data, and create a SD curve specific to backwater condition caused by weeds (WDS curve Table 3.2 above). The tabular results are better understood graphically. The next two figures (fig. 3.24 & 3.25) show the weed data and corresponding SD model alone, and in comparison to the original model.

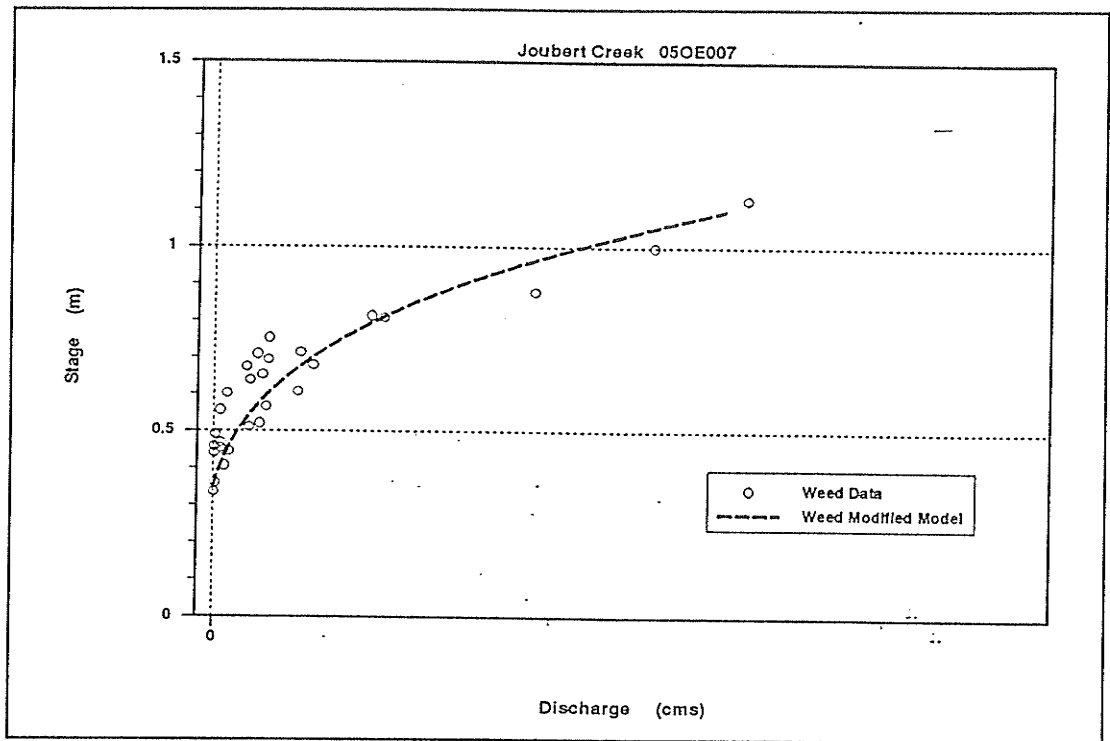


Figure 3.24: Weed Data and SD Model

It is interesting to see the effective stage range of the weed curve, and that its shape returns to the original model at the end of its range. This is an expected result, because backwater due to weed growth is usually ineffective at higher stages, when flood waters flatten weeds along the bed.

The Modified model is stored in the database, and can be used in the application of the gauging record to produce daily discharges. The effective time frame of the WDS model is for the months of June and July, and caution must be taken when applying the model. The SD measurements and the gaugings should correspond before application is performed.

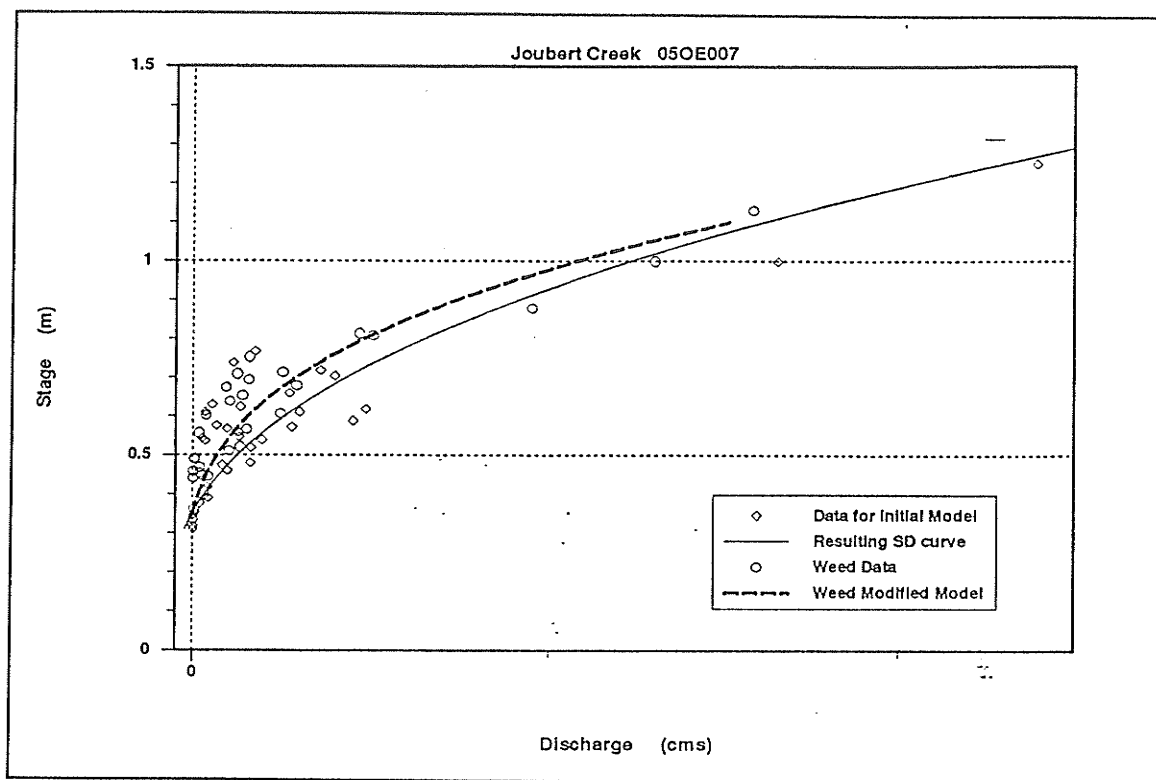


Figure 3.25: Comparison of Models for Joubert Creek

Curve Extrapolation

The last mode is again illustrated by the Hydsys Test Station, because the knowledge of the hydraulic control is necessary for all extrapolation methods. The curves selected prior to the analysis are the same as those found in Table 3.1 and Figure 3.19. The analysis performed involved all three methods. For the extension of the curve by the Manning's equation method, no coefficients for roughness and slope were entered. Therefore, the default K was used in this scenario.

As expected the three methods give quite different results ranging from 808 cms to over 1300 from an extrapolated stage of 5.25 meters. This is largely due to the shape

of the corresponding extended curves for each method (Figure 3.26). It is succeeded by the *extrapolation report* of results as viewed during the consultation.

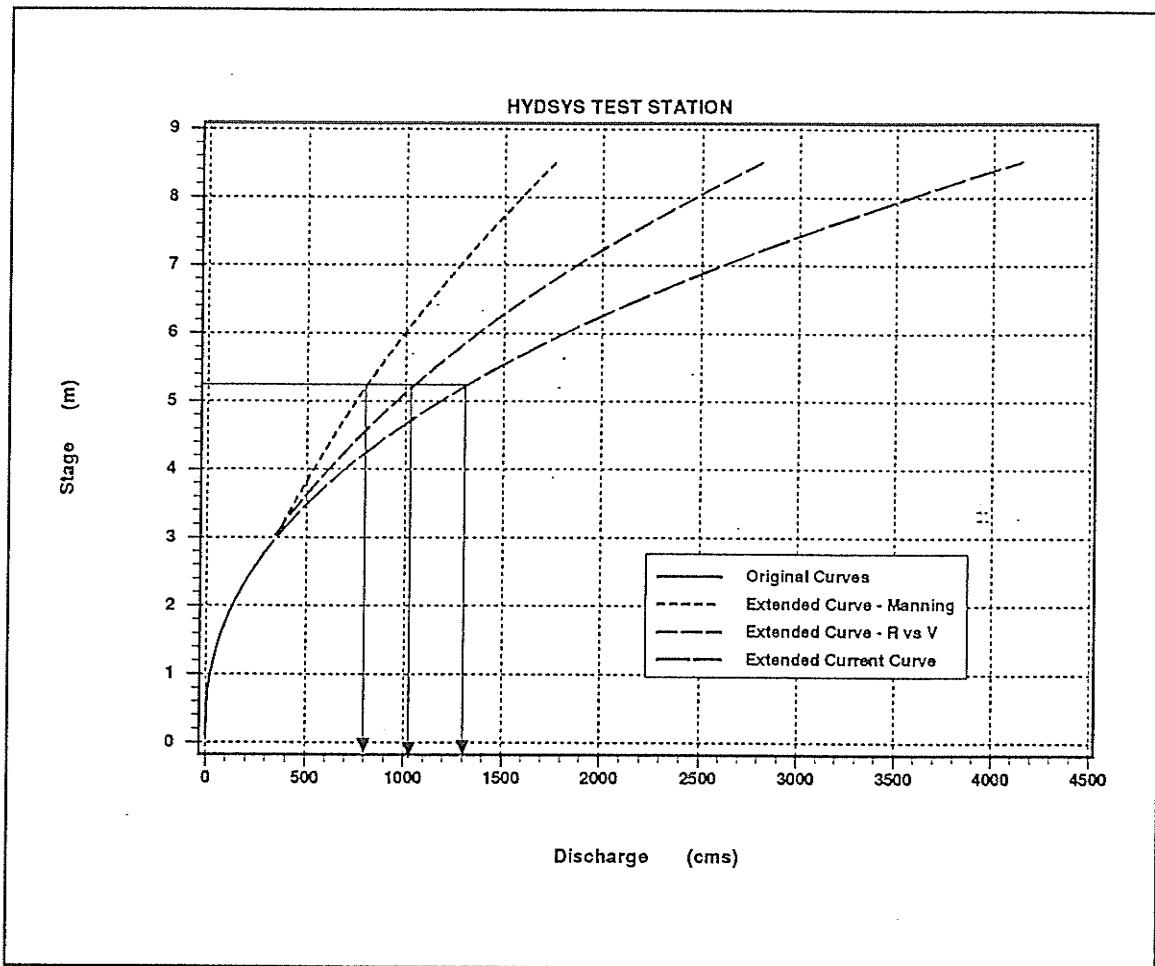


Figure 3.26: Results of Curve Extrapolation

The determination of the best extrapolation estimate is left up to the user. The presentation for the Manning's equation method are quite misleading. If adequate values for slope and n were known for the extended stages, better estimates could be made. Future data gathering missions should not ignore the value of the information obtained from water surface slope, roughness estimates and cross-sectional profiles. This would most certainly improve the reliability of the estimates provided by the SDDSS.

EXTRAPOLATION REPORT						
GIVEN DATA					EXTRAPOLATED VALUE	
VARIABLE	VALUE	METHOD	SLOPE	n	VARIABLE	VALUE
-----	-----	-----	-----	-----	-----	-----
STAGE	5.250	MANN	N/A	N/A	DISCHARGE	802.105
STAGE	5.250	RvsV	N/A	N/A	DISCHARGE	1030.273
STAGE	5.250	SD	N/A	N/A	DISCHARGE	1243.608
-----	-----	-----	-----	-----	-----	-----

3.4 User Manual

The on-line user manual provides a comprehensive library of explanations regarding the use of the SDDSS, as well as explanations for the methods, and background theory behind the processes of the SDDSS. In addition, the manual pages describe the functionality and ease of use of the system. The manual also provides documentation and standardization of the procedure for SD analysis. It is a key function which adds to an all encompassing system to rigorously provide standardized stage-discharge rating curve analysis. The following sections emphasize the implementation platform, and overall organization of the on-line help manual system

3.4.1 Implementation

The on-line help manual is developed using a public domain software, XMAN, available over the UNIX network. XMAN provides an excellent means to look up

explanations for key-words highlighted by the SDDSS system. Key-words are stored within sections that correspond to the user modes of the system. Manual pages are accessed through a hierarchy of pull-down section menu and look-up key words.

The XMAN icon is displayed in the upper left corner of the monitor display at all times during the operation of the SDDSS. From the icon a click of the mouse on the Manual Page button, at anytime during the consultation, opens a window which allows the user to browse through a system of developed help text (manpages). The operation and manual page selection are totally window and menu driven.

3.4.2 Framework and Description

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. Figure 3.27 shows the position of the icon and the manual page with respect to the main menu in the session window of the SDDSS. The initial manual page contains further information regarding the help manual browser. Further information regarding the SDDSS is supplied through a pull-down menu, and keyword activated manual pages.

Clicking on the "Sections" button (upper left corner of manual page) pulls down the sections menu. This is the table of contents of the library of manual pages. The sections are relevant to those illustrated in this thesis. For example, all manual pages regarding the Stream Classification section of the SDDSS are under the "Stream Classification" section of the manual browser. Selecting a section reveals a listing of all

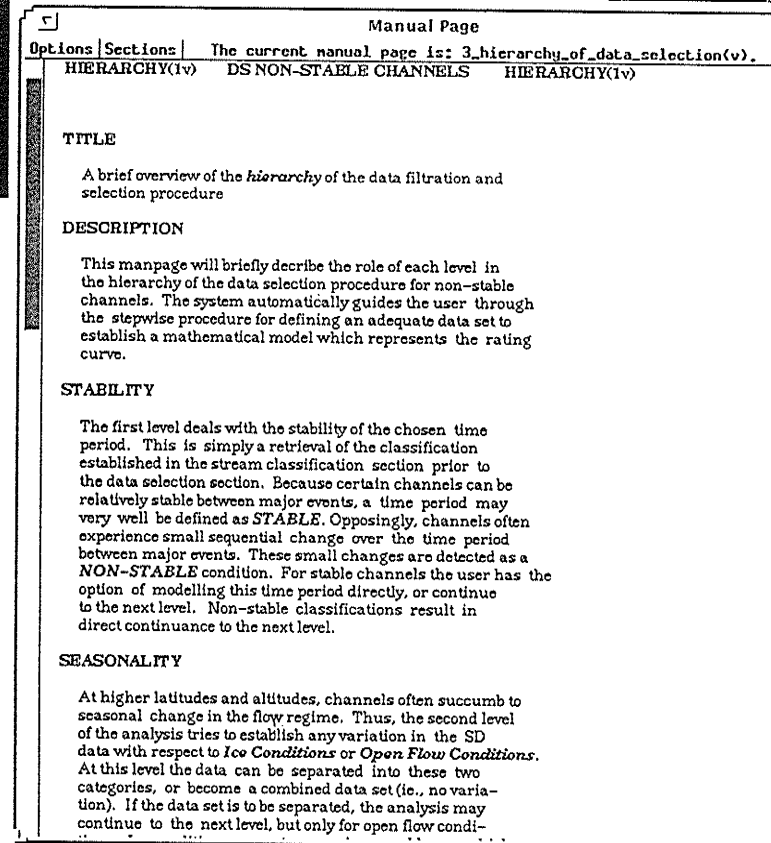
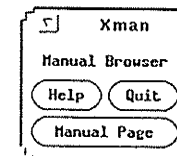
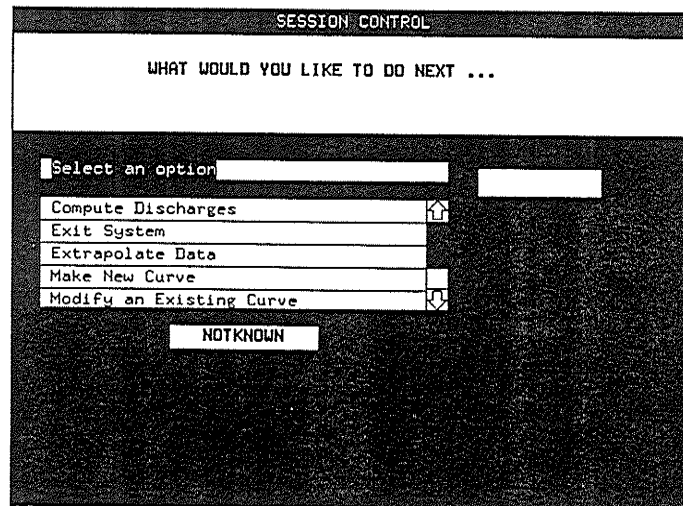


Figure 3.27: Xman Help Manual

manual pages within the section. The manual pages are identified by keywords that describe the topic of the manual page. For example, clicking on the keyword "Specific Gauge" would load up a manual page that displays information text on the specific gauge plot, its function and use in the SDDSS. Below (Table 3.3) is a complete listing of the hierarchy of manual sections, and their respective keyword manual pages.

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. Each manual page in the table listing is included in Appendix A. As can be seen the manual page is quite explicit, and detailed. As expertise is incorporated and sophisticated routines added, the on-line help manual will expand. Eventually, it is suggested to move the help manual to a graphical user interface (GUI) format. In this form, the availability of the help will simply be at the push of a button within each window of the consultation. This will eliminate the need for the keyword search. Also, the GUI method will employ more flexible text display, and possibly access to graphic displays of Bitmap files (digital photos or pictures), and sample graphs. The use of graphics will greatly increase the power of the help system.

Table 3.3: Manual Page Listing for SDDSS On-Line Help Manual**(1) SDDSS Overview**

1 More Help	2 SDDSS Overview	3 System Platform
4 Curve Development	5 Curve Use	6 Curve Modification
7 Curve Extrapolation	8 Acronyms	

(2) Curve Development

1 CD Objectives	2 CD Architecture	3 Stream Classification
4 Data Selection Stable Controls	5 Data Selection Non-Stable Controls	6 Mathematical Modelling
7 Outlier Analysis		

(2.1) Stream Classification

1 classification	2 stability analysis	3 specific gauge
4 difference plot	5 residuals of gauge	6 preliminary curve
7 stability criteria	8 sediment type	9 channel pattern

(2.2a) Data Selection (Stable Channels)

1 overview	2 general procedure	3 select all
4 select specific	5 ice selection	6 open selection
7 time selection	8 zero flow stage	9 curve type codes

(2.2b) Data Selection (Non-Stable Channels)

1 overview	2 general procedure	3 hierarchy of data selection
4 seasonal variation	5 variation due to hysteresis	6 variation by stage
7 transition zones	8 curve type codes	9 ICE conditions

(2.3) Mathematical Modelling Procedures

1 overview	2 auto stat modelling	3 manual stat modelling
4 transformations	5 statistics	6 stat test
7 skew kurt	8 residual plot	9 probability plot
9a optimal model		

(2.4) Outlier Analysis

1 overview	2 general procedure	3 beaver activity
4 meander cut-offs	5 debris on control	6 rising-falling stage
7 tributary effects	8 wind effects	9 vegetal growth

(3) Curve Use

1 overview	2 stable curve use	3 non-stable curve use
4 daily discharge predictions	5 discharge at 15 min intervals	6 lookup discharge table
7 default curves		

(4) Curve Modification

1 overview	2 SC modification	3 NSC modification
4 modifying data sets	5 modified models	6 NSC diagnostics

(5) Curve Extrapolation

1 overview	2 extrapolation procedure	3 selecting curves
4 current curve method	5 R vs V method	6 Mannings Eqn method
7 choosing a method	8 evaluating the extrapolation	

4. MULTI-OBJECTIVE STAGE-DISCHARGE EVALUATOR (MOSDE)

4.1 Introduction

Recent computer based procedures have utilized many statistical curve fitting techniques to establish the rating curve. Several types of data transformations are suggested (Gawne and Simonovic, 1993 and HYDSYS Pty Limited, 1991). The main problem arises when trying to establish *which transformation reveals the best fitted curve*. Another problem arises when the *single equation is used over the entire range of stage*. There are several hydraulic and hydrologic reasons why the stage-discharge relation changes for different ranges of stage (for example in-bank stage and bank-full stage) (Anderson, 1988). To date no technique can properly address these two issues without the technician having prior knowledge of the control, and a good grasp of the statistical procedures.

This chapter is exploring the use of computed statistical measures of fit, and a systems analysis approach to find an "optimum" mathematical model for the SD rating curve. The developed approach, named MOSDE (Multi-Objective Stage-Discharge Evaluator), is organizing the data by stage, choosing a portion of the data set at a time, and recursively evaluating the appropriate SD relationship (DeGagné and Simonovic, 1994). The objective is to determine the range of stage for which a specific SD relationship applies. The evaluation is based on the application of multiobjective Compromise Programming technique. Compromise Programming is able to identify the

compromise solution defined as the solution closest to the ideal point, as determined by some measure of distance (Cochrane and Zeleny, 1973; Goicoechea et al., 1982).

The description includes a computer based approach (MOSDE) that employs regression analysis for the development of stage-discharge rating curves. The regression is done recursively as the program steps through the data set, by adding one point at each iteration. Compromise Programming evaluates the improvement or deterioration of the model using a set of statistical criteria. The overall task is to fit a proper curve, or curves, to any given SD data set. Also, the key transition points in the SD relation are identified. This process eliminates ambiguity or subjectivity associated with current methods used for the development of SD relationships.

The problem domain and the methodology incorporated in the MOSDE are discussed in the next section. The following section deals with the implementation of the method. The chapter concludes with the presentation of one complete case study.

4.2 Prototype System and Methodology

The MOSDE is a completely independent procedure in its development. The formal program was implemented using the NEXPERT OBJECT 2.0, software tool. However, it is not to be considered a decision support system because it does not interact with the user once it is started. A complete analysis is performed by the system once it is initiated. NEXPERT OBJECT was chosen as the development environment because it has the capabilities of manipulating data accessed from a database, and it can execute external subroutines easily. Also, the development environment parallels that of the

SDDSS presented in Chapter 3. A complete listing of the MOSDE code is given in Appendix B.

The MOSDE system functions in an iterative manner. It recursively: (a) generates subsets of the data to be used for SD relation development; (b) ranks several possible generated SD relations for each data subset; and (c) compares the highest ranked SD relations for two consecutive data subsets. The process starts with the first seven data points of the total set, adding a subsequent SD point in each new iteration. The objective at this stage is to identify discontinuity points in the particular SD relation. Several checks are incorporated to maintain realistic and reliable results. Figure 4.1 shows a flow chart of the MOSDE system.

There are four main phases incorporated into the system: (i) generation of data subsets; (ii) development of several regression models and their respective evaluation parameters; (iii) multiobjective ranking of regression models; and (iv) checking for outliers, checking the slope and storing a curve into the data base. In the third phase a compromise between regression models of the same data set is performed to find a best model for each data subset generated (regression of $\mathbf{Bmod}_j$ and $\mathbf{Bmod}_{j+1}$). Then, the comparison of the two best models is performed. Based on the result, the system makes a decision to continue or subject the best models and data to further analysis (phase four).

4.2.1 Data Subset Generator - Phase One

The modelling process starts by breaking down the set of stage-discharge data into

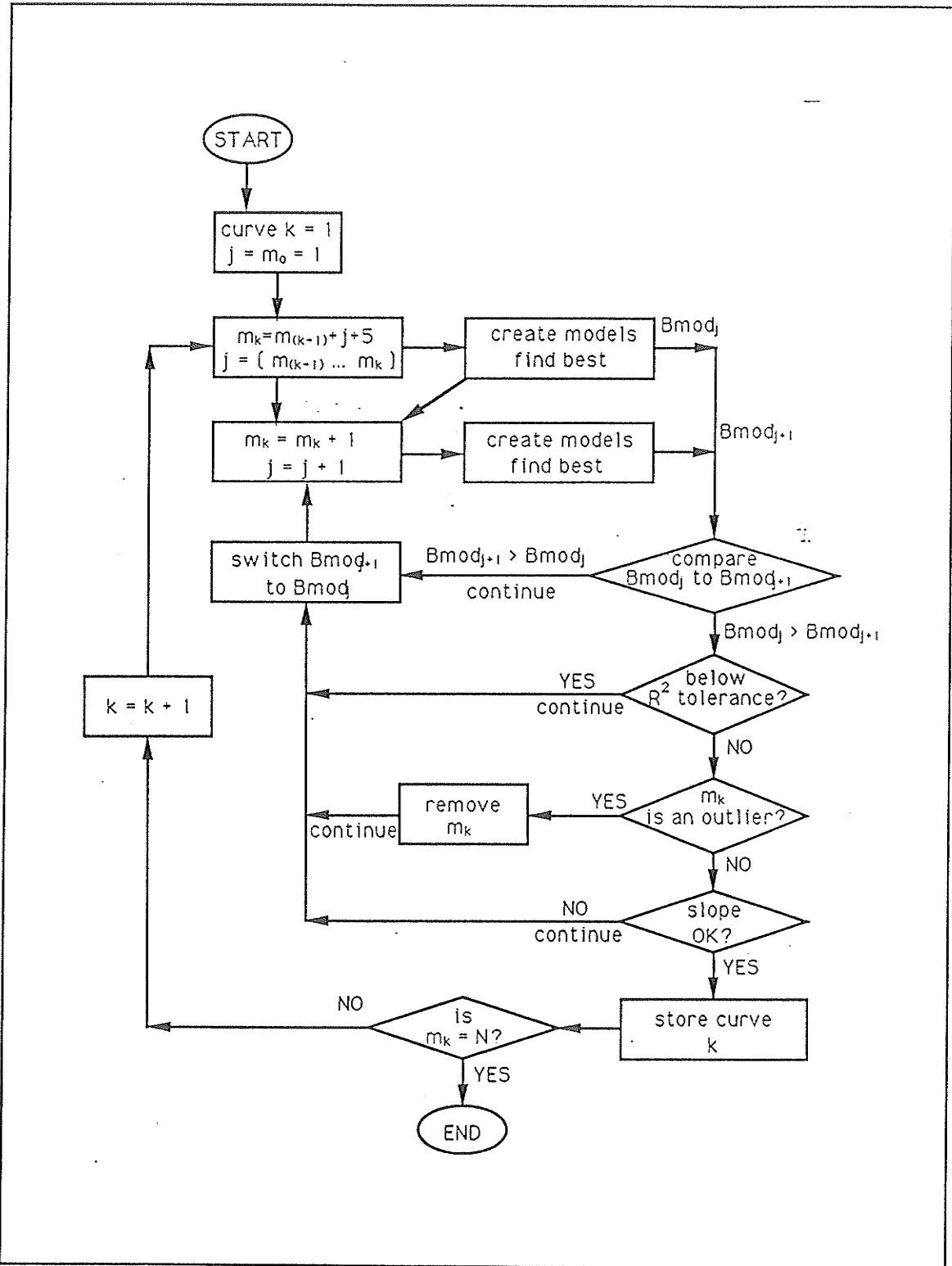


Figure 4.1: MOSDE System Overview

many subsets. It is important to note that the data must be sorted in ascending order of stage before it can be modelled. The first subset consists of the first seven data points. Each subsequent data set builds from this subset by adding an additional stage-discharge point in every iteration. The following expression illustrates the function of the data subset generator:

$$SD_j^k = \{ SD_j \in SD \mid SD_{m_{k-1}}^k, \dots, SD_{m_{k-1}+j+5}^k \} \quad (4.1)$$

where:

SD_j^k	=	the generated subset of SD data;
SD	=	the complete set of SD data;
k	=	index for curve number;
j	=	index for subset iteration of the curve;
m	=	index for beginning and ending SD points for each curve subset;
j,k	=	1,2,3,...;
m_0	=	1 ;
m_k	=	7,8,9,...,N for $k > 1$; and
N	=	the total number of SD points.

In the beginning the program builds subset $j = 1$, for curve $k = 1$. This subset has the first seven SD measurements in it. Therefore, the point index spans from $m_0 = 1$ to $m_k = 7$. Regression models are made for this data subset before m_k is increased by one (ie., the eighth point of the SD data set is added). The process is iterative, allowing the program to step through the SD data set one point at a time.

4.2.2 Model Generator - Phase Two

The model generating subroutine takes the SD data subset, and transforms it many

times to perform a regression analysis on it. Three transformation types are used. They are: (i) the power transformation of stage; (ii) the BOX/COX transformation; and (iii) the power 2/5 transformation of discharge.

The first type of transformation involves transforming the independent data and performing a linear regression analysis to the first polynomial. Equation 4.2 illustrates the transformation.

$$S_i = S^{TX} \quad (4.2)$$

where

S	=	measured stage;
S_i	=	transformed stage; and
TX	=	transformation exponent.

Applicable ranges of transformation exponents are from 1.5 to 3.5. The system automatically steps through this range with a 0.05 step value creating 41 different regression models for this transformation type. The resulting SD model is of the form:

$$D_m = b_0 + b_1 S_i \quad (4.3)$$

where

D_m	=	model predicted discharge;
b_0	=	regression coefficient; and
b_1	=	regression coefficient.

Next, the subroutine steps through a series of BOX/COX transformations on the dependant discharge data, and applies these transformations to the regression analysis.

This technique can produce results that conform to strict statistical requirements for a linear regression (eg., a uniform variance of residuals). The transformation is outlined as follows:

$$D_t = \ln(D), \quad \text{for } \lambda = 0.0 \quad (4.4.1)$$

$$D_t = \frac{D^\lambda - 1}{\lambda}, \quad \lambda = 0.0 \quad (4.4.2)$$

where

D = measured discharge;
D_t = transformed discharge; and
λ = BOX/COX parameter.

The applicable range for the λ parameter is between 0 and 1.0, and the system automatically steps through this range at an increment of 0.05. The result is 21 regression models of the form:

$$D_t = b_0 + b_1 S \quad (4.5)$$

According to Chester (1986) there is significant hydraulic evidence that gives rise to transforming the discharge with an exponent of 2/5. Therefore the last model that the modelling subroutine produces is in effect the transformation outlined below:

$$D_t = D^{2/5} \quad (4.6)$$

Unlike the previous two transformation types only one model is produced in the same form as equation 4.5.

As each regression model is produced, the modelling subroutine also calculates six statistical measures of fit. They are: (i) the R-squared statistic (R^2); (ii) the standard error of estimate (SEE); (iii) the calculated number of outliers (OUT); (iv) the water balance error (WBE), a measure of total error; (v) the relative absolute error (RAE), a measure of average error; and (vi) the explained variance (EV). Derivations of each of these parameters is provided in the Appendix C. Each of these measures explains the accuracy of the regression model to the particular data subset, and each variable tends towards an optimal value. Therefore, it is these six measures that are used as objectives in the multiobjective analysis for evaluating the models, and determining the best fit model.

4.2.3 Multiobjective Analysis - Phase Three

To find a model yielding the minimum SEE, the maximum R^2 , the minimum number of outliers OUT, the minimum water balance error WBE, the minimum RAE and the maximum EV of all models generated is very unlikely (if not impossible). Therefore, a multi-objective technique named Compromise Programming (Appendix D) has been used to find the best compromise between six criteria which is called the most appropriate model.

Compromise Programming is a method appropriately used in a multiple linear objective context (Cochrane and Zeleny, 1973). However, a variation of this method has also been used in the analysis of discrete objective problems similar to the one of ranking

SD models. The method of Compromise Programming identifies solutions which are closest to the ideal solution. They are called *compromise solutions* and constitute the *compromise set*. For a more explicit understanding of what is meant by a compromise solution an ideal solution must be defined and the particular distance measure specified.

The ideal solution is defined as the vector $\mathbf{z}^* = (z_1^*, z_2^*, \dots, z_p^*)$ where the z_i^* is the solution of the following problem:

$$\max z_i(\mathbf{x}) \quad (4.7)$$

subject to:

$$\mathbf{x} \in \mathbf{X}$$

$$i = 1, 2, \dots, p$$

where: $\mathbf{X}$ is a feasible region; $\mathbf{x}$ set of decision variables; z objective function (criteria); and p is the number of objective functions.

If there were a feasible solution vector, $\mathbf{x}^*$, common to all p problems, then this solution would be the optimal one since the non-dominated set (in objective space) would consist of only one point, namely $\mathbf{z}^*(\mathbf{x}^*) = (z_1^*(\mathbf{x}^*), z_2^*(\mathbf{x}^*), \dots, z_p^*(\mathbf{x}^*))$.

Obviously, this is most unlikely, and the ideal solution is generally not feasible. However, it can serve as a standard for evaluation of the attainable solutions. Since all would prefer the ideal point if it were attainable (as long as the individual underlying utility functions are increasing), then it can be argued that finding solutions that are as close as possible to the ideal solution is a reasonable surrogate for maximization.

The procedure for evaluation of the set of non-dominated points is to measure how close these points come to the ideal solution. One of the most frequently used measures

of closeness, and the one used in this work, is a family of L_s , *metrics*, defined as:

$$L_s = \left[\sum_{i=1}^p \alpha_i^s (z_i^* - z_i(x))^s \right]^{1/s} \quad (4.8)$$

where $1 \leq s \leq \infty$ and $\{\alpha_1, \alpha_2, \dots, \alpha_p\}$ is a given set of weights used to emphasize the importance of different objectives.

Finally, a compromise solution with respect to s is defined as x_s^* such that

$$\min \left[L_s(x) = \sum_{i=1}^p \alpha_i^s \left(\frac{z_i^* - z_i(x)}{z_i^* - z_i^{**}} \right)^s \right] = L_s(x_s^*) \quad (4.9)$$

subject to:

$$x \in X.$$

Elements of vector x , in our case, are different SD models generated in the second phase. Statistics, introduced earlier and calculated for each SD model, are values of objective function $z_i^*(x)$. The vector of worst values defines the minimum objective function values, z_i^{**} (the largest SEE, the smallest R^2 value, the largest OUT, the largest WBE, the largest RAE and the smallest EV). Following recommendations from the literature on Compromise Programming (Goicoechea et al ,1982), parameter s is set to 2. By assigning equal weights to different objectives, the algorithm is able to rank the alternative solutions according to their distance from the ideal point.

The compromise program is used twice in the MOSDE system. Once, to select the highest ranked $\mathbf{Bmod}_j$ and the highest ranked $\mathbf{Bmod}_{j+1}$, and once to rank $\mathbf{Bmod}_j$ and

Bmod_{j+1}.

4.2.4 Analysis of the Results - Phase Four

After completing the multiobjective ranking of the best models of data subsets j and $j+1$ (ie., Bmod _{j} and Bmod _{$j+1$}), the system takes one of two courses based on the results. If Bmod _{$j+1$} is a preferred model over Bmod _{j} , the system continues to the next iteration since the addition of point m_k has improved the model. The system then adds a new point (m_k+1) to a new data set ($j+2$), and performs the model generation and evaluation on the new data set to find Bmod _{$j+2$} . This is illustrated in Figure 4.1 as a switch from Bmod _{$j+1$} to Bmod _{j} , and the creation of a new Bmod _{$j+1$} . The system handles the model parameters in this fashion to simplify the programming effort. On the other hand, if Bmod _{j} is a preferred model, then the program takes another course of action. It tries to establish why the addition of point m_k+1 to data subset $j+1$ has degenerated the SD rating relation. It is a three step process of checks and corrections that try to keep the model accurate, reliable and realistic.

The first test of the continuing analysis is to check the level of degradation of the R^2 statistic. The R^2 statistic is chosen because it takes a value between 0 and 1. Therefore its variation can be represented easily as a percentage. A point that varies only slightly from the regression model may only degrade the measure of fit slightly. This may be acceptable if, in the next iteration, the model improves again. Therefore, a level of R^2 tolerance is defined prior to the system execution. It is based on the percent difference of R^2 from Bmod _{j} to Bmod _{$j+1$} . The level is arbitrarily set by the user of the system, and

its value is sensitive to the variability of the data. Usually a five percent error is used, but some data require a stricter tolerance in order not to miss the identification of transition points. If the calculated percent difference of R^2 is below the tolerance level the system continues to the next iteration. However, the system has the ability to detect two consecutive occurrences of a degenerating R^2 . In this case, the computation will not continue, and the system will try to store the model at point m_{k-2} pending if it passes the remaining tests. Alternatively, if the calculated R^2 percent difference is higher than the tolerance level the system automatically tries to store the curve pending further analysis.

The second test of the continuing analysis tries to identify points of large error, named outliers. These points plot significantly outside the domain of the curve for some reason, and when identified, are **excluded** from the data set and further modelling. If the calculated R^2 difference is outside the allowable range the system identifies the point m_k (the last point of subset $j+1$) as an outlier. The system temporarily removes this point from the data set, and produces a subset $j+2$. After comparing $Bmod_{j+2}$ to $Bmod_j$, the system decides if the removed point is an outlier. If $Bmod_{j+2}$ is the preferred model then m_k is an outlier, and the program continues to the next iteration. The justification for this is that the model has improved after removing the point in question. If the model doesn't improve (ie., $Bmod_j$ is still preferred) then $Bmod_j$ is sited for storage, and the point m_k is not an outlier, but rather, a point of transition. In this case, the model $Bmod_j$ must pass one more test before it is stored in the database.

The third test is to verify the curve. First, the R^2 statistic must be greater than 0.65 which improves the reliability of the overall model. Secondly, the curve must

exhibit a positive slope. This is important in order to preserve the reality of all stage-discharge relations which show a decreasing positive slope with stage. If the model B_{mod_j} - equal to curve k - passes these two tests, it is deemed suitable for storage, and the system can continue from point m_k with a new model (curve $k+1$), as long as m_k is not equal to N .

To illustrate MOSDE application two case studies have been completed. The following section outlines the data used, the analysis performed, and the results provided by the application of this method.

4.3 Case Study

Two data sets were chosen for the analysis. The data sets were selected from two completely different sources. The first was obtained from the HYDSYS (1991) database as described in Chapter 3, and the second was obtained from the Environment Canada archives. The extracted data for the *Hydsys Test Station* spans the years between 1979 and 1991, and has a stage range of 0 to 1.5 meters. The station chosen from the Environment Canada archive is the *Bow River at Calgary* (05BH004). This station represents a fairly stable regime, with a simple trough shaped cross-section. Thus, a detectable transition point is not expected. The data extracted from the archive ranges from 1980 to 1992, and has a stage range of 0.9 to 2.6 meters. It is assumed that for both data sets the measured stage-discharge readings were taken during normal open flow conditions. Figures 4.2 and 4.3 illustrate the stage-discharge data before it has been subjected to analysis.

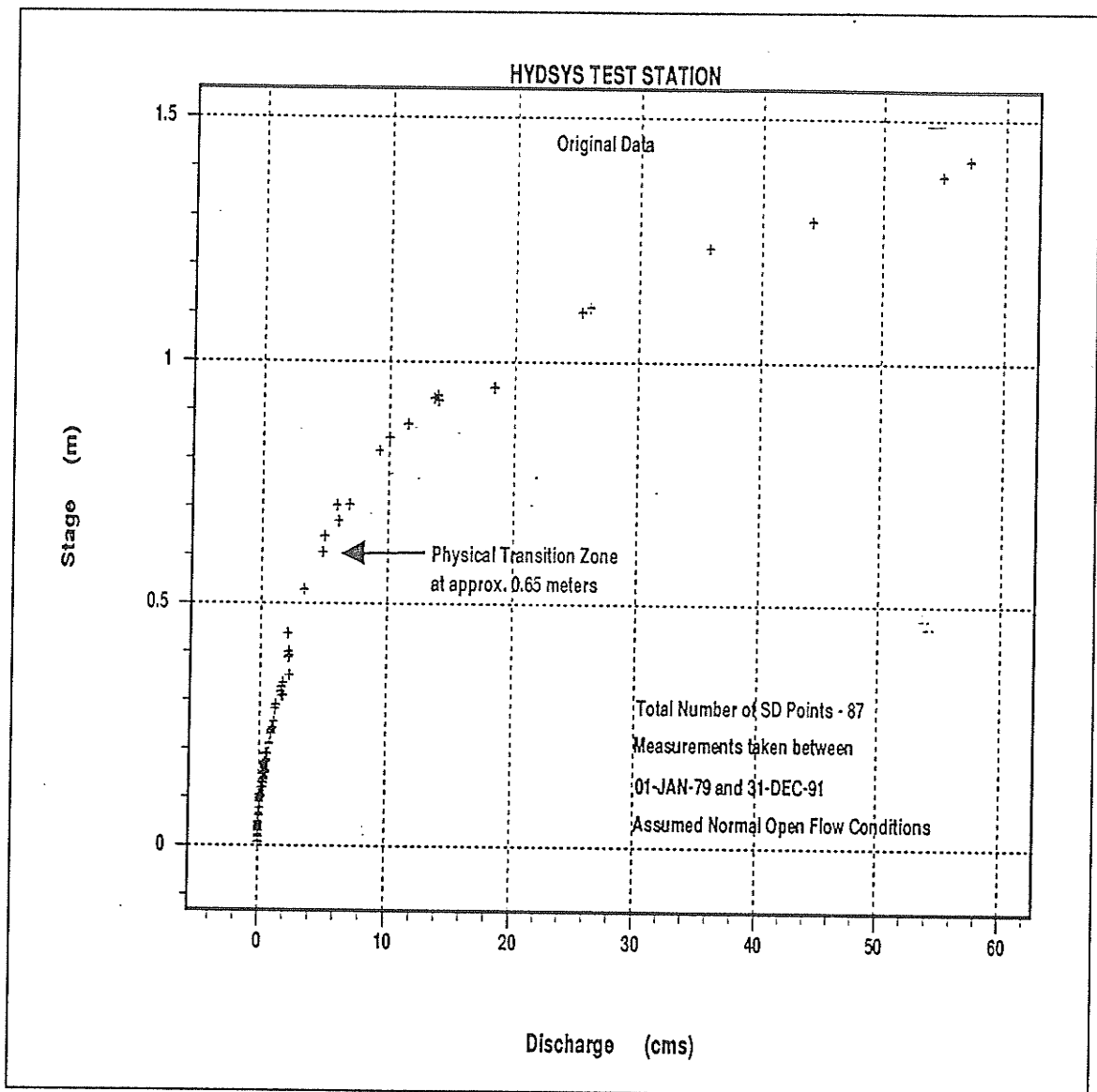


Figure 4.2: Original Data - Hydsys Test Station

The above data was subjected to the MOSDE analysis. The first data set went through 71 iterations, and achieved four models. The second data set achieved three models in 104 iterations. It is important to note that the criteria for R^2 tolerance was 1 and 5 percent respectively.

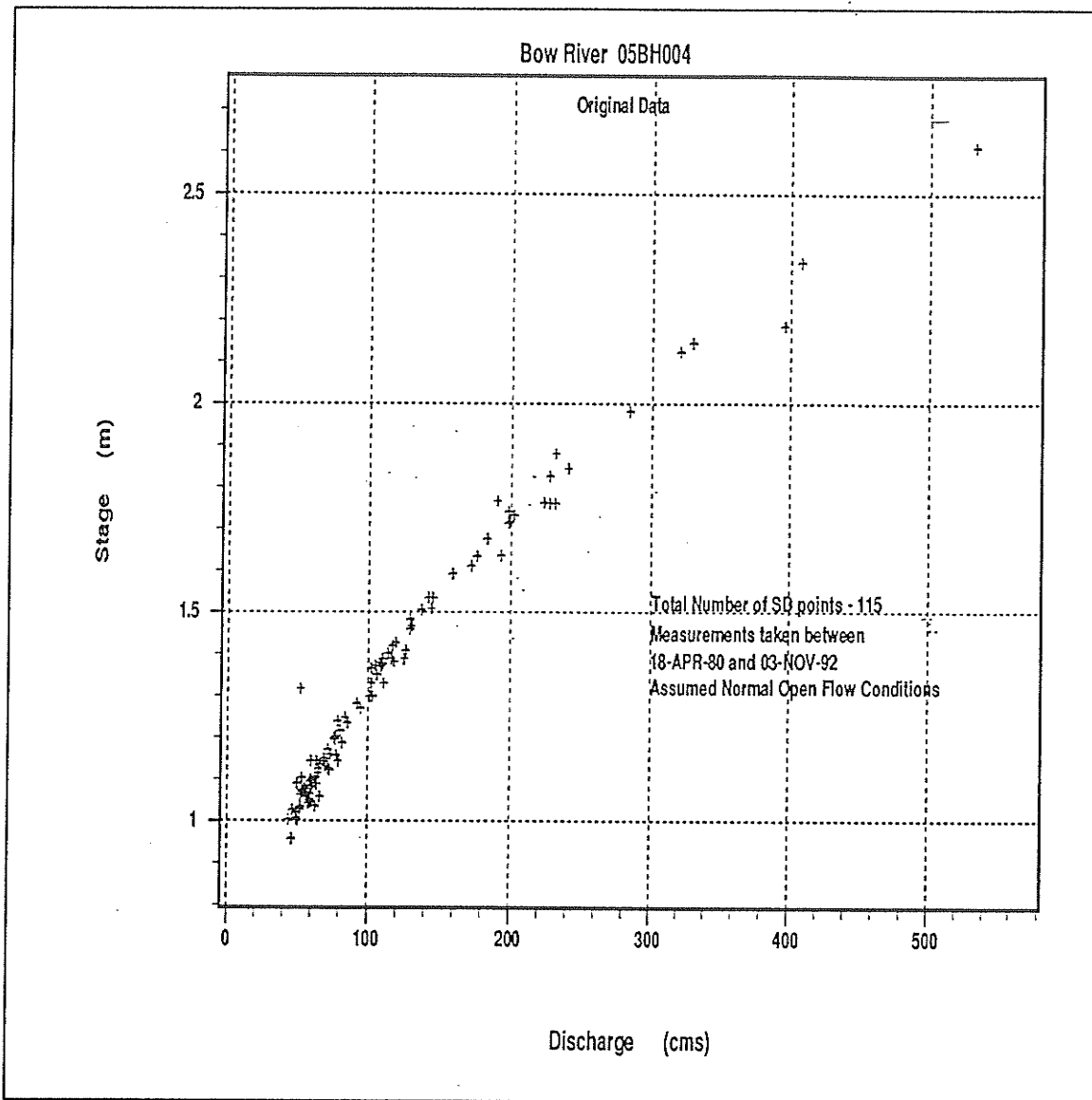


Figure 4.3: Original Data - Bow River

4.3.1 Results of the MOSDE Analysis

The following two tables (Table 4.1 and 4.2) outline the calculated optimal model results for the two analyses. For clarity only the first and last few iterations are shown. The values shown are the best models evaluated after each iteration. That is, the best

Table 4.1: Iteration results for Hydsys Test Station

Curve #	Iter #	First Point	Last Point	R^2	SEE	OUT	WBE	RAE	EV
1	1	1	7	0.58083	0.00382	2	0.00000	0.26379	0.58083
1	2	1	8	0.66888	0.00350	1	0.00000	0.21009	0.66888
1	5	1	11	0.83500	0.00296	2	0.00000	0.13984	0.83500
1	6	1	12	0.84457	0.00287	2	0.00000	0.12888	0.84457
1	7	1	13	0.84053	0.00286	2	0.00000	0.12688	0.84053
1	8	1	14	0.59079	0.00449	4	0.00000	0.21896	0.59079
2	9	13	19	0.86787	0.01384	3	0.00000	0.17338	0.86787
2	10	13	20	0.89197	0.01265	3	0.00000	0.14021	0.89197
2	13	13	23	0.92118	0.01095	3	0.00000	0.09887	0.92117
2	14	13	24	0.93069	0.01033	3	0.00000	0.08544	0.93069
2	15	13	25	0.92408	0.01301	3	0.00000	0.11435	0.92408
2	16	13	26	0.70370	0.05188	9	0.00000	0.32282	0.70370
3	17	25	31	0.03306	0.08255	4	0.03485	0.23678	0.01564
3	18	25	32	0.23731	0.08213	2	0.04734	0.23317	0.23351
3	51	25	65	0.97566	0.10109	5	0.00000	0.09327	0.97566
3	52	25	66	0.97813	0.10065	5	0.00001	0.08893	0.97813
4	56	67	73	0.96922	0.31593	0	0.00000	0.05684	0.96922
4	57	67	74	0.96576	0.35836	0	0.00000	0.05828	0.96576
4	70	67	87	0.99851	0.68683	0	0.00000	0.03018	0.99851
4	71	67	87	0.99695	0.95689	0	0.00001	0.03680	0.99695

Table 4.2: Iteration Results for Bow River

Curve #	Iter #	First Point	Last Point	R^2	SEE	OUT	WBE	RAE	EV
1	1	1	7	0.22968	2.22361	0	0.00001	0.02602	0.22970
1	2	1	8	0.27434	2.03195	0	0.00001	0.02329	0.27435
1	16	1	22	0.66545	3.44643	0	0.00009	0.04759	0.66545
1	17	1	23	0.65806	3.42355	0	0.00009	0.04769	0.65805
1	18	1	24	0.59853	3.61566	0	0.00007	0.05097	0.59853
1	19	1	24	0.53034	4.14269	0	0.00015	0.05944	0.53033
2	20	23	29	0.35743	2.24616	0	0.00006	0.03009	0.35741
2	21	23	30	0.00000	2.48354	0	0.00007	0.03400	0.62035
2	37	23	46	0.83403	2.77164	0	0.00037	0.03816	0.83415
2	38	23	47	0.72497	3.47144	0	0.00051	0.04358	0.72525
2	39	23	48	0.61878	4.09942	0	0.00021	0.04737	0.61896
2	40	23	48	0.47739	4.61171	0	0.00048	0.05613	0.47764
3	41	47	53	0.14504	7.14923	0	0.72862	0.06973	0.13414
3	42	47	54	0.37384	6.55462	0	0.91415	0.06092	0.36349
3	103	47	115	0.99019	8.9293	0	0.0014	0.03913	0.99019
3	104	47	115	0.99031	8.82805	0	0.00209	0.03918	0.99031

models selected from the comparison of **Bmod_j** and **Bmod_{j+1}**. The information provided, details the curve number that the iteration belongs to, the first and last points, and the calculated values of the decision criteria. The models highlighted mark the optimum models selected before storing them in the database. Notice that the system performs two additional iterations after the model is stored. These iterations provide comparison, and show that by adding more points, the relation is degrading in quality, and that it must change. Attention must be paid to the R^2 statistic, and note how it increases, and maintains a level above 0.65 for the stored models.

The overall results supplied by the analysis, are very close to what was expected. Firstly, 12 of the original stage-discharge measurements were excluded from the Bow River data set, and 5 were taken out of the Hydsys data set. The excluded points were mostly in the lower stage region, where the effect of variation has a greater impact on the algorithms. However, the Bow River has one point at approximately the 1.3 meter stage that is significantly to the left of the rest of the data. This point was excluded as a true outlier. Also, the Hydsys data set has one point near the 1 meter level that plots to the right of the group, and it too was excluded. MOSDE was very efficient in detecting the points that were to be excluded. However, it may be hard to justify the exclusion of so many points in the lower stages.

The highlighted iterations in Tables 4.1 and 4.2 have been placed in the final results tables (Tables 4.3 and 4.4) with their corresponding model parameters and stage ranges. It can be seen that the Hydsys data set has been fragmented into four data sets, and four coinciding models. Three models represent the lower stage region (0.0 - 0.4

meters) and one model represents the high end of the relation (0.4 - 1.4 meters). This is slightly different from what was expected, since a transition at around the 0.6 meter stage was expected because overbank flow occurs at this point. The inaccuracy may be due to the data's inability to reflect the reality of the hydraulic control, or the transition may not be significant enough to actually be detected properly. Another reason for the inaccuracy at this station is that the gaugings may be taken at two distinct controls for low and high water measurements. It is interesting to note that the difference in slopes between the first three curves is minimal, and they appear to be relatively continuous. However, the analysis has underestimated the transition by 0.2 meters. The Bow River data has similar

Table 4.3: Final Models for Hydsys Test Station

Curve Id	Tran Type	B0	B1	Trans Exp	R ²	SEE	OUT	First Point	Last Point	Min Stage	Max Stage	WRE	RAE	EV
1	1	0.00140	8.62006	2.00	0.84053	0.00286	2	1	12	0.009	0.047	0.00000	0.12688	0.84053
2	1	0.00279	16.61333	2.20	0.92408	0.01301	3	13	24	0.048	0.106	0.00000	0.11435	0.92408
3	1	-0.04947	12.45671	1.75	0.97734	0.10629	5	25	66	0.120	0.393	0.00000	0.09027	0.97734
4	1	1.38723	16.77285	3.50	0.99851	0.68683	0	67	87	0.400	1.418	0.00000	0.02976	0.99850

Table 4.4: Final Models for Bow River

Curve ID	Tran Type	B0	B1	Tran Exp.	R ²	SEE	OUT	First Point	Last Point	Min Stage	Max Stage	WRE	RAE	EV
1	1	7.87017	41.22615	3.50	0.65806	3.42355	0	1	22	0.959	1.065	0.00009	0.04769	0.65805
2	1	-33.07395	69.12926	3.50	0.86251	2.47501	0	23	46	1.068	1.143	0.00012	0.03412	0.86251
3	1	-23.63404	67.59828	2.20	0.99031	8.82805	0	47	115	1.144	2.614	0.00209	0.03918	0.99031

results. Three models were formed over the entire range of stage where only one was expected. Also, the curves appear to be rather discontinuous, especially the first and second.

Accompanying the tables is the graphical representation of the data (Figure 4.4 and 4.5), excluded points (circled) and the curves. Although the results are not quite as expected, the curves appear to adequately represent the data in their respective regions. This is an indication that the multiobjective analysis is an effective optimization tool. The results also show that all the optimal models are of the power transformation type, which may indicate an inadequacy of the other two types of transformation.

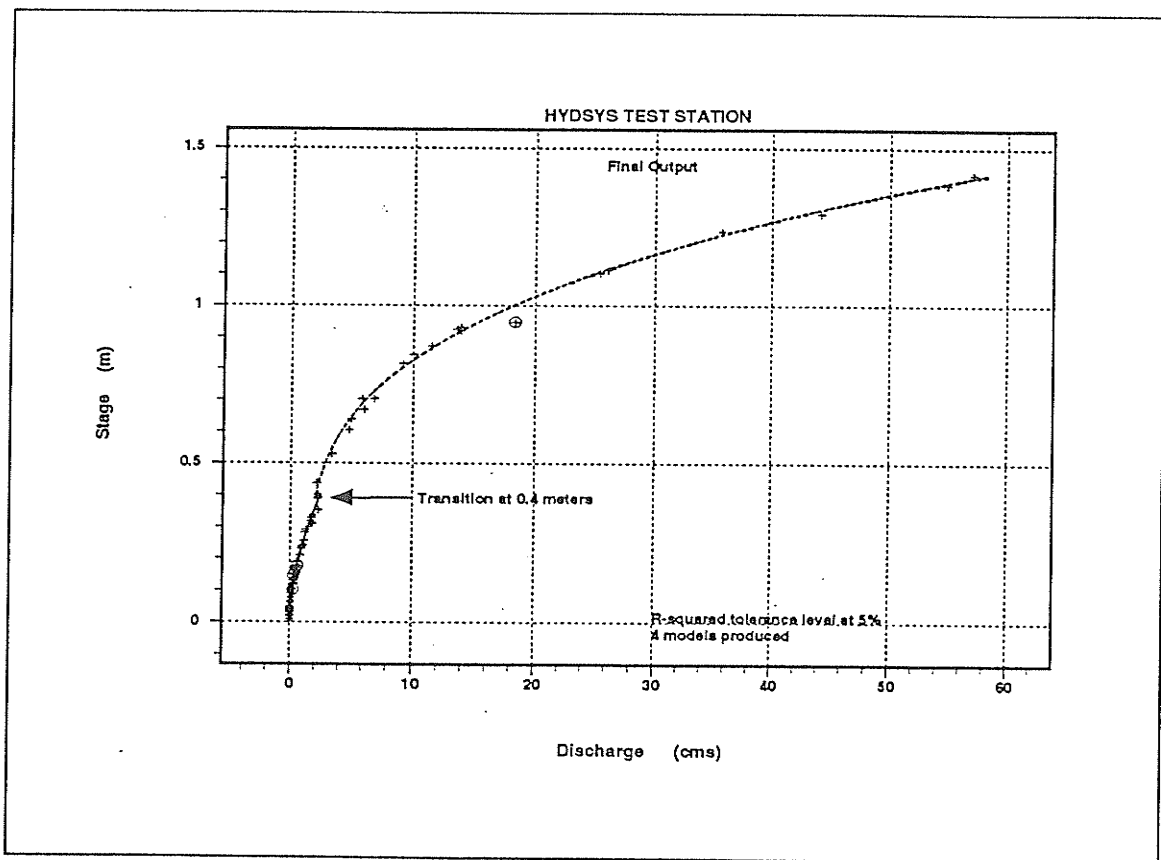


Figure 4.4: Results of Hydsys Data Analysis

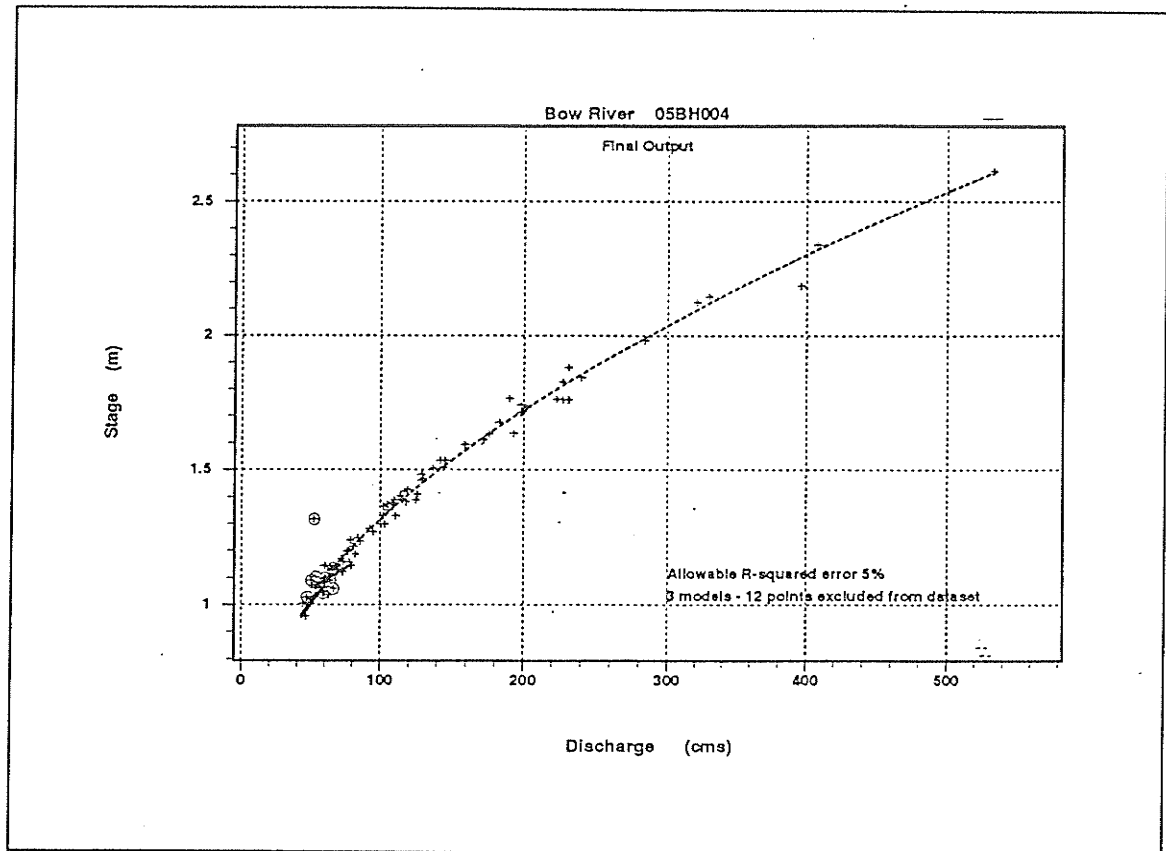


Figure 4.5: Results of Bow River Data Analysis

Overall the iterative compromise between consecutive data sets displays promising results. The models produced fit closely to the data that they represent. However, the data does not always model the reality of the hydraulic control, which determines the ultimate stage-discharge relation, in the best way.

4.3.2 Evaluation of the MOSDE

The multiobjective stage-discharge evaluation system presented provides an excellent tool and a good basis for a standard method of establishing rating curves for different hydrometric sites. In addition, the rating curve development process has been

taken one step further, with the ability of the system to identify true outliers, and key transitions in stage that affect the overall SD relation. Accurate statistical methods are proven to be of considerable help in establishing SD relationships that are non-biased and provide high level of accuracy. Establishing confidence intervals around the SD rating curves has not been addressed in this research, but the use of confidence intervals for each curve created could be incorporated into the MOSDE. The addition of an algorithm to smooth the SD relation at the transition points would greatly improve the overall curve fitting process.

In conclusion, the MOSDE system rigorously and unbiasedly evaluates the rating curve development process. The MOSDE can allow technicians more time to provide better quality assurance in the data collected. In addition, the MOSDE could possibly be integrated as part of the SDDSS (Chapter 3) as a key contribution towards effectively evaluating many transformation types and scenarios.

5. HYSTERESIS ERROR ANALYSIS SYSTEM

5.1 Introduction

As described previously, hysteresis produces differences in discharge for given water levels on the rising and falling limb of a hydrograph. In this chapter error associated with hysteresis is discussed and a Hysteresis Error Analysis System (HEAS) framework is developed.

5.2 Methodology for Error Analysis

Hysteresis error analysis was discussed in Chapter 2 (Section 2.4.2). It is proposed to make an assessment of error based on statistical measures of the points about a normal curve. A normal curve is produced in keeping with accepted practice (Rantz et al, 1983 and Anderson, 1988). By establishing error for each measurement, weights can be assigned to each SD point in order to better define their role in the regression analysis. That is, a SD point with greater error will have less effect on the shape of the curve. Add to this a confidence factor for the resulting "corrected" curve, and the accuracy and reliability of future predictions should be increased.

Since each measurement is subject to a quantitative analysis, it is proposed to implement the technique in a computer environment. However, the analysis is not as always as straight forward as directly applying the measurements to statistical algorithms. Often, technicians have a very intuitive idea of the nature of the relation they are trying to model, and the data may be subject to special conditions. Incorporating this expertise

within a system not only demands knowledge implementation, but user consultation. Complicating the implementation is the heuristic nature of key aspects of the assessment process. Expert system technology is well suited to incorporate direct algorithms, heuristics and user consultation within a computer environment. It also provides good communication between database sources, modelling components, knowledge inference and the user. The resulting prototype system will provide a rigorous, standardized means of assessing error to data points that are subject to hysteresis effects.

It is necessary to reveal the methodology behind the assignment of error, which each point in the chosen data set is subjected to. The general procedure for the error assignment is illustrated in the following flow chart (Figure 5.1), and it can be seen that actual assignment is performed in two steps: Error due to position and error due to the hysteresis (rate of change of stage). After the program assesses the error for an individual measurement it is shown to the user for agreement. The user can then decide to agree with the assigned error, or impose their own assessment on the analysis, thereby overriding the previous analysis.

The error assignment is not based on the hydraulics of hysteresis, but rather on the SD point's relative position with the normal curve and its relative rate of change of stage. The chosen method gives acceptable results, although it is not scientifically based, or based on known behaviour, but rather statistical means. However, the objective of this part of the research was to establish a reasonable approach for including quantitative error in rating curve analysis. Therefore, the methodology of the framework for error analysis is considered more important than the error assignment.

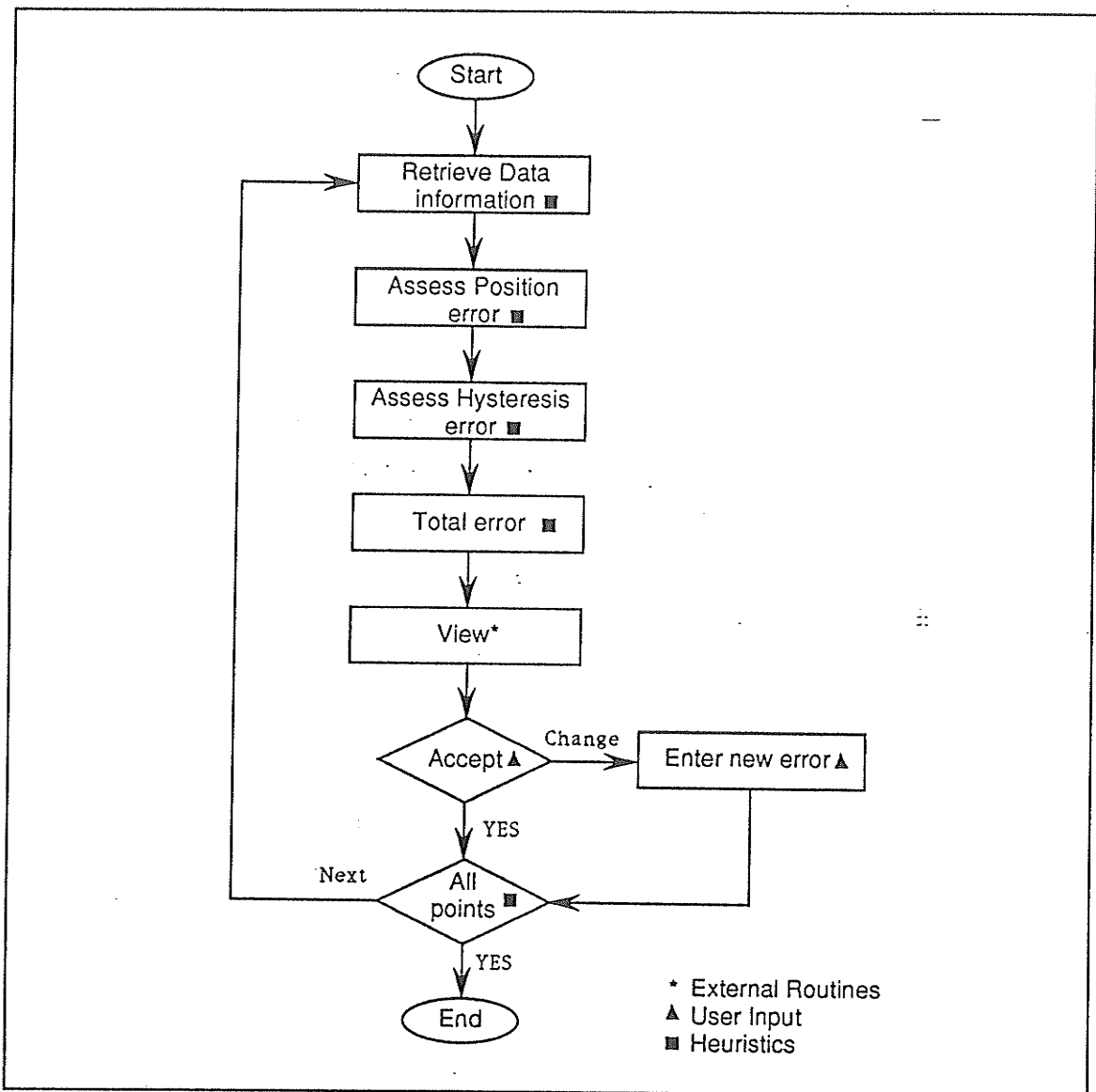


Figure 5.1: Error Analysis Framework

If the considered SD point does not plot in an expected position relative to the normal curve, then it is assigned a 5 percent position error. The following rule illustrates the position error assignment strategy.

IF

The SD point is on the rising limb and plots above the curve **OR**
The SD point is on the falling limb and plots below the curve **OR**
The SD point is neither rising nor falling (ie., Stable) and
plots off the normal curve

AND

The point is a distance greater than 5 percent of the modelled
discharge away from the normal curve

THEN

The SD point is assigned an error of 5 percent.

The rule is stated as so because points that are rising, falling or neither that plot very close to the normal curve are considered acceptable. Also, no error is assigned to SD points that plot in expected positions (ie., rising below, falling above and stable on or very near).

The relative rate of change of stage can also induce error into the measurement. This type of error is considered next, and is based on the **absolute** rate of change of stage of one SD point as it is related statistically to the others in the data set. A positive rate indicates a rising stage measurement. Negative indicates falling. The production of the preliminary curve is to represent the normal curve, or the curve of zero rate or expected average. A comparison of the expected average, and the actual distribution of the data about it reveals the relative or "hysteresis" error (Figure 5.2). The assignment is based on the distribution of absolute rate of change of stage about the expected mean. SD points whose rates are between the expected and actual sample mean are assigned 0 percent error. The error is then increased by 5 percent for each standard deviation from the sample mean to a maximum 15 percent. The total error can then be calculated by

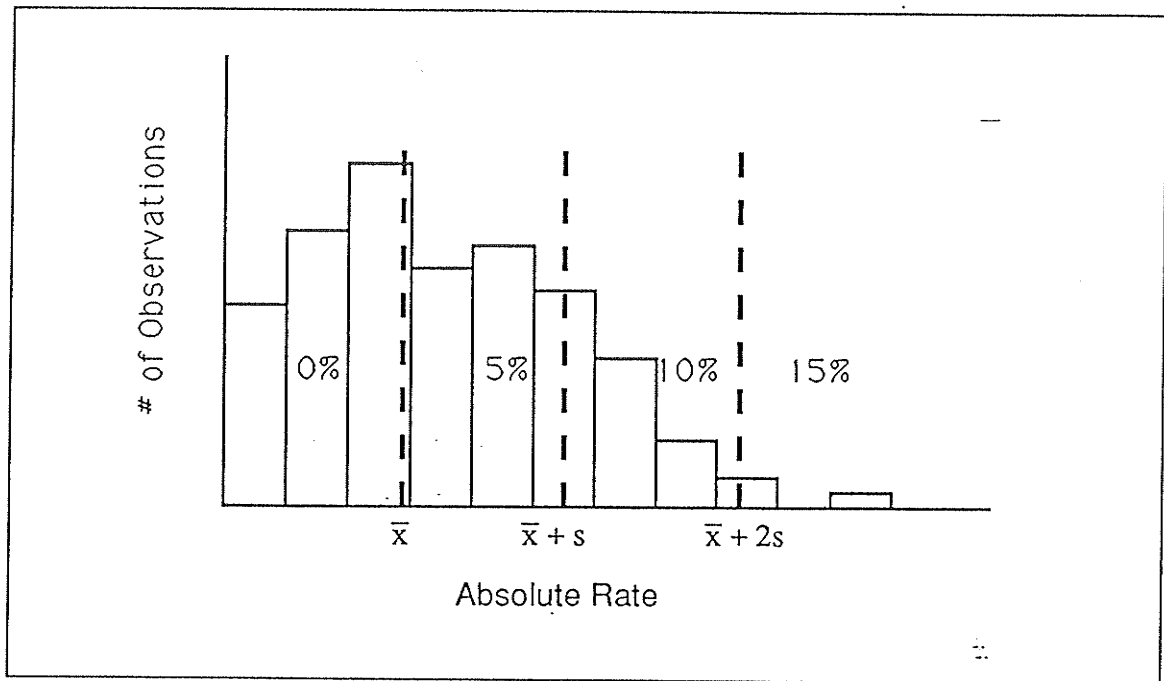


Figure 5.2: Error Assignment for Hysteresis

adding the position error to the hysteresis error. The resulting maximum error is 20 percent. This analysis is highly subject to the distribution of the measured SD points about the expected mean rate, but in scenarios where fairly equal distributions of rising and falling stage measurements exist an effective analysis can be provided.

5.3 Prototype System Framework

The problem has been addressed in the decision support system environment. The prototype has been developed using VP-Expert (Sawyer B., 1987). This software provides the knowledge base, and inference engine which controls the execution of the system. The model base consists of several FORTRAN programs, which provide some data manipulation, and regression analysis. The user interface is provided through

VP-Expert, and the graphical representation of the data is provided by external programs written in QuickBASIC (Microsoft, 1988). Figure 5.3 illustrates the structure schematically.

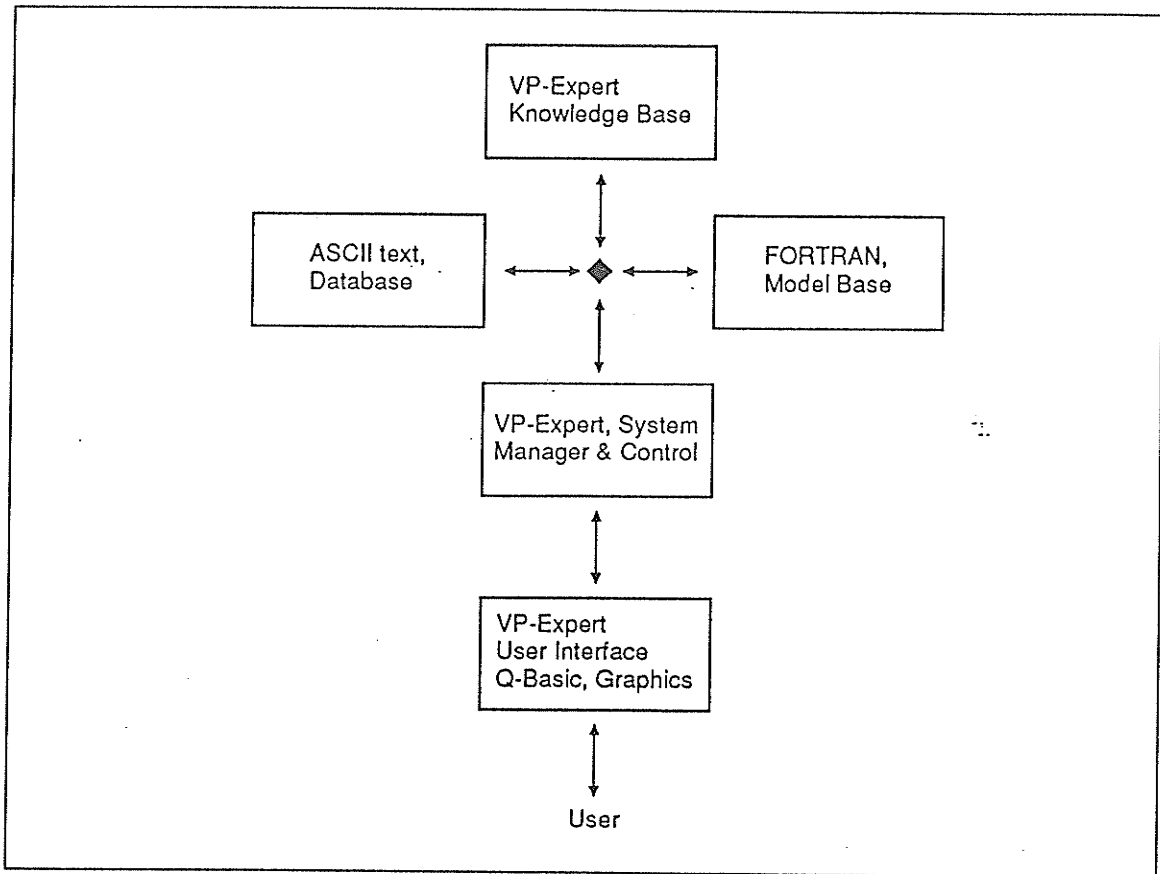


Figure 5.3: HEAS System Structure

A logical framework for addressing the problem has been implemented for the prototype development. Figure 5.4 illustrates the system consisting of four basic parts: Data Selection; Construction of the Preliminary Curve; Error Analysis; and Construction of the Final Curve and its Level of Confidence. Although all components are within one knowledge base, each are coded as a separate entity, which is discernable, integrative and

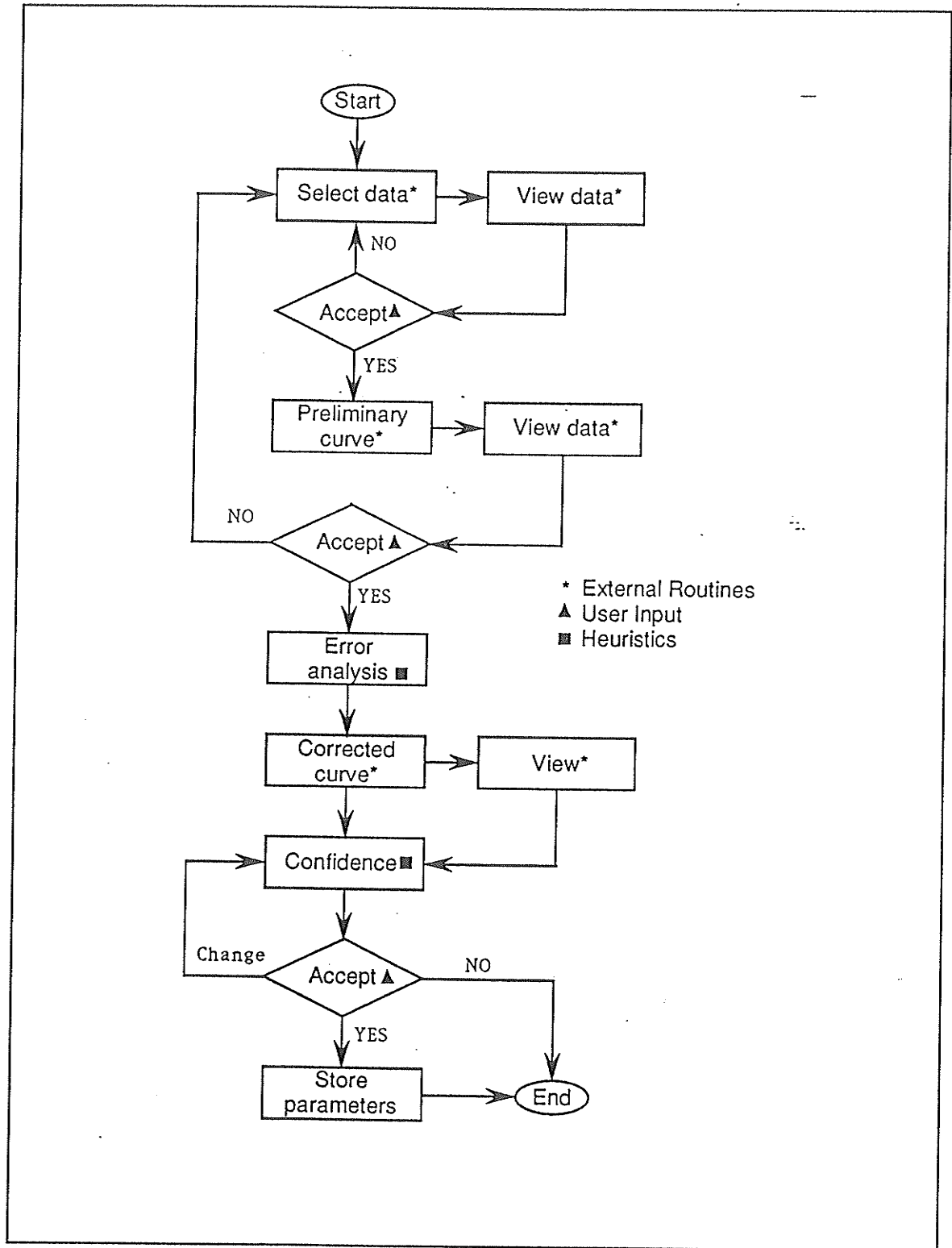


Figure 5.4: HEAS System Framework

expandable. The consultation supports decision making through diagnostic graphical representation of the data. Approval of the analysis must be given before advancement to the next level.

Because the HEAS is designed as a sub-component of the larger SDDSS (Chapter 4), the data selection routines are quite rudimentary at this time. It is expected that with future development the implementation of an error analysis will be performed within the SDDSS framework presented earlier. The data selection process is necessary to find an adequate data set for modelling, and it is performed through an external routine (SELECT.EXE). Decisions of adequacies are based on graphical presentation of the data (PLOT.EXE and RF_PLOT.EXE). It is possible to view the data grouped by year of measurement or rising and falling stage.

After selecting data representing a reasonable hysteresis loop, the system activates external routines to create and display the preliminary "normal" curve. The first routine, TRAN.EXE, creates 41 candidate models based on several exponential transformations (exponents from 1.5 to 3.5) of stage. This program also generates a set of six statistical measures of fit with each model: R-squared statistic (R^2), Standard error of estimate (SEE), number of outliers (OUT), water balance error (WBE), relative absolute error (RAE) and the explained variance (EV) (Chapter 4). The results of the models are stored in a file and manipulated for input into a Compromise Programming routine - COMPRO.EXE - by the FSTAT.EXE routine. The compromise routine evaluates trade offs for the different objectives to arrive at the "best-fit" model. Finally a set up program - SETUP.EXE - is run before the curve and data are shown for evaluation.

After establishing the expected mean curve (normal curve), the system enters the iterative error analysis, where errors are assigned to each SD measurement as described above. The errors are subject to approval at the end of each iteration. Each SD point is assigned a weight corresponding to the assigned error. The weight is simply calculated by subtracting the error from unity. Thus, a SD point that has been assigned 10 percent error will receive a corresponding 0.9 weighting coefficient. These weights are used in a weighted regression scheme (WGTD_TRA.EXE) to create a final weighted SD curve. The best curve is then chosen by the same compromise programming routine used earlier. The resulting curve has an associated confidence limit based on the average error assigned to all points. The confidence limit or factor can then be used as a reliability estimate for discharge predictions made from the final curve. The final "corrected" curve parameters can then be stored with the confidence factor for later use.

5.4 Red River Case Study

To illustrate the process of determining suitable error for measurements that are influenced by hysteresis the Red River near Emerson station was chosen. It is a fairly large river subject to significant flood events throughout its history with fairly stable banks and gentle slope that make it a prime site for hysteresis. Past observations show the influence of hysteresis on the SD relation, and the year 1975 is particularly interesting because a significant number of measurements have been taken, and the hysteresis pattern is clearly established.

5.4.1 Consultation and Results

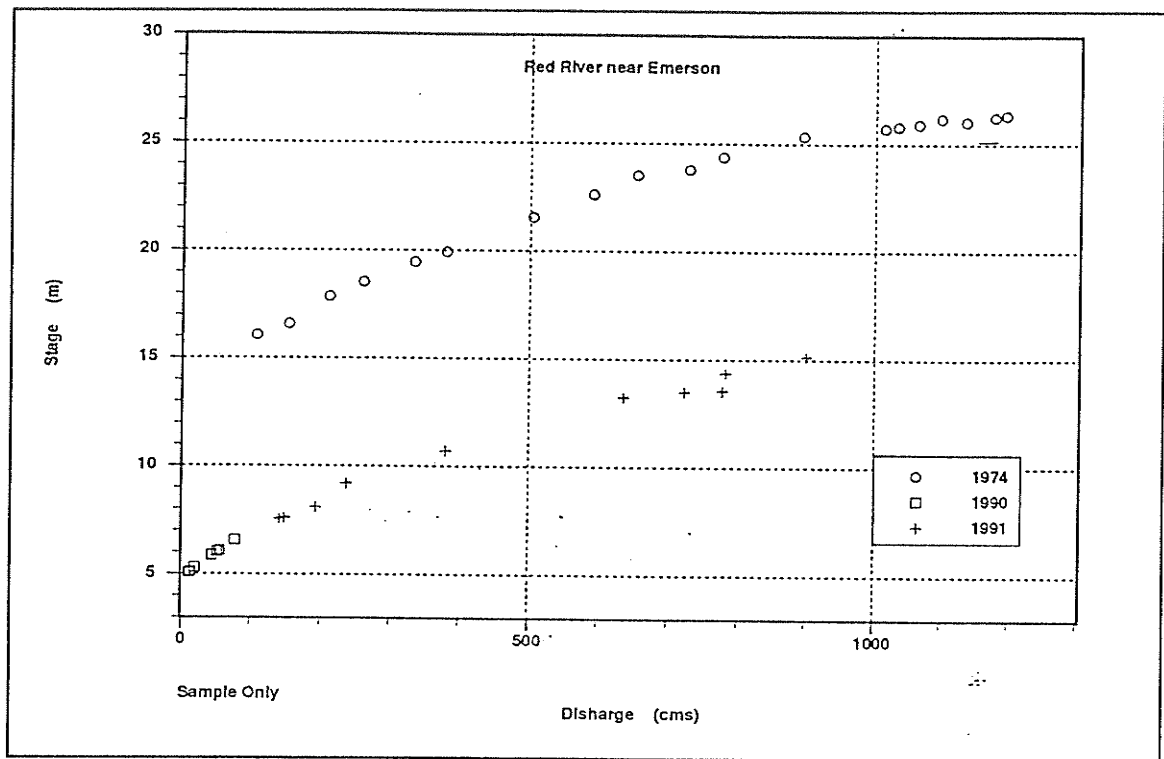
From the discussion of the flow of the program, the first priority of the system is to establish an appropriate data set for analysis, which is triggered after some introductory remarks are presented. The selection is based on data grouped by year, so it is possible to retrieve one or more years of data from the database. A graphical display of the initial selection (each year a different colour) for the Red River is shown in Figure 5.5. This data set was later reduced to those data measured only in 1975. The plot of the accepted data for modelling, is shown in Figure 5.6 (rising and falling measurements in different colours). The Red River shows significant differences for the data prior to 1979 than post 1979 (fig 5.5). This is due to the conversion of imperial system measurements to metric, and the change of the datum from one period to the next. As can be seen in Figure 5.6 the hysteresis pattern is clearly established from the recorded measurements of 1975.

The 1975 data represents a satisfactory data set for modelling. A preliminary model was made and it is presented graphically in Figure 5.7. The corresponding equation deemed best to represent the preliminary model for the Red River follows:

$$\text{Discharge} = -177.7253 + 0.0253 * \text{Stage}^{3.35} \quad (5.1)$$

The model is represented as model number 38, in the actual program graphics. This means that 3.35 is the 38th transformation of the stage variable, and it yields the best results.

Continuing from the preliminary model phase, the error analysis was entered. This analysis is an iterative procedure, which starts when pertinent data for the



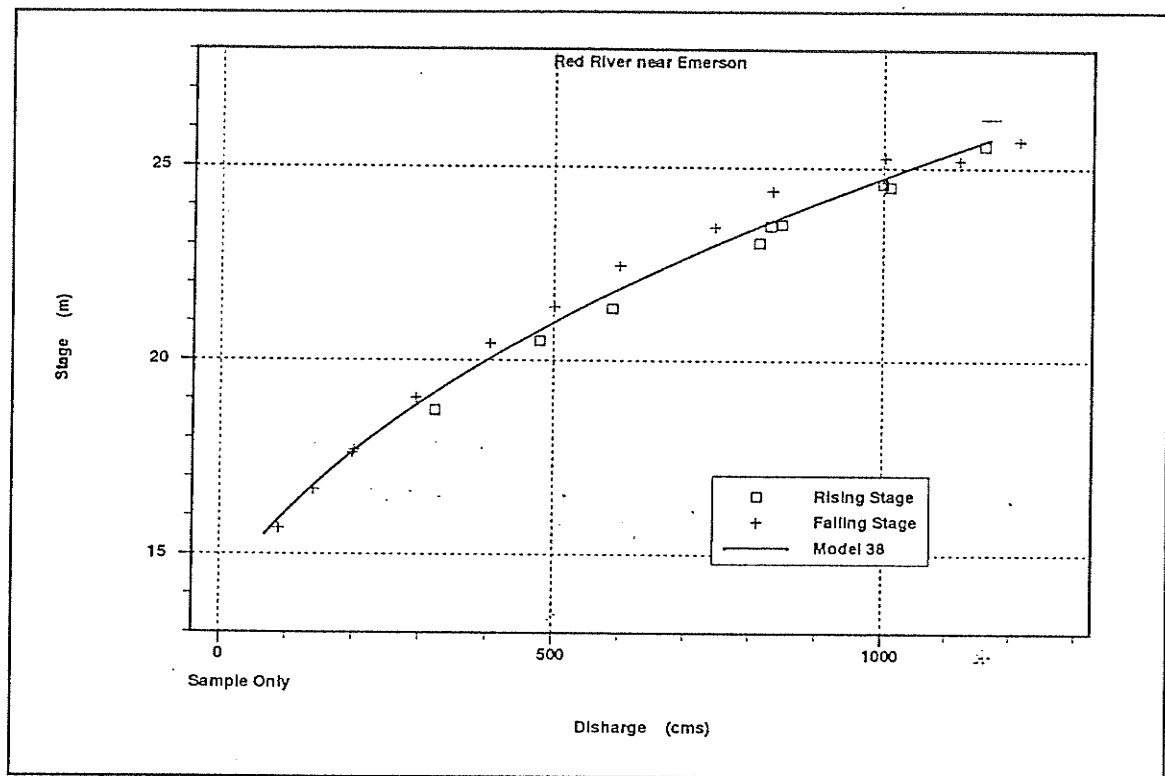


Figure 5.7: Preliminary "Normal" Model

measurement - Stage, Discharge, Modelled Discharge, Rate etc., - are retrieved from the database. This is followed by the allocation of the position error, hysteresis error and total error. The viewing screen at this point is represented in Figure 5.8. After viewing the information, it is presented graphically (Figure 5.9). The SD point under consideration is shown as a different colour from the rest. The error is also given, and the curve is shown for confirmation of the points position.

The error analysis for the Red River is summarized in Table 5.1 and Figure 5.10. They show the unchanged results for all 23 SD points for 1975. The rate analysis is based on the following statistics generated by HEAS:

Average Absolute rate: 0.397
Standard Deviation: 0.477

Assigned Hysteresis Error

0% between 0 - 0.397
5% between 0.398 - 0.875
10% between 0.876 - 1.352
15% greater than 1.352

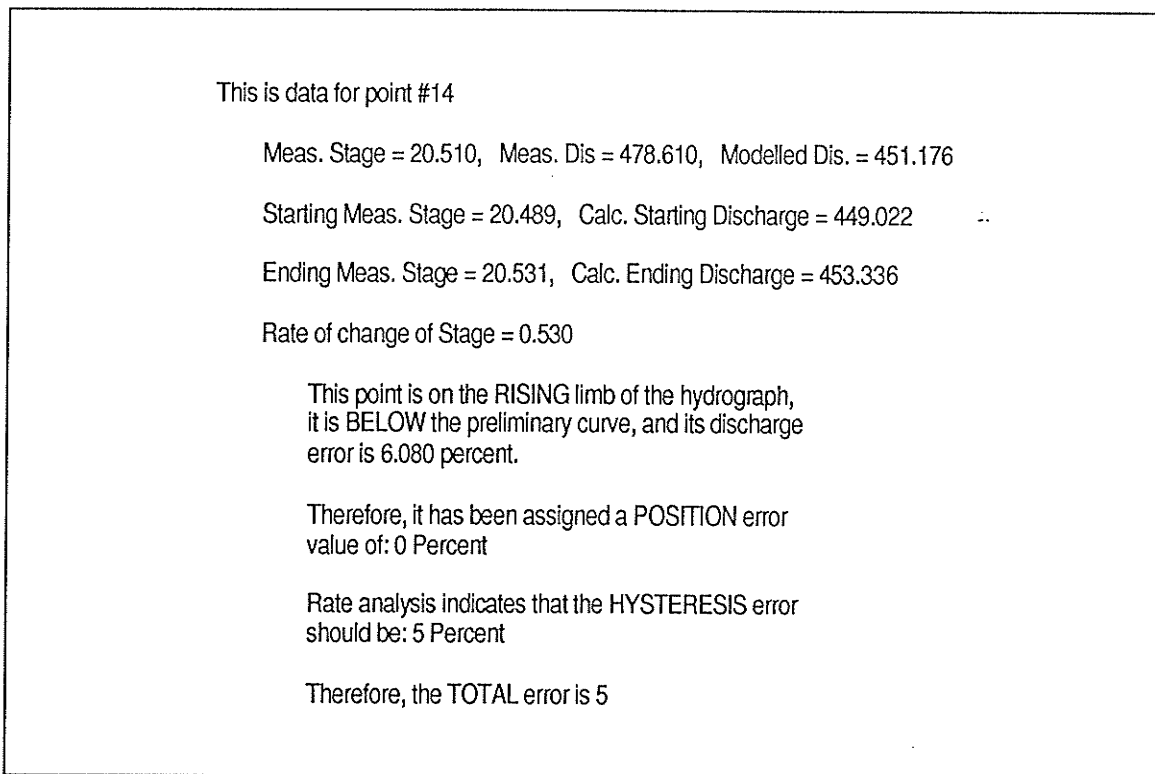


Figure 5.8: Screen Dump of Error Analysis Report

As seen in Figure 5.10 and Table 5.1, many points are not assigned an error, due to their proximity to the normal curve, and their lack of significant rate of change of stage. The total confidence factor for this curve is shown in the table and is discussed later.

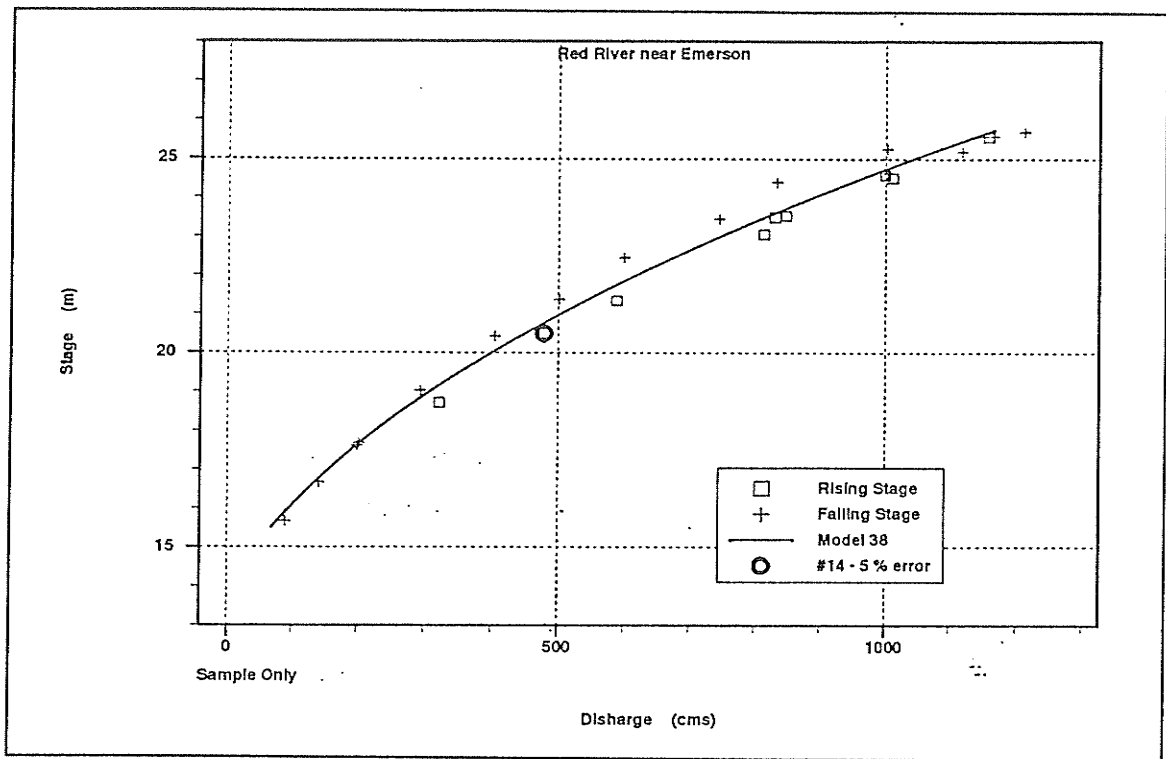


Figure 5.9: Graphical Representation of Error

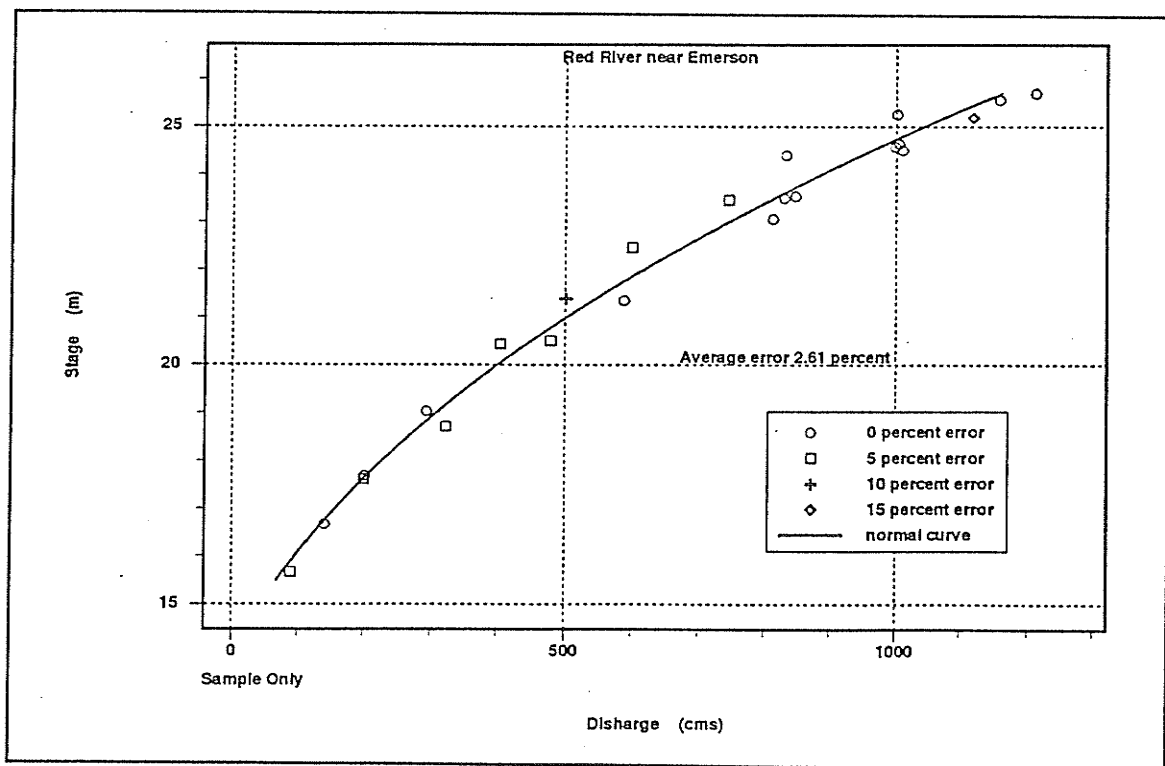


Figure 5.10: Error Analysis Results

Table 5.1: Results of Error Analysis

Y	MON	YEAR	RATE	STAGE	DIS	MOD DIS	DIS ERROR	TYPE & POS	POS ERROR	HYS ERROR	TOTAL ERROF
4		1975	0.190	23.50	829.78	814.42	1.886	RB	0	0	0
4		1975	0.290	24.58	999.70	975.59	2.471	RB	0	0	0
5		1975	-2.340	25.19	1118.64	1074.30	4.127	FB	0	15	15
5		1975	0.080	25.56	1158.29	1136.98	1.874	RB	0	0	0
5		1975	-0.070	25.70	1212.10	1161.25	4.387	FB	0	0	0
5		1975	-0.180	25.26	1002.53	1085.99	7.685	FA	0	0	0
5		1975	-0.330	24.40	832.61	947.54	12.120	FA	0	0	0
5		1975	-0.640	22.46	600.38	674.83	11.030	FA	0	5	5
5		1975	-0.590	20.44	404.98	444.02	8.791	FA	0	5	5
5		1975	-0.370	19.03	294.53	311.62	5.485	FA	0	0	0
6		1975	-0.130	17.68	202.49	204.72	1.086	FA	0	0	0
6		1975	-0.070	16.67	141.88	136.31	4.083	FB	0	0	0
6		1975	0.400	18.71	322.85	284.60	13.440	RB	0	5	5
7		1975	0.530	20.51	478.61	451.18	6.080	RB	0	5	5
7		1975	0.330	21.35	589.06	541.69	8.744	RB	0	0	0
7		1975	0.120	23.06	812.78	753.55	7.860	RB	0	0	0
7		1975	0.160	23.54	846.77	820.09	3.253	RB	0	0	0
7		1975	0.100	24.51	1011.02	964.62	4.810	RB	0	0	0
7		1975	-0.030	24.64	1005.36	985.05	2.062	FB	0	0	0
7		1975	-0.520	23.46	744.82	808.77	7.907	FA	0	5	5
8		1975	-0.880	21.39	501.26	546.22	8.230	FA	0	10	10
8		1975	-0.750	17.61	199.66	199.67	0.003	FA	0	5	5
8		1975	-0.040	15.67	90.06	77.53	16.150	FB	5	0	5
									Average		2.61
									Confidence		97.39
END FOR TYPE & POSITION											
- Falling stage & Above normal curve - expected position											
- Falling stage & Below normal curve - error											
- Rising stage & Below normal curve - expected position											
- Rising stage & Above normal curve - error											

After all SD points have been assigned an error the program enters the final step. The weighted regression routine is exercised, and the "best" model is determined. The corrected model for the Red River is illustrated in Figure 5.11, along with the SD data and the original model each in a different colour. It may be difficult to distinguish the "corrected" model from the original model because of expected similarities, but the parameters for both are very different. The inclusion of the confidence limit provides a reliability estimate in the predictions made from the rating curve. The comparison of the normal preliminary model and the corrected model for the Red River (Equation 5.2) show

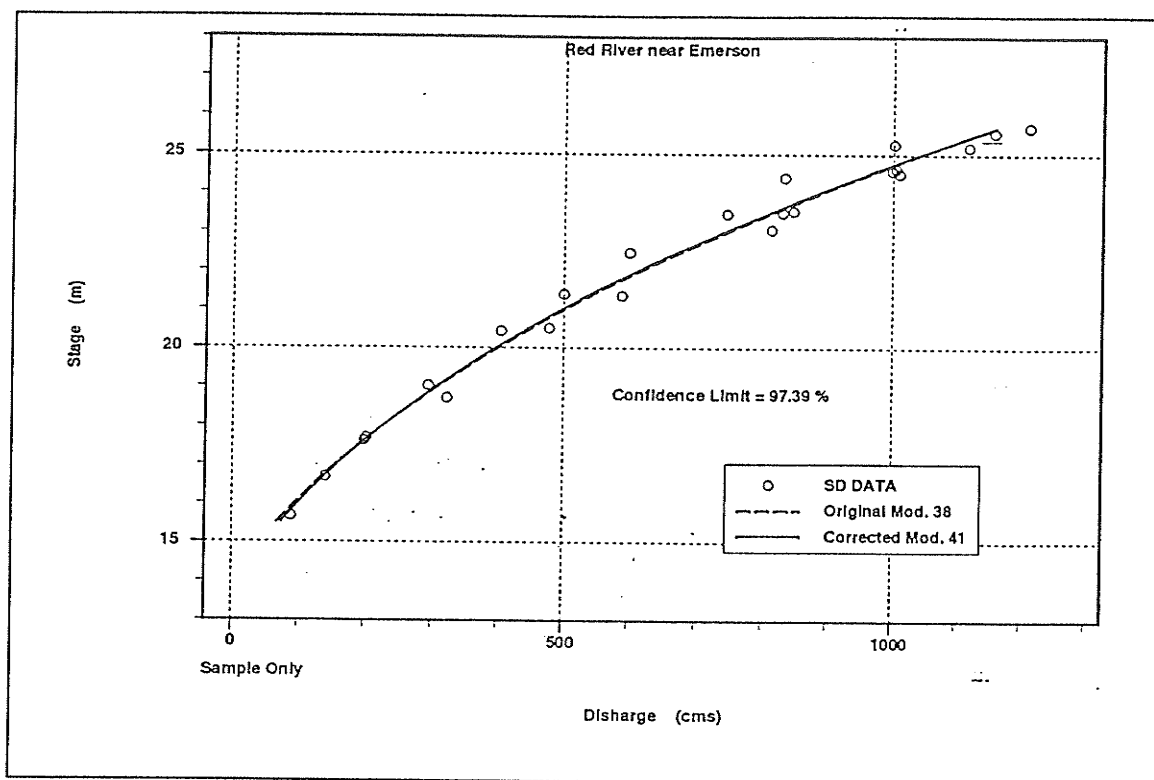


Figure 5.11: Final Results

a significant difference in the models.

$$\begin{aligned}
 &\text{Normal Preliminary Curve No. 38} \\
 &\text{Discharge} = -177.7235 + 0.0253 * \text{Stage}^{3.35} \\
 &\text{Corrected Curve No. 41} \\
 &\text{Discharge} = -148.1061 + 0.0152 * \text{Stage}^{3.50} \\
 &\text{Confidence Limit} = 97.39 \text{ percent}
 \end{aligned}
 \tag{5.2}$$

The graphical presentation of the final results is directly followed by the presentation of the final model's parameters, and the establishment of the confidence of future predictions. For the Red River the determined confidence limit for the corrected curve is 97.39 percent. This seems to be an acceptable measure because the effect due

to hysteresis is not severe. Accepting or changing the confidence is then followed by the storage of these parameters in the database before exiting.

5.4.2 Evaluation of HEAS

The results are indicative of the magnitude of error often experienced when creating normal curves. However, the assignment strategy relies heavily on the distribution of the points about the preliminary curve. It is most desirable to have an even distribution of rising and falling stage measurements. Although this technique provides a fair means of assessing the error, it lacks scientific justification and essential expertise specific to the current station. Better results could be realized using more scientifically based analysis. The analysis should include such factors as water surface slope and wave velocity. This may be particularly important for smaller streams where the wave fronts move very rapidly and do not have lengthy attenuation. In addition, it may also be more effective to separate rising, falling and stable stage (as is the case with the SDDSS, Chapter 3) measurements before creating curves and assigning the error. In this way each curve would have greater accuracy accompanied by a reliability estimate. The possibility of including these and other principles could be incorporated easily into the framework provided in the prototype.

The final results provided by the system are very useful. The weighted regression scheme tends to mimic the original curves produced, but the associated confidence factor provides a reliability estimate that currently does not exist. At the same time, the general framework of HEAS is flexible, and it shows the effectiveness of a general error analysis framework. The structure of the prototype is very similar to the Stage-Discharge Decision

Support System (SDDSS, see Chapter 3) produced in a UNIX environment with OPENLOOK (window) capabilities. This provides the possible incorporation of the error analysis prototype into the SDDSS taking full advantage of its database integration, and window and graphic capabilities.

6. CONCLUSIONS AND FUTURE RESEARCH

6.1 Evaluation of Prototype Systems

The prototype systems presented in the thesis illustrate the broad context of Stage-Discharge analysis. The comprehensive Stage-Discharge Decision Support System (SDDSS) and its would be sub-systems, the Multi-Objective Stage-Discharge Evaluator (MOSDE) and Hysteresis Error Analysis System (HEAS), all display new procedural frameworks for rating curve analysis of non-stable channels. The dynamics of the problems have been address by the development of a logical framework for rigorous and standardized analysis.

The SDDSS now displays the ability to comprehensively develop, use, modify and extrapolate from SD curves for both stable and non-stable channels. Also, an effective means for classifying the channels has been put forward. This is very important because the stream classification defines stability through analysis which indicates relations which have or have not changed in time. More importantly those times of change are monitored and used in further analysis. The remainder of the system now analyzes SD data and developed curves with important graphical diagnostic tools. However, the technicians experience is not left out of the process, but instead, enhanced by the progressive and logical hierarchy of analysis.

The system does, however, have some inadequacies regarding the development of the SD relations. A lack of coherence exists between stable and non-stable analysis. For example, more options exist for stable channels when applying curves to gauging records,

and the automated statistical modelling feature is not able to force-fit curves through the zero flow stage.

The two smaller proposed sub-systems also show promise. The MOSDE illustrates the effectiveness of the multi-objective Compromise Programming routine when evaluating the generated statistics from many transformations of the SD data. If this procedure alone were to be incorporated into SDDSS, efficient and unbiased evaluation of representative models would be realized. As well, the HEAS system for error analysis shows its promise when utilizing quantitative error analysis into the regression scheme. By implementing a weighted regression analysis on the SD data, less bias is shown in the resulting models, and a certain level of confidence can be associated with the resulting optimal model. The inclusion of error as a means of weighting SD measurements provides greater accuracy and reliability in discharge predictions. Also, the framework for the error assignment is adaptive to different kinds of error.

6.2 Future Research Work

There have been many advancements made during phase 2 of the development of the SDDSS. The framework implemented attempts to provide a basis for understanding, modelling and representing more accurately the S-D rating relation for the many types of natural streams and rivers that the Department of Environment is responsible for. The framework for logical procedure has been set. The analysis is effective, but the criteria and analysis require some "fine tuning" and improvement. The current framework provides a catalyst for future investigation and improvement. The flexibility of the

organization of the programs make integration of new analysis relatively easy. Further implementation of "expertise" into the system will lead to a comprehensive system able to completely handle the many variations experienced in hydrometric data analysis. The ensuing section highlights some important aspects that should be addressed in the near future.

Ice Conditions

Modelling the S-D rating for measurements affected by ice conditions poses an interesting and complex problem. The procedure should analyze the data with respect to the four most common situations found in natural channels subject to ice conditions. First, consideration should be given to partial ice conditions that occur during freeze over and/or break up. Then, consideration should be given to measurements which are taken during complete ice cover. The latter situation can create three scenarios: The ice cover could be suspended above the water surface, and essentially the flow is unrestricted; the ice cover could be floating on the water restricting flow (increased friction surface); or alternatively, the ice can cause pressurized (pipe flow) flow in the channel when it is buoyant on the water surface (eg., spring thaw of water upstream of a stable ice cover could be "pushed" through in the lower reach).

The current SDDSS framework only indicates that these are necessary requirements for analysis, but the process knowledge has not yet been implemented. The future development of this analysis will be subject to the adequate development of a database for ice measurements. The problems lie within the accuracy and use of the

coding system currently employed by EC technicians. The coding system should be rigorously applied, and should be coupled with a reliability estimate, even as simple as a scale of 1 to 10. Such information is invaluable to analysis of any data.

Although the scope of the problem is known, the problem arises in identifying and dealing with the measurements taken during "ICE" season. The objective is to develop the database which identifies such measurements, and implement the rules and knowledge base to deal with the creation of the S-D relation for the above situations. Ice conditions are a reality in Canada today. Addressing the problem should be a step undertaken in the future to more accurately define the S-D relationship.

Smoothing the Transition Zones

Unstable channels are often susceptible to ratings which have a zone where the relation changes dramatically. The transitions can occur when the rating shifts with stage (example at bank-full stage), or at the point where the hysteresis loop changes from rising limb to falling limb. The framework has been set for the first condition, but a suitable function or method has not been found and implemented. Methods for smoothing have been successfully implemented in the TIDEDA (Rodgers and Thompson, 1991) and HYDSYS/TS (Hydsys Pty Limited, 1991) systems, and future research should look to these methods for possible implementation into the SDDSS. On the other hand, the debate for the purpose and need of smoothing continues, as well as the debate on the physical behaviour or the rating in the transition zones. Future research should address this problem because it also can enhance the accuracy of the S-D relation.

Once developed the relations within the transition zones must then be transferred for use in the other three modes. It is important to establish effective methods which can then be applied in the Curve Use, Modification and Extrapolation modes.

Incorporation of Error

The incorporation or estimation of error associated with each measurement is often a taboo subject. However, no analysis or measurement method is completely error free. In chapter 5, a proposed sub-system has introduced the subject of incorporating error into the analysis when hysteresis affects the relation. The same type of scenario should be extended to all facets of analysis within the SDDSS.

The current error assignment is strictly from a statistical point of view that assigns deviations to errors not hydraulic realities. There is a need to know the physical measurement error. Therefore, the incorporation of technical expertise to the process knowledge framework should not be ignored. Much expertise in interpreting the behaviour of the relation, and its associated measurements is missed in the current framework. Employing a measure of error into the analysis will create a more effective measure of confidence in the application of the established curves.

Graphical User Interface

Enhancing the current level of development of SDDSS is important. Further development of the knowledge bases with expertise is essential to completely define all possible situations encountered when establishing a rating relation. The implementation

of a graphical user interface will increase the capability of the SDDSS at all levels of the development and use of the rating curve. Therefore, it is important to explore and develop this type of tool, which would definitely overcome the inadequacies found in the current graphical tool. Producing such a tool would complete the SDDSS. The system would then be able to function as an operational tool to be used for developing, using, modifying and extrapolating from an accurate representation of the S-D relation for all types of natural and man-made channels.

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APPENDIX A - On-line Help Manual

The following pages represent the actual On-line help manual system of "manpages" as viewed by the user of SDDSS during the consultation. Referenced in Chapter 4, the manual is divided into the following sections:

	Page
(1) SDDSS Overview	146
(2) Curve Development	157
(2.1) Stream Classification	169
(2.2a) Data Selection (Stable Channels)	186
(2.2b) Data Selection (Non-Stable Channels)	203
(2.3) Mathematical Modelling Procedures	219
(2.4) Outlier Analysis	238
(3) Curve Use	256
(4) Curve Modification	272
(5) Curve Extrapolation	289

Section (1) - SDDSS Overview

MORE_HELP(1v)

SYSTEM OVERVIEW

MORE_HELP(1v)

TITLE

Stage-Discharge On-Line Help Manual

DESCRIPTION

As described in the previous help manpage, this manual browser is setup to aid the user in developing and using the stage-discharge relationship provided by this system. The manpages are setup in different sections and are indicated by keywords. By clicking on the key words the specific manpage can be viewed. Manpages are setup to aid in both the understanding of the system, and its procedures. The manpages also help in explaining procedures, and judgements or input demanded by the users.

USE

XMAN is always present in the top right hand corner of the screen. It should be left there always, and used only when it is needed.

MORE ABOUT THE MOUSE

The user may find that the mouse doesn't work exactly like that explained in the previous help section. To activate a manpage place the pointer on the manpage button, and hold the middle mouse button down while pressing the left button. This should work.

TITLE

Stage-Discharge Decision Support System (*SDDSS*) Overview

DESCRIPTION

This Manpage will try to explain the objectives and uses of the concepts behind the implementation of the *SDDSS*. It is a complete computer program for *stage-discharge* rating curve analysis. It allows the user to:

- 1) *Develop* a rating relationship or multiple relations for gauging stations throughout the jurisdiction of Environment Canada.
- 2) *Use or Apply* those developed relations to systematic gauging records.
- 3) *Modify* existing relations with new and different data.
- 4) *Extrapolate* from existing relationships to estimate stage or discharge beyond the measured stage range.

It follows from the above mentioned functions that the system is separated into four user modes, each of which, allows the user to perform all necessary tasks in the four areas mentioned. Each area is programmed independently from the rest, but relies on communication with the user, the database, and external routines to perform the functions inherent in each mode.

The Stage-Discharge Decision Support System behaves interactively with the user. It guides the user through all logical steps in the development and use of the S-D analysis. The system also provides the user with several diagnostic tools and other options to enhance the decisions made by the user. In most cases the data acquisition from the data base is made automatically by the system and presented for approval to the user.

USER MODES

All four user modes are briefly discussed in this chapter and a separate section of this on-line manual is dedicated to each mode. Each Section is subdivided into manpages which describe individual procedures and objectives of those procedures. The purpose of this manual is to aid and enhance the users understanding of the *SDDSS*, its procedures, and the logic behind its procedures.

PLATFORM(1v)

SYSTEM OVERVIEW

PLATFORM(1v)

TITLE**HARDWARE** and **SOFTWARE** of the SDDSS**DESCRIPTION**

The basis for implementation of the **SDDSS** is to provide a rigorous and user friendly environment for Stage-Discharge rating curve analysis. The system was implemented to build on the current methods used, as well as, incorporate the many years of expertise and knowledge implemented in the analysis. For these reasons a **DECISION SUPPORT** system with an **EXPERT SYSTEMS** component has been implemented in a computer-based environment

HARDWARE

The Hardware consists of a SUN SPARC workstation. The operating system is produced by Sun Microsystems and is a UNIX platform. All the software tools are implemented within the OPENWINDOWS environment which provides a window environment with multi-task capabilities.

SOFTWARE

The software that provides the expert system shell, as well as the main controlling environment is produce by NEURON DATA and is called **NEXPERT OBJECT**.

This shell tool can access the **ORACLE** database via a software bridge included in the NEXPERT package. Oracle provides the user with a complete relational database management system, whereby the data is accessed via the **SQL** language. NEXPERT can also execute any external **FORTRAN** or **UNIX SCRIPT** routines which can ease file and data manipulation and processing. These external routines are run in the background and the user's direct interface is with the NEXPERT OBJECT tool. Finally any graphical representation is provided to the user through two graphing tools. The most widely used throughout the program is a public domain software called **XGRAPH** and a plotting tool produced by DUX software called **XPLOT** is used to a somewhat lesser extent. The only additional peice of software provided to the user is this manual page browser, **XMAN**, which is also public domain.

DEVELOPMENT(1v) SYSTEM OVERVIEW DEVELOPMENT(1v)

TITLE

Developing the Stage-Discharge Relationship

DESCRIPTION

The most important aspect of the overall stage-discharge rating curve analysis is **building or developing** the relationship between stage and discharge. Due to the dynamic nature of natural river systems it is necessary to accurately define the **S-D relation** with respect to time and specific hydraulic and hydrologic conditions affecting the channel reach where the stage-discharge measurements are taken. The definition of the relation is provided by means of a mathematical model which represents the relation. With the mathematical model, it is possible to statistically represent the S-D measurements and perform tests to specify accuracy of the fit. Also, any points which do not fit within a specified tolerance boundary are considered as outliers and are further subject to analysis. From all of this, the **Curve Development Section** is composed of several subsections such as:

- 1) **Stream Classification** - An analytical means for defining the stability of the reach in question, and the time periods between major hydraulic events that may have altered the stage-discharge relation
- 2) **Data Selection** - Separated into two groups, data selection tasks are performed differently for **stable** and **non-stable** channels. The objective of this section is to define the data set for a particular hydraulic phenomenon that represents the stage-discharge relation more accurately.
- 3) **Mathematical Modelling** - In this section S-D measurement data sets are fit with a mathematical model. Statistical tests help the user to decide which model best represents the data. Two methods are currently available: Automated Statistical Modelling and Manual Statistical Modelling. Each provides the user with several options for fitting the curve.
- 4) **Outlier Analysis** - Any S-D points which are detected as outliers can be further investigated in regards to their cause as outliers. The system leads the user through a series of questions to determine the reason the point plotted outside the allowable tolerance boundary of the curve. These points can be further used within the knowledge extracted from the database to develop curves that are specific to the cause for

DEVELOPMENT(1v) SYSTEM OVERVIEW DEVELOPMENT(1v)

outliers. (eg., a curve that is used in backwater conditions due to heavy vegetal growth in the channel).

PROCEDURE

Currently the computer program takes the user through the above sections in the order they are presented. The *Curve Development* procedures are activated when the user chooses the following option from the main menu: *Make a New Curve*. The architecture of the program completes each task in sequence according to a set logical framework for the analysis.

SEE ALSO

Each of the above sections are further outlined under their respective headings in this manual page browser.

DEVELOPMENT(1v) SYSTEM OVERVIEW DEVELOPMENT(1v)

TITLE

Use and Application of Stage-Discharge Rating to Systematic Record of Gauge

DESCRIPTION

The objective of any hydrometric program is to supply an end user with a database of water quantity data for analysis of public and private water resources projects. The EC's network of gauging stations throughout Canada provides many institutions with such a database, and the computation of daily discharge using the S-D rating relation is a key component of this database. Therefore, the *Stage-Discharge Decision Support System* has a component that utilizes any previously developed mathematical relations and the systematic record of gauge produced at each station. The *Curve Use* section is currently separated in two parts. The first, deals with applying a channel that has relatively stable relations to the record of gauge. The second, deals with the complexities of a channel that is relatively non-stable in its environment.

STABLE CHANNEL CURVE USE

A station which is on a channel analyzed as stable has a curve or curves developed for its particular channel control. These curves can then be chosen to be applied to a systematic record of gauge. The available options to the user are as follows:

- 1) Compute *Average Daily Discharge Predictions Only* from a systematic record of gauge and a chosen S-D curve. These predictions are not accompanied by confidence intervals. The discharge table is shown to the user, and can be saved for hardcopy production.
- 2) Compute *Average Daily Discharge Predictions with Confidence Bounds* from a systematic record of gauge. Confidence bounds can be produce for 80, 90 and 95 percent confidence intervals. The discharge table is shown to the user, and can be saved for hardcopy production.
- 3) Compute *Discharge at 15 Minute Intervals* from a systematic record of gauge. Confidence bounds can be produce for 80, 90 and 95 percent confidence intervals. The discharge table is shown to the user, and can be saved for hardcopy production.

DEVELOPMENT(1v) SYSTEM OVERVIEW DEVELOPMENT(1v)

- 4) **LOOKUP TABLE** - This is a production of the rating table in the standard EC lookup format. The discharges can be produced at stage intervals of 0.001, 0.010 and 1.000 meters.

UNSTABLE CHANNEL CURVE USE

A station which is on a channel which has been analyzed as non-stable has curves developed according to the natural behavior of the channel control. This may also include curves determined for several different periods in time. The SDDSS allows the user to apply these curves to a systematic record of gauge. Only the first two options from the above list are available in this mode at this time. Also, default curves are set for computational use. However, the user is allowed to override this setting, and apply different curves if necessary. The chosen curves are applied to the gauging record automatically according to the conditions for which they apply (eg., a rising limb curve would only be applied to gauging points on the rising limb of the hydrograph).

PROCEDURE

The procedures differ only slightly for stable and non-stable sites. Please refer to *section 3* which deals with *Curve Use*.

SEE ALSO

Section 3 - Curve Use

DEVELOPMENT(1v) SYSTEM OVERVIEW DEVELOPMENT(1v)

TITLE

Modification of Stage-Discharge Rating Curve with new data or data affected by backwater conditions.

DESCRIPTION

After developing a rating relation it is often necessary to see how the relation is affected by new measurements. The **SDDSS** currently handles curve modification separately for stable and non-stable channels. However, the process is very similar in both cases. The user is allowed to choose the path taken when altering the S-D curve. Any alterations made can be stored in the database as new curves, while the original S-D relation is still held in tact, as it did before the modification process.

STABLE CHANNEL CURVE MODIFICATION

For those channels that were determined to be stable, it is possible to modify the original curve(s) with any new S-D measurements taken after the last measurement of the original curve. The new measurements may show that the relationship is changing or, as expected with stable channels, not changing. The new data can be modelled as part of the original curve (ie., updating the old curve) or separately, without the old curve, creating a totally new and unique relationship.

UNSTABLE CHANNEL CURVE MODIFICATION

A station situated on a non-stable channel has more options to explore in addition to the above option for stable channels. Original curves for non-stable channels are made for open, non-obstructive or uninfluenced flow measurements (ie, normal flow). However, sometimes a measurement is taken during some backwater period, or other influence. By recording these influences it is possible to see how several commonly influenced "back-water" measurements can affect the *stage-discharge relation*. Therefore, *Curve Modification* for non-stable channels also includes the option for modifying the S-D relation according to those measurements that were not taken during normal conditions.

PROCEDURE

For general and more specific procedural information for stable and non-stable sites. Please refer to *section 4* which deals with *Curve Modification*.

DEVELOPMENT(1v) SYSTEM OVERVIEW DEVELOPMENT(1v)

TITLE

Extrapolation of Stage-Discharge Rating Curve beyond the maximum measured stage value.

DESCRIPTION

It is often required that discharges be predicted for peak stages. However, it is very common that peak discharges occur at stages that are greater than the highest measured stage. For this reason it becomes necessary to extrapolate information from the current S-D relation and knowledge of the stations hydraulic control. The purpose of the *Curve Extrapolation* procedure is to provide the user with a means of estimating a discharge or stage beyond the range for which the currently established S-D relation is valid.

METHODOLOGY

Three techniques are used in the SDDSS, and all are taken from the International Standards Organization (ISO) **STANDARDS HANDBOOK 16** Measurement of liquid flow in open channels. They include:

- 1) Extension of the current S-D relation - Using the mathematical model and knowledge of the hydraulic control
- 2) Extension of the logarithmic plot of hydraulic radius (R) and mean velocity (v) - Hydraulic radius is derived from the hydraulic control's cross section, and mean velocity is measured.
- 3) Extension using the basic Manning's equation for flow in open channels.

In some cases assumptions are made to improve the process. The methodology used is the same for stable and non-stable channel controls.

PROCEDURE

The user is taken through logical steps to arrive at appropriate estimations for extrapolated discharge or stage. The options provided to the user are explained throughout the procedure, and enhanced by this user manual. Please refer to section 5 which deals with the *Curve Extrapolation* mode.

ACRONYMS(1v)

SYSTEM OVERVIEW

ACRONYMS(1v)

TITLE

List of Acronyms

ACRONYMS USED IN SDDSS HELP MANUAL

A.S.M. - Automated Statistical Modelling
DS - Data Selection
KB - Knowledge Base
SC - Stable Channels
NSC - Non-Stable Channels
SDDSS - Stage-Discharge Decision Support System
VBS - Variation by Stage

Section (2) - Curve Development

OBJECTIVES(1v) CURVE DEVELOPMENT OBJECTIVES(1v)

TITLE

Objectives of the Curve Development Module in the SDDSS

DESCRIPTION

The SDDSS is now fully capable of analyzing and modelling the stage-discharge data for many stations within the network maintained by Environment Canada. The analysis is a group of three components, two of which are prior to the mathematical modelling and representation of the curve, and one after the modelling is complete. The mathematical modelling sub-section provides the user with a rigorous method for representing the stage-discharge rating relation with a mathematical modelling equation. Therefore, the main objective of the SDDSS's *Curve Development Mode* is to produce a single relation or a set of relations that accurately define the stage-discharge rating.

PROCEDURE

The user is taken through a series of logical procedures to make better decisions for S-D analysis. The series of sub-sections within the *Curve Development* are:

- 1) *Stream Classification* - This sub-section attempts to provide the user with analytical tools to determine if the channel control has been relatively stable or non-stable in time.
- 2) *Data Selection* - This sub-section is separated for those channels that were determined to be stable or non-stable. Stable channels select stage-discharge measurements on the basis that the relation has not changed much throughout the entire period of record for the gauging station. On the other hand, non-stable channels are further subject to analysis, where the stage-discharge measurements are grouped and analyzed with respect to time and other hydraulic phenomenon. The result is a set of curves that more accurately define the relationship between stage and discharge.
- 3) *Mathematical Modelling* After a data set is approved by the user for modelling the mathematical tools are activated. Currently, two methods are employed. A *Manual Statistical Modelling Procedure* and a *Automated Statistical Modelling Procedure* both provide similar results, but with quite different procedures.

The result is the representation of the stage-discharge measurements with a mathematical model. From here, the

OBJECTIVES(1v)

CURVE DEVELOPMENT

OBJECTIVES(1v)

model can be stored in the database for future use or subjected to further analysis in regards to those points which plot outside a predetermined allowable error (Outlier Analysis).

- 4) **Outlier Analysis** This section, although optional, is very important. By analyzing those points which are determined to be outliers it is possible to gain and use more knowledge from the database. The outliers are identified as to their cause for plotting above or below the curve. The user is guided through a series of questions that will hopefully explain the cause of each outlier, which is then stored in the database for future use.

SEE ALSO

In this section all of the above sub-sections are briefly described in their own manual page. Also each sub-section has its own section in this manual page browser which attempts to completely define and explain all facets of the *Curve Development Mode*.

ARCHITECTURE(1v) CURVE DEVELOPMENT ARCHITECTURE(1v)

TITLE

Curve Development system architecture within the SDDSS

INTRODUCTION

The *Curve Development Mode* of the SDDSS is represented by several Knowledge Bases (KBs) within the framework of the system. Each KB performs specific tasks with respect to the sub-sections of the Curve Development Mode. The KBs can act interactively when it is necessary, and all interaction is controlled by NEXPERT OBJECT.

DESCRIPTION

The following is a brief list and description of the KBs involved in the Curve Development Mode:

- 1) *SC.tkb* - This knowledge base handles the *Stream Classification* procedures and analysis
- 2) *NSA.tkb* - This knowledge base controls the analysis for data selection of non-stable channel controls only.
- 3) *SC_DS.tkb* - this knowledge base consists of the framework for data selection in non-stable channels, as well as, the retrieval of data points from the database prior to modelling from all other KBs.
- 4) *MODEL.tkb* - this knowledge base provides the user with the two tools for mathematical representation of the *stage-discharge rating curve*.
- 5) *FILTER.tkb* - the last knowledge base works interactively with the previous to provide an analysis of the outliers determined from the mathematical modelling procedures.

SEE ALSO

1_CD_Objectives for an explanation of the overall structure and description of the Curve Development Mode

CLASSIFICATION(1v) CURVE DEVELOPMENT CLASSIFICATION(1v)

TITLE

Stream Classification Section

DESCRIPTION

Stream Classification represents the first section in the overall development of the *Stage-Discharge* relation. Because different types of channels behave differently, and therefore, are modelled differently, it is necessary to segregate certain regimes of flow.

USE

The first step is to classify streams according to stability of the regime. Thus, we have two classifications:

- 1) *Stable Channels*
- 2) *Non-Stable Channels*

The SDDSS analyzes historical data through graphical representation and numerical analysis to arrive at this initial classification. The procedure is outlined in the *Stability_Analysis* file in this section.

Each of two stability criteria is further developed separately. However, both are further categorized according to:

- 1) *Sediment Type*
- 2) *Pattern*

Each stream's particular classification is then stored in the database for later use in the development of the *Stage-Discharge* curve.

This further classification allows for specific stage-discharge development according to its particular regime.

PROCEDURE

NEXPERT uses information resulting from analysis of a *Specific Gauge Plot*, and user prompted information. User prompts will be aided by the use of this help manual.

DS-STABLE(1v) CURVE DEVELOPMENT DS-STABLE(1v)

TITLE

Data Selection Procedure and Description for Stable Channel Controls

DESCRIPTION

The data selection for stable channels is very rudimentary, because it is expected that the channel control behaves quite consistently. It is a hierarchical process which allows the user full control of the data set to be modelled. The Section is loaded up directly after the stream classification section has been completed and the stream in question was determined to be stable.

FUNCTIONS

The hierarchy of the data selection is quite simple the levels are as follows:

- 1) *All S-D measurements* - Simply all measurements are retrieved from the database for the entire record of the station and under all conditions.
- 2) *Specific Measurements* - This option allows the user to specify special data sets in several categories:
 - 2.1) ICE CONDITIONS - Separated into *Complete Ice Cover* and *Partial Ice Cover* and *Other*, the data sets should be retrieved according to the users wishes.
 - 2.2) OPEN FLOW - this option will automatically retrieve all data that were taken during normal open flow conditions in the channel.
 - 2.3) TIME - The user can define certain periods of time (eg., the month of JULY for all years or a certain span of years). The query string is built by NEXPERT and the data is retrieved automatically for modelling.

PROCEDURE

The user is guided through the hierarchical structure by a series of questions (and options for answer) to find out more about the data set that he/she desires to model.

SEE ALSO

Section 2.2a Data Selection (Stable Channels) this section completely describes all aspects of the data selection process for *Stable Channels*.

NS-ANALYSIS(1v) CURVE DEVELOPMENT NS-ANALYSIS(1v)

TITLE

Data Selection Procedure and Description for Non-Stable Channel Controls

DESCRIPTION

A logical framework of analysis has been set in order to more accurately define the segmentation of the overall data set. The data set has already been separated into different time periods in the Stream Classification section, and now each time period is subjected to further analysis that will try to identify any hydraulic or hydrologic phenomenon that are effecting the channel control, and likewise the *Stage-Discharge* rating relation.

Once a time period is selected for further analysis the user is systematically guided through a hierarchical structure of data filtration.

DATA SELECTION HIERARCHY

Each section of the hierarchy is briefly highlighted here:

- 1) *Stability* - Although a channel can be deemed as unstable, it is possible for individual time periods to be relatively *stable*. In this case, the S-D data is shown to the user, and put forward to be modelled. The user has the choice of modelling this data set, or to continue with the analysis and go to the next level in the hierarchy.
If the individual time period is determined to be *Non-Stable* the program automatically continues to the next level in the hierarchy.
- 2) *Seasonal Variation* - This level uses several graphical aids as diagnostic tools to aid the user's choice for seasonal variation. The objective here is to allow the user to determine if there is a difference in the models for *open flow data* and *ice flow data* (.ie, the control has two separate relations seasonally).
- 3) *Variation due to Hysteresis* - The third level also produces several graphical aids which distinguish between those measurements taken during *rising stage* and *falling stage* conditions. These diagnostic aids help the user to decide if the S-D relation is quite different for the two hydraulic conditions. If so the data set is separated accordingly, and the user can model each separately or continue to the last level of the hierarchy.

NS-ANALYSIS(1v) CURVE DEVELOPMENT NS-ANALYSIS(1v)

- 4) *Variation with Stage* - Many natural channels have complex geometrical shapes that greatly effect the S-D rating. This level aids the user in deciding if the relation differs at certain stage levels of the channel control. For example, at bank-full stage the relation may change due to the configuration of the flood plain. The graphical tools used here aid the user's decision to pin-point the level where the relation differs.

SEE ALSO

Section 2.2 (b) has a complete outline and description of all the data selection procedures, and interpretation of the graphical tools used for non-stable channel analysis. Therefore, the user is referred to this section for further help.

MODELLING(1v)

CURVE DEVELOPMENT

MODELLING(1v)

TITLE

Mathematical Modelling Sub-Section of the Curve Development Mode.

DESCRIPTION

Within this section are all the nescessary procedures for fitting a mathematical model to the data set selected by the user for modelling. The section provides a means for statitcal tests for evaluating the appropriateness of each fit. Also, the statistical measures are later used to establish confidence limits on predictions of discharge.

PROCEDURES

The procedure for fitting a model is fairly straight forward and systematic. The user is guided through each step, and many options are possible to allow for flexibility. The main procedures are highlighted below:

- 1) **Data Retrieval** - This procedure simply retrieves the data set to be modelled from the **ORACLE** database. This is done automatically once the user decides that he/she wants to model a particular set of data.
- 2) **Zero Flow Stage** - the default is the highest zero flow stage in the data set, if one exists. If not, the default becomes zero. However, this can be set by the user.
- 3.1) **Analyze Rating Table from H.D. Curve** This section allows the user to apply the statistical tests of **R-squared** and **Standard Error of Estimate (SEE)** and **The Number of Outliers** to the rating table produced from a hand drawn curve. It can then be compared to that of the regression models produced by the computer. This is more of an anesthetic feature because the rating tables cannot be stored in the database at this time.
- 3.2) **Automated Statistical Modelling** - This procedure automatically creates 63 different models according to several **POWER** transformation of stage and several transformations of discharge using the **BOX/COX** transformation method. The models are then screened automatically for **skewness and kurtosis** and then presented to the user under further tests for distribution of **residuals** and **normal probability**. These statistical tests ensure the accuracy and appropriateness of the model (ie., **NORMALITY**). Once a satisfactory model is created and accepted it can be stored in the **ORACLE** database

for later use or subjected to the outlier analysis.

3.3) *Manual Statistical Modelling* - Choosing this method allows the user to control and input the exact power transformation exponent desired. A number of iterations can be performed, with the simple power transformation of stage. After each iteration statistical goodness of fit tests are shown for evaluation. Also, the user can choose to force-fit the curve through the zero flow stage (ie., fix the intercept) or allow for the regression analysis to set the intercept. After choosing a best fit model the model can be stored in the database or the data set and model can be further analyzed with respect to the number of outliers.

4) The last step occurs after the evaluation step within each of the previous modelling procedures (3.1, 3.2 and 3.3 above). It is up to the user to decide if the **Best Model** evaluated is to be stored in the database or to be subject to the outlier analysis. Also, the procedure can be re-iterated or exited at the users discretion.

SEE ALSO

Section 2.3 - Mathematical Modelling Procedures

This section complete defines all procedures and interpretations necessary for building the mathematical models that represent the stage-discharge rating relation. Also see the next manual page for more information on the *Outlier Analysis*

OUTLIERS(1v)

CURVE DEVELOPMENT

OUTLIERS(1v)

TITLE

Outlier Analysis sub-section of the Curve Development Mode

DESCRIPTION

The purpose of this section is to identify the cause of deviation from the curve of any points beyond the allowable error. The objective is to attach a specific code to each outlier. The code will identify the cause of the outlier, and flag it as such for future use in the stage discharge analysis. If the point in question does not already have an EC code for its cause questions are asked to the user which will categorize the outlier point as one of eight possible cause for plotting as an outlier.

CATEGORIES

The following are the categories for outlier analysis. It is possible to fit the outlier as a multiple cause, and in this case the outlier is attached with a special *MU* code.

- 1) **Beaver Activity** - which is separated into activity down stream or up stream influences.
- 2) **Meander Cut-Offs** - Any meander cut-offs completed near the gauging location can greatly affect the stage-discharge relation.
- 3) **Debris** - Any fallen debris (or man-made) blocking the channel will also alter the relation. Deviations of the point are dependant on the location of the debris with respect to gauge.
- 4) **Rapidly Rising or Falling Stage** - Hysteresis effects also alter the positions of the point on the curve.
- 5) **Tributary Effects** - The confluence of a tributary can also affect the relation. Again, the location and flow regime of the tributary have different altering effects.
- 6) **Wind** - Especially on the praries, the influence of wind can be dramatic at times.
- 7) **Weeds and Vegetation** - Heavy vegetal growth can also affect the the behavior of the stage-discharge curve, and is an important factor especially in the low flow stages.

If the outlier can not be explained by any of the above causes, the outlier is coded as unexplainable (*UX*). All the

Options	Sections	The current manual page is: 7_Outlier_Analysis(v).	
OUTLIERS(1v)	CURVE DEVELOPMENT	OUTLIERS(1v)	

outlier points are stored in the database separately with their respective codes and the curve number for which they apply. This is for future use of the curve and also for future use of the outliers themselves.

PROCEDURE

The system illustrates to the user one outlier at a time, and then asks the appropriate questions to the user for the outlier identification. After the questions are answered the information is stored in the database. When all outliers have been identified, the user is shown the outliers and accepted data. He/she then has the option to remodel the accepted data, abort and exit, or simply review the outliers just shown.

SEE ALSO

Section (2.4), Outlier Analysis for complete details and options.

Section (2.1) - Stream Classification

CLASSIFICATION(1v) STREAM CLASSIFICATION CLASSIFICATION(1v)

TITLE

Stream Classification Section

DESCRIPTION

Stream Classification represents the first section in the overall development of the *Stage-Discharge* relation. Because different types of channels behave differently, and therefore, are modelled differently, it is necessary to segregate certain regimes of flow.

USE

The first step is to classify streams according to stability of the regime. Thus, we have two classifications:

- 1) *Stable Channels*
- 2) *Non-Stable Channels*

The SDDSS analyzes historical data through graphical representation and numerical analysis to arrive at this initial classification. The procedure is outlined in the *Stability_Analysis* file in this section.

Each of two stability criteria is further developed separately. However, both are further categorized according to:

- 1) *Sediment Type*
- 2) *Pattern*

Each stream's particular classification is then stored in the database for later use in the development of the *Stage-Discharge* curve.

This further classification allows for specific stage-discharge development according to its particular regime.

PROCEDURE

NEXPERT uses information resulting from analysis of a *Specific Gauge Plot*, and user prompted information. User prompts will be aided by the use of this help manual.

ANALYSIS(1v) STREAM CLASSIFICATION ANALYSIS(1v)

TITLE

Stability Analysis Procedure

DESCRIPTION

It will be emphasized throughout this section the importance of the ability to classify any channel with respect to its stability. Whether it be *stable* or *non-stable*, a proper stage-discharge relation can only be modelled after it has been properly classified. SDDSS brings the user through a series of simple steps in order to make a decision in regards to stability.

PROCEDURE

The following is a list of steps taken by SDDSS to arrive at a classification of stable or non-stable. The list is followed by a brief description of each step.

- 1) The first step of the analysis uses the knowledge of the *two*, *five* and *ten* year flood return periods. Provided by EC from a flood frequency analysis, most of these (and others) flood values are in the ORACLE database. The three floods retrieved from the database represent the *low*, *mid* and *high* flows respectively, and provide an analysis for the entire flow regime experienced by the river. Although these values are used as the default the user has the option of overriding these values.
- 2) Display of *Specific-Gauge Plot*.
- 3) Link to *Mathematical Modelling Sub-Section* in order to prepare first preliminary curve to establish 10 percent bound for absolute difference plots.
- 4) Display of *Absolute Difference Plots* for low, mid and high flow conditions.
- 5) Detection and display of any *jumps* determined from the absolute difference plots
- 6) Iterative process of establishing preliminary curve(s), +/- 5 percent bound(s), display of *Residuals of Gauge*, and determination of stability classification for each type of flow and each segment between "jumps" as determined by the absolute difference plot.
- 7) Determination of overall stability classification on the basis of established individual classification for each segment.

SPECIFIC_GAUGE(1v) STREAM CLASSIFICATION SPECIFIC_GAUGE(1v)

TITLE

Specific Gauge Plot and Use

DESCRIPTION

The specific gauge plot refers to the use of a graphics display of gauge reading for a specific (*given*) discharge. Thus, it is a visual record of a specific gauge with respect to time, allowing the user to view the behaviour of the channel (over a specified period) in regards to its water level.

Three specific gauge readings are displayed for three different discharges corresponding to:

- 1) The discharge in cms for the *Two* year return period.
- 2) The discharge in cms for the *Five* year return period.
- 3) The discharge in cms for the *Ten* year return period.

The above return periods are chosen to represent discharges correlating to low flow, mid flow, and high flow situations.

USE

The ultimate use of the *Specific Gauge Plot* is to determine the stability of the channel. By noting, analyzing, and determining any jumps in the gauge reading, and identify points out of tolerable limits between the determined jumps, the behaviour of the stream can be assumed *stable* or *non-stable*. Therefore, defining the jumps (beyond a boundary line determined from a stage variation relating to a +/- 5 percent variance in discharge, see: Preliminary_Curve this Section) between consecutive points leads to a point of instability. Then determining if greater than 90 percent of those points between jumps are within the same bounds, SDDSS will be able to determine if each segment is *stable* (90% *in bounds*) or *non-stable* (> 10 % *out of bounds*). An overall stability classification of *non-stable* is given to the reach if even one flow type (low, mid, high) is determined as non-stable. Otherwise, a *stable* classification is given.

PROCEDURE

SDDSS tries to retrieve the flood return values from the database. If they do not exist in the database the user is prompted for the information regarding the *two*, *five* and *ten* year flood values. Once obtained the values are fed into an external FORTRAN program along with all S-D data. The specific gauge plot is a result of the linear interpolation performed by the program. Upon viewing the specific gauge plot. The user is asked a question regarding its usefulness. If the user finds that there is significant data for all three representative flows he/she may answer the question by double clicking on *Continue Specific Gauge Analysis*. However, if the data presented is not sufficient for analysis the user may choose *Reset Flood Frequencies* or *Skip Specific Gauge Analysis*. Choosing the last option will automatically progress the user to a default conclusion of a *STABLE* channel. The user then progresses with the classification of sediment type and channel pattern, after which he/she may override the default classification setting.

SEE ALSO

Classification Difference_Plot Preliminary_Curve
Stability_Criteria Stability_Analysis Residuals

DIFFERENCE_PLOT(1V) STREAM CLASSIFICATION DIFFERENCE_PLOT(1V)

TITLE

Absolute Difference Plot and Use

DESCRIPTION

The absolute difference plot refers to a graphic display of differences between consecutive points from the *Specific Gauge Plot*. The absolute value of these points is displayed for convenience of computation and representation. There are three plots presented one for each flood return period as defined by the user. The plot is created for use in distinguishing slips or jumps.

USE

The *Absolute Difference Plot* is used as the first step in analyzing the specific gauge readings presented first in the overall stability classification section of the program. By noting the magnitude of the difference between consecutive points, it is possible to note, and indicate any slips or jumps in the *Specific Gauge Plot*. A slip or a jump will be defined as that point which falls outside a given tolerance level of 10%. The 10 percent boundary is established on the basis of preliminary stage-discharge curve. This is created by the user from the five most recent years of data that represent open flow conditions. A jump in the specific gauge will indicate a point of instability. This point of instability may represent a major degradation of the channel bottom, or some aggradation, or any other event that alters the stage of the channel, thus, affecting the discharge. It is at this point that the stage-discharge relation changes. The result is a need for a new curve. Thus, by distinguishing points of instability it is possible to identify the time period within the history of available data that corresponds to a single curve (ie., the period between jumps). The next step is to determine if the segment for a curve will be modelled as stable or unstable.

CRITERIA

The criteria for a jump is based on whether the difference exceeds the given boundary conditions for all three level of flows. Therefore, each flow type *low*, *middle*, *high* must present a jump within a one year period. The one year period which a jump has been detected is then excluded from stability analysis, because the nature of the jump (ie, instability) is not known at this particular time.

PROCEDURE

NEXPERT calls an external FORTRAN program which prepares the data from the specific gauge plot for the absolute difference plot, which is then displayed on the XGRAPH screen.

SEE ALSO

Classification	Specific_Gauge	Residuals
Preliminary_Curve	Stability_Analysis	Stability_Criteria

RESIDUALS(1v) STREAM CLASSIFICATION RESIDUALS(1v)

TITLE

Residuals Plot and Use

DESCRIPTION

Following the display of the absolute difference plots and the establishment of the "jumps" that occur in the specific gauge plot is a process where by three graphs showing *Residuals* of the specific gauge are used to establish stability criteria for each segment as determined from the previous process. Each Residual plot reflects the residuals from each series in the specific gauge. That is, there is a residual plot for each return period as defined by the user. 10 percent boundary lines are also displayed for use in establishing the criteria for stability

Residuals are computed by taking the difference of the observed gauge value and mean gauge value. By plotting the residuals over the time period, it is hoped to establish an overall classification for the stability of the reach in question.

USE

The ultimate use of the *Residual plot* is to determine if the reach in question has behaved in the past and presently as a stable or non-stable channel. By establishing the period between *jumps* (see *Difference_Plot* this section) as being stable or non-stable, the *stage-discharge* relation can be modelled accordingly. The criteria for stability is to establish bounds that a stable channel should fit in, and monitoring the percentage of points in each time segment that fall out of established bounds. If more than 10 percent of all points within a segment lie outside of established boundaries than the channel is said to be non-stable for that segment.

PROCEDURE

NEXPERT uses the data established in the specific gauge procedure to establish the residuals using an external FORTRAN program. Then the Residuals are plotted by XGRAPH to establish the final *Residual Plot* Bounds are established for each segment according to a procedure where a preliminary curve is established from stage and discharge data within the segments time frame (see *Preliminary_Curve* this section)

PRE_CURVE(1v) STREAM CLASSIFICATION PRE_CURVE(1v)

TITLE

Preliminary Curve Use and Procedure

DESCRIPTION

The *Preliminary Curve* is an equation produced by the user and SDDSS that defines the stage-discharge relation for a channel with some specific constraints. The first curve that the user produces is for the last five years of recorded data. This provides the base for establishing a 10 percent error bound for the absolute difference plot. The next curve(s) provide error bounds for residuals of each particular segment in the residual plots.

USE

As noted above the preliminary curve is used to establish error bounds for the various plots. An error bound is a line of significance. Any point within the boundary is *insignificant* with respect to its change from the last point. A point that lies outside of a given bound is flagged as *significant*. Significant points are analyzed according to which plot they belong to.

Error bounds cannot be established upon gauge height alone.

It is not enough to say that a 10 percent change in gauge height is a significant change, because gauge heights are set with respect to an arbitrary datum. However, it is proper to say that the change in gauge height corresponding to a 10 percent change in discharge is significant. Therefore, a *preliminary stage-discharge relation* allows the development of bounds based on this criteria. Once the curve is made an external FORTRAN program varies the low, mid, and high flow discharges defined by the user by +/- 5 percent, evaluates the stages at these points and uses these levels as significant levels of error.

PROCEDURE

SDDSS will notify the user when it is time to make the preliminary curve, and automatically link into the curve development mode for the purpose of developing the relation. At this point the curve is established on the basis that it is assumed stable. However, the preliminary curve will provide the user with the best *guess* as to what the error bounds should be. The following is a procedural list for the preliminary curve development.

- 1) Upon entering the the *Mathematical Modelling Sub-Section* the data for making the curve is pre-set by SDDSS and *automatically* retrieved from the ORACLE database. So, the first thing the user sees is the graph of the data to be modelled along with a text screen explaining the data set and its number of points.
- 2) The second step occurs when the computer asks the user if he/she would like to specify the *Zero Flow Stage*. It is not necessary to do so at this time. CLICK on the *NO* answer.
- 3) After skipping the no flow stage, the system asks: "How to proceed? ". Simply choose *Model Data* at this time.
- 4) The default *Allowable Error* is 20 %. The user has the option to change this value. However, this is not necessary at this time. Answer the question in the session window with the answer *NO*.
- 5) The user is now brought into the modelling procedure by answering the next displayed question by clicking twice on *Manual Statitital Modelling* . The user now enters the modelling procedure.
- 6) SDDSS will now go through an iterative process with the user to arrive at the "BEST FIT CURVE"
- i) SDDSS prompts the user for a transformation exponent
- ii) SDDSS then asks if the user wants to force-fit the curve through the *Zero Flow Stage*. Answer with *NO* because you did not accurately specify it previously.
- iii) SDDSS provides the user with modelled data and representative curve graphically.
- 7) The user is allowed to generate another model curve or evaluate the curve(s) already modelled.
- 8) Select *Evaluate Models* if the desired preliminary model has been reached, or select *Generate Another Model* if the model(s) already generated do not represent a good fit to the data. Then repeat steps 6 through 8.

- 9) After selecting *Evaluate Models* SDDSS asks the user to

PRE_CURVE(1v) STREAM CLASSIFICATION PRE_CURVE(1v)

select the justification for a "BEST FIT CURVE" Make your selection based on the following:

- a) Standard error of estimate
 - b) Minimum number of outliers
 - c) Minimum R² Value
- 10) SDDSS will choose the best curve based on the above selection and then the next step is to select *Store Model* and SDDSS will display the equation of the stored curve and return you to continue with the stability analysis for the current station.

SEE ALSO

Classification	Difference_Plot	Preliminary_Curve
Residuals	Specific_Gauge	Stability_Analysis
Stability_Criteria		

STABILITY(1v) STREAM CLASSIFICATION STABILITY(1v)

TITLE

Stability Classification and Definition

DESCRIPTION

The criteria for channel stability is set by the program. It is important to determine the stability of a particular regime, in order to determine properly the behaviour of the channel and its effect on the *Stage-Discharge* relation. SDDSS determines stability based on past record and behaviour of the stage. By analyzing the specific gauge chart, a trend is established and future behaviour recognized for the establishment of stability. Based on statistical procedures a classification for stability can be reached and a regime can be determined by SDDSS to be either *Stable* or *Non-Stable*.

DEFINITION

Stability of a regime is a relative term, since no natural channel is truly stable no matter how much mankind has *channelized* the reach in question. A *Stable* channel is one that basically has little or no change in its morphological behaviour. That is, the channel is subject to little change in bed and bank movement, whether that movement be horizontal or vertical. This type of behaviour would be realized in a specific gauge plot that exhibits little movement over time (ie. a smooth horizontal line). In turn this would complement a single stage-discharge relation over time. Although one would expect a river that is bed rock controlled or has undergone significant channelization to be stable, some alluvial channels also exhibit relatively stable regimes.

Conversely, a *Non-Stable* channel is one that displays significant morphological change with time. This also includes the reaches behaviour over short periods of time, such as flood events. Channels which are subject to significant local and general bed scour or deposition will undoubtedly be characterized as unstable. Other factors of instability are those dealing with bank erosion and fill (horizontal movement of the channel), and such things as meander cut-offs, or near by tributary activities which also affect the channels capacity of flow and in turn its stage-discharge relationship. As one could obviously conclude non-stable channels tend to display specific gauge readings that are more erratic over time or display some sort of trend, be it increasing, decreasing, or stepping trend.

By classifying a channel with respect to its stability, its stage-discharge curve can be more accurately depicted by specifying key parameters that relate the channels behaviour to the overall curve development.

SEE ALSO

Classification Specific_gauge Sediment_type
Channel_pattern

SEDIMENT_TYPE(1v) STREAM CLASSIFICATION SEDIMENT_TYPE(1v)**TITLE**

Sediment Classification and Definition

DESCRIPTION

It is equally important when classifying an alluvial channel to distinguish its sediment characteristic and behaviour within the context of sediment discharge and its effect on river morphology. Therefore, the logical step after determination of a rivers stability is to determine what type of sediment the river is carrying. Classifying rivers and streams by: *Sand, Sand-Gravel and Gravel* allows further and more complete development of the stage-discharge relation with the ability to tailor the development to a specific sediment type.

DEFINITION

Sediment can be defined as those materials which are transported downstream by the river. Rivers transport sediment both in suspension, the suspended load, and by rolling, sliding, and bouncing ("saltating") material along the bed, the so-called bed load. It is not necessary to distinguish the two at this time, however, it is necessary to quantify the total load, and classify it according to its size, shape and density. Channels are often said to be sandy or muddy, which implies that the size of the material being transported through the channel is of key importance. Although it is true that there can be great changes in the morphology of a stream when the median size of bed material is essentially constant, given a specific reach of river, its median grain size of distribution and its present morphological state a well defined stage-discharge relation can be presented. Factors affecting the amount of sediment include:

- 1) Material available upstream for transport downstream.
- 2) The amount of flow in the channel.

It is easiest to quantify the classification according to the median sediment size, therefore the following should be used as a guide line for the classification of the sediment type:

1) *Sand*

Those rivers whose bed form consist entirely of material which is composed of sand sizes. This may include the banks and floodplain of the reach, but not necessarily. Sand sizes constitute grain sizes *smaller than 2 millimetres* in diameter. However, this should not include clay materials which range below 0.01 millimetres because their behaviour is much different then that of sand particles.

2) *Sand-Gravel*

These reaches should include all intermediate grain sizes, ranging from *2 millimetres* up to, and including *16 millimetre* sizes.

3) *Gravel*

Gravel bed rivers are those that consist of materials larger than *16 millimetres*. It must be noted that sizes above 256 millimetres constitute small boulders, and these rivers must maintain higher flows to transport this type of sediment. Thus, one can expect that these rivers are heavily "armoured" and tend to be more stable.

SEE ALSO

Classification	Stability	Channel_pattern
Specific_Gauge		

CHANNEL_PATTERN(1v) STREAM CLASSIFICATION CHANNEL_PATTERN(1v)

TITLE

Channel Pattern Classification and Definition

DESCRIPTION

After describing and categorizing the river reach with respect to its stability and sediment type, the channel pattern must be established. It is relevant to establish channel pattern to further break down exactly what type of channel SDDSS is dealing with. Describing the condition of a river's morphology in plan form can lead to a great deal of the processes currently being engaged by a river. By establishing pattern on the basis of *Straight, Meandering, or Braided*, it is possible to better quantify a more exact stage-discharge relation for a particular regime.

DEFINITION

Defining the pattern can be complicated, but it is best to describe the reach in the three general categories mentioned above. A key definition for sinuosity of a channel must be presented first. Sinuosity is the ratio of the length of the channel to the length of the valley. Sinuosity is a key for defining the relative pattern of a stream. It may also be necessary to mention that although there is a wide variety of classifications for alluvial channels most can be fit into one of the three basic patterns described below:

1) *Straight*

Straight channels can be described as smooth streams in plan view that do not exhibit high sinuosity or much meandering. A rule of thumb is to classify a stream as straight if it does not display a sinuous pattern above 1.5. Note, rivers seldom remain straight for more than ten river widths, so it is best to describe straight rivers as irregular, sinuous, or non-meandering. Even if a river displays small depositional bars along the banks, its thalweg remains relatively straight, and thus, it should be considered a straight channel.

2) *Meandering*

Most channels present a pattern of wandering throughout their respective floodplain. Channels exhibiting sinuous patterns higher than 1.5 are usually considered meandering. Meandering channels can range from those that are regular meanders to irregular and tortuous meanders. It is important to realize the effect of the meanders on the channels

CHANNEL_PATTERN(1v) STREAM CLASSIFICATION CHANNEL_PATTERN(1v)

lateral activity and migration. Progression of meanders can lead downstream, or can lead to cut-offs or both. Meandering may be restricted by bank stability (bedrock controlled, or cohesive banks) or it may be allowed to migrate laterally sometimes following a completely different path in the valley floodplain. Meandering streams can be divided into two separate basic channel patterns

- a) Uniform channel width, small point bars. Channel is stable but neck cut-offs can occur.
- b) Channel wider at bends, large point bars. Chute and neck cut-offs and meander shifts produce a relatively unstable channel.

3) *Braided*

The separate channels of a braided stream are divided by channel islands or bars. Channel islands are normally well vegetated surfaces reaching to at least plain elevation. Lower, unvegetated or lightly vegetated surfaces are channel bars. Most channel bars are products of accumulated bed material. Their shape and rate of deformation or movement often allows qualitative and quantitative analysis of bed material type and rate of transport. Braided rivers generally follow a relatively straight floodplain weaving in split or anastomosing networks in random fashion within its confines. The simplest way to sum up the braided classification is as follows

Braided channel - Unstable channel with multiple thalweg, and numerous bars and islands.

One must be careful of this classification because many reaches experience a braided meander transition, where multiple thalwegs can be dispersed through many stable channel islands, and large point bars with frequent chute cut-offs.

SEE ALSO

Classification Stability_Criteria Sediment_type

Section (2.2a) - Data Selection (Stable Channels)

OVERVIEW(1v)

DSSTABLE CONTROLS

OVERVIEW(1v)

TITLE

Data Selection Procedure and Description for Stable Channel Controls

DESCRIPTION

The data selection for stable channels is very rudimentary, because it is expected that the channel control behaves quite consistently. It is a hierarchical process which allows the user full control of the data set to be modelled. The Section is loaded up directly after the stream classification section has been completed and the stream in question was determined to be stable.

FUNCTIONS

The hierarchy of the data selection is quite simple the levels are as follows:

- 1) *All S-D measurements* - Simply all measurements are retrieved from the database for the entire record of the station and under all conditions.
- 2) *Specific Measurements* - This option allows the user to specify special data sets in several categories:
 - 2.1) ICE CONDITIONS - separated into *Complete Ice Cover*, *Partial Ice Cover* and *Other* the data sets are retrieved according to the users wishes.
 - 2.2) OPEN FLOW - this option will automatically retrieve all data that were taken during normal open flow conditions in the channel.
 - 2.3) TIME - The user can define certain periods of time (eg., the month of JULY for all years or a certain span of years). The query string is built by NEXPERT and the data is retrieved automatically for modelling.

SYSTEM FRAMEWORK

The *SC_DS.tkb* contains all *Data Selection* procedures, and is completely interactive with other knowledge bases. That is, it is called from many other procedures. For *Stable Channel Data Selection* the *SC_DS.tkb* is called from the main program handler *MASTER.tkb*. All of the data selection variables must defined by the user through the guidance of this knowledge base and the *SDDSS*

PROCEDURE

The user is guided through the hierarchical structure by a series of questions (and options for answer) to find out more about the data set that he/she desires to model. Retrieval from the ORACLE database is performed by the system, and the data is presented to the user. At this time, it is up to the user to decide to model the data, or redefine his/her measurement selection.

SEE ALSO

The user is referred to all other files in this section for more information and details of the *Data Selection Procedure* for *Stable Channels*.

TITLE

The general procedure for *Data Selection of Stage-Discharge Measurements* from channels with *Stable Controls*.

DESCRIPTION

The overall procedure is set in a hierarchical framework of possible options and alternatives for defining the data set. Each step is in place to select a data set that is particular to some phenomenon that effects the control, and in turn, the *Stage-Discharge Relation*. However, because the channels you are dealing with at this time have been determined as *STABLE*, the process of selecting the data set should be relatively easy. The S-D relation should represent the entire period of record, and the hydraulic control should show little activity.

PROCEDURE

The procedure for data selection is itemized below in a sequential fashion.

- 1) *Load SC_DS.tkb* and initiate the data selection procedure.
- 2) *Phase 1* The user is asked the question;

"What kind of selection would you like ? ..."

At this point the user has two options. Either he/she chooses to stay in phase 1 of the selection process by double clicking on the answer; *All S-D Measurements*, and goto *item 7*)

or

the user decides to move to *phase 2* by choosing *Specific Measurements*, and goto the next item.

At the beginning of the procedure, it is probably best to select *All S-D Measurements*, because the channel that one is dealing with is supposed to be relatively stable. This will give the user a look at all of the data, and it is always possible at the end of the data selection to return to this step, and begin again.

- 3) *Phase 2 - Specific Measurements*

The user has entered the next level in the hierarchy of data selection, and is presented with three options. Each option may then have further options to advance to another level.

PROCEDURE(1v) DS STABLE CONTROLS PROCEDURE(1v)

i) ICE CONDITIONS

Here the data set can be stratified according to measurements which were taken during **Complete Ice Cover Conditions** or **Partial Ice Cover Conditions** or measurements that were influenced by some **Other** ice related phenomena. See manpage 5_ice_selection for more details.

ii) OPEN FLOW

No further stratification is necessary. Only those measurements taken during **Normal Open Flow Conditions** are considered when retrieved out of the database. See manpage 6_open_selection for more information.

iii) TIME

With this option, it is possible to select S-D measurements from a particular span of time for the entire period of record or for a specific period of years. The objective is to see how the S-D relation may behave seasonally. See manpage 7_time_selection for more details.

4) Data Retrieval

From the knowledge gained from the answered questions NEXPERT builds the **Query String** accordingly, and through the NEXPERT-ORACLE bridge software selects the appropriate S-D measurements from the database. The S-D measures are filtered for the **highest** Zero Flow Stage if one exists. If not, the default becomes 0. After the retrieval process is complete the user sees a message text, which explains the **Retrieval type** see (manpage 9), **Total Number of measurements retrieved**, **The number of Zero Flow measurements** and **The Size of the data set**

5) Setting the Zero Flow Stage (ZFS)

While viewing the current data set the user is faced with the task of setting the zero flow stage. (For definition see 8_zero_flow_stage) the system asks the question:

"Would you like to specify the ZERO FLOW STAGE?"

The options are simply **NO** or **YES**. Choosing **NO** allows the user to accept the default ZFS, and the **YES** choice will allow the user to specify the ZFS. See manpage 8_zero_flow_stage for the procedure.

6) *Proceeding to the Modelling Sub-Section*

After the Zero Flow Stage level the user arrives at the final decision for the **Data Selection Procedure**. To complete the loop and move on to the Mathematical Modelling section answer the question in the session window by double-clicking the mouse pointer on **Model Data**. If the data set shown in the XGRAPH window is not satisfactory for modelling and you would like to respecify the data set, choose **Redefine measurement selection**, and the program will take you back to the beginning the loop with item 2). The last option, **Exit Curve Dev.**, should be chosen only if the user is not satisfied with any of the final data sets from completion of the previous routine.

SEE ALSO

3_select_all 4_select_specific 5_ice_selection
 6_open_selection 7_time_selection 8_zero_flow_stage
 9_curve_type_codes

ALL_S-D(1v) DSSTABLE CONTROLS ALL_S-D(1v)

TITLE

Selecting *All S-D Measurements* for data selection.

DESCRIPTION

Choosing this option at **Phase 1** of the stable channel control data selection procedure will automatically indicate to the system that it should retrieve the entire record of S-D measurements. The query string will automatically be built by the system and the S-D measurements will be extracted out of the database via a UNIX SCRIPT file which produces a SQL*REPORT generator to retrieve the measurements directly into a special file called *main_DS.dat* (/home/SDDSS/NXP/DAT). This is the file that NEXPERT continues to manipulate throughout the data selection and modeling procedures.

CRITERIA

The criteria for selection of all measurements is simple. It is important to mention that all data stored in the database is entered according to *Environment Canada's* R56 file format. This includes the remark codes taken during the time of the measurement. Choosing the *All S-D Measurements* option will signal to NEXPERT that all the measurements are to be retrieved regardless of their EC code. Therefore, this option will retrieve all the *open flow*, *ice flow* and any *backwater* measurements taken throughout the entire period of record stored in the database at this time.

The above selection may result in a very complex data set. However, it is a good idea to start with this selection, because it gives the user a chance to view the entire data set graphically. It is easy to then retrace your steps, and choose specific measurements at this level the next time around.

SEE ALSO

4_select_specific

TITLE

Selecting *Specific S-D Measurements* for data selection

DESCRIPTION

Choosing *Specific Measurements* from the phase 1 level of the data selection process for *stable channels* allows the user to move to *phase 2*, and select a particular set relevant to some hydraulic phenomenon. The choice automatically leads the user to answer more questions to more accurately define the stage-discharge rating relation.

OPTIONS

The "Specific Measurements" option at phase one leads to several more options for data selection. The list below illustrates all the options and details of their criteria, and usage:

1) ICE CONDITIONS

This specifies that you would like to view and possibly model S-D data that was measured during some ice related condition that was effecting the control at the time of the measurement. This category is further separated into three groups of ice data. (See 5_ice_selection manpage for more information)

- i) **Complete Cover** - Selecting this option would retrieve all data that has been taken during winter months when the control at the gauging station is completely covered with ice. The query string is built and automatically executed by the system after choosing this option.
- ii) **Partial Cover** - This option will retrieve all those S-D measurements taken during conditions in which the control is not completely covered with ice. The **border ice** situation would most likely create a different S-D rating than complete ice cover, therefore they are separated at this time.
- iii) This option selects those measurements that are only temporary ice conditions such as backwater due to ice jams, slush ice and other similar phenomenon.

Again one would expect a different relationship to emerge from the above three options. It is also important that the retrievals from the database are only as accurate as the coding scheme at the time of the entry of the measurements into the database. Any errors or neglected coding remarks

SPECIFIC_S-D(1v) DSSTABLE CONTROLS SPECIFIC_S-D(1v)

will not be detected by the program.

2) OPENFLOW

This selection is quite obvious. All the S-D measurements taken during *normal* open flow will be retrieved. These include only those measurements that are not coded. It is the assumption that if a measurement does not have a *backwa-*
ter code, that it is normal open flow. Therefore, this option is also dependant on the accuracy of the entered codes in the database. No further stratification is needed at this time since you are supposed to be dealing with a *stable channel*. For more information see the 6_open_selection manpage

3) TIME

The last option of phase 2 deals with possible seasonality of the data. One may want to make a spring run-off curve for the months of April and May. This can be accomplished with choice of *TIME*. The option is further stratified according to the span of years that the user wants to include in the retrieval (*all years* or *specific years*), and also the time span within the year for which the retrieval will be limited to. For example, it is possible to select all measurements taken between *April 15* and *July 31* for the span of years between *1984* and *1988*, if any measurements exist in the database for this scenario. The manpage 7_time_selection will completely detail this option.

SEE ALSO

5_ice_selection 6_open_selection 7_time_selection

TITLE

Selecting *ICE* measurements from the database for modelling purposes.

DESCRIPTION

It is possible to extract from the ORACLE database only those measurements which were taken during some experienced ice related phenomenon. The purpose of this manpage is to further describe the exact nature of the extraction and the particular coding scheme used for the extraction. The ice data measurements are coded as per the *Environment Canada's* coding scheme. The following section highlights the three sub-categories under the *ICE CONDITIONS* option. The main coding scheme used is that from section B of EC's coding chart, because this section is related to those measurements taking during some *backwater* or related condition.

RETRIEVING ICE CONDITION DATA

COMPLETE COVER

Measurements extracted from the ORACLE database for the condition when the channel is completely covered by ice are extracted regardless of the thickness of the ice. The following three codes are included when extracting the measurements.

11 - COMPLETE ICE COVER *general*

12 - COMPLETE ICE COVER < 2 m

13 - COMPLETE ICE COVER < 1 m

All measurements with the above remark codes attached will be extracted and used in the modelling process at the user's discretion.

PARTIAL ICE COVER

With this option all stage-discharge measurements which were taken during a time when the hydraulic control at the measurement site was only partially covered with ice. This includes all *border ice* growth and decay. The partial ice is separated from the complete cover because the two conditions are quite different. The following codes in the remark B section apply.

9 - PARTIAL ICE COVER *general*

10 - ICE ON SIDES

ICE(1v)

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OTHER

All other ice related backwater conditions are then included in this category. They include such things as ice jams, and bed ice when the flow runs over the ice. The following remark codes apply:

14 - DRIFTING ICE

15 - SLUSH UNDER ICE

16 - FLOW OVER ICE

18 - BACKWATER DUE TO ICE JAMS

Although the codes seem to cover a wide array of ice conditions it is not necessary at this time to include them all in different categories. Instead they are grouped together because it is believed that they will produce a very similar relation.

SEE ALSO

2_general_procedure 4_select_specific

OPEN_FLOW(1v) DS STABLE CONTROLS OPEN_FLOW(1v)

TITLE

Selecting **OPEN FLOW** measurements from the database for modelling purposes.

DESCRIPTION

Referring to open flow conditions means that it assumed that every aspect of the hydraulic control is assumed to be in **normal unobstructed** condition, all flow is regular. Therefore, it is assumed that any measurement taken that **does not** have an attached remark B code and is not influenced by any "backwater" conditions is normal open flow.

RETRIEVING OPEN FLOW DATA

There is no further subdivision of this option. When selecting **OPEN FLOW** from the session window the query string is constructed according to the above criteria. Therefore the query string is simply:

.... **AND REM_B IS NULL.**

Simply put, if the remark B column of the database has no entry or coded remark then it is assumed that the S-D measurement was taken during normal unobstructed flow, ie., **OPEN FLOW**.

SEE ALSO

2_general_procedure 4_select_specific

TIME(1v) DS STABLE CONTROLS TIME(1v)

TITLE

Making a specific time selection of stage-discharge data from the database.

DESCRIPTION

It is possible to further breakdown the data selection according to a specific period of time during the year. This works similarly to a *seasonal* breakdown of the measurements. That is to say, it is possible to retrieve all data for the spring season (May 1 - June 30) for all years, or a specific span of years for example. The next section illustrates the proper procedure for a *TIME* stage-discharge measurement selection.

PROCEDURE

Selecting *TIME* from the specific measurements sub-menu initiates the procedure. An itemized list follows:

- 1) SDDSS then asks the user if he/she would like to include *All Years* in the measurement selection, or *Specific Years* (a span of years) in the selection. At this time a message window appears which shows the total range of years for the particular gauging station in question. The user chooses one of these options. The first option advances the user to item 3. The second option allows the user to specify the time period.

- 2) Upon selection of *Specific Years* the user is then asked to input the beginning year to start with. The user then inputs the year in the format of

76 for 1976 or 81 for 1981

this input marks the *First Year* of the *TIME* data selection procedure. The next step is to specify the *Last Year* of the desired time span. The input is in the same format as above.

- 3) The last step is to specify the time range within the year. The format and procedure is simple:
 - i) First, enter the number of the *First Month* (eg. enter 5 for the month of May).
 - ii) Second, enter the number of the *First Day* (eg. enter 1 for the first of May).
 - iii) Next, enter the ending or *Last Month* (eg. enter 7 for

the month of July).

- iv) Lastly, enter the day of the last month which indicates the **Last Day** (eg. enter 31 for July 31st).

the above entries tells SDDSS to retrieve all S-D measurements taken between the days of May 1 to July 31 for all years or a specific span years. May 1 and July 31 are then converted to the day that they correspond to between 1 and 365.

May 1 is the **121st** day of the year, and July 31 is the **212th** day of the year. Therefore the query string looks like

.... (DAY OF THE YEAR) BETWEEN 121 AND 212

This ensures an accurate retrieval of the proper S-D measurements.

SUGGESTED USE

The TIME option is put in place to look at possible seasonal differences in the S-D measurements, and their effect on the stage-discharge rating. Therefore, the use of this option should be used with care, because it is expected that the channels being dealt with have been determined to be **Stable**, and thus, should have a fairly constant relation throughout the year. Also, this option may be used to limit the data selection when an inadequately coded database, has been realized. However, a warning is in place to guard against abuse of this option.

SEE ALSO

2_general_procedure 4_select_specific

ZERO_FLOW(1v) DSSTABLE CONTROLS ZERO_FLOW(1v)

TITLE

Establishing the *Zero Flow Stage (ZFS)* in the data selection procedure.

DEFINITION

The term *Zero Flow Stage* refers to the point where the flow of water past the gauge ceases. Measured as a level of stage it is important to at least define the point where the water no longer moves through the channel. This does not necessarily mean the bottom of the channel or that because there is water in the channel that it is flowing. Pools of stagnant water often form in many natural channels, and can trap water in them without creating or allowing any flow of water. Also, because channels are dynamic in nature and erosion and deposition of sediment are always relevant, it is possible for a channel to experience several zero flow stages over the entire history of the measurements.

It is also important to define the *ZFS* because it is the intercept of the Y-axis or *B0* in the mathematical equation which represents the S-D rating. The equation is of the form

$$DIS = B0 + B1 * STAGE ^ EXP$$

where

DIS = Discharge
B0 = Intercept estimated in regression analysis
B1 = Slope estimated in regression analysis
EXP = Transformation exponent

Above B0 is said to be estimated by the linear regression sub-routine, but if it is defined on some physical basis relevant to the control, the intercept can be fixed before it enters the equation. This would definitely benefit the analysis for mathematical modelling, and give more accuracy to the model.

DEFAULT SETTINGS

The program detects all zero flow stages (if any exist) during the retrieval process. It then selects the *highest* zero flow stage for the default. If, on the other hand, no zero flow stage measurements have been taken of experienced by the channel the default zero flow stage is set to *zero*. The program then asks you if you would like to *specify the ZERO FLOW STAGE*.

ZERO_FLOW(1v) DSSTABLE CONTROLS ZERO_FLOW(1v)

SETTING THE ZFS

The **YES** answer from the above question tells the program that you want to set the **ZERO FLOW STAGE**, and prompts you to enter the value that you desire as the **ZFS**. At this time the choice of **ZFS** is arbitrarily set by the user. With knowledge of the curve's behavior and of the channel control, the user should be able to provide the best estimate for this stage at this time. It may be useful to refer to any notes that may be available, or any longitudinal profiles of the gauging site. However, if the user is not sure of the zero flow stage, it is always possible to have it estimated by the regression sub-routine.

After setting the zero flow stage the program will run a subroutine that will eliminate any points that are below the zero flow stage, and present them graphically to the user. The user is then asked if he/she would like to **CONTINUE** with the modelling of this data set or **RESET** the **ZFS**.

CODES(1v) DS STABLE CONTROLS CODES(1v)

TITLE

Coding system to identify the type of curve selected for development.

PURPOSE

When the user is developing a curve for stable channels. It often becomes necessary to separate the data according to some criteria (ICE, TIME OR OPEN flow conditions). When data is selected from the database for possible modelling a **TYPE CODE** is attached to the data set for future reference during the curve modelling, use, modification and extrapolation procedures. The following is a list of possible codes for *stable* channels only.

CODES

- ALL -
All SD Measurements
- ICECOM -
ICE conditions COMPLETE COVER
- ICEOTH -
ICE conditions OTHER DATA
- ICEPAR -
ICE conditions PARTIAL COVER
- OPEN -
OPEN flow conditions
- TIME -
Measurements based on a time interval, whether it is for all years or just a specific number of years.

SEE ALSO

- 1_overview
- 2_general_procedure
- 3_select_all
- 4_select_specific
- 5_ice_selection
- 6_open_selection
- 7_time_selection

Section (2.2b) - Data Selection (Non-Stable Channels)

OVERVIEW(1v) DS NON-STABLE CHANNELS OVERVIEW(1v)

TITLE

General overview of data selection procedure for non-stable channels.

DESCRIPTION

A logical framework of analysis has been set, in order to more accurately define the segmentation of the overall data set. The data set has already been separated into different time periods in the Stream Classification section, and now each time period is subjected to further analysis that will try to identify any hydraulic or hydrologic phenomenon that are effecting the channel control and likewise the *Stage-Discharge* rating relation.

Once a time period is selected for further analysis, the user is systematically guided through a hierarchical structure of data filtration.

DATA SELECTION HIERARCHY

Each section of the hierarchy is briefly highlighted here:

- 1) **Stability** - Although a channel can be deemed as unstable, it is possible for individual time periods to be relatively *stable*. In this case the S-D data is shown to the user and put forward to be modelled. The user has the choice of modelling this data set, or to continue with the analysis and go to the next level in the hierarchy.
If the individual time period is determined to be *Non-Stable* the program automatically continues to the next level in the hierarchy.
- 2) **Seasonal Variation** - This level uses several graphical aids as diagnostic tools to aid the user's choice for seasonal variation. The objective here is to allow the user to determine if there is a difference in the models for *open flow data* and *ice flow data* (i.e. the control has two separate relations seasonally).
- 3) **Variation due to Hysteresis** - The third level also produces several graphical aids which distinguish between those measurements taken during *rising stage* and *falling stage* conditions. These diagnostic aids help the user to decide if the S-D relation is quite different for the two hydraulic conditions. If so the data set is separated accordingly, and the user can model each separately or continue to the last level of the hierarchy.

OVERVIEW(1v) DS NON-STABLE CHANNELS OVERVIEW(1v)

- 4) *Variation with Stage* - Many natural channels have complex geometrical shapes that greatly effect the S-D rating. This level aids the user in deciding if the relation differs at certain stage levels of the channel control. For example, at bank-full stage the relation may change due to the configuration of the flood plain. The graphical tools used here aid the user's decision to pin-point the level where the relation differs.

SEE ALSO

- 2_general_procedure
- 3_hierarchy_of_data_selection
- 4_seasonal_variation
- 5_variation_due_to_hysteresis
- 6_variation_by_stage
- 7_transition_zones
- 8_curve_type_codes

PROCEDURE(1v) DS NON-STABLE CHANNELS PROCEDURE(1v)

TITLE

The general procedure for *Data Selection of Stage-Discharge Measurements* from channels with *Non-Stable Controls*.

DESCRIPTION

The overall procedure is set in hierarchical fashion in which the SDDSS system guides you through each step. A complete decision support framework has been developed in order to help simplify the complex nature of the data due to the channels instability. Along with graphical diagnostic tools, the user is prompted to answer specific questions relating to each level of analysis, and aided with text support throughout. The following is a step by step procedure of the *Data Selection* process for non-stable channels.

PROCEDURE

The procedure for data selection is itemized below in a sequential fashion.

- 1) Channels determined to be *Non-Stable* move from the SC.tkb to the data selection knowledge base called *NSA.tkb*.
- 2) After the above knowledge base is loaded the user is shown the *STREAM CLASSIFICATION SUMMARY*. It consists of a general classification summary, and the classification results for each time period identified in the classification process.
- 3) The user is then prompted to select a time period to work with. This is done by entering the corresponding *SEGMENT NUMBER* in the session control window.
- 4) A check has then been put in place to allow you to change your selection. If you do not wish to change your selection double click on *NO*, and continue to the next step. Otherwise, a *YES* answer allows you to go back to step 2).
- 5) The user then enters the data selection procedure. Initially, all points from the chosen time period are forwarded to the analysis. The user then steps through a hierarchical procedure of data filtration to arrive at specific subsets of data, that represent defined phenomena which may be affecting the reach in question. The user is now referred to manpage 3) *hierarchy of data selection* for a greater understanding of the data filtration process.

PROCEDURE(1v) DS NON-STABLE CHANNELS PROCEDURE(1v)

- 6) After the user has completed a possible suite of curves for one time period, the system allows the user to choose another time period for the same analysis. Unless, of course, the user has already completed all analysis for all time periods. In this case, the user is returned to the main menu.

SEE ALSO

3 hierarchy of data selection 4 seasonal variation
5 variation due to hysteresis 6 variation by stage
7 transition zones 8 curve type codes

HIERARCHY(1v) DS NON-STABLE CHANNELS HIERARCHY(1v)

TITLE

A brief overview of the *hierarchy* of the data filtration and selection procedure

DESCRIPTION

This manpage will briefly describe the role of each level in the hierarchy of the data selection procedure for non-stable channels. The system automatically guides the user through the stepwise procedure for defining an adequate data set to establish a mathematical model which represents the rating curve.

STABILITY

The first level deals with the stability of the chosen time period. This is simply a retrieval of the classification established in the stream classification section prior to the data selection section. Because certain channels can be relatively stable between major events, a time period may very well be defined as **STABLE**. Opposingly, channels often experience small sequential change over the time period between major events. These small changes are detected as a **NON-STABLE** condition. For stable channels the user has the option of modelling this time period directly, or continue to the next level. Non-stable classifications result in direct continuance to the next level.

SEASONALITY

At higher latitudes and altitudes, channels often succumb to seasonal change in the flow regime. Thus, the second level of the analysis tries to establish any variation in the SD data with respect to **Ice Conditions** or **Open Flow Conditions**. At this level the data can be separated into these two categories, or become a combined data set (ie., no variation). If the data set is to be separated, the analysis may continue to the next level, but only for open flow conditions. Ice conditions present very unique problems, which solutions for are not addressed by the SDDSS (see 9_ICE_conditions, this section).

HYSTERESIS

The next level deals with the effects of the phenomenon **Hysteresis**, which can occur in many natural channels. The phenomenon is evident by a "loop" in the rating, where rising stage data plot to the right of falling stage data due to variations in the energy slope of the flood wave, and/or possibly variations in the bed roughness (bed form lags behind wavefront). The results of hysteresis effects should

HIERARCHY(1v) DS NON-STABLE CHANNELS HIERARCHY(1v)

be the separation of the data into three distinct groups: *Rising Stage*; *Falling Stage*; and *Stable Stage* (neither rising nor falling). Following the separation each group may subsequently be modelled, or taken to the next level in the hierarchy.

VARIATION WITH INCREASING STAGE

The last level of the hierarchy allows the user to discern a changing relation with increasing stage. It is often found that a relation may be significantly different due to such things as geometric constraints of the channel or changing roughness. For example, often times in bank stages have significantly different relations than above bank-full stages. This scenario is common, and the SDDSS provides a means for separating the curve into three possible groups according to stage: *Low Stages*, *Mid Stages* and *High Stages*. All groups do not have to be used at this level. The user may decide that the control only has one transition point. In this case, the control would be separated according to low and high categories only.

NOTES

At each level the user decides to either separate the data or to continue to the next level without taking into account any of the effects at the current level. Also, at the end of each level the user may decide that he/she has an adequate data set that represents a specific SD rating. In this case, the user may temporarily exit the data selection scheme, and model the particular data set chosen. Upon completion of the modelling the user re-enters the data selection procedure to continue selecting more subsets for modelling, or to choose a new time period for modelling.

SEE ALSO

- 1 overview
- 2 general procedure
- 4 seasonal variation
- 5 variation due to hysteresis
- 6 variation by stage
- 9 ICE_conditions

SEASONS(1v) DS NON-STABLE CHANNELS SEASONS(1v)

TITLE

A description of the procedure, and interpretation of provided tools for ascertaining *Seasonal Variation* in the stage-discharge relation.

DESCRIPTION

The second level of the data selection procedure deals with a varying stage-discharge relation with the seasons. Currently, this includes two seasons: openflow season and ice conditions season. It is almost a certainty that Canadian streams are subject to these two conditions, and although the timing of seasonal change is different from year to year, it is common to see the SD points plot similarly for the same season in a particular time period between major hydraulic events. For these reasons, the data are diagnosed within a single time frame as either *Open Flow Conditions*, *Ice Flow Conditions* or *No Seasonal Variation* (ie., a combined data set).

PROCEDURE AND DIAGNOSTICS

The system takes the user into the seasonal variation level from the previous level automatically. The user is shown three plots simultaneously: *Stage vs Discharge*, *Stage vs Width* and *Stage vs Area*. Accompanying these graphs is a text window explaining its use, and a question in the session window. The question reads.

Do you see a direct correlation between the Ice Conditions and the Open Flow conditions?

The user must answer YES or NO. The graphs provide a means for answering the question. Simply, if the two data sets (ICE COND, in red and OPEN FLOW in green) plot in distinct patterns, groups or populations, they do not correlate well, and should be separated. That is, the answer is *NO*. Otherwise, the answer is obviously *YES*.

The three graphs disappear after you answer the question. The program then continues. If the answer is *NO*, the data will be separated. If the answer is *YES*, the data will be combined. Regardless of the answer the user will view a plot of the stage-discharge data (OPEN FLOW for *NO*, BOTH data sets for *YES*, ie., combined), and be asked the following question:

Would you like to try to model this data or continue?

At this point if you see a relatively scatter free data set, adhering to a particular pattern, it may be best to try to

SEASONS(1v) DS NON-STABLE CHANNELS SEASONS(1v)

fit a mathematical model to the data. In this situation choose *Model this Data*. Alternatively, you can choose to subject the data to further analysis, and *Continue Non-Stable Analysis*.

When the data set is separated, the open flow data is analyzed first. The ice condition data is held in reserve until a suitable model has been constructed for all corresponding open flow situations. Then, and only then, will the ice conditions data be considered for modelling. However, because the ice conditions create such a complex and different set of effects on the Stage-Discharge relation, we are unable to implement a proper strategy of analysis for this scenario. Therefore, no suitable model can be developed for Ice Conditions at this time.

SEE ALSO

- 1 overview
- 2 general procedure
- 3 hierarchy of data selection
- 8 curve type codes
- 9 ICE conditions

HYSTERSIS(1v) DS NON-STABLE CHANNELS HYSTERSIS(1v)

TITLE

A description of the procedure, and interpretation of provided tools for ascertaining *Variation due to Hysteresis* effects in the stage-discharge relation.

DESCRIPTION

The third level of the data selection procedure deals with a varying stage-discharge relation due to the effects of the phenomenon known as *Hysteresis*.

Hysteresis, or looped, rating relationships may occur in both stable and non-stable channels where channel control is effective (ie., 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 and others, 1982). 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 these reasons, a strategy has been put forward to investigate these effects on the current gauging station. The following illustrates the methods employed by the SDDSS for distinguishing between a channel that is under hysteresis effects and one that is not.

PROCEDURE AND DIAGNOSTICS

If the user decides to continue from the previous level (seasonal), the system automatically proceeds to the hysteresis level (depending if there is adequate data in the database or not). Again, you are shown three plots simultaneously: *Stage vs Discharge*, *Stage vs mean Velocity* and *Discharge vs mean velocity*. These particular parameters are chosen because hysteresis effects are a function of velocity. Accompanying these graphs is a text window explaining its use, and a question in the session window. The question reads.

Is there evidence that the data set is subject to hysteresis?

The user must answer YES or NO. The graphs provide a means for answering the question. The graphs illustrate the rising stage measurements (in red) separately from the falling stage measurements (in green). The point of the graphs is

HYSTERSIS(1v) DS NON-STABLE CHANNELS HYSTERSIS(1v)

to show you any dissimilarities in the data sets. In order for there to be a hysteresis pattern, you should be looking for the red points to plot consistently to the right of the green points in all three graphs.

From the above paragraph, if the two data sets plot in fairly distinct populations, in a loop pattern then the data should be separated, and the answer to the question in the session window is **YES**. Else, the answer is **NO**.

A YES answer will separate the data into three classes: **Rising Stage**, **Falling Stage** and **Stable stage**. The user will then be able to subject each data to the modelling routine, or continue with the data set to the next level. For example, the first data set to be seen after the answer is the **Rising Stage** data. The user views this data, and is asked another question:

Would you like to try to model this data or continue?

At this point if you see a relatively scatter free data set, adhering to a particular pattern, it may be best to try to fit a mathematical model to the data. In this situation choose **Model this Data**. Alternatively, you can choose to subject the data to further analysis, and **Continue Non-Stable Analysis**. After the Rising stage measurements are viewed, modelled or continued through the analysis. The user then does the same routine for the Falling stage measurements, followed by the Stable stage measurements.

A NO answer to the hysteresis question will automatically tell the system that you do not feel that this station is subject to hysteresis, and it will automatically continue to the next level of analysis. The data set is left intact (no further separation at this point).

SEE ALSO

- 1 overview
- 2 general procedure
- 3 hierarchy of data selection
- 8 curve type codes
- 9 ICE conditions

REFERENCES

Rantz S. E., et al., (1983). Measurement and Computation of Streamflow: Volume 2. Computation of Discharge. *Geological Survey Water-Supply Paper 2175*, Washington D.C.

TITLE

A description of the procedure, and interpretation of provided tools for ascertaining any *Variation* in the stage-discharge relation with *Increasing Stage*.

DESCRIPTION

The last level of the data selection procedure deals with a varying stage-discharge relation with increasing stage. The objective of this level is to provide the user with a means of separating the data set into stage ranges (eg., Low, Mid and High stage ranges). Abrupt changes in the SD 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. Diagnostic tools are provided as a means of determining these transition zones. Then the user is allowed to model the data for each range he/she specifies. The following illustrates the process of filtering the data set by stage.

PROCEDURE AND DIAGNOSTICS

Upon entrance to the last level of the hierarchy, the user is shown a graphical representation of the most recent control cross section and the SD measurements from the previous level (this could be level 2 or level 3). Accompanying these graphs is a text window explaining its use, and a question in the session window. The question reads.

How many TRANSITION POINTS are CLEARLY evident in this Stage-Discharge relationship?

The answer is dependent on your estimation of significant transition points on the graph. An integer of 1 or 2 is allowed as possible answers. After entering one of these numbers the system responds with the following question:

Enter the FIRST Stage (in METERS) where an inflection or transition point occurs in the relation...

This point can be discerned from the graph by pressing and holding the right mouse button down. Cross-hairs appear on the graph and the coordinates of the cross are shown in the upper left corner of the graph. The stage value at the transition is the *Y coordinate*. Enter the appropriate value in the session window. The session will display the first stage range (ie., *Low* stage range) to you, and then automatically bring you into the modelling section, with the appropriate data set (data filtration and retrieval is automatic between the system and the database).

STAGE VARIATION(1v) DS NON-STABLE CHANNELS STAGE VARIATION(1v)

After completing the modelling, the system will ask you for the second transition point (if you entered 2 for number of transitions) or it will automatically complete the filtration process from the first transition point to the highest maximum stage (ie., **High** stage range). The system will again link to the modelling section allow you to create a mathematical model that represents the stage-discharge relation for the high stage range.

Following the modelling of stage ranges the system will show you completed curves simultaneously, and allow you to smooth between the curves at the transition zones (see 7_transition_zones for further details).

SEE ALSO

- 1 overview
- 2 general procedure
- 3 hierarchy of data selection
- 7 transition zones
- 9 ICE conditions

TRANSITIONS(1v) DS NON-STABLE CHANNELS TRANSITIONS(1v)

TITLE

Description of procedure and tools for smoothing the developed SD relation between curves at the **TRANSITION ZONES**.

DESCRIPTION

When more than one curve is made over the entire stage range, it is possible to see major differences in the curves at the point where they intersect. Sometimes they can be disjointed, and have varying slopes from one curve to the next. Also, it is possible to have the beginning stages of the upper curve to have smaller discharges (plot to the left) than the latter stages of the lower curve. This scenario is highly unrealistic because one would expect the discharge to increase continually with an increase in stage. For these reasons, a smoothing process has been put in place inside the data selection and filtration procedure.

PROCEDURE

After the user has completed and stored all the models with respect to Low, optional Mid and High stage ranges. The curves are shown to the user on one plot, and he/she is asked the following question.

Would you like to smooth the curve between STAGE SEGMENTS?

A NO answer simply ends the curve development process, and if the user has designed mathematical rating relations for all open flow scenarios, he/she is then guided through the process of establishing the SD curve for ice conditions data before concluding the analysis for the current time period.

A YES answer allows the user to enter the smoothing algorithms section. However, due to inadequacies of the graphing tool and the lack of appropriate algorithms for smoothing, this option is currently **NOT AVAILABLE**. Instead a simple text screen appears and tells the user that the option is not available and the program will continue to the next step of the analysis.

SEE ALSO

- 1 overview
- 2 general procedure
- 3 variation by stage
- 4 ice conditions

TITLE

A Description of the *Coding System* for curve type identification.

DESCRIPTION

A coding system has been put in place within the data selection environment. The purpose of this coding system is to provide a means of identifying curves as to their particular development and use. For example, a curve that is made for low stages of open flow has a specific code attached to it to define the type of data selection used when developing the curve, and to define the type of curve it is for use in the other three modes of the SDDSS system; namely, Curve Use, Curve Modification and Curve Extrapolation.

The codes for the curve are shown to the user at the beginning of the modelling phase once the data has been retrieved from the database. The codes are a maximum of 8 characters long, but when developing the curves the number of characters in each code is limited to 5. The other three are added if these curves are later modified (see Manpage 5 modified models, Section (4) Curve Modification). At each level a certain number of characters are assigned to the code. As the user moves through the levels in the data selection hierarchy, the characters from previous levels can be combined to new ones or changed according to the decisions made at each level. The following illustrates the code listings with examples.

CODES

LEVEL 1

The first level in the hierarchy simply attaches the *DAT* code to the data, because all data are included in a stable or non-stable data set for the time period

LEVEL 2 SEASONALITY

The seasonal level separates the data into open or ice data, or the data may be combined. The following is a list of possible codes or rather code characters at this level.

C - COMBINED DATA SET
O - SEGREGATED OPEN FLOW DATA SET
ICED - ICE CONDITION DATA

Therefore, a possible curve code at this level would be *ODAT*. This means the user has decided to model the open flow data without further analysis.

ICE(1v) DS NON-STABLE CHANNELS ICE(1v)

TITLE

The procedure for modelling *ICE Condition* data.

DESCRIPTION

Ice condition data are analyzed only after all open flow measurements and scenarios have been modelled by the user. Although the SDDSS does not have the capacity to fully analyze the SD measurements effected by ICE conditions, the framework for the analysis is in place. The following is an explanation for the framework and procedure to analyze ICE data.

PROCEDURE

After all scenarios and curves have been established for Open Flow data, the ICE data is ready to be modelled. The SDDSS displays the ICE data graphically along with an explanatory text screen. It then asks the user the following question:

Would you like to try to model this data or continue?

At this point if you see a relatively scatter free data set, adhering to a particular pattern, it may be best to try to fit a mathematical model to the data. In this situation choose *Model this Data*. Alternatively, you can choose to subject the data to further analysis, and *Continue Non-Stable Analysis*.

Continuing the analysis tells the SDDSS to load in a new knowledge base called *ICE.kb*. This knowledge base is specifically for the ICE data, however only the structure for analysis is in place at this time. What the user sees is a demonstration of future considerations needed in order to provide adequate analysis. The demo consists of the presentation of three diagrams and their explanation. The three diagrams are:

- 1) *Partial Ice Cover*
- 2) *Complete Ice Cover - pipe flow*
- 3) *Suspended Ice Cover*

These three aspects are key to the modelling of ice data, but due to a lack of database development, time and measured parameters specific to ICE data, the SDDSS does not actually deal appropriately with ICE data.

Section (2.3) - Mathematical Modelling Procedures

OVERVIEW(1v)

MODELLING

OVERVIEW(1v)

TITLE

Mathematical Modelling Sub-Section of the Curve Development Mode.

DESCRIPTION

Within this section are all the necessary procedures for fitting a mathematical model to the data set selected by the user for modelling. The section provides a means for statistical tests for evaluating the appropriateness of each fit. Also, the statistical measures are later used to establish confidence limits on predictions of discharge.

PROCEDURES

The procedure for fitting a model is fairly straight forward and systematic. The user is guided through each step, and many options are possible to allow for flexibility. The main procedures are highlighted below:

- 1) **Data Retrieval** - This procedure simply retrieves the data set to be modelled from the **ORACLE** database. This is done automatically once the user decides that he/she wants to model a particular set of data.
- 2) **Zero Flow Stage** - the default is the highest zero flow stage in the data set, if one exists. If not, the default becomes zero. However, this can be set by the user.
- 3.1) **Analyze Rating Table from H.D. Curve** This section allows the user to apply the statistical tests of **R-squared** and **Standard Error of Estimate (SEE)** and **The Number of Outliers** to the rating table produced from a hand drawn curve. It can then be compared to that of the regression models produced by the computer. This is more of an aesthetic feature because the rating tables cannot be stored in the database at this time.
- 3.2) **Automated Statistical Modelling** - This procedure automatically creates 63 different models according to several **POWER** transformation of stage and several transformations of discharge using the **BOX/COX** transformation method. The models are then screened automatically for **skewness and kurtosis** and then presented to the user under further tests for distribution of **residuals** and **normal probability**. These statistical tests ensure the accuracy and appropriateness of the model (ie., **NORMALITY**). Once a satisfactory model is created and accepted it can be stored in the **ORACLE** database for later use or subjected to the outlier analysis.

OVERVIEW(1v)

MODELLING

OVERVIEW(1v)

3.3) *Manual Statistical Modelling* - Choosing this method allows the user to control and input the exact power transformation exponent desired. A number of iterations can be performed, with the simple power transformation of stage. After each iteration statistical goodness of fit tests are shown for evaluation. Also, the user can choose to force-fit the curve through the zero flow stage (ie., fix the intercept) or allow for the regression analysis to set the intercept. After choosing a best fit model the model can be stored in the database or the data set and model can be further analyzed with respect to the number of outliers.

4) The last step occurs after the evaluation step within each of the previous modelling procedures (3.1, 3.2 and 3.3 above). It is up to the user to decide if the *Best Model* evaluated is to be stored in the database or to be subject to the outlier analysis. Also, the procedure can be re-iterated or exited at the users discretion.

SEE ALSO

2_auto_stat_modelling
3_manual_stat_modelling
4_transformations
5_statistics
6_stat_test
7_skew_kurt
8_residual_plot
9_probability_plot
9a_optimal_model

and

Section 2.4 - Outlier Analysis

ASM.(1v) MODELLING ASM.(1v)

TITLE

Automated Statistical Modelling

DESCRIPTION

The Curve Fitting section contains a modelling procedure, Automated Statistical Modelling (ASM), as an alternative to the Model Data option. ASM is an indepth modelling option that automatically generates a large number of *Stage-Discharge* models which includes two methods of data transformation. The ASM alternative also tests all models created for the requirements of a statistically correct linear regression. Similar to the Model Data option, ASM concludes with the optimal *Stage-Discharge* relationship for the current set of stream data.

USE

The first step of ASM is the automated procedure of creating multiple *Stage-Discharge* linear regression models. Through the execution of an external FORTRAN program, the models are created by stepping through a range of data transformations and performing a linear regression analysis on each transformed Stage-Discharge data set. Two types of transformations are used, the Power and Box-Cox transformations. Also in the first step, three statistics are calculated for each regression model to be later optimized to determine the *BEST Stage-Discharge* model (final step).

The second level of ASM includes testing procedures to confirm that the *Stage-Discharge* relationships generated prove to be valid linear regression models, those models testing as invalid are discarded. The procedure is comprised of three testing stages, *Skewness* and *Kurtosis*, *Residual Plots*, and *Probability Plots*.

Selection of the optimal *Stage-Discharge* model constitutes the final step of Automated Statistical Modelling. Here, NEXPERT outputs to the user a maximum of three models selected as optimal based on the statistics calculated. The user is required to select the one relationship to complete the modelling process.

PROCEDURE

The Automated Statistical Modelling procedure is governed by NEXPERT, calling various FORTRAN programs and XGRAPH scripts as well as prompting the user for input regarding plots and model selection. A detailed description

ASM.(1v) MODELLING ASM.(1v)

of each level of ASM is available in this help section.

SEE ALSO

transformations	statistics
stat_test	optimal_model

MANUAL PROCEDURE(1v) MODELLING MANUAL PROCEDURE(1v)

TITLE

The procedure for establishing the mathematical model according to the *Manual Statistical Modelling* methods.

DESCRIPTION

This method allows the user to control the direction of the modelling. It is fully supported by graphical and statistical measures of fit. The user may specify any power transformation of stage between 1.5 and 3.5 before modelling. The user also has the option of fixing the intercept in this mode. The following is a step by step procedure for manual statistical modelling within the SDDSS.

PROCEDURE

- 1) Select *Manual Statistical Modelling* from the session window menu to initiate the procedure.
- 2) The system prompts the user for an exponent. The session window is aided by a text screen, which illustrates the function of the exponent in the model. The question reads:

Please enter a REAL number for the Transformation Exponent (TX), in the box provided ...

At this point enter the appropriate desired exponent between 1.5 and 3.5. If you do not enter a correct number, the system will warn you, and allow you to enter a new one.

- 4) The system now asks you:

Would you like to force-fit the model through the zero flow stage = (0.2840 eg.)?

Answer YES, if you would like to fix the intercept of the model at the ZFS value. Otherwise, answer NO.

- 5) Regardless of the answer in 4, the system performs the necessary transformation of stage, and regression analysis. It then displays the results to you through the **MODEL SUMMARY SHEET**, which looks alot like:

MANUAL PROCEDURE(1v) MODELLING MANUAL PROCEDURE(1v)

MODEL SUMMARY SHEET

Model Name	Transform Exponent	Number Outliers	S.E.E.	R2
ML1	2.80	91	4.276	0.6314

Along with the above summary, the results are shown graphically. The model (green), S-D measurements (red) and outliers (blue) are shown on the same graph. Using these two tools, it is up to you to decide the next step. The system prompts you with the following:

What would you like to do next? ...

You then have the option to *Evaluate Models*, based on the provided statistics, *Generate Another Model*, and goto step 2, or *QUIT Modelling System*, which exits the system and brings back to the point where you loaded the modelling section from.

- 6) If you chose to *Evaluate Models*, the SDDSS asks you this question:

What method is to be used in determining the BEST MODEL

Accompanied by the following options:

Maximum R2 value
Minimum Number of Outliers
Standard Error of Estimate

It is now your decision based on the above three criteria, which curve you feel is the best model. Choosing any of the options signals the system to sort through the models generated and select the best model according to the chosen criteria.

- 7) The system then displays the *BEST CURVE* graphically, and in text according to your selected criteria. It then tells you:

MANUAL PROCEDURE(1v) MODELLING MANUAL PROCEDURE(1v)

You now have the following options ...

Abort Modelling
Identify Outliers
Store Model

The first option allows you to exit the procedure. The second allows you to proceed with further analysis (Outlier Analysis). The last stores all relevant model parameters into the database, and ends the modelling procedure after doing so.

SEE ALSO

1 overview
4 transformations
5 statistics
Section 2.4 Outlier Analysis

TRANS(1v) MODELLING TRANS(1v)

TITLE

Data Transformations

DESCRIPTION

The *Stage-Discharge* relationship is obtained by executing a linear regression analysis on the stage-discharge data. This requires a linear relationship of the data being modelled. Transformations of the data set are performed prior to the analysis in attempt to reach a linear relationship.

Two types of data transformations are used:

1) Power Transformation

The Stage (independent) data is transformed using a range of exponents (tx) as follows:

$$S' = S^{tx}$$

where

S = stage

S' = transformed stage

tx = transformation power

A range of transformation powers (1.50 – 3.50) are stepped through using increments of 0.05. A linear regression analysis is performed on each set of transformed stage and discharge data. Thus, the *Stage-Discharge* relations resulting from the *Power Transformation* are of the form:

$$D_m = b_0 + b_1 * S'$$

where

b_0 = regression constant

b_1 = regression coefficient

D_m = model predicted discharge value

2) Box-Cox Transformation

The *Box-Cox Transformation* is also used to generate a number of data sets, from which linear regression models of

TRANS(1v) MODELLING TRANS(1v)

the *Stage-Discharge* relationship are created. The Discharge (dependent) data is transformed, indexed by an unknown parameter *lambda*. The form of the transformation is as follows:

$$D' = \ln(D), \quad \text{lambda} = 0.00$$

$$D' = (D^{\text{lambda}} - 1) / \text{lambda}, \quad \text{lambda} \neq 0.00$$

where

D = discharge

D' = transformed discharge

lambda
= Box-Cox parameter

As with the power transformation, a range of transformation parameters is stepped through resulting in a number of linear regression parameters. A range of 0.00 to 1.00 is used for the *Box-Cox* parameter, *lambda*. The resulting linear regression *Stage-Discharge* relationships are of the form:

$$D_m = \text{EXP}(b_0 + b_1 * S), \quad \text{lambda} = 0.00$$

$$D_m = (\text{lambda} * (b_0 + b_1 * S) + 1)^{1/\text{lambda}}, \quad \text{lambda} \neq 0.00$$

USE

The transformations are used to create a number of data sets, of which an external FORTRAN program performs linear regression analysis to generate numerous *Stage-Discharge* rating models.

PROCEDURE

NEXPERT provides a table of all regressions created along with statistics measuring the fit of each *Stage-Discharge* relationship. The statistics are outlined in the Statistics file of this section.

STATS(1v)

MODELLING

STATS(1v)

TITLE

Statistics

DESCRIPTION

The purpose of the Curve Fitting section in the development of the *Stage-Discharge* relation is to create a *Best Fit* linear regression. That is, a relationship that best represents the particular data set being modelled. The system generates numerous rating models, of which the optimal relationship is chosen based on the values of three statistics.

The three statistics are outlined:

1) *Standard Error of Estimate (SEE)*

SEE is a statistic based on the square of the residuals, the residuals being the difference between the model predicted discharge and the observed discharge ($D_m - D_o$). **SEE** is calculated as:

$$SEE = (SSE/(n-2))^{1/2}$$

where

n = number of stage-discharge measurements

SSE = sum of the squared residual

Clearly, the minimum **SEE** value is desired as it represents the magnitude of error inherent in the model.

2) *R Squared*

R Squared expresses the proportion of the total variation in the predicted "discharge" value that can be accounted for or explained by a linear relationship with the values of the random "stage" measurements (transformed stage - discharge values, see Transformations file of this section). **R Squared** is a function of both the regression sum of squares (**SRR**) and the sum of the squared error (**SSE**). **R Squared** is given as:

$$r^2 = SRR / (SEE + SRR)$$

where

SSR = sum of the squared deviations from the mean discharge

STATS(1v)

MODELLING

STATS(1v)

The optimal *R Squared* value is 1, that is 100 % of the variation of the model discharge is described by a linear relationship with the "stage" data. Therefore, based on this statistic, the optimal *Stage-Discharge* model will yield the *R Squared* value closest to unity.

3) Number of Outliers

The *Number of Outliers* is simply the number of predictions that differ from the measured value by a percentage greater than the allowable error (a user entered value). Thus, the *ith* measurement is considered an outlier if the following condition is true:

$$\text{ABS} [(D_i - D_{mi})/D_{mi}] * 100 > E_a$$

where

D_i = measured discharge *i*

D_{mi} = model predicted discharge *i*

E_a = user entered allowable error

The model yielding the least *Number of Outliers* is chosen as optimal with respect to this statistic.

USE

The statistics calculated are used by NEXPERT as well as external FORTRAN programs to determine the optimal *Stage-Discharge* relationship for the current data selection. NEXPERT provides the user with a maximum of three models chosen as optimal. The reason for a possible of three is that three separate objective functions are used, maximize *SEE*, maximize *R Squared*, and minimize *Number of Outliers*. It is important to note that not all models created in Automated Statistical Modelling (ASM) are evaluated to determine the optimal relationship. ASM includes procedures which screen out invalid linear regression models (see *stat_testing* file of this section).

PROCEDURE

An external FORTRAN program calculates the three statistics for each model generated, the results are displayed by NEXPERT in a *Model Information Sheet*. The statistics are later used to determine the optimal *Stage-Discharge* model (see 8_optimal_model).

STAT_TEST(1v) MODELLING STAT_TEST(1v)

TITLE

Statistical Testing

DESCRIPTION

The Automated Statistical Modelling section includes procedures to confirm that all linear regression models developed are statistically correct. A valid linear regression requires that three criteria be met of the residuals of the model, that is, the deviation of the model predicted discharge from the measured discharge.

The three requirements of a linear regression are as follows:

- 1) *The residuals must be independent.*

Independence means that a residual is not a function of other residual(s).

- 2) *The residuals must be of uniform variance.*

Uniform variance of residuals exists when the magnitude and/or sign of the residual is not a function of the stage (independent) data.

- 3) *The residuals are normally distributed.*

The residuals of the linear regression model should follow a normal probability distribution.

PROCEDURE

NEXPERT and a number of FORTRAN programs are used to screen out linear regression models violating the above mentioned criteria. The process consists of three steps:

- 1) *Skewness and Kurtosis* tests for normality of residuals (automated).
- 2) *Residual Plot*, analysis for testing of both independence and uniform variance of residuals (user interactive).
- 3) *Probability Plot*, a further test for a normal distribution of residuals (user interactive).

Information is available regarding the three testing procedures used in the Xman files: skew_kurt; residual_plot; and probability_plot.

STAT_TEST(1v)

MODELLING

STAT_TEST(1v)

The arrangement of tests provide a narrowing process of the list of candidate *Stage-Discharge* models. Upon completion of the screening, NEXPERT is left with a list of models from which an optimal model is selected.

SEE ALSO

skew_kurt
probability_plot

residual_plot

TEST(1v)

MODELLING

TEST(1v)

TITLE

Skewness and Kurtosis Tests

DESCRIPTION

Evaluation of the *Skewness and Kurtosis coefficients* provide an efficient test for a normal distribution of residuals, a requirement of a linear regression (see `stat_test`). Generally, the coefficients indicate the deviation of the residual distribution from the shape of the normal bell curve. *Skewness* of the residuals exists when the distribution is non-symmetric, that is the distribution is *skewed* to the left or right of the mean. *Kurtosis*, the fourth moment, can be described graphically as the narrowing or flattening of the normal bell curve. The ideal value of both coefficients is zero, indicating a perfect normal distribution of residuals.

USE

The *Skewness and Kurtosis* test is the first of three to confirm validity of all regressions performed (see `stat_test`). The procedure determines if the coefficients lie between calculated boundaries, which have been established as $\pm$ three times the standard deviation of the coefficients. If the model in question yields unacceptable skewness and/or kurtosis coefficients it is labeled non-normal and the model is discarded. Models producing acceptable coefficients are forwarded to the second step in the testing procedure (see `residual_plot`).

PROCEDURE

An external FORTRAN program is used to calculate *Skewness and Kurtosis coefficients* for all linear regression *Stage-Discharge* models created. *Skewness and Kurtosis coefficients* are calculated to provide a test for a normal distribution of residuals, the program forwards the models deemed acceptable to the next level of testing. NEXPERT provides a test status sheet, informing the user of the number of regression models passing the first level of testing.

SEE ALSO`stat_test` `residual_plot`

RES_PLOT(1v) MODELLING RES_PLOT(1v)

TITLE

Residual Plot

DESCRIPTION

The **Residual Plot** is a plot of the residual versus the Stage (independent) data, where the residual is the difference between the model predicted Discharge and the measured Discharge. Analysis of the **Residual Plot** constitutes the second level of the testing procedure for valid linear regressions, included in the Automated Statistical Modelling section. The graphical representation of the residuals is provided so the user may confirm that residuals are uniformly distributed and independent, two requirements of a linear regression (see `stat_test`).

USE

The **residual plot** is to be analyzed by the user to determine if the residuals are independent and of uniform variance, if so the current plot is labelled **acceptable**.

Ideally, the plot will display a uniform band of residuals about the abscissa (stage). An **acceptable** residual plot will not contain points that tend to describe some form of relationship, the plot should appear random. With regards to the requirements of a linear regression, independence of residuals will be confirmed if no relationship among the residuals is displayed. The second requirement, uniform variance of residuals, is followed if no relationship between the Stage and residual is described by the plot.

If the **Residual Plot** describes a possible relationship then it is classified as **unacceptable** by the user. Some examples of **unacceptable Residual Plots** are:

- 1) The residuals increasing in average magnitude with increasing Stage values - a band of residuals about the abscissa widening significantly across the plot.
- 2) A detectable curve function.

PROCEDURE

A FORTRAN program is executed which creates data files containing the necessary information to create the **Residual Plot**. NEXPERT then executes an external graphing utility, XGRAPH, which displays the plot. NEXPERT prompts the user as to accept or reject the model.

RES_PLOT(1v)

MODELLING

RES_PLOT(1v)

This process is repeated for each linear regression model passing the previous *Skewness* and *Kurtosis* tests (see *skew_kurt*). Each model labelled as acceptable on the basis of the *Residual Plot* test is forwarded to the final level of testing, the *Probability Plot*.

SEE ALSO

stat_test
probability_plot

skew_kurt

PROB_PLOT(1v) MODELLING PROB_PLOT(1v)

TITLE

Probability Plot

DESCRIPTION

The **Probability Plot** is a graphical representation of the residuals and the expected value of the residual under a normal distribution. The **Probability Plot** is a decision tool which enables the user to confirm that a linear regression model satisfies the normal distribution of residuals criteria (see `stat_test`). The graph of residual versus expected residual under normality will plot as a straight line if a normal distribution exists.

USE

The **Probability Plot** is analyzed by the user to determine if a linear relationship exists, if so the normality requirement of a linear regression is confirmed and the plot is classified as *acceptable*. Ideally, the plot will display a perfect linear relationship between the residual and the expected value of the residual under normality.

If the **Probability Plot** does not describe a line, the user classifies the plot for that particular **Stage-Discharge** model as *unacceptable*. The model is subsequently discarded as it does not follow a normal distribution.

PROCEDURE

A FORTRAN program is executed which creates data files containing the necessary information to create the **Probability Plot**. NEXPERT then executes an external graphing utility, XGRAPH, which displays the plot. NEXPERT prompts the user as to accept or reject the **Stage-Discharge** model. This process is repeated for each linear regression model passing the previous **Residual Plot** tests (see `residual_plot`). Each model classified as acceptable on the basis of the **Probability Plot** test is added to a list of statistically correct **Stage-Discharge** models (see `stat_test`). From this list, the optimal **Stage-Discharge** model(s) are selected by NEXPERT and associated FORTRAN programs (see statistics).

SEE ALSO

statistics `stat_test`
`residual_plot`

OPT_MOD(1v) MODELLING OPT_MOD(1v)

TITLE

Optimal Model

DESCRIPTION

Determining the optimal *Stage-Discharge* rating model is the final step of the Curve Fitting process. The optimization is based on three statistics, *SEE*, *R Squared*, and *Number of Outliers*.

PROCEDURE

NEXPERT calls an external FORTRAN program that selects the model(s) (of the remaining linear regression models following testing - see stat_test file) yielding the best value of each of the three statistics. Note that because three different statistics are used (three separate objective functions) the number of models selected will range from one to three. For each model labelled "optimal" XGRAPH displays the curve. If more than one model is selected the user is required to choose, of the two or three "optimal" models, the final *Stage-Discharge* relationship to complete the modelling process. However, if one model is determined to be the best fitting curve by all statistics, NEXPERT will automatically conclude the process with that one model and prompt the user to continue with:

- 1) Outlier Analysis
- 2) Reselect the Data
- 3) Store the Model.

SEE ALSO

statistics

Section (2.4) - Outlier Analysis

OVERVIEW(1v)

OUTLIER ANALYSIS

OVERVIEW(1v)

TITLE

Outlier Analysis sub-section of the Curve Development Mode

DESCRIPTION

The purpose of this section is to identify the cause of deviation from the curve of any points beyond the allowable error. The objective is to attach a specific code to each outlier. The code will identify the cause of the outlier, and flag it as such for future use in the stage discharge analysis. If the point in question does not already have an EC code for its cause questions are asked to the user which will categorize the outlier point as one of eight possible causes for plotting as an outlier.

CATEGORIES

The following are the categories for outlier analysis. It is possible to fit the outlier as a multiple cause, and in this case the outlier is attached with a special **MU** code.

- 1) **Beaver Activity** - which is separated into activity down stream or up stream influences.
- 2) **Meander Cut-Offs** - Any meander cut-offs completed near the gauging location can greatly affect the stage-discharge relation.
- 3) **Debris** - Any fallen debris (or man-made) blocking the channel will also alter the relation. Deviations of the point are dependant on the location of the debris with respect to gauge.
- 4) **Rapidly Rising or Falling Stage** - Hysteresis effects also alter the positions of the point on the curve.
- 5) **Tributary Effects** - The confluence of a tributary can also affect the relation. Again, the location and flow regime of the tributary have different altering effects.
- 6) **Wind** - Especially on the praries, the influence of wind can be dramatic at times.
- 7) **Weeds and Vegetation** - Heavy vegetal growth can also affect the behavior of the stage-discharge curve, and is an important factor especially in the low flow stages.

If the outlier can not be explained by any of the above causes, the outlier is coded as unexplainable (**UX**). All the

OVERVIEW(1v)

OUTLIER ANALYSIS

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outlier points are stored in the database separately with their respective codes and the curve number for which they apply. This is for future use of the curve and also for future use of the outliers themselves.

PROCEDURE

The system illustrates to the user one outlier at a time, and then asks the appropriate questions to the user for the outlier identification. After the questions are answered the information is stored in the database. When all outliers have been identified, the user is shown the outliers and accepted data. He/she then has the option to remodel the accepted data, abort and exit, or simply review the outliers just shown.

SEE ALSO

- 2_general_procedure
- 3_beaver_activity
- 4_meander_cut-offs
- 5_debris_on_control
- 6_rising_falling-stage
- 7_tributary_effects
- 8_wind_effects
- 9_vegetal_growth

TITLE

Method and Procedure for Outlier Analysis of the SDDSS

DESCRIPTION

The *Outlier Analysis* is an expert system component of the overall SDDSS which tries to identify the cause of certain measurements that have plotted beyond the defined allowable error. The number of outliers is simply the number of predictions that differ from the observed value by a percentage greater than the allowable error. An outlier is defined by the following equation:

$$ABS(D_o - D_m) / D_m * 100 > \text{allowable error}$$

where

D_o = Observed Discharge
 D_m = Modelled Discharge

The system distinguishes between S-D points which plot above and below the modelled curve, because there are different reasons to make a point plot in the respective positions. The following procedure outlines the method of analysis to determine the cause of all determined outliers.

PROCEDURE

The outlier analysis is an *iterative* procedure, where-by a series of questions is asked for each outlier to determine its cause. Upon entry of the outlier analysis section of the program a message window is shown for the first outlier. It tells the user the present outlier number and the total number in the set. It also displays the *date* when the measurement was taken, the *stage* and the *discharge*. It also shows the model response for this observation, and advises the user to refer to his/her field notes and answer the questions in the *SESSION WINDOW*. The following questions are then asked:

- 1) *Rising and Falling Stage* - The first question pertains to measurements which were possibly taken during rapidly rising or rapidly falling stage events. The effect of error due to these conditions determines the plotting position of the SD point, and the system asks the questions accordingly.

If a SD point has plotted **ABOVE** the curve, the system tries to determine the possibility of the measurement taken during rapidly falling stage conditions, and the following question appears in the *SESSION CONTROL*

WINDOW:

WAS THE MEASUREMENT TAKEN DURING *Rapidly Falling Stage* CONDITIONS?

If a SD point has plotted **BELOW** the curve, the system tries to determine the possibility of the measurement taken during rapidly rising stage conditions, and the following question appears in the SESSION CONTROL WINDOW:

WAS THE MEASUREMENT TAKEN DURING *Rapidly Rising Stage* CONDITIONS?

Answering either of the above question with **YES** or **NO** allows the outlier analysis to continue with question 2.

- 2) **Beaver Activity** - The second question tries to establish if the outlier was caused by some backwater created by some beaver activity near the gauging site. A common occurrence in Canada the question asks:

WAS THERE *Beaver Activity* NEAR THE SITE DURING THE MEASUREMENT?

The options for answer are *Down Stream*, *Nil* or *Up Stream*. The user is advised to check his/her notes and answer the question accordingly.

- 3) **Meander Cut-Offs** - The affect of meander cut-offs can greatly alter the stage-discharge relation, and the third question addresses this problem:

HAS THERE BEEN ANY RECENT *Meander Cut-Offs* NEAR THE SITE?

The options for answer are *Down Stream of Gauge*, *None* or *Up Stream of Gauge*. The user is advised to check his/her notes and answer the question accordingly.

- 4) **Debris** - Again, error in the measurement can also be affected by any trapped debris in the channel, and its location with respect to the measurement site. The question is

WAS THERE ANY TRAPPED *Debris* AFFECTING THE MEASUREMENT?

The same options as question 3 are available for answer.

- 5) **Tributary Influence** - Now the system tries to identify

PROCEDURE(1v) OUTLIER ANALYSIS PROCEDURE(1v)

whether or not the measurement was influence by some unusual acitivity in a near by tributary. The question that appears is:

DURING THE MEASUREMENT, WERE THERE ANY NEARBY TRIBU-TARIES WITH ...

There are five options for answer. They include:

All Tributaries: Normal Flow
D/S: Higher than Normal Flow
D/S: Lower than Normal Flow
U/S: Higher than Normal Flow
U/S: Lower than Normal Flow

The abbreviations *D/S* and *U/S* mean down stream and up stream respectively.

- 6) **Wind** - Wind can have a great affect on the associated error in a SD measurement, especially at those stations located on prarie streams. The question for wind is:

WAS THERE ANY Wind AT THE SITE DURING MEASUREMENT ?

and the following are possisble reponses:

DOWNSTREAM
Nil
UPSTREAM

- 7) **Weed Growth** - Additional error can occur when the gauging site is inundated with vegetal growth and weeds. Therefore, the last question establishes if at the time of measurement substantial weed growth in the cross-section may have caused the outlier. The question is:

WAS THERE SUBSTANTIAL Weed Growth IN THE MEASUREMENT CROSS-SECTION ?

The possible answers are *None* and *Yes*

After answering the seven questions for one outlier the system searches for the next outlier in the set, and displays its relative information to the user. The user is then asked all seven questions again. The process is repeated until all outliers have been identified by the user.

Once all questions are answered for all outliers, the results are displayed graphically and in a text window. The text window defines the number of explained and unexplained measurements. It also displays the number of measurements that may be influenced by multiple conditions if any. It

PROCEDURE(1v) OUTLIER ANALYSIS PROCEDURE(1v)

displays the number of outliers and the number of accepted measurements as well. The graphical display on the right of the session window, illustrates the above information where-by each group of outliers (and accepted data) is represented by a separate colour. At this point in the program the session is halted, and the user must press on the continue button in the session window to proceed. The system then responds with the question:

What Next?

and the available options are as follows:

- 1) Abort Outlier Analysis
- 2) Continue...Model ACCEPTED Data
- 3) Review Outliers

Choosing the **first** option will exit the outlier analysis and return you to the point in the program from which you entered the outlier analysis. The **second** option allows the user to remodel only those data which are not outliers, ie., **ACCEPTED** measurements. This will bring the user back to the modelling component of the system. If further outliers are determined by the program, the user will not be allowed to determine any more outliers. Therefore, the model must be accepted and **STORED** or **ABORTED**. The **last** choice will allow the user to review the data with or without the model. This is simply a quick step back to the previous portion of the outlier analysis. The above choices are the end of the outlier analysis. Once the user leaves this section of the program he/she will be automatically allowed to resume with the program from where they entered it. Thus, they may be able to remodel, or re-select more SD measurements for modelling.

SEE ALSO

- 1_overview
- 3_beaaver_activity
- 4_meander_cut-offs
- 5_debris_on_control
- 6_rising_falling-stage
- 7_tributary_effects
- 8_wind_effects
- 9_vegetal_growth

BEAVERS(1v)

OUTLIER ANALYSIS

BEAVERS(1v)

TITLE

Functional Description and Identification of Outlier due to Beaver activity.

DESCRIPTION

It is an often occurrence for beavers in Canada to build a dam on smaller streams in remote areas. These natural engineers can often disrupt flow totally, or back up water behind the dam altering the Stage-Discharge rating greatly. When an outlier is identified it is important to clearly explain the nature of its occurrence. The system holds as one option the possibility of any beaver activity near the measurement site that may have influenced the measurement, and induced some error.

The second question in the series of explanatory outlier questions deals with beavers. The key to answering the question is to refer to the field notes taken during such a measurement, and the plotting position of the outlier with respect to the model.

OUTLIER ABOVE MODEL

When an outlier plots above the model, the cause is probably due to some *backwater* phenomena. A beaver dam is certainly one of these, a beaver dam constructed *down stream* of a site will back the water up, and force a measurement to plot above the normal flow curve. The position is above the curve due to a decrease in the average velocity of the flow across the control. Thus, the water rises to compensate. If your notes say that a *beaver dam* was constructed *down stream* of the measurement site, and the outlier plots *above* the model then answer the Question 2 in the session window by double clicking on the *Down Stream* option

OUTLIER BELOW MODEL

Beaver activity will rarely cause an outlier to plot below the curve. A plotting position below the curve often means an increase in water surface slope, and/or velocity. It may also mean the section control has been altered to increase the capacity of the channel, or decrease the stage. Beaver Dams built up stream of the gauge should produce little influence, except that the flow will slow. The rating and gauge record will simply show a period of low flow, not an altering of the stage-discharge relation (i.e., an outlying measurement). If, however, you saw that there was significant beaver activity *Up Stream* of the measurement site, which had increased the channels capacity for flow, and the outlier plots *Below* the curve double click on the *Up Stream*

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option for answer to question 2.

NO BEAVER ACTIVITY

If there was no beaver activity at the time of the measurement which influenced it in any way simply answer question 2 in session window by double clicking on *Nil*. This will tell the system that the outlier was not influenced by beavers, and the program will continue.

SEE ALSO

1_overview

2_general_procedure

TITLE

Functional Description and Identification of Outliers due to Meander Cut-Offs.

DESCRIPTION

Meandering rivers and streams that have unstable banks may be subject to changing channel morphology. One such occurrence can be the meander cut-off. It is highly possible that a near by meander that is separated from the channel by the cut-off process will change the stage-discharge relation. These changes would be reflected in the measurements taken at the gauging site.

The third part of the outlier analysis addresses this phenomenon. The question asks if there has been any *recent* meander cut-offs near the measurement site. The possible answers are *Down Stream of Gauge, Nil* or *Up Stream of Gauge*. The user is then referred to his/her notes, and told to answer the question by double clicking on one of the options. The following sections may help in your answer. Note, it is important to observe the *plotting position* of the outlier with respect to the current model, and make accurate reference to field notes taken on the date of the measurement.

OUTLIER ABOVE MODEL

It is unlikely that an outlier whose plotting position is above the current model will be the effect of a meander cut-off. Cut-offs *up stream* of the gauge may have some influence, but the effect should be negligible because the control geometrics are unchanged at the site. The influence may change the water surface slope and alter the capacity of flow in the channel. Therefore, an outlier that plots *above* the current model would most likely be influenced by a meander cut-off *up stream* of the gauging measurement site.

OUTLIER BELOW MODEL

It is much more likely that a recent meander cut-off below (down stream) the gauging site will have a greater effect on the stage-discharge measurement and corresponding relation. The effect of the meander cut-off will shorten the distance that the water has to travel from one level to the next resulting in an increase in the slope of the channel. This corresponds to an increase in the capacity of flow in the channel. From Manning's equation of flow in an open channel, an increase in slope will increase the mean velocity in the channel, and increase the discharge for the same level of flow previously encountered before the cut-off. The

MEANDER_CUT-OFFS(1v) OUTLIER ANALYSIS MEANDER_CUT-OFFS(1v)

result is a shift of the SD curve to the left, or measurements which will plot to the left or **BELOW** previous measurements at the same stage. The conclusion is simple. If a channel has experienced a recent meander cut-off *down stream* of the measurement site then the plotting position of the outlier should be below the current curve.

NO MEANDER CUT-OFFS

Meander cut-offs seem to occur in non-stable channels, in a cyclical pattern. If there has been no recent meander cut-off activity simply answer question 3 of the outlier analysis by double clicking the mouse pointer on *Nil*.

SEE ALSO

- 1_overview
- 2_general_procedure

DEBRIS(1v) OUTLIER ANALYSIS DEBRIS(1v)

TITLE

Functional Description and Identification of Outlier due to Debris on Control.

DESCRIPTION

Rivers and streams often find floating debris and natural objects throughout their course. Problems often occur when the normal flow is obstructed by debris that becomes trapped within the banks near the hydraulic control of a hydrometric station. The debris can consist of all sorts of man made materials, as well as log jams, fallen trees and branches. Often times gauging stations are located near bridges, and these sites are prime locations to trap such articles. Whether the debris blocks flow across part or all of the cross-section can determine the effect it has on the stage-discharge relation.

Part 4) of the outlier analysis tries to identify the cause of an outlier due to some disruption of flow caused by trapped debris near the control. It establishes the location of the debris with respect to the gauge (ie., *down stream* or *up stream*). The location of the debris will have an effect on the plotting position of the outlier against the current model. The answer will be dependent on these factors.

OUTLIER ABOVE MODEL

This is probably the most common plotting position of an outlier, because the greatest effect that occurs from trapped debris is a *backwater* phenomenon caused by the restricted flow. The amount of backwater is dependent on the relative restriction caused by the debris. A partial restriction of flow will have a smaller backwater effect than a complete cross-section restriction such as a log jam. The location of the restriction would certainly have to be *down stream* of the measurement site in order to force the outlier to plot above the curve.

OUTLIER BELOW MODEL

A restriction of flow from debris above the gauging site will probably have little effect on the rating, and the position of an outlier. An outlier that plots below the current model is unlikely to be caused by trapped debris *up stream* of the gauge. However, it may be possible to lower the stage for some time and increase the velocity of flow at the measurement.

DEBRIS(1v)

OUTLIER ANALYSIS

DEBRIS(1v)

NO TRAPPED DEBRIS

If there was no debris near the site at the time of the measurement, or if the debris near the site was negligible, answer question 4 of the outlier analysis with *Nil*.

SEE ALSO

1_overview

2_general_procedure

RISE-FALL(1v)

OUTLIER ANALYSIS

RISE-FALL(1v)

TITLE

Functional Description and Identification of Outlier due to measurements taken during RAPIDLY RISING or FALLING stage at the Control.

DESCRIPTION

Natural and man made sand channels are sometimes subject to a *hysteresis* effect, more commonly known as a loop rating. This effect is caused when the passing of a flood wave changes the bed forms of the river. However, the bed forms have a certain lag behind the changing velocity of the river. It is this lag that causes the hysteresis effect. The user is referred to - *Measurement and Computation of Streamflow: Volume 2. Computation of Discharge*, a Geological Survey Water-Supply Paper, number 2175 (1983), pages 378-379 - for more information on bed formations, and their effect on the rating relation. Note, this phenomenon is most severe for *rapidly* rising or falling stages.

Rigid channels can also be subject to a loop rating if the slope of the channel is flat enough to allow this phenomenon to occur. Again the user is referred to the above USGS paper, pages 390 & 413-415, for more information. The loop is also illustrated on page 413. It shows the common characteristic rating curve where the rising stages plot on the lower loop and the falling stages plot on the upper loop.

It is the responsibility of **Part 1** of the outlier analysis to investigate the possibility that the outlier was caused due to offset of a rapidly rising or falling stage measurement.

OUTLIER ABOVE MODEL

If the outlier plots above the established curve, the expert system asks if the measurement was taken during rapidly *rising* stage conditions. The user is asked to refer to his/her field notes and answer the question with a **YES** or **NO** answer.

OUTLIER BELOW MODEL

If the outlier plots below the established curve, the system automatically assumes the possibility that the measurement was taken during rapidly *falling* stages. Refer to your field notes and answer the question in the session window with a **YES** or **NO** answer.

TRIBUTARY(1v) OUTLIER ANALYSIS TRIBUTARY(1v)

TITLE

Functional Description and Identification of Outlier due to nearby tributary effects.

DESCRIPTION

Gauging stations are sometimes situated near or on tributaries of other streams. The flow in the nearby tributary, if abnormal, can alter the stage-discharge relationship enough to cause measurements taken during these periods to plot as outliers. The location and behaviour of the tributary will ultimately affect the stage-discharge in different ways. That is why *Part 5* of the outlier analysis explores the possibility of the outlier being caused by some abnormal event in a nearby tributary.

OUTLIER ABOVE MODEL

If the outlier plots above the established curve it is probably due to an decrease in the velocity of the flow, or backwater due to a nearby river with an above average runoff. The river could be either *downstream* or *upstream*. Check your field notes and answer the question if this is the case. The answers would be:

D/S: Higher than Normal Flow
or
U/S: Higher than Normal Flow

OUTLIER BELOW MODEL

Otherwise, tributaries with lower than normal flow will allow main streams to spill water into their channels. This will cause the appearance of increased capacity in the main channel, and lower the stage for a given discharge. The result is SD measurements that would seem to plot below an established curve. If this is the case for either *upstream* or *downstream* channels, the answer would be:

D/S: Lower than Normal Flow
or
U/S: Lower than Normal Flow

Once again check your field notes for reference.

TRIBUTARY(1v) OUTLIER ANALYSIS TRIBUTARY(1v)

NO TRIBUTARY EFFECTS

If the outlying measurement was not affected by any abnormal flow in nearby tributaries, or all flows are relatively normal in the area, answer the question in the session window by double clicking the mouse pointer on

All Tributaries: Normal Flow

SEE ALSO

- 1_overview
- 2_general_procedure

WIND(1v) OUTLIER ANALYSIS WIND(1v)

TITLE

Functional Description and Identification of Outlier due to Wind effects.

DESCRIPTION

Part 6 of the outlier analysis deals with the effect of wind on the stage-discharge rating relation. Wind can have a great affect on the associated error in a SD measurement, especially at those stations located on prarie streams. The question for wind is:

WAS THERE ANY Wind AT THE SITE DURING MEASUREMENT ?

and the following are possible reponses:

DOWN STREAM

Nil

UP STREAM

The **DOWN STREAM** answer is meant to indicate that the wind is blowing in the down stream direction, and the **UP STREAM** answer indicates wind blowing in the up stream direction.

OUTLIER ABOVE MODEL

An outlier plotting above the curve is most likely caused by a backwater affect due to wind blowing in the **UP STREAM** direction. Make sure your field notes indicate that it was an above average windy day before concluding with this answer.

OUTLIER BELOW MODEL

On the other hand, wind blowing in the **DOWN STREAM** direction will effect the velocity profile of the stream (higher surface velocities result in overall higher average velocity), and temporarily increase the capacity of flow. This will shift the SD measurements to the right. If field notes concur with this answer the question in the session window accordingly.

NO WIND

If there was no wind at the site at the time of the measurement, or if the wind was negligible, answer question 6 of the outlier analysis with **Nil**.

VEGETATION(1v) OUTLIER ANALYSIS VEGETATION(1v)

TITLE

Functional Description and Identification of Outlier due to abundant weed or vegetal growth at the Control.

DESCRIPTION

Additional error in the SD measurement may occur when the cross-section at the measurement site has become inundated with weeds or vegetation. The vegetation can severely impede the flow in the cross-section creating a *backwater* effect. Therefore, if the outlier plots **ABOVE** the current curve and field notes indicate that substantial weed growth was present at the time of the measurement, answer the question in the session window with *Yes*. Otherwise, answer *None*

SEE ALSO

1_overview
2_general_procedure

Section (3) - Curve Use

OVERVIEW(1v)

CURVE USE

OVERVIEW(1v)

TITLE

General overview of the **CURVE USE** mode in the SDDSS program.

DESCRIPTION

Once a stage-discharge model rating curve is established, and/or modified and stored in the database, it is then possible to make use of the curve and apply it to an applicable continuous record of gauge to produce calculations of discharges. The discharges can appear in several forms; as average daily discharge, with or without confidence limits, and other forms. It is the purpose of the **CURVE USE** mode to make use of the curves established and stored in the database. However, the system distinguishes between the use of curves developed for stable channels and those developed for non-stable channels.

START UP AND INITIAL PROCEDURE

To initiate the curve use mode the user selects **Compute Discharges** from the main menu. The system then activates the curve use mode by first retrieving the classification information on the current station from the database. Two separate directions are then taken according to the classification of the station. If a station has previously been classified as a **stable** channel, the user is automatically brought through a procedure to allow for the calculation of average daily discharges, discharges at 15 minute intervals, or the computation of a look up rating table. Alternatively, if the current station has been considered as a **non-stable** channel, the user is only allowed to compute average daily discharges. This procedure is quite different, however, than the stable channel curve use, because it has to deal with the complexities and nature of the control, and the application of the curves to the gauging record according to the development of the relation.

SET UP

The two procedures are commonly linked, but are separated into two distinct entities within the system framework. The **stable** curve use procedure is completed within the **SCUSE.tkb**, and the **non-stable** curve use procedure has its knowledge base as a separate unit in **NSCUSE.tkb**. This allows for more efficient and understandable programming, as well as providing for an easier framework for further development.

SC_CURVE_USE_PROC(1v) CURVE USE SC_CURVE_USE_PROC(1v)

TITLE

General Procedure for the use of stage-discharge rating curves in stable channels.

DESCRIPTION

The following sections will outline the general procedure and available options when using previously developed stage-discharge relations for the computation of discharge from a *systematic record of gauge*. The procedure is only applicable if the current station has previously been determined as a **STABLE** channel. It is important to utilize the stability classification at this point, because of the differences in how the curves can be made. Although the options are very similar to the use of non-stable channel curves, the method of application to the systematic record of gauge is quite different.

PROCEDURE

- 1) Upon the selection of *Compute Discharges* from the main menu the CURVE USE MODE is activated by the system. The current stability classification is extracted from the database, and if the current gauging station is on a **STABLE** channel, the following procedure will apply.
- 2) Upon entry into the curve use section for stable channels, a list of all curves previously created and stored (in the database) is compiled and shown to the user. The user is then prompted to enter a *curve identification number*. The following question appears in the session window.

Select a Curve Id. Number ...

The user then enters an curve id. integer from the list of curves to apply its corresponding model to the record of gauge.

- 3) The next step is to choose a method of output for the calculation of discharge. Below is the prompt from the SESSION window, and the available options.

SELECT FORMAT OF DISCHARGE TABLE TO BE GENERATED ...

DAILY DISCHARGE Predictions only
DAILY DISCHARGE with confidence bounds
DISCHARGE: 15 min
LOOKUP_TABLE

Selecting one of the above four options will result in the computation of discharges according to different

SC_CURVE_USE_PROG(1v) CURVE USE SC_CURVE_USE_PROG(1v)

schemes.

Each option is further explained in their respective manpages in this section.

- 4) After completing the computation of the respective tables, the program resumes by allowing the user to save the discharge table. The session window reads:

WOULD YOU LIKE TO SAVE THE DISCHARGE TABLE ?

NO

YES

A NO answer brings the user back to the main menu, and ends the CURVE USE mode. A YES answer will provide the opportunity for the discharge table to be stored in ASCII text form in a file, or printed on the default printer. After saving the file the CURVE USE mode is complete and the system returns to the main menu.

SEE ALSO

4_daily_discharge_predictions.lv
5_discharge_at_15_min_intervals.lv
6_lookup_discharge_table.lv

TITLE

General procedure for the use of stage-discharge rating curves developed for non-stable channels.

DESCRIPTION

The following sections will outline the general procedure and available options when using previously developed stage-discharge relations for the computation of discharge from a *systematic record of gauge*. The procedure is only applicable if the current station has previously been determined as a **NON-STABLE** channel. It is important to utilize the stability classification at this point, because of the differences in how the curves can be made. Although the options are very similar to the use of stable channel curves, the method of application to the systematic record of gauge is quite different.

PROCEDURE

- 1) Upon the selection of *Compute Discharges* from the main menu the CURVE USE MODE is activated by the system. The current stability classification is extracted from the database, and if the current gauging station is on a **NON-STABLE** channel, the following procedure will apply.
- 2) After realizing that it is dealing with a non-stable control, the system tells the user that it is linking to the NON-STABLE CURVE USE SECTION, and it loads in the NSCUSE.tkb.
- 3) The first step of the NON-STABLE curve use section is to choose a time segment that is applicable to your gauging stations data. A text screen is shown to the user with the time segments and corresponding first and last years. The session window reads

Enter the Applicable Segment Number now...

The user enters the integer of the time segment, and only those curves developed for this time frame will be considered for use.

- 4) The system proceeds depending on the nature of the control and how previous curves were developed. *If* the curves were segmented *Seasonally* the following question will appear in the session window

Is your Digitized Gauging Data Affected by Open Flow Conditions or Ice Conditions?

This also affects the curves to be considered depending on your answer. For example, if *Open Flow* is your answer, only those curves made with data for open flow conditions will be considered for curve use, likewise for Ice Conditions. If, however, the control is unaffected by seasonal variation in the data, the above question and step will be skipped.

- 5) The next text screen to be shown is a list of applicable curves for the chosen time segment, and development conditions. In addition any modified curves are also shown, to allow the user to apply these to an appropriate gauging record. The user is asked to **KEEP** this screen and **CONTINUE** to the next screen.
- 6) The sixth step is a safety function of the SDDSS. It allows the user to override the default curve settings. If you want to use the modified curves you must choose to change the default curves. For more information on this topic see the manpage (Default Curves). The option is simple if you would like to change the default settings choose **YES**. if you want to keep the default curves choose **NO**. A YES answer allows the user to re-specify the necessary curves. The system will guide you through this process. A NO answer continues to step 7.
- 7) Enter the name of the water level record file now. Remember it must be in the */home/SDDSS/NXP/WATLEVREC* directory. It should be in standard Environment Canada form, in hourly or fifteen minute readings. If you do not enter an existing file the system will warn you and you can try to re-enter the correct file name.
- 8) Enter the year that the gauging record was taken (ie., if the record is for water level readings taken in 1988. Enter **1988**)
- 9) The second to last step is to decide which format you want the discharge results posted. The options are:

Daily Discharge Predictions Only
 Daily Discharge Predictions with Confidence Bounds

The execution of the correct external program will result from your decision. Then you can view your discharge table. For more information on the results of the above two options see the manpage on **daily discharge predictions**. For more information on the computation of discharge for non-stable channels see the manpage **discharge_computation_NSC**. NSC stands for non-stable channels.

NSC_CURVE_USE_PROC(1v) CURVE USE NSC_CURVE_USE_PROC(1v)

- 10) The last step allows the user to produce a hardcopy of the discharge table. A YES answer will print the document from the printer. A NO answer simply continues with the display of a text screen telling the user that he/she has reached the end of this CURVE USE session. The program then returns to the main menu.

SEE ALSO

4_daily_discharge_predictions
7_discharge_computation_NSC
8_default_curves

TITLE

Explanation and Description of the computation of *Average Daily Discharge*.

COMPUTATION OF DISCHARGE

STABLE CHANNELS

It is assumed that stable channels have relatively simple Stage-Discharge rating relations for the entire period of record, and for the entire range of stage. That is why it is only necessary to enter one SD model (curve) for the use in the computation of discharge. When the value of the *Curve Identification Number* is known to the system, it can then apply the model parameters to the gauging record to compute discharge from stage or gauge readings.

Average daily discharge is computed by first computing hourly discharges, and then averaging those discharges to arrive at the final determination of average daily discharges. If the gauging record is in 15 minute intervals, an average hourly stage is computed, before the hourly discharges are computed.

Again, only a *single curve* is applied to the systematic record of gauge for *stable* channels.

UNSTABLE CHANNELS

The computation of average daily discharge is more complex for gauging sites located on non-stable channels, because of the possibilities and combinations of curve sets that have been made previously. Information regarding the SD relations subjectivity to *seasonal variation*, *hysteresis* and *variation with stage* is stored in the database during the development of the overall relation for the site in question. During the curve use mode this information is used to guide the user in applying the correct curves to the systematic record of gauge to compute average daily discharge.

For example, through previous development of the rating relation it is known that the current station has had curves developed which are applicable to open flow measurements, separate from ice condition measurements (*seasonal variation*). In addition the geometrics of the channel control are such that two separate relations were developed for stages from 0.25 to 1.38 m and 1.38 to 2.96 m (*variation with stage*). Form this scenario, the system will ensure that the user chooses to apply a curve applicable to low stages and a curve applicable to high stages, and that both curves were

developed for open flow data only. The system will also automatically choose the correct external routine to apply these curves to your systematic record of gauge. That is the routine will analyze the gauging record and apply each curve to the appropriate range of stages.

OPTIONS

DISCHARGE PREDICTIONS ONLY

This option will produce a table of average daily discharges for the period of systematic record in the file specified by the user. The table produced includes the Current Date, the Station Id. Number and Title and Year of Record in the header. The main section of the table displays the daily discharge in cubic meters per second where the months are displayed in columns and the days are displayed in rows. The table also includes: monthly maximums, minimums and means, as well as the maximum daily flow and minimum daily flow. Discharges are computed only for the period of record covered in the gauging file. Therefore, a file containing water level records from March 16 to September 23 will produce a table of daily discharges for that period.

DISCHARGE PREDICTIONS WITH CONFIDENCE BOUNDS

A table with similar format to the above can also be produced with the addition of a confidence interval for each daily discharge produced. The confidence interval appears in parentheses to the right of the computed daily discharge. Three levels can be obtained for **80, 90 and 95 percent confidence**. For example, the user chooses 95 percent confidence level, and the result of the computed daily discharge is **154.67 (4.387)**. The meaning of this result is that the model has predicted that the average daily discharge for that day was 154.67 cms **plus or minus** 4.387 cms within 95 percent accuracy or confidence.

The confidence interval is calculated from the following formula:

$$CI = +/- (t(n-2)*s(STh))$$

where

CI = confidence interval
 $t(n-2)$ = t-distribution value at $n-2$
 $s(STh)$ = root of STh variance
 STh = Stage observation at h

DD_PREDICTIONS(1v) CURVE USE DD_PREDICTIONS(1v)

PROCEDURE

The procedure to calculate average daily discharge according to either of the above to options is available in the CURVE USE mode for both *STABLE* and *NON-STABLE* channel analysis. It is a four step procedure:

- 1) First Choose one of the above options from the appropriate menu. If you chose the first option, skip to step 3.
- 2) If you chose the second option, enter the desired confidence interval for discharge estimations ... **80, 90** or **95** percent.
- 3) Now enter the filename containing the water level record. The record should be in standard Environment Canada format either in 1 hour or 15 minute interval readings. Also, the file must be in the */home/SDDSS/NXP/WATLEVREC* directory. If the filename entered does not exist, the system will warn you and you will have to re-enter a correct filename.
- 4) The system will automatically select and execute the correct external computational program according to the specifications outlined, and the results will be tabulated and shown to the user. Just follow the directions on the screen.

For more information on the overall procedure please see additional manpages in the section. The listing follows.

SEE ALSO

1_overview
2_stable_curve_use
3_non-stable_curve_use

TITLE

Explanation and Description of the computation of *Discharge in 15 minute intervals*.

DESCRIPTION

This option is available for the computation of instantaneous discharge at 15 minute intervals. It is available within the CURVE USE module, and is presently activated only for those gauging stations situated on channels that have been classified as *STABLE*. The following manpage will explain the application of the developed SD relations (curves) to a systematic record of gauge.

PROCEDURE

During the consultation of the CURVE USE module there comes a time to choose a format of discharge table to generate. To activate the discharge predictions at 15 minute intervals option double click on - *DISCHARGE: 15 min* - from the appropriate menu. The resulting computations and presentation of the results becomes a 4 step process.

- 1) The system requires that the user enters a desired confidence interval for discharge estimations ... Select one of *80, 90 or 95* percent options.
- 2) Now enter the filename containing the water level record. The record should be in standard Environment Canada format in 15 minute interval readings. Also, the file must be in the */home/SDDSS/NXP/WATLEVREC* directory. If the filename entered does not exist, the system will warn you and you will have to re-enter a correct filename.
- 3) The Datum must now be entered. Refer to the station description notes and enter the appropriate value. The value must be in *meters* referenced from sea level.
- 4) A text window will appear telling you that it is currently running an external routine to compute the discharges. The results will then be displayed following the execution of the routine. Simply follow the direction on the screen to view the output. After viewing the output, the system will allow you to save it as an ASCII text file, or print it.

DIS_15_MIN(1v) CURVE USE DIS_15_MIN(1v)

RESULTS

The result of the computation is a series of pages with the calculations of instantaneous discharge. Each page has a header explaining that the document is from *Water Survey of Canada*. As well, the header contains the date the document was made, station number, and the title - **DISCHARGE IN CUBIC METERS PER SECOND** with the desired confidence interval measure below (eg., 90 %). The body of each page is a table of 7 columns and 24 rows. The first column expresses the day, month and year of the discharges. Columns 2 and 7 express time in fifteen minute intervals. Columns 3 to 6 express the computed instantaneous discharge and associated confidence interval for every 15 minute gauge reading. Therefore, each line represents one hour of gauge readings expressed as a discharge measurement.

SEE ALSO

2_stable_curve_use

DIS_15_MIN(1v)

CURVE USE

DIS_15_MIN(1v)

TITLE

Explanation and Description of the computation and display of the *lookup discharge table*.

DESCRIPTION

This option is available for the computation and display of a stage-discharge lookup table (ie., a *rating table*). It is available within the CURVE USE module, and is presently activated only for those gauging stations situated on channels that have been classified as **STABLE**. The following manual page will explain the application of the developed SD relations (curves) to a systematic record of gauge.

PROCEDURE

During the consultation of the CURVE USE module there comes a time to choose a format of discharge table to generate. To activate the discharge lookup table option double click on - **LOOKUP TABLE** - from the appropriate menu. The resulting computations and presentation of the results becomes a 3 step process.

- 1) The rating table output can be in three different forms according to the desired stage increments of the user. Therefore, the first step after choosing to display a lookup table is to choose a suitable stage increment. The three options are: Stage increments of

0.001 meters or 1 mm
0.010 meters or 1 cm
1.000 meters

The user is asked to select one of the above options according to the desired output.

- 2) The Datum must now be entered. Refer to the station description notes and enter the appropriate value. The value must be in *meters* referenced from sea level. The datum will be added to each stage measurement. For example, if the datum is 212.35 meters above sea level, the lowest stage in the lookup table will be 212.35 meters, and each additional stage measurement will have the above selected increment added to the datum.
- 3) A text window will appear telling you that it is currently running an external routine to compute the lookup table. The results will then be displayed following the execution of the routine. Simply follow the direction on the screen to view the output. After viewing the output, the system will allow you to save

DIS_15_MIN(1v) CURVE USE DIS_15_MIN(1v)

it as an ASCII text file, or print it.

RESULTS

The result is a lookup rating table in standard Environment Canada format. It displays a typical header showing the station information, date, title, and that the document is a product of Water Survey of Canada. All displayed discharges are in *cubic meters per second*. The body of the report includes the computed results of discharge from the chosen curve parameters for each stage increment starting from the user inputted datum. A single curve was previously selected by the user, and only its parameters are used to define the discharge at each stage.

SEE ALSO

2_stable_curve_use

DEFAULTS(1v)

CURVE USE

DEFAULTS(1v)

TITLE

Explanation and use of default curves during the consultation for *Non-Stable* CURVE USE.

DESCRIPTION

The most important aspect when applying a curve or set of curves to a systematic record of gauge for the computation of discharge, is making sure that the user applies the correct curves to the record. The system retains information about the current station according to the development of the curves that are in the database and ready for use. The information retained corresponds to the *stability of the station*, and whether the channel characteristics are such that the rating relation is subject to *seasonal variability*, *variability due to hysteresis* or *variability with stage*.

For example, let's say the station in question is highly subject to hysteresis. A curve set for this case would include separate curves for measurements taken during *Rising Stage* conditions, *Falling Stage* conditions and *Stable Stage* conditions. The current station has also had two curve sets made for the same time period for various reasons. One set was made on October 21, 1992. The other was made on November 2, 1992. The decision for default curves is arbitrarily set at the earliest curves made. Therefore, the curves made on October 21, 1992 will be selected as the default curve settings for this example. If the user wishes to override the default settings the system will allow him to do so, but the user must still select a rising, falling and a stable stage curve to complete a set. The system will guide the user through this process, just follow the instructions on the screen.

NOTES

When changing the default curves for a gauging station affected by a *variation with stage*, make sure you enter the appropriate number of curves. Pay attention to the curve listing. If **NO** middle stage curve code appears (ie., **ONHMD** code), then only enter 2 curves, one for **LOW** stages and one for **HI** stages. If you do not do this the computations will not work or will be erroneous.

SPECIFYING MODIFIED CURVES

If you would like to specify a modified curve for use, you must choose to override the default settings. After you choose **YES** to override, the system asks you if you would like to choose some alternate combination of normal flow curves (*Use Normal Flow Curves* option), or a modified curve

DEFAULTS(1v)	CURVE USE	DEFAULTS(1v)

(*Use Modified Curves* option). If you choose the modified curve use option the system will instruct you to enter the desired curve identification number, and then the program will resume as it did before. The results are presented identically, its just that you have now altered the results due to the specification of a different model.

SEE ALSO

3_non-stable_curve_use.lv

Section (4) - Curve Modification

OVERVIEW(1v)

CURVE MODIFICATION

OVERVIEW(1v)

TITLE

General overview of the **CURVE MODIFICATION** mode in the SDDSS program.

PURPOSE

The aim of the curve modification process is to utilize new or different data sets in comparison to data sets used in existing models, to create modified SD relations using combined data or separate relations (new relations) using only the new or different data sets.

DESCRIPTION

The third module of the overall **SDDSS** allows the user to modify a curve. It is necessary to see the existing curves and compare the data used in constructing the curve to other data sets pertaining to the same gauging site or channel control. This is especially true for new data. It is often necessary to see how closely new data measurements follow the most recent or even previously made SD rating curves for different time segments. However, due to the differences when making curves for **stable** and **non-stable** channels, it is necessary to modify existing relations with separate analysis. That is why the system has been created to handle the **CURVE MODIFICATION** process for stable and non-stable channels separately.

START UP AND INITIAL PROCEDURE

To initiate the **CURVE MODIFICATION** mode the user selects **Modify an Existing Curve** from the main menu. The system then activates the **CURVE MODIFICATION** mode by first retrieving the classification information on the current station from the database. Two separate directions are then taken according to the classification of the station. If a station has previously been classified as a **stable** channel, loads a separate knowledge base exclusively for the purpose of modify established SD rating models for stations situated on stable channels. Alternatively, if the current station has been considered as a **non-stable** channel, the system takes the user into a different knowledge base devoted to the modification of curves developed for sites on non-stable channels. The following section illustrates the system architecture more fully.

SET UP

The two procedures are commonly linked, but are separated into two distinct entities within the system framework. The **stable** **CURVE MODIFICATION** procedure is completed within the

OVERVIEW(1v)

CURVE MODIFICATION

OVERVIEW(1v)

A-5.tkb, and the *non-stable* curve use procedure has its knowledge base as a separate unit in *NSCMOD.tkb*. This allows for more efficient and understandable programming, as well as providing for an easier framework for further development. Both knowledge bases run in similar patterns, however, due to the nature of the development of curves, the analysis is quite different. The user is not subjected to the intricacies of the analysis, because the complexities and differences are handled by the system in the background. The user need only concern his or her self with understanding the process of CURVE MODIFICATION.

In addition, the two knowledge bases are linked with the modelling components of the system in a very similar fashion. This is to utilize the creation of modified or separate curves arising from the modification analysis.

SEE ALSO

2_SC_modification
3_NSC_modification

SC and NSC stand for *Stable Channels* and *Non-Stable Channels* respectively.

SCMOD PROCEDURE(1v) CURVE MODIFICATION SCMOD PROCEDURE(1v)**TITLE**

An explanation of theory and procedure for the *Modification* of established rating curves for *Stable Channels (SC)*.

OBJECTIVES

Curve Modification for stable channels is concerned with updating established rating curves as new SD measurements become available. It is the objective of the system to allow the user to compare the plotting position of new measurements with respect to the measurements that were previously used to create the curve. The measurements can be viewed with or without the curve to be modified. The user then has the option to re-model the curve incorporating the new measurements in the model.

With the above objective in mind it is easy to see that the curve modification procedure will be able to communicate with the database, as well as the mathematical modelling sub-system of the SDDSS.

SET UP

The knowledge components of curve modification for stable channels are developed within the *SCMOD.tkb* (Stable Channel Modification). The knowledge base is automatically loaded once the user has chosen to modify a stable channel.

PROCEDURE

After specifying the station you would like to investigate choose *Modify an Existing Curve* from the main menu. If the current station has been defined as a stable station then the **CURVE MODIFICATION** mode for stable channels will be activated. Just follow the procedure!!

- 1) The system first compiles and displays a **CURVE LIST SUMMARY SHEET**. It displays the Curve Id Number, the date of the last measurement used in the model, the Curve Type, and the stage range (min and max) for the curve. From this list the system asks you to choose one of the curves to possibly modify it.

Note: Be careful in your choice. Pay attention to the Curve Type and the Date of Last Msr. columns. These columns will tell you the age of the curve and the application of the curve. For example, a curve whose Date of Last Msr. is "03-NOV-92" is a fairly new curve, and if it is a TIME: 1 to 365 type curve, it is relevant for the whole year. To modify this curve would mean that you need measurement data that is post

SCMOD PROCEDURE(1v) CURVE MODIFICATION SCMOD PROCEDURE(1v)

1992 in the data base.

- 2) The modification procedure continues after the user enters the Curve Id. Number in the session window. The system then tells the user that it is connecting to the modification for stable channels. It automatically starts by retrieving the **OLD** and **NEW** SD measurements. After a successful retrieval process the **DATA RETRIEVAL SUMMARY** is shown to the user. The summary looks something like:

DATA RETRIEVAL SUMMARY

The current curve was modelled from OLD measurements recorded on or before 7-NOV-1985.

of OLD msrs = 62
of NEW msrs = 53

ZERO Flow Stage = 0.0 m.

OLD zero flow msrs, excluded = 0
NEW zero flow msrs, excluded = 0

NEW msrs shown above will be added to the OLD msrs and a new model will be formulated, based on this new combined set.

Note that the zero flow measurements listed above will be excluded from the combined set.

As can be seen the definition or explanation of OLD and NEW measurements is given in the above text display. The user must tell the computer how he/she wants to see the new and old data sets. The options are: **With Old Curve** or **without Old Curve**. That is, it is possible to see the data sets graphically with or without the previously selected mathematical model (curve) superimposed on the graph. The choice is arbitrary. If you are not happy with the outcome of the choice, you will get a second chance to re-view the plots.

- 3) Regardless of the above choice, the user then sees a graphical representation of the OLD and NEW data sets. The legend indicates the colour of each set. The user is supposed to use this graph as a means to decide if

SCMOD PROCEDURE(1v) CURVE MODIFICATION SCMOD PROCEDURE(1v)

the OLD and NEW data should be modelled together.

If the patterns of the data seem very close, then the user is recommended to follow through with the modification process, and join the OLD and NEW data sets and represent them with a single *Modified Curve* (Choose

"Continue -> CHANGE CURVE"

from the session window menu. If the data sets differ significantly, choose

"Abort -> Main Menu"

from the session window menu. This will allow you to go back to the main menu and initiate the development of a new curve with just the NEW DATA data set.

However, if you are not sure of the pattern for the two data sets, it is suggested that you *Re-View Plot* and choose the alternate plotting option in step two, and re-view your data before making a more informed choice.

- 4) If you chose to continue, and "change the curve", the system will automatically take you into the modelling section of the SDDSS, and allow you to create, filter and store a curve that has been modified with NEW data. Otherwise, you have reached the end of the *CURVE MODIFICATION* mode.

SEE ALSO

1_overview

Section 2.3 - Mathematical Modelling Procedures

NSCMOD PROCEDURE(1v) CURVE MODIFICATION NSCMOD PROCEDURE(1v)

TITLE

An explanation of theory and procedure for the *Modification* of established rating curves for *Non-Stable Channels* (NSC).

OBJECTIVES

Curve Modification for non-stable channels is concerned with updating established rating curves as new SD measurements become available. It also goes one step beyond stable channels analysis by allowing the user to also choose one of 6 different modifying data sets according to measurements explained by 6 different "backwater" conditions (see manual page 5_modifying_data_sets this section).

It is the objective of the system to allow the user to compare the plotting position of new or "backwater" measurements with respect to the measurements that were previously used to create the curve. The measurements can be viewed with or without the curve to be modified and an additional "pseudo" hydrograph for diagnostics. The user then has the option to re-model the curve incorporating the new measurements in the model or model the NEW or modifying data as a separate model.

With the above objective in mind it is easy to see that the curve modification procedure will be able to communicate with the database, as well as the mathematical modelling sub-system of the SDDSS.

SET UP

The knowledge components of curve modification for non-stable channels are developed within the *NSCMOD.tkb* (Non-Stable Channel Modification). The knowledge base is automatically loaded once the user has chosen to modify a non-stable channel.

PROCEDURE

After specifying the station you would like to investigate choose *Modify an Existing Curve* from the main menu. If the current station has been defined as a non-stable station then the **CURVE MODIFICATION** mode for non-stable channels will be activated. Just follow the procedure!!

- 1) Once the system realizes that it is dealing with a non-stable channel, it automatically loads up the proper KB, and displays a text screen telling the user that it is doing so. The first step in the procedure is to define a time period to work with. The time periods were defined in the Stream Classification procedure before any curves were made. A text screen pops-up displaying the time period information. Simply

NSCMOD PROCEDURE(1v) CURVE MODIFICATION NSCMOD PROCEDURE(1v)

choose a time period (by number) and this will limit the curve search to those curves made especially for this time segment.

- 2) The system then compiles a list of curves applicable to the time period, and displays it to the user. The user then must specify the necessary curve or curves to modify. It is important to observe that if the channel control is such that the rating changes with stage (VBS), the user must specify a *low stages (LW)* type curve, a *high stages (HI)* type curve and, if applicable, a *middle stages (MD)* curve. Do not worry the system knows when you will have to enter such curves, and it will guide you through the selection with the proper questions in the session window.

Enter the proper Curve ID or IDs (Crv_id) Now ...

- 3) The system then takes the information regarding the selected curve and retrieves all SD measurements taken after the last applicable *time period*. It also retrieves data from the database which were taken during the time period, but were effected by one of six "backwater" conditions. The result of the retrieval is a small report of the relevant information that looks like:

The Current Station is: JOUBERT CREEK

The following is a report on the number of measurements affected by the chosen time period and the selected curve(s).

NOTE: The NEW MEASUREMENTS are those taken after the last applicable Time Period ending: 31-DEC-88

The Number of OLD Measurements is: 41

1. The Number of NEW Measurements is: 7

Measurements in current TIME PERIOD under backwater conditions

2. # of Measurements affected by Beaver activity is: 3
3. # of Measurements affected by Wind activity is: 0
4. # of Meas. affected by Debris on the Control is: 0
5. # of Meas. affected by Weeds on the Control is: 23
6. # of Meas. affected by a near by Tributary is: 0
7. # of Meas. affected by Unexplained backwater is: 4

Please choose the data set you wish to modify your curve with now by entering the number corresponding to

NSCMOD PROCEDURE(1v) CURVE MODIFICATION NSCMOD PROCEDURE(1v)

your choice. NEXPERT will then ask you if you wish to view the modifying data set *Alone, with old data or with old data and curve.*

As can be seen from the above report, it is now your choice to decide which data set you would like to use as the **Modifying Data Set** (For more information on this please refer to manpage #5 modifying data sets).

Enter the data set number in the session window

- 4) After choosing the data set number the system processes the data for graphical presentation, and it allows you to see the data sets in two formats. The first format is the modifying data set with the OLD data with the existing selected curve (**WITH OLD CURVE**). The second is to view the data sets **WITHOUT OLD CURVE**. Double click the mouse pointer on your choice at this time. **NOTE:** if your choice does not lead to a suitable evaluation for making a decision you will have the opportunity to retrace your steps, and re-view the data by the method not yet chosen.
- 5) Regardless of the above decision the consultation continues. Two graphs appear on the right half of the screen, a text window appears in the bottom left hand corner, and several options are now available in the session window.

The graphs and text screen are to be used as diagnostic tools, in order to decide which option to choose in the session window. The graphs presented are: a **pseudo hydrograph** showing the OLD and modifying (MOD) data sets in different colours, and the chosen method of display of the OLD and MOD Stage-Discharge measurements, also in different colours (WITH or WITHOUT THE OLD CURVE). For more information on the interpretation of these graphs refer to manpage 7 NSC diagnostics this section. As the user, you must interpret the presented data, and make an informed choice for continuing the modification procedure. The options in the session window are:

Exit Curve Modification
Model Modifying Data Only
Model Old and Modifying Data Together
Re-Start Modification Process
Re-View Plots

These five options can be used based on your interpretations of the available data, and your confidence in it. The first

NSCMOD PROCEDURE(1v) CURVE MODIFICATION NSCMOD PROCEDURE(1v)

option *quits* the modification process. The second option will allow you to model a *new* curve with only the Modifying data set. This option should be implemented if you feel that the data plots significantly different from that of the old data. The third option allows you to create a *modified* relation by grouping the OLD and MOD data sets together as one data set for modelling. The fourth option allows the user to *start over*, and choose a new time period and curve(s) for modification. The final option gives the user the chance to take *one step backwards*, and re-view the data according to one of the two options in step four.

When choosing one of the modelling options (see 6 modified models mapage this section for more information) the system will take the user into the modelling section with the appropriate data set. The user will then be able to create a new or modified curve to the full extent of the system. Upon completion of the modelling the system will return the user to the main menu. This concludes the *Curve Modification* procedure.

SEE ALSO

- 4_existing_curve_selection
- 5_modifying_data_sets
- 6_modified_models
- 7_NSC_diagnostics

DATASETS(1v) CURVE MODIFICATION DATASETS(1v)

TITLE

An explanation of the types of data sets that can be used in the *Curve Modification of Non-Stable channels*.

INTRODUCTION

During the consultation for modification of established curves developed for gauging stations situated on non-stable channels, it is necessary to define the set of data to compare to the data set (OLD) originally used in the creation of the curve. There are seven possibilities for types of data sets. One of the data sets is concerned with **NEW MEASUREMENTS**, or those measurements taken after the last applicable time period. The other six are concerned with additional measurements not originally included in the curve data set. They are those measurements taken during some **BACKWATER** event. A further interpretation of these is explained in the following.

NEW MEASUREMENTS

The best way to explain the use of **NEW MEASUREMENTS** is by starting with an example. Let us begin by noting that the current station has curves developed in three different time periods. Let's say:

Period 1: 1961 - 1966
Period 2: 1968 - 1978
Period 3: 1980 - 1988

This scenario illustrates that some hydraulic or hydrologic event took place in 1967 and 1979 that significantly altered the Stage-Discharge relation. It is also known that some SD measurements were taken in 1988 and 1989, ie., these are **NEW MEASUREMENTS**.

Because the current station is situated on an unstable channel, it may be necessary to compare the **NEW** data with any one of the three time periods. This may be true especially if the control experiences a cycle of scour and fill. It may be that in 1967 a large flood event occurred and produced a scour effect that lowered the effective stage for the SD relation, and in 1979 a period of low flows was capped off by a rather large deposition of sediment that returned the relation to a similar pattern that was evident prior to 1967. If all this is true it may be more interesting to compare the **NEW MEASUREMENTS** to the first time period curve(s) because of the re-establishment of prior rating relation, or it may be necessary to compare the measurements with the second time period SD rating(s) because of a recent flood event. It also may be necessary to compare the

DATASETS(1v) CURVE MODIFICATION DATASETS(1v)

current trend in the SD rating with the new data, and that would mean a comparison of the NEW data to the data measured in the last time period.

The information gained from all of this is that, if the current SD rating trend is similar to that in the past, *already established curves may be applied to current systematic records of gauge because of the scour and fill cycle*. This feature allows the technician to more closely monitor the behavioural patterns that a gauging station's SD rating relation is subject to. It can also confirm that the key to what is happening now, may already have taken place.

From the above scenario, when one is trying to evaluate the current trend of the SD data, it is possible to start at the present and work your way backwards in time. By selecting the time periods and appropriate curves it may be possible to include new data in the modelling procedure to update and/or modify existing curves. On the other hand it may also be realized that existing curves can be applied to new stream gaugings without alteration of the model. This is the function of applying NEW MEASUREMENTS in the curve modification process.

BACKWATER MEASUREMENTS

When an initial curve set is developed for a gauging station which is situated on a non-stable channel, the selected data for the models is assumed to be collected only under open water conditions with normal unobstructed flows. However, this is not always the case. Often times channels are subject to abnormal conditions that can effect the stage-discharge relation, and SD measurements taken under such conditions can appear to have very different stage-discharge ratings than normal flows. The Curve Modification procedure for non-stable channels has the ability to display to the user several possible data sets that have caused some influence on the rating. There are six options altogether. These data sets could have been identified by the technician and placed in the data base before any relations have been established, or these data types are the same as those identified by the filtering process of outlier analysis (see Outlier Analysis section 2.4). The possible data sets are identified as *backwater* effects, and are those measurements affected by: recent *Beaver Activity*, influencing *Wind Conditions*, *Debris on the Control*, *Weeds on the Control*, influencing *near by Tributaries* and measurements *Not Explained* as errors.

It is suggested if a significant number of these "backwater" measurements is listed for the chosen time period, choose

DATA SETS(1v) CURVE MODIFICATION DATA SETS(1v)

the data set for possible modification of the current curve(s). The data set will become the **MOD** data set, and will be presented graphically to contrast the points used in the current curve(s). It then becomes your decision (using the diagnostic graphs, see: 6_NSC_diagnostics this section) to incorporate these data points into a modified model (see manpage 5_modified_models) or to create a curve especially for this backwater type. For example, the current station experiences obstructing vegetal growth on the control that effects the stage-discharge relation (shift to the left) in the summer months. It will be possible to use any weed measurements, to create a curve that will be applied to the gauge record which experiences a shift due to the obstruction of weeds in the channel.

SEE ALSO

5_modified_models
6_NSC_diagnostics

Section 2.4 - Outlier Analysis

This section provides more information on the nature and identification of the backwater measurements.

MODIFIED MODELS(1v) CURVE MODIFICATION MODIFIED MODELS(1v)

TITLE

A general overview of modified models, their creation, and use.

INTRODUCTION

The purpose of developing modified models was described in the overview manpage of this section here it is again revisited -

The aim of the curve modification process is to utilize new or different data sets in comparison to data sets used in existing models, to create modified SD relations using combined data or separate relations (new relations) using only the new or different data sets.

MODIFIED MODEL TYPES

After deciding that you would like to create a modified model, or a separate model based only on the modifying data set, the development of the curve is standard to that of any other curve (please refer to the *Mathematical Modelling Procedures* section for complete details). However, since the models are different they are identified in a different manner. Upon entry into the modelling section the data set is put forward for modelling automatically by the system. The system will tell you that it is *compiling the data* for modelling, and when it is ready it will show you the data set you have chosen to model (as the modified or new model). The retrieval summary will also tell you the new designation of curve type, and this variable is dependant upon the type of modifying data set that has been selected by you the user. The following is a list of possible curve types that could be developed as modified models.

**CONTROL CODES FOR MODIFIED MODEL TYPES
WHEN ONLY THE MODIFYING DATA SET
IS SELECTED FOR MODELLING**

Data Set	Code Name
New Data Only	NEW
Wind Data Only	WND
Weed Data Only	WDS
Debris Data Only	DBR
Nearby Tributary Data Only	TRB
Beaver Data Only	BVR
Unexplained or Other Data Only	OTH

If the data sets chosen are to be modeled with the **OLD** data set (ie., you are creating a modified model of the chosen

MODIFIED MODELS(1v) CURVE MODIFICATION MODIFIED MODELS(1v)

curve), then the above codes would simply be attached to the existing code of the OLD curve. For example, the chosen curve for modification is an open flow data curve. The corresponding code for this curve type is ODAT. Thus, the **OLD CODE** is ODAT. Then you decide that the new data does not differ significantly from the old data, but it could improve the model, and therefore, you would like to create a modified model (OLD and NEW data together). The new curve type code would be ODAT + NEW or **ODATNEW**. This code simply tells you that you modified an open flow data curve with new data.

USING MODIFIED MODELS

When you want to use a modified model, ie., you want to apply it to some record of stream gaugings. You must exit the Curve Modification mode, and enter the *Curve Use* mode (See CURVE USE - Section 3) to select these modified curves. The system will show you a list of permanent curves, as well as a list of modified curves. To select a modified curve for use, the user must override the default curve settings and follow the path to choose the modified curves. The system will help you in your selections.

SEE ALSO

Section 2.3 Mathematical Modelling Procedures
Section 3 Curve Use
3_NSC_modification this section

DIAGNOSTICTOOLS(1v) CURVE MODIFICATION DIAGNOSTICTOOLS(1v)

TITLE

An explanation and use of the diagnostic tools presented during the consultation for *Curve Modification*

GENERAL

During the consultation the data is presented to the user (graphically) in order to help he/she better interpret the nature of the data. Two graphs are provide simultaneously on the right half of the screen. The upper graph is titled **Hydrograph** (unstable channels only), and the lower is a graph of the original Stage-Discharge data juxtaposed with the chosen **Modifying** data (eg., NEW data or WEED data). A broader explanation to interpret these two graphs is in the following two sections.

STAGE VS DISCHARGE GRAPH

The lower graph contrasts the old and modifying SD measurements against each other, as well as the optional original curve. The data should be interpreted, according to the established pattern of the old data. If the modifying data set **does not** follow the same pattern, or if the pattern is predominately to the left or right of the original data, then the data sets should remain separate, and a new model should be ceated to represent **only** the so-called modifying data set. Otherwise, if the data sets plot in very similar patterns, and you feel that the modifying data set will **improve** the model, then your choice should be to join the data into a composite data set, and create a modified model of the original curve. However, if you do not feel that an improvement will be made by the addition of new or other modifying data to the original curve, you should exit the curve modification procedure or re-start the consultation to try other original curves, or other time periods.

HYDROGRAPH

For unstable channels an additional diagnostic tool is presented. It is used to confirm the interpretations you have made with the above graph. The hydrograph simply represents the **stage measurements** of the data from the two opposing sets in time. It is useful because it shows how the modifying data set of data behaves over time with respect to the old data set. It should be used to determine if the SD measurements in the modifying data set define a completely random set. That is to say that the points are scattered throughout the stage range, and **do not** follow any similar pattern to that of the original data. If this is the case the data sets may have to remain separate, and the modifying data should be represented by a model of its own.

DIAGNOSTICTOOLS(1v) CURVE MODIFICATION DIAGNOSTICTOOLS(1v)

Otherwise, the hydrograph may confirm a strong similarity in the patterns established by the data sets (a more systematic pattern), and you should act accordingly using the advice given above.

SEE ALSO

1_overview.lv
3_NSC_modification.lv

Section (5) - Curve Extrapolation

OVERVIEW(1v)

CURVE EXTRAPOLATION

OVERVIEW(1v)

TITLE

General overview of the **CURVE EXTRAPOLATION** mode in the SDDSS program.

PURPOSE

It is often required that discharges be predicted for peak stages. However, it is very common that peak discharges occur at stages that are greater than the highest measured stage. In order to estimate discharges more accurately for stage beyond the current measured range, the *Curve Extrapolation* mode has been implemented into the SDDSS. Its purpose is to provide proper methods for extrapolating stage or discharge using knowledge of the hydraulic control and three standardized methods for extrapolation. It provides the user with a means of estimating a discharge or stage beyond the range for which the currently established S-D relation is valid.

SET UP

The program contents of the Extrapolation mode are stored within the *EXTRA.tkb*. This knowledge base handles the extrapolation for stable and non-stable channel controls similarly.

METHODOLOGY

Three techniques are used in the SDDSS, and all are taken from the International Standards Organization (ISO) **STANDARDS HANDBOOK 16** Measurement of liquid flow in open channels. They include:

- 1) Extension of the current S-D relation - Using the mathematical model and knowledge of the hydraulic control
- 2) Extension of the logarithmic plot of hydraulic radius (R) and mean velocity (v) - Hydraulic radius is derived from the hydraulic control's cross section, and mean velocity is measured.
- 3) Extension using the basic Manning's equation for flow in open channels.

In some cases assumptions are made to improve the process. The methodology used is the same for stable and non-stable channel controls.

OVERVIEW(1v) CURVE EXTRAPOLATION OVERVIEW(1v)

PROCEDURE

The user is taken through logical steps to arrive at appropriate estimations for extrapolated discharge or stage. The options provided to the user are explained throughout the procedure, and enhanced by this user manual. Decisions made by the user are aided by several diagnostic tools, and any interpretations necessary are supported in this section of the manual.

SEE ALSO

- 2_extrapolation_procedure
- 3_selecting_curves
- 4_current_curve_method
- 5_RvsV_method
- 6_Mannings_Eqn_method
- 7_choosing_a_method
- 8_evaluatong_the_extrapolation

TITLE

General overview of the procedure to *Extrapolate* data beyond a given Stage-Discharge relation.

OBJECTIVES

The extrapolation procedure is concerned with providing you with the appropriate tools to estimate the stage or discharge from an entered discharge or stage respectively. These tools include graphical representation of the data, three methods of extrapolation, execution of the appropriate algorithms, and a method for evaluating the success of the extrapolation. The following manual page gives an in depth outline of the procedure for the extrapolation procedure.

SET UP

Execution of the extrapolation procedure occurs directly after the user selects *Extrapolate Data* from the main menu. The SDDSS system loads in the EXTRA.tkb and begins the extrapolation process.

PROCEDURE

A text screen appears telling you the the system is linking to the EXTRAPOLATION SECTION of the system. Once the EXTRA.tkb knowledge base is loaded the system analyzes the previously stored classification of the current station.

- 1) If the station is non-stable the first task is to choose a time period to work with. Stable channels only have one time period so the program continues to the next step automatically.
- 2) The second step is where the user must select a curve or set of curves (non-stable only) to extrapolate from. The initial curve will effect the extrapolation, and this step is very important. When dealing with non-stable channels, it may be necessary to provide the system with a list (set) of curves (those stations whose controls are subject to variation in stage). If this is the case the system will ask the appropriate questions. It is important to follow the dialog in the session window. For more help see manual page 3: selecting curves, this section.
- 3) Following the curve selection process, a text screen and two graphical plots appear on the screen. The text screen is an on-line explanation of the two graphs. The plots are there to aid you in deciding which method for extrapolation to choose. It is all right to

experiment with the methods because the system allows you to re-iterate any or all extrapolation methods. After interpreting the graphs (see manpage 4,5,6 for more information on the three methods, and manpage 7 about choosing a method), close the text screen to continue.

- 4) Now choose one of the following three methods for extrapolation:

Extrapolate using Manning's Equation
 Extrapolate using R vs V
 Extrapolate using SD relation

Again the description of each method is contained with manpages 4, 5 and 6 of this section. Choosing any of the methods will trigger the correct algorithm to apply to the current data. Choosing the first method will allow you to continue to step 5. The last two methods continue to step 6 where a stage or discharge is entered.

- 5) Manning's equation method assumes that above the maximum measured stage the values of slope and Manning's n are relatively constant. However, the SDDSS provides you with the opportunity to override this assumption. When the question is posed to you simply answer YES to override or NO to continue to step 6. The YES answer will activate the override and the system will prompt you for a slope and Manning's n value to include in the Manning's equation algorithm. Once these two factors are entered the program catches up with the other two methods in step 6.
- 6) The SDDSS has the ability to compute an extrapolated stage value given the discharge, and the ability to compute a discharge value given the stage. It is at this point that the choice is given to the user. If you want to compute a discharge from the value of stage (your input) then simply double click the mouse pointer on the *Extrapolate Discharge from Stage* option. Alternatively, the *Extrapolate Stage from Discharge* option allows you to input a discharge value, and extrapolate the stage value.
- 7) Depending on the above choice, the system will ask you to input the stage value (in meters) or the discharge value (in cubic meters per second).
- 8) After entering the stage or discharge the proper algorithm is executed, and the system allows the user to evaluate the appropriateness of the extrapolation. This is completed through the interpretation of two

more graphs along with an explanatory text screen. These two graphs try to illustrate the transition between the current SD curve(s) and the extrapolated curve according to the chosen method. For more information please refer to manual page: 8 - evaluating the extrapolation. Close the text window to continue.

- 9) The **EXTRAPOLATION REPORT** is then shown to the user. It looks something like:

EXTRAPOLATION REPORT

Given Data				Extrapolated Data			
Var.	Value	Method	Slope	n	Var.	Value	

Stage	5.000	MANN	.00075	0.031	Dis.	264.271	
Stage	5.000	MANN	N/A	N/A	Dis.	735.439	
Dis.	1100.00	RvsV	N/A	N/A	Stage	5.455	

The report displays the results for all the iterations completed. It gives the input variables - Stage/Discharge, the Value entered, Method, and slope and Manning's n if applicable - and the output (extrapolated) data - Discharge/Stage and the Extrapolated Value.

After viewing the report the user is asked whether or not he/she would like to perform another extrapolation. A **YES** answer, allows the user to go back to step 4, and choose a method (new or same method). A **NO** answer signals the system to end the extrapolation procedure

- 10) Before ending the system asks the user if he/she would like a **hardcopy** of the extrapolation report. Answer **YES** to receive a print out before quitting, or **NO** to quit the session and return to the main menu.

TITLE

A guide to selecting the proper curves in the EXTRAPOLATION procedure.

PURPOSE

It is important when selecting a curve or curves for extrapolation that the user has an understanding of the nature of the control, and the types of curves developed for the current station. The following manpage tries to explain the proper selection of curves according to various types of channels and curve types.

SELECTING CURVES FOR STABLE CHANNELS

Stable channels are generally more simple than non-stable channels. Usually, one curve will be used to define the entire measured stage range, therefore only one curve is selected. It is important to note, however, that certain curves are made for certain periods of time of the year. For example, a curve defined by measurements taken during the summer months would not necessarily apply in the extrapolation for a peak spring runoff hydrograph. Therefore, it is important to pay attention to the information provided in the *Curve List Summary Sheet* when entering the *Curve Id.* for extrapolation purposes. It is suggested that the user fully utilizes the curve type, period, and minimum - maximum stage information provided in this window when selecting the curve for extrapolation purposes.

SELECTING CURVES FOR UNSTABLE CHANNELS**GENERAL**

The SDDSS knows what types of curves have been developed for the current station. It will use this information to guide you, when selecting curves for extrapolation. For example, if the channel in question was determined to have rating which varied by stage, the system will show you the appropriate *HI*, *LOW* and *MID* stage range curves, and ask you to choose one of each. The following is a guide in how to choose from the different types of curves.

SIMPLE CURVES

This category is a loose interpretation, because there really is never a simple stage-discharge rating for unstable channels. For argument's sake simple curves will be defined as either open flow (ODAT) or ice flow (ICED) curves. That is these curves are not subject to any hysteresis effects, or any variation with stage. If the system determines that the selected time period of the current station has these types of curves in the database it will prompt the user to

enter one *Curve Id* for extrapolation purposes. Note, pay close attention to the curve list, and the codes for each curve before you make a selection.

CURVES SUBJECT TO HYSTERESIS

It is very hard to choose a curve for extrapolation purposes if it was developed to handle rising and falling stages exclusively. The best approach for this scenario, is to select a STABLE STAGES CURVE (STAT). These curves are applied to data that were taken under relatively stable conditions, and would be most useful in the extrapolation procedure. Otherwise, a *rising limb* curve, or a *falling limb* curve would produce inaccurate results, due to their bias when fitted to data. It is most often necessary to estimate peak discharge at the peak stage on the hydrograph. Since the peak occurs between the rising and falling limbs of the hydrograph, it is very hard to apply a rising or falling stage curve to an estimation of peak discharge. It is important to note that the system will ask for only *one Curve Id* to be entered for this situation.

CURVES SUBJECT TO VARIATION WITH STAGE

These curves are generally easier to establish for extrapolation purposes. When the system realizes that the current station has developed curves which are subject to some variation in stage, it will ask the user to input a **LOW** stages curve first. Then it will ask the user to enter a *Curve Id* for a **HIGH** stages curve. It then follows this by establishing the **MID** stages curve. If it is not applicable - ie., the curve has only one transition zone - the user is told to enter the number 9999. This will ensure that no curve is applied for the middle stages, since one does not exist. The user must pay attention to the codes shown for each curve and enter the correct values of curve identification numbers in order to achieve a successful extrapolation.

COMBINATION CURVES

Combination curves will incorporate aspects of both hysteresis and variation with stage. The system will prompt you for information regarding **LOW**, **HIGH** and possible **MID** stage curves. It will be important to choose the appropriate curves that are made for stable stages only. Therefore, the last four letters of the codes will be: **HSLW**, **HSMD** and **HSHI**. The H signifies Hysteresis, the S signifies Stable Stages, and the LW, MD and HI signify LOW, MID and HIGH stages respectively. The first letter of the code will be a C or an O depending on the seasonal variation. Please refer to the **DATA SELECTION (NON-STABLE CHANNELS)**, section 2.2b for more information on the codes and their interpretation.

C CMETHOD(1v) CURVE EXTRAPOLATION C CMETHOD(1v)

TITLE

An explanation and use of the *Current Curve* method of extrapolation.

THEORY

In the curve development process mathematical models are fitted to data by means of linear regression analysis. These models can be of one of two forms (BOX/COX or POWER transformations), and it is possible to compute any discharge for a given stage, or any stage for a given discharge using the models' parameters. Therefore, it is possible to simply extend this model beyond the measured stage range, and extrapolate stage or discharge data using a selected model.

EXTRAPOLATION

When selecting this method for extrapolation purposes the system utilizes the knowledge of the current mathematical model which represents the SD rating curve. After you enter the desired data request (ie., stage from discharge, or discharge from stage), and the proper variable value. The system enters the known parameter into the model and solves for the unknown. An example follows:

You want to find the corresponding discharge at a stage level of 6.25 meters above the datum.

Choose *Extrapolate using SD Relation*

Choose *Extrapolate Discharge from Stage*

Enter 6.25

And the extrapolation is performed by the system, when the 6.25 meter stage value is entered into the current rating model, and the corresponding discharge (in cubic meters per second) is computed. The results are shown promptly in graphical and tabular form for evaluation.

SEE ALSO

- 1_overview
- 2_procedure
- 3_selecting_curves
- 7_choosing_a_method
- 8_evaluating_the_extrapolation

R vs VMETHOD(1v) CURVE EXTRAPOLATION R vs VMETHOD(1v)

TITLE

An explanation and use of the method for extrapolating from a *Hydraulic Radius (R)* versus *Mean Velocity (V)* curve.

THEORY

According to the **ISO STANDARDS HANDBOOK 16 (1983)**, section ISO 1100/2-1982 (E), Annex D.4, it is possible to extend the mean velocity curve by the following procedure:

The hydraulic mean radius (Rh) can be found for all stages from the cross-section.

A logarithmic plot of mean velocity against hydraulic mean radius generally shows a linear relationship, for the higher measurements and the values of mean velocity for the range to be extrapolated may be obtained therefrom.

From the above procedure it is possible to extrapolate a mean velocity. Since the cross-section must be known to compute the hydraulic mean radius, it can also be utilized to compute the area of flow. Thus, knowing a value for mean velocity and area, it is possible to compute an extrapolated **DISCHARGE**.

EXTRAPOLATION

When this type of extrapolation is activated, an external routine creates a hydraulic radius vs mean velocity curve, performs a regression analysis on the points of the curve, and uses the resulting equation to extrapolate a mean velocity curve for incremental stage starting from the maximum measured stage, up to the highest stage of the known cross-section. This extrapolated mean velocity curve is then combined with the computed stage area curve to produce an **extrapolated Stage-Discharge** relation. Then any extrapolated discharge or stage value can be read from this "generic" curve for output. The output is the graphical representation of this curve and the extrapolated value desired. An example follows:

You want to find the corresponding discharge at a stage level of 6.25 meters above the datum.

Choose **Extrapolate using R vs V**

The system (transparently) takes the R vs V, stage-mean velocity curve (shown in the upper right corner of the session window at the time of method selection) and combines it with stage-area curve (bottom right corner graph) to arrive at the extrapolated stage-discharge curve.

R vs VMETHOD(1v) CURVE EXTRAPOLATION R vs VMETHOD(1v)

Next Choose *Extrapolate Discharge from Stage*

Enter 6.25

And the extrapolation is performed by the system, when the discharge corresponding discharge to the 6.25 meter stage value is read from the extrapolated stage-discharge relation. The results are shown promptly in graphical and tabular form for evaluation.

SEE ALSO

- 1_overview
- 2_procedure
- 3_selecting_curves
- 7_choosing_a_method
- 8_evaluating_the_extrapolation

TITLE

An explanation and use of an extrapolation method using *Manning's* formula for open channel flow.

THEORY

According to the *ISO STANDARDS HANDBOOK 16 (1983)*, section ISO 1100/2-1982 (E), Annex D.5, a possible "variation of the last method (RvsV) is by the use of Manning's formula."

$$Q = Av = A(Rh^{2/3})S^{1/2}(1/n)$$

where

- Q = discharge
- A = cross-sectional area
- Rh = hydraulic mean radius
- S = Slope
- n = Manning's coefficient of roughness

The standard continues the explanation of the method by making the assumption that $S^{1/2}/n$ remains constant. If this assumption holds true it is possible to create a stage-discharge curve if the cross-sectional properties of the control are known. The standard continues by saying: "After bankfull stage, the discharge of the spill portion will have to be worked out separately by assuming an appropriate value of n. If accurate gauges do not exist for computing the slope, it may roughly be estimated from the flood marks."

The SDDSS incorporates this theory. When this method is chosen the value of $S^{1/2}/n$ is set to equal *k*, a constant value calculated from the current curve at the *maximum measured stage*. This value of *k* is then substituted into the Manning's formula for computation of discharge or stage. However, the user has the opportunity to override this setting, and enter his/her own values for S and n.

EXTRAPOLATION

When this method is chosen the default values for S and n (ie., *k*) are calculated. The stage velocity curve then becomes a straight line above the maximum measured stage. This curve is then coupled with the stage area curve to compute a generic extrapolated stage-discharge curve. Otherwise, the override function allows you the user to specify the values of S and n in order to create a more specific generic stage-discharge curve. Regardless, of the path you take in this method, once you have established the generic SD curve, any value of stage or discharge can be *extrapolated* from it. An example follows:

MANNINGSMETHOD(1v) CURVE EXTRAPOLATION MANNINGSMETHOD(1v)

You want to find the corresponding discharge at a stage level of 6.25 meters above the datum. And you know that the average slope is about 0.0075 m/m and that the Manning's coefficient is roughly 0.028. If you have this information and want to use it follow the systems questions in the session window. It should go something like this:

Choose *Extrapolate using Manning's Equation*

If you want to over-ride the default calculated values of slope and n, or more specifically *k*, then, at this time, choose YES

Now enter the values of slope and n Slope first. Enter
0.0075

Next Manning's n. Enter **0.028**

Now proceed by telling the computer that you want to *Extrapolate Discharge from Stage*

Enter the stage **6.25**

The discharge is then calculated using the Manning's equation, and your inputted values of stage - which determines the value of A and Rh - slope and Manning's n. The output follows in the usual formats; graphical and text.

SEE ALSO

- 1_overview
- 2_procedure
- 3_selecting_curves
- 7_choosing_a_method
- 8_evaluating_the_extrapolation

TITLE

A guide to choosing the proper method for extrapolation purposes.

DESCRIPTION

During the consultation for Curve Extrapolation the SDDSS displays a text window and a two graphs simultaneously. Directly following this the graphs remain and you are asked to choose a method for extrapolation. This manpage will help you to interpret the graphs and make better decisions for extrapolating more accurate information for your site and its stage-discharge relation.

Two graphs are supplied for diagnostic use, to aid in your extrapolation method decision. These graphs are aided by an on-line text screen which describes their content. The first is a stage vs mean velocity curve. The curve illustrates mean velocities for the following:

- The current curve in the stage range for which it was developed (*red*).

- The extrapolated mean velocity curve for the current SD relation in use (*green*).

- The extrapolated mean velocity curve according to the hydraulic mean radius versus mean velocity method (R vs V) in *blue*.

- And the extrapolated velocity curve for Manning's Equation method where k is held constant at the calculated k for the maximum measured stage (*yellow*).

The second graph illustrates the cross-sectional properties of the control, and the corresponding stage area curve derived from the cross-section.

These two graphs are very important in your decision, especially if the technician has any knowledge of velocity or slope or Manning's n at the stage level he is interested in extrapolating from or to. Peak discharges are often very hard to measure, but it is sometimes possible to estimate or measure velocities at these high stages. This knowledge can be applied to the upper graph to choose the method which most suits the velocity in the region one is interested in. The lower curve can illustrate the behavior of the SD relation. A continuous, uniform cross-section will allow for better extensions of the current curve or by the R vs V method. Otherwise, a complex and variable cross-section may

CHOOSING A METHOD(1v) CURVE EXTRAPOLATION CHOOSING A METHOD(1v)

be more suited to the Manning's Equation method. A subsection of each method follows.

CHOOSING TO EXTEND THE CURRENT CURVE

The method of using the current curve to extrapolate stage or discharge can give very accurate results. It is suggested to use this method for relatively stable controls, and/or controls that do not vary significantly with stage. That is, if a control's cross-section is relatively uniform, this method may very well give adequate results. Another aspect for attention, is the diversity of vegetation and the uniformity of the bank material. An increase in vegetation and/or a change in material type of the bank at higher stages may restrict flow significantly, and thus make the current curve an inadequate source for extrapolation. If knowledge of the material is known it will be possible to estimate a Manning's n , and incorporate it into the third method.

USING THE R VS V METHOD

This method is particularly good if any knowledge of mean velocity at the higher stages can be acquired. It often more accurately describes the behavior of the velocity of a stream better than the extrapolation of the current curve method. Sometimes it may be wise to extrapolate using both methods, and compare the results (which are often close). The best way to decide between these two methods is to understand which one best describes the stage - mean velocity curve.

CHOOSING MANNINGS METHOD

The choice of this method, is best if one has knowledge of the slope of the water surface, and knowledge of the influence of the roughness factor throughout the range of stage. No values of slope and Manning's n need be entered if the cross-section does not vary significantly in roughness and slope from the point of maximum measured stage, to the stage where you desire the extrapolation. However, if factors affecting the relation of roughness and stage are variable then, one can use various tables to estimate the roughness coefficient. This can then be incorporated into the analysis, with an adequate value for slope. The results of the Manning's equation can be very accurate with the proper estimation, of slope and Manning's n . However, one must be careful, because the application of Manning's n is taken over the entire cross-section. This may produce severe error if Manning's n is different over the cross-section. For example, in bank stages are often much smoother than, over bank stages. The user, may be better off to make hand

CHOOSING A METHOD(1v) CURVE EXTRAPOLATION CHOOSING A METHOD(1v)

calculations for better estimates in this case.

REFERENCES

For more information on the estimation of Manning's n , it is suggested that the user reference the following:

Chow, V. T., *Open Channel Hydraulics*. McGraw-Hill Book Company, Singapore, 1973.

Section 5-6. The Manning Formula, pages 98-123

and

Section 6-5. Flow in a Channel Section with Composite Roughness.

Subsection *Channels of Compound Section*.
pages 138-140.

SEE ALSO

- 1_overview
- 2_extrapolation_procedure
- 4_current_curve_method
- 5_RvsV_method
- 6_Mannings_Eqn_method

EVALUATION(1v) CURVE EXTRAPOLATION EVALUATION(1v)

TITLE

A guide for using the extrapolation *evaluation* tools.

DESCRIPTION

After all the extrapolation method is chosen and all parameters are entered correctly, the results of the extrapolation are shown to the user, first graphically and then in tabular form. It is necessary to show the graphical results to make a correct evaluation of the extrapolation. That is, does the extrapolated Stage-Discharge curve make sense in relation to the curve selected at the beginning for extrapolation purposes (ie., the current curve). The two graphs attempt to help in your evaluation. They are titled; *Behaviour of K*, and *Extrapolated S-D* respectively.

EVALUATION

The upper curve shows the behaviour of k , which is a function of slope and Manning's n ($k = S^{1/2} / n$). The behavior of k is subject to many factors, but it should be relatively constant if the channel control is relatively uniform throughout the stages. For example, the curve should attenuate to some constant value of k for higher stages. Then attenuation is based on many factors. At this time the user must utilize any knowledge of the cross-section to verify this curve and its accuracy. This curve will look much like the previous stage - mean velocity curve because it is derived from Manning's equation where:

$$v = R^{2/3} * S^{1/2} * (1/n).$$

For the Manning's Equation method the behaviour of k will be a straight vertical line, which may very well be valid for high stages.

The second curve juxtaposes the current SD relation with the extrapolated SD relation for the chosen method. This curve should be used to interpret the transition between the two curves. A smooth transition should be realized if a good extrapolation is to be predicted. Also, the user may pay attention to the curvature or slopes of the curves. Once again, a relatively smooth transition between the two curves is desired. Unless, of course, a dramatic change in the hydraulic control dictates a severe change in the SD relation. The user is called upon to apply his/her knowledge of the particular control when deciding upon the effectiveness of the extrapolation.

APPENDIX B - MOSDE Knowledge Base

The following Appendix is a complete disclosure of the MOSDE program as it was coded in NEXPERT OBJECT 2.0. This knowledge base possesses the syntax of the process knowledge, and control structure for the MOSDE program outlined in Chapter 5 of this thesis.

```
*****
#*   Nexpert Object 2.0 KB Code:   MOSDE.tkb   *
#*****
```

```
(@VERSION= 020)
(@PROPERTY= alt @TYPE=Integer;)
(@PROPERTY= b0 @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= b1 @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= counter @TYPE=Integer;)
(@PROPERTY= crvid @TYPE=Integer;)
(@PROPERTY= discharge @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= ev @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= first @TYPE=Integer;)
(@PROPERTY= id @TYPE=Integer;)
(@PROPERTY= int @TYPE=Integer;)
(@PROPERTY= last @TYPE=Integer;)
(@PROPERTY= maxs @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= mins @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= moddis @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= modnum @TYPE=Integer;)
(@PROPERTY= outliers @TYPE=Float;@FORMAT="u.";)
(@PROPERTY= perc @TYPE=Float;@FORMAT="u.00";)
(@PROPERTY= r2 @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= rae @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= resets @TYPE=Boolean;)
(@PROPERTY= see @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY= set1 @TYPE=String;)
```

```

(@PROPERTY=      set2      @TYPE=String;)
(@PROPERTY=      stage     @TYPE=Float;@FORMAT="u.00000";)
(@PROPERTY=      temp      @TYPE=String;)
(@PROPERTY=      texp      @TYPE=Float;@FORMAT="u.00";)
(@PROPERTY=      type      @TYPE=Integer;)
(@PROPERTY=      wbe       @TYPE=Float;@FORMAT="u.00000";)

```

```

(@OBJECT=      Best
  (@PROPERTIES=
    alt
  )
)

```

```

(@OBJECT=      Best_Mod
  (@PROPERTIES=
    Value @TYPE=Boolean;
  )
)

```

```

(@OBJECT=      Check_Outliers
  (@PROPERTIES=
    Value @TYPE=Boolean;
  )
)

```

```

(@OBJECT=      Coder
  (@PROPERTIES=
    int
  )
)

```

```

(@OBJECT=      Comp_Mod
  (@PROPERTIES=
    Value @TYPE=Boolean;
  )
)

```

```

(@OBJECT=      Compare
  (@PROPERTIES=
    Value @TYPE=Boolean;
  )
)

```

```

(@OBJECT=      Compro
  (@PROPERTIES=
    Value @TYPE=Boolean;
  )
)

```

```

(@OBJECT=      Cursor

```

```

        (@PROPERTIES=
            Value @TYPE=Integer;
        )
    )

    (@OBJECT= Curve_Check
        (@PROPERTIES=
            Value @TYPE=Boolean;
        )
    )

    (@OBJECT= Data_Set
        (@PROPERTIES=
            set1
            set2
            temp
        )
    )

    (@OBJECT= Def_Outlier
        (@PROPERTIES=
            Value @TYPE=Boolean;
        )
    )

    (@OBJECT= discharge
        (@PROPERTIES=
            Value @TYPE=Float;
        )
    )

    (@OBJECT= Dum_BoxCox
        (@PROPERTIES=
            Value @TYPE=Boolean;
        )
    )

    (@OBJECT= Dum_Eval
        (@PROPERTIES=
            Value @TYPE=Boolean;
        )
    )

    (@OBJECT= Dum_Mod
        (@PROPERTIES=
            Value @TYPE=Boolean;
        )
    )

    (@OBJECT= Dum_Out
        (@PROPERTIES=

```



```

        counter
        discharge
        id
        moddis
        perc
        stage
    )
)

(@OBJECT=    dummy
  (@PROPERTIES=
    counter
    int
    set1
    set2
  )
)

(@OBJECT=    D_mod
  (@PROPERTIES=
    b0
    b1
    ev
    modnum
    outliers
    r2
    rae
    see
    texp
    type
    wbe
  )
)

(@OBJECT=    End_Test
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Fcrv
  (@PROPERTIES=
    b0
    b1
    crvid
    ev
    first
    last
    maxs
    mins
    outliers

```

```

        r2
        rae
        see
        texp
        type
        wbe
    )
)

(@OBJECT=    Flip
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Former
  (@PROPERTIES=
    int
  )
)

(@OBJECT=    Id
  (@PROPERTIES=
    counter
    Value    @TYPE=Integer;
  )
)

(@OBJECT=    Iterations
  (@PROPERTIES=
    counter
  )
)

(@OBJECT=    Make_Mod
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Max
  (@PROPERTIES=
    id
    int
  )
)

(@OBJECT=    Mod1
  (@PROPERTIES=
    b0
    b1

```

```

        ev
        modnum
        outliers
        r2
        rae
        see
        texp
        type
        wbe
    )
)

(@OBJECT=    Mod2
  (@PROPERTIES=
    b0
    b1
    ev
    modnum
    outliers
    r2
    rae
    see
    texp
    type
    wbe
  )
)

(@OBJECT=    Mod_Set
  (@PROPERTIES=
    temp
  )
)

(@OBJECT=    Next_Step
  (@PROPERTIES=
    Value    @TYPE=String;
  )
)

(@OBJECT=    Out_Anal
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Out_Back
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

```

```

(@OBJECT=    Out_Best
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Outlier
  (@PROPERTIES=
    discharge
    id
    int
    perc
    stage
  )
)

(@OBJECT=    Proj_Control
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Proj_Sys
  (@PROPERTIES=
    resets
    Value    @TYPE=String;
  )
)

(@OBJECT=    Qual_Check
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Quality
  (@PROPERTIES=
    Value    @TYPE=String;
  )
)

(@OBJECT=    Ret_DS
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Ret_minmax
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

```

```

)

(@OBJECT=    Ret_Outliers
  (@PROPERTIES=
    counter
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Retr_Prev_Crv
  (@PROPERTIES=
    counter
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Set_Mod
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Set_Parameters
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Slope_Check
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Start
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Step
  (@PROPERTIES=
    Value    @TYPE=String;
  )
)

(@OBJECT=    Store_Crv
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

```

```

(@OBJECT=    Store_Last
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Store_Out
  (@PROPERTIES=
    Value    @TYPE=Boolean;
  )
)

(@OBJECT=    Stored
  (@PROPERTIES=
    b0
    b1
    crvid
    ev
    first
    last
    maxs
    mins
    outliers
    r2
    rae
    see
    texp
    type
    wbe
  )
)

(@SLOT=      Check_Outliers
  (@CACTIONS=
    (Do      (0)      (Cursor))
    (Reset   (Ret_Outliers))
    (Do      (Ret_Outliers) (Ret_Outliers))
    (Execute ("Tkb/out")   (@TYPE=EXE;))
    (Reset   (Check_Outliers))
  )
)

(@SLOT=      Compro
  (@CACTIONS=
    (Execute ("compro")   (@TYPE=EXE;))
    (Reset   (Cursor))
    (Retrieve ("compro.NXP") (@TYPE=NXPDB;@END="RELEASE";\
@SLOTS=Best.alt;\@FIELDS="alt";@CURSOR=Cursor;))
    (Reset   (Compro))
  )
)

```

```

(@SLOT=      Data_Set.set1
  (@INITVAL=  "Tkb/SD_set1.dat")
)

(@SLOT=      Data_Set.set2
  (@INITVAL=  "Tkb/SD_set2.dat")
)

(@SLOT=      Flip
  (@CACTIONS=
    (Do      (Mod2.modnum) (Mod1.modnum))
    (Do      (Mod2.type)   (Mod1.type))
    (Do      (Mod2.texp)   (Mod1.texp))
    (Do      (Mod2.b0)     (Mod1.b0))
    (Do      (Mod2.b1)     (Mod1.b1))
    (Do      (Mod2.r2)     (Mod1.r2))
    (Do      (Mod2.see)    (Mod1.see))
    (Do      (Mod2.outliers) (Mod1.outliers))
    (Do      (Mod2.wbe)    (Mod1.wbe))
    (Do      (Mod2.rae)    (Mod1.rae))
    (Do      (Mod2.ev)     (Mod1.ev))
    (Do      (Data_Set.set2) (Data_Set.temp))
    (Do      ("Model2")    (Mod_Set.temp))
    (Do      (dummy.int+1) (dummy.int))
    (Reset   (End_Test))
    (Do      (End_Test)    (End_Test))
    (Reset   (Flip))
  )
)

(@SLOT=      Former.int
  (@INITVAL=  1)
)

(@SLOT=      Id.counter
  (@INITVAL=  0)
)

(@SLOT=      Make_Mod
  (@CACTIONS=
    (Execute   ("Tkb/SD_set @V(Id.counter) @V(dummy.int)
@V(Data_Set.temp)") (@TYPE=EXE;))
    (Execute   ("cp @V(Data_Set.temp) Trans/SD.dat") (@TYPE=EXE;))
    (Execute   ("Trans/tran") (@TYPE=EXE;))
    (Execute   ("Trans/fstat") (@TYPE=EXE;))
    (Do      (TRUE)          (Compro))
    (Reset   (Cursor))
    (Retrieve  ("Trans/fstat.NXP") (@TYPE=NXPD;@END="RELEASE";\
@SLOTS=D_mod.modnum,D_mod.type,D_mod.texp,D_mod.b0,D_mod.b1,D_mod.r2,D_mod.see,\
D_mod.outliers,D_mod.wbe,D_mod.rae,D_mod.ev;@FIELDS="modnum","type","texp","b0","b1",\
"r2","see","out","wbe","rae","ev";@QUERY="alt = @V(Best.alt)";@CURSOR=Cursor;))
  )
)

```

```

        (Do (Iterations.counter+1) (Iterations.counter))
        (Execute ("echo '@V(Stored.crvid) @V(Iterations.counter) @V(Id.counter)
@V(dummy.int) @V(D_mod.r2) @V(D_mod.see) @V(D_mod.outliers) @V(D_mod.wbe)
@V(D_mod.rae) @V(D_mod.ev)' >> Tkb/best.txt") (@TYPE=EXE;))
        (Reset (Make_Mod))
    )
)

(@SLOT= Proj_Sys.resets
(@CACTIONS=
    (Reset (Ret_DS))
    (Reset (Comp_Mod))
    (Reset (Best_Mod))
    (Reset (Out_Anal))
    (Reset (Def_Outlier))
    (Reset (Proj_Sys.resets))
)
)

(@SLOT= Ret_minmax
(@CACTIONS=
    (Reset (Cursor))
    (Retrieve ("mark/scoupe") (@TYPE=ORACLE;@END="RELEASE";
@SLOTS=Stored.maxs,Stored.mins;@FIELDS="max(stage)","min(stage)";@QUERY="proj_msr_data where
id between @V(Stored.first) and @V(Stored.last)";@CURSOR=Cursor;))
    (Execute ("echo '@V(Stored.b0) @V(Stored.b1) @V(Stored.texp) @V(Stored.type)
@V(Stored.mins) @V(Stored.maxs)' > PROG/in.dat") (@TYPE=EXE;))
    (Execute ("PROG/gcrv") (@TYPE=EXE;))
    (Do (STRCAT("DATA/crv",INT2STR(Stored.crvid))) (dummy.set1))
    (Execute ("mv PROG/crv.dat @V(dummy.set1)") (@TYPE=EXE;))
    (Reset (Ret_minmax))
)
)

(@SLOT= Retr_Prev_Crv
(@CACTIONS=
    (Reset (Cursor))
    (Retrieve ("mark/scoupe") (@TYPE=ORACLE;@END="RELEASE";\
@SLOTS=Fcrv.crvid,Fcrv.type,Fcrv.b0,Fcrv.b1,Fcrv.texp,Fcrv.r2,Fcrv.first,Fcrv.last,Fcrv.maxs,\
Fcrv.see,Fcrv.outliers,Fcrv.mins,Fcrv.wbe,Fcrv.rae,Fcrv.ev;@FIELDS="CRVID","TYPE","B0","B1","TE\
XP","R2","FIRST","LAST","MAXS","SEE","OUT","MINS","WBE","RAE","EV";\
@QUERY="MODELS WHERE CRVID = @V(Stored.crvid)";@CURSOR=Cursor;))
    (Reset (Retr_Prev_Crv))
)
)

(@SLOT= Set_Parameters
(@CACTIONS=
    (Do (Stored.crvid+1) (Stored.crvid))
    (Do (Mod1.type) (Stored.type))

```



```

        (Do (Mod1.texp) (Stored.texp))
        (Do (Mod1.b0) (Stored.b0))
        (Do (Mod1.b1) (Stored.b1))
        (Do (Mod1.r2) (Stored.r2))
        (Do (Mod1.see) (Stored.see))
        (Do (Mod1.outliers) (Stored.outliers))
        (Do (Mod1.wbe) (Stored.wbe))
        (Do (Mod1.rae) (Stored.rae))
        (Do (Mod1.ev) (Stored.ev))
        (Reset (Set_Parameters))
    )
)

(@SLOT=      Store_Crv
  (@CACTIONS=
    (Execute ("rm -f Tkb/Out_set.dat") (@TYPE=EXE;))
    (Execute ("rm -f Tkb/Out.dat") (@TYPE=EXE;))
    (Do (0) (Dum_Out.counter))
    (Do (Id.counter) (Stored.first))
    (Do (TRUE) (Check_Outliers))
    (Reset (Compare))
    (Do (Compare) (Compare))
    (Reset (Store_Crv))
  )
)

(@SLOT=      Store_Last
  (@CACTIONS=
    (Do (D_mod.type) (Mod1.type))
    (Do (D_mod.texp) (Mod1.texp))
    (Do (D_mod.b0) (Mod1.b0))
    (Do (D_mod.b1) (Mod1.b1))
    (Do (D_mod.r2) (Mod1.r2))
    (Do (D_mod.see) (Mod1.see))
    (Do (D_mod.outliers) (Mod1.outliers))
    (Do (dummy.int) (Stored.last))
    (Do (TRUE) (Store_Crv))
    (Reset (Store_Last))
  )
)

(@SLOT=      Store_Out
  (@CACTIONS=
    (Reset (Cursor))
    (Write ("mark/scoupe") (@TYPE=ORACLE;@FILL=ADD;@END="COMMIT"\n
@NAME="ID!";@PROPS=id,stage,discharge;@FIELDS="ID","STAGE",
"DISCHARGE";@QUERY="OUTLIERS";@ATOMS=Outlier;))
    (Do (1) (Former.int))
    (Do (Data_Set.set2) (Data_Set.temp))
    (Do ("Model2") (Mod_Set.temp))
    (Do (dummy.int+1) (dummy.int))
  )
)

```

```

        (Reset (End_Test))
        (Do (End_Test) (End_Test))
        (Reset (Store_Out))
    )
)

(@SLOT=      Stored.crvid
 (@INITVAL=  0)
)

(@RULE=      Find_Best_Model_2
 (@LHS=
    (=      (Best.alt)      (2))
 )
 (@HYPO=      Best_Mod)
 (@RHS=
    (Do      ("Out_Anal")    (Next_Step))
 )
)

(@RULE=      Find_Best_Model_1
 (@LHS=
    (=      (Best.alt)      (1))
 )
 (@HYPO=      Best_Mod)
 (@RHS=
    (Do      (ABS(Mod1.r2-Mod2.r2)/Mod1.r2*100)    (Outlier.perc))
    (Do      ("Out_Anal")    (Next_Step))
 )
)

(@RULE=      Compare_Mod1_to_Mod2
 (@LHS=
    (=      (1)      (1))
 )
 (@HYPO=      Comp_Mod)
 (@RHS=
    (Execute      ("echo '      6      2' > compro.dat")    (@TYPE=EXE;))
    (Execute      ("echo '3.0' >> compro.dat")    (@TYPE=EXE;))
    (Do      ((0-1.0)*Mod1.wbe)    (D_mod.wbe))
    (Do      ((0-1.0)*Mod1.rae)    (D_mod.rae))
    (Execute      ("echo '@V(Mod1.r2) -@V(Mod1.see) -@V(Mod1.outliers)
@V(D_mod.wbe) @V(D_mod.rae) @V(Mod1.ev)' >> compro.dat")    (@TYPE=EXE;))
    (Do      ((0-1.0)*Mod2.wbe)    (D_mod.wbe))
    (Do      ((0-1.0)*Mod2.rae)    (D_mod.rae))
    (Execute      ("echo '@V(Mod2.r2) -@V(Mod2.see) -@V(Mod2.outliers)
@V(D_mod.wbe) @V(D_mod.rae) @V(Mod2.ev)' >> compro.dat")    (@TYPE=EXE;))
    (Execute      ("echo '1.0 1.0 1.0 1.0 1.0 1.0' >> compro.dat")
    (@TYPE=EXE;))
    (Do      (TRUE)    (Compro))
    (Do      ("Best_Mod")    (Next_Step))
 )
)

```

```

)
)

(@RULE=      No_Outliers_Store
  (@LHS=
    (=      (Dum_Out.counter)      (0))
  )
  (@HYPO=      Compare)
  (@RHS=
    (Do      (TRUE)      (Set_Parameters))
    (Do      (TRUE)      (Ret_minmax))
    (Write    ("mark/scoupe"))
  )
  (@TYPE=ORACLE;@FILL=ADD;@END="COMMIT";@NAME="CRVID!";@PROPS=crvid,type,b0,b1,\
  texp,r2,see,outliers,first,last,mins,maxs,wbe,rae,ev;@FIELDS="CRVID","TYPE","B0","B1","TEXP",\
  "R2","SEE","OUT","FIRST","LAST","MINS","MAXS","WBE","RAE","EV";@QUERY="MODELS";\
  @ATOMS=Stored;))
    (Do      (dummy.int-1)  (Id.counter))
    (Do      (Id.counter+6)  (dummy.int))
    (Do      (Data_Set.set1) (Data_Set.temp))
    (Do      ("Model1")     (Mod_Set.temp))
    (Do      (1)            (Former.int))
  )
)

(@RULE=      Are_there_Outliers
  (@LHS=
    (>      (Dum_Out.counter)      (0))
  )
  (@HYPO=      Compare)
  (@RHS=
    (Do      (Data_Set.set2) (Data_Set.temp))
    (Execute  ("Tkb/SD_set @V(Id.counter) @V(dummy.int) @V(Data_Set.temp)")
  )
  (@TYPE=EXE;))
    (Execute  ("cp @V(Data_Set.temp) Trans/SD.dat") (@TYPE=EXE;))
    (Execute  ("cat Tkb/Out_set.dat >> Trans/SD.dat") (@TYPE=EXE;))
    (Execute  ("Trans/tran") (@TYPE=EXE;))
    (Execute  ("Trans/fstat") (@TYPE=EXE;))
    (Do      (TRUE)      (Compro))
    (Reset    (Cursor))
    (Retrieve  ("Trans/fstat.NXP") (@TYPE=NXPD;@BEGIN="Dummy.ev";\
  @END="RELEASE";@SLOTS=D_mod.modnum,D_mod.type,D_mod.texp,D_mod.b0,D_mod.b1,\
  D_mod.r2,D_mod.see,D_mod.outliers,D_mod.wbe,D_mod.rae,D_mod.ev;@FIELDS="modnum","type",\
  "texp","b0","b1","r2","see","out","wbe","rae","ev";@QUERY="alt = @V(Best.alt)";@CURSOR=Cursor;))
    (Do      (Iterations.counter+1) (Iterations.counter))
    (Execute  ("echo '@V(Stored.crvid) @V(Iterations.counter) @V(Id.counter)
  @V(dummy.int) @V(D_mod.r2) @V(D_mod.see) @V(D_mod.outliers) @V(D_mod.wbe)
  @V(D_mod.rae) @V(D_mod.ev)' >> Tkb/best.txt") (@TYPE=EXE;))
    (Do      (D_mod.modnum) (Mod2.modnum))
    (Do      (D_mod.type) (Mod2.type))
    (Do      (D_mod.texp) (Mod2.texp))
    (Do      (D_mod.b0) (Mod2.b0))

```

```

        (Do (D_mod.b1) (Mod2.b1))
        (Do (D_mod.r2) (Mod2.r2))
        (Do (D_mod.see) (Mod2.see))
        (Do (D_mod.outliers) (Mod2.outliers))
        (Do (D_mod.wbe) (Mod2.wbe))
        (Do (D_mod.rae) (Mod2.rae))
        (Do (D_mod.ev) (Mod2.ev))
        (Execute ("echo ' 6 2' > compro.dat") (@TYPE=EXE;))
        (Execute ("echo '3.0' >> compro.dat") (@TYPE=EXE;))
        (Do ((0-1.0)*Mod1.wbe) (D_mod.wbe))
        (Do ((0-1.0)*Mod1.rae) (D_mod.rae))
        (Execute ("echo '@V(Mod1.r2) -@V(Mod1.see) -@V(Mod1.outliers)
@V(D_mod.wbe) @V(D_mod.rae) @V(Mod1.ev)' >> compro.dat") (@TYPE=EXE;))
        (Do ((0-1.0)*Mod2.wbe) (D_mod.wbe))
        (Do ((0-1.0)*Mod2.rae) (D_mod.rae))
        (Execute ("echo '@V(Mod2.r2) -@V(Mod2.see) -@V(Mod2.outliers)
@V(D_mod.wbe) @V(D_mod.rae) @V(Mod2.ev)' >> compro.dat") (@TYPE=EXE;))
        (Execute ("echo '1.0 1.0 1.0 1.0 1.0 1.0' >> compro.dat")
(@TYPE=EXE;))
        (Do (TRUE) (Compro))
        (Reset (Out_Best))
        (Do (Out_Best) (Out_Best))
    )
)

(@RULE= Check_Adequacy_of_Curve_B
  (@LHS=
    (< (Mod1.r2) (0.65))
  )
  (@HYPO= Curve_Check)
  (@RHS=
    (Do (TRUE) (Flip))
  )
)

(@RULE= Check_Adequacy_of_Curve_A
  (@LHS=
    (>= (Mod1.r2) (0.65))
  )
  (@HYPO= Curve_Check)
  (@RHS=
    (Reset (Slope_Check))
    (Do (Slope_Check) (Slope_Check))
  )
)

(@RULE= Define_Outlier_F
  @INFCAT=20;
  (@LHS=
    (= (Former.int) (2))
    (= (Coder.int) (1))
  )
)

```

```

    )
    (@HYPO=      Def_Outlier)
    (@RHS=
      (Do      (Coder.int)      (Former.int))
      (Do      (TRUE)           (Flip))
    )
  )

  (@RULE=      Define_Outlier_E
    @INFCAT=20;
    (@LHS=
      (=      (Former.int)      (2))
      (=      (Coder.int)       (2))
    )
    (@HYPO=      Def_Outlier)
    (@RHS=
      (Do      (Coder.int)      (Former.int))
      (Do      (TRUE)           (Flip))
    )
  )

  (@RULE=      Define_Outlier_D
    @INFCAT=20;
    (@LHS=
      (=      (Former.int)      (2))
      (=      (Coder.int)       (3))
    )
    (@HYPO=      Def_Outlier)
    (@RHS=
      (Do      (dummy.int-2)    (Stored.last))
      (Reset   (Curve_Check))
      (Do      (Curve_Check)    (Curve_Check))
      (Reset   (End_Test))
      (Do      (End_Test)       (End_Test))
    )
  )

  (@RULE=      Define_Outlier_Continue_B
    (@LHS=
      (=      (Former.int)      (1))
      (=      (Coder.int)       (2))
    )
    (@HYPO=      Def_Outlier)
    (@RHS=
      (Do      (Coder.int)      (Former.int))
      (Do      (TRUE)           (Flip))
    )
  )

  (@RULE=      Define_Outlier_Continue
    (@LHS=

```

```

        (=      (Former.int)      (1))
        (=      (Coder.int)      (1))
    )
    (@HYPO=      Def_Outlier)
    (@RHS=
        (Do      (Coder.int)      (Former.int))
        (Do      (TRUE)          (Flip))
    )
)

(@RULE=      Define_Outlier_Check_Outlier
    (@LHS=
        (=      (Former.int)      (1))
        (=      (Coder.int)      (3))
    )
    (@HYPO=      Def_Outlier)
    (@RHS=
        (Do      (Coder.int)      (Former.int))
        (Do      (dummy.int)      (Outlier.int))
        (Reset   (Cursor))
        (Retrieve      ("mark/scoupe")
    (@TYPE=ORACLE;@END="RELEASE";@SLOTS=Outlier.id,Outlier.stage,Outlier.discharge;\
    @FIELDS="ID","STAGE","DISCHARGE";@QUERY="PROJ_MSR_DATA WHERE ID =\
    @V(Outlier.int)";@CURSOR=Cursor;))
        (Reset   (Cursor))
        (Retrieve      ("mark/scoupe") (@TYPE=ORACLE;@BEGIN="DELETE FROM
PROJ_MSR_DATA WHERE ID = @V(Outlier.int)";@END="COMMIT;RELEASE";))
        (Do      (Data_Set.set2)  (Data_Set.temp))
        (Do      ("Model2")      (Mod_Set.temp))
        (Do      (dummy.int+1)    (dummy.int))
        (Reset   (End_Test))
        (Do      (End_Test)      (End_Test))
    )
)

(@RULE=      Define_Outlier_C
    @INFCAT=30;
    (@LHS=
        (=      (Former.int)      (3))
        (=      (Coder.int)      (1))
    )
    (@HYPO=      Def_Outlier)
    (@RHS=
        (Do      (TRUE)          (Store_Out))
    )
)

(@RULE=      Define_Outlier_B
    @INFCAT=30;
    (@LHS=
        (=      (Former.int)      (3))

```

```

        (=      (Coder.int)      (2))
    )
    (@HYPO=      Def_Outlier)
    (@RHS=
        (Do      (TRUE)          (Store_Out))
    )
)

(@RULE=      Define_Outlier_A
    @INFCAT=30;
    (@LHS=
        (=      (Former.int)      (3))
        (=      (Coder.int)      (3))
    )
    (@HYPO=      Def_Outlier)
    (@RHS=
        (Write ("mark/scoupe") (@TYPE=ORACLE;@FILL=ADD;@END="COMMIT";\
@NAME="!ID!";@PROPS=id,stage,discharge;@FIELDS="ID","STAGE","DISCHARGE";\
@QUERY="PROJ_MSR_DATA";@ATOMS=Outlier;))
        (Do      (dummy.int-2)    (Stored.last))
        (Reset   (Curve_Check))
        (Do      (Curve_Check)    (Curve_Check))
        (Reset   (End_Test))
        (Do      (End_Test)      (End_Test))
    )
)

(@RULE=      BOXCOX_exp_Not_0
    (@LHS=
        (<>      (Mod1.texp)      (0))
    )
    (@HYPO=      Dum_BoxCox)
    (@RHS=
        (Do      (POW(((Mod1.b0+Mod1.b1*Dum_Out.stage)*Mod1.texp+1),\
(1/Mod1.texp))) (Dum_Out.moddis))
    )
)

(@RULE=      BOXCOX_exp_0
    (@LHS=
        (=      (Mod1.texp)      (0))
    )
    (@HYPO=      Dum_BoxCox)
    (@RHS=
        (Do      (EXP((Mod1.b0+Mod1.b1*Dum_Out.stage))) (Dum_Out.moddis))
    )
)

(@RULE=      Outlier_Out
    (@LHS=
        (>      (Dum_Out.perc) (20))

```

```

    )
    (@HYPO=      Dum_Eval)
)

(@RULE=      Outlier_Back_In
  (@LHS=
    (<=      (Dum_Out.perc) (20))
  )
  (@HYPO=      Dum_Eval)
  (@RHS=
    (Do      (Dum_Out.counter+1)      (Dum_Out.counter))
    (Execute      ("echo      '@V(Dum_Out.discharge)      @V(Dum_Out.stage)'      >>
Tkbn/Out_set.dat")      (@TYPE=EXE;))
    (Execute      ("echo      '@V(Dum_Out.id)      @V(Dum_Out.stage)
@V(Dum_Out.discharge)' >> Tkbn/Out.da\
t")      (@TYPE=EXE;))
  )
)

(@RULE=      Compute_Dum_Mod_Dis_Type_twofifths
  (@LHS=
    (=      (Mod1.type)      (3))
  )
  (@HYPO=      Dum_Mod)
  (@RHS=
    (Do      (POW((Mod1.b0+Mod1.b1*Dum_Out.stage),(1/Mod1.texp)))
(Dum_Out.moddis))
  )
)

(@RULE=      Compute_Dum_Mod_Dis_Type_POWER
  (@LHS=
    (=      (Mod1.type)      (1))
  )
  (@HYPO=      Dum_Mod)
  (@RHS=
    (Do      (Mod1.b0+(Mod1.b1*POW(Dum_Out.stage,Mod1.texp)))      (Dum_Out.moddis))
  )
)

(@RULE=      Compute_Dum_Mod_Dis_Type_BOX
  (@LHS=
    (=      (Mod1.type)      (2))
  )
  (@HYPO=      Dum_Mod)
  (@RHS=
    (Reset      (Dum_BoxCox))
    (Do      (Dum_BoxCox)      (Dum_BoxCox))
  )
)

```



```

(@RULE=      The_end_B
  (@LHS=
    (<      (Max.int-dummy.int)    (0))
  )
  (@HYPO=      End_Test)
  (@RHS=
    (Reset  (Cursor))
    (Retrieve      ("mark/scoupe"))
  (@TYPE=ORACLE;@END="RELEASE";@SLOTS=Id.counter;\
  @FIELDS="FIRST";@QUERY="models where crvid = @V(Stored.crvid)";\
  @CURSOR=Cursor;))
    (Do  (Max.int)      (dummy.int))
    (Do  (TRUE)      (Make_Mod))
    (Do  (TRUE)      (Store_Last))
    (Execute      ("Tkb/OutX")  (@TYPE=EXE;))
    (Do  ("OFF")      (Proj_Sys))
  )
)

(@RULE=      The_end_A
  (@LHS=
    (=      (Max.int-dummy.int)    (0))
  )
  (@HYPO=      End_Test)
  (@RHS=
    (Do  (Max.int)      (dummy.int))
    (Do  (TRUE)      (Make_Mod))
    (Do  (TRUE)      (Store_Last))
    (Execute      ("Tkb/OutX")  (@TYPE=EXE;))
    (Do  ("OFF")      (Proj_Sys))
  )
)

(@RULE=      Not_the_end
  (@LHS=
    (>      (Max.int-dummy.int)    (0))
  )
  (@HYPO=      End_Test)
  (@RHS=
    (Do  ("Ret_DS")      (Next_Step))
  )
)

(@RULE=      Test_perc_if_LE_10_continue
  (@LHS=
    (=      (Best.alt)      (1))
    (<=      (Outlier.perc)  (5.0))
  )
  (@HYPO=      Out_Anal)
  (@RHS=
    (Do  (2)      (Coder.int))
  )
)

```

```

        (Reset (Def_Outlier))
        (Do (Def_Outlier) (Def_Outlier))
    )
)

(@RULE=      Test_perc_if_GT_10_outlier
  (@LHS=
    (=      (Best.alt)      (1))
    (>      (Outlier.perc)  (5.0))
  )
  (@HYPO=      Out_Anal)
  (@RHS=
    (Do (3) (Coder.int))
    (Reset (Def_Outlier))
    (Do (Def_Outlier) (Def_Outlier))
  )
)

(@RULE=      Continue_if_best_alt_Mod2
  (@LHS=
    (=      (Best.alt)      (2))
  )
  (@HYPO=      Out_Anal)
  (@RHS=
    (Do (1) (Coder.int))
    (Reset (Def_Outlier))
    (Do (Def_Outlier) (Def_Outlier))
  )
)

(@RULE=      Sequentially_put_back_outliers
  (@LHS=
    (>=      (Cursor)      (0))
  )
  (@HYPO=      Out_Back)
  (@RHS=
    (Retrieve ("Tkb/Out.NXP") (@TYPE=NXPD;@END="RELEASE";\
@SLOTS=Dum_Out.id,Dum_Out.stage,Dum_Out.discharge;@FIELDS="ID","STAGE","DISCHARGE";\
@CURSOR=Cursor;))
    (Retrieve ("mark/scoupe") (@TYPE=ORACLE;@BEGIN="DELETE FROM
OUTLIERS WHERE ID = @V(Dum_Out.Id);@END="COMMIT;RELEASE";))
    (Write ("mark/scoupe") (@TYPE=ORACLE;@FILL=ADD;
@END="COMMIT";@NAME="!ID!";@PROPS=id,stage,discharge;@FIELDS="ID","STAGE",\
"DISCHARGE";@QUERY="PROJ_MSR_DATA";@ATOMS=Dum_Out;))
    (Reset (Out_Back))
  )
)

(@RULE=      No_more_outliers_to_put_back
  (@LHS=
    (<      (Cursor)      (0))

```

```

    )
    (@HYPO=      Out_Back)
)

(@RULE=      Store_model_with_outliers_if_best_alt_2
  (@LHS=
    (=      (Best.alt)      (2))
  )
  (@HYPO=      Out_Best)
  (@RHS=
    (Do      (0)      (Cursor))
    (Reset   (Out_Back))
    (Do      (Out_Back)      (Out_Back))
    (Do      (Stored.crvid+1) (Stored.crvid))
    (Do      (Mod2.type)      (Stored.type))
    (Do      (Mod2.texp)      (Stored.texp))
    (Do      (Mod2.b0)      (Stored.b0))
    (Do      (Mod2.b1)      (Stored.b1))
    (Do      (Mod2.r2)      (Stored.r2))
    (Do      (Mod2.see)      (Stored.see))
    (Do      (Mod2.outliers) (Stored.outliers))
    (Do      (Mod2.wbe)      (Stored.wbe))
    (Do      (Mod2.rae)      (Stored.rae))
    (Do      (Mod2.ev)      (Stored.ev))
    (Do      (TRUE)      (Ret_minmax))
    (Write   ("mark/scoupe") (@TYPE=ORACLE;@FILL=ADD;@END="COMMIT";\
@NAME="!CRVID!";@PROPS=crvid,type,b0,b1,texp,r2,see,outliers,first,last,mins,maxs,wbe,rae,ev;\
@FIELDS="CRVID","TYPE","B0","B1","TEXP","R2","SEE","OUT","FIRST","LAST","MINS",\
"MAXS","WBE","RAE","EV";@QUERY="MODELS";@ATOMS=Stored;))
    (Do      (dummy.int-1) (Id.counter))
    (Do      (Id.counter+6) (dummy.int))
    (Do      (Data_Set.set1) (Data_Set.temp))
    (Do      ("Model1")      (Mod_Set.temp))
    (Do      (1)      (Former.int))
  )
)

(@RULE=      Store_model_if_best_alt_1
  (@LHS=
    (=      (Best.alt)      (1))
  )
  (@HYPO=      Out_Best)
  (@RHS=
    (Do      (TRUE)      (Set_Parameters))
    (Do      (TRUE)      (Ret_minmax))
    (Write   ("mark/scoupe") (@TYPE=ORACLE;@FILL=ADD;@END="COMMIT";\
@NAME="!CRVID!";@PROPS=crvid,type,b0,b1,texp,r2,see,outliers,first,last,mins,maxs,wbe,rae,ev;\
@FIELDS="CRVID","TYPE","B0","B1","TEXP","R2","SEE","OUT","FIRST","LAST","MINS",\
"MAXS","WBE","RAE","EV";@QUERY="MODELS";@ATOMS=Stored;))
    (Do      (dummy.int-1) (Id.counter))
    (Do      (Id.counter+6) (dummy.int))
  )
)

```

```

        (Do (Data_Set.set1) (Data_Set.temp))
        (Do ("Model1") (Mod_Set.temp))
        (Do (1) (Former.int))
    )
)

(@RULE= Turn_System_ON
  (@LHS=
    (Is (Proj_Sys) ("ON"))
  )
  (@HYPO= Proj_Control)
  (@RHS=
    (Do (\Next_Step\Value) (Step))
    (Do (TRUE) (Proj_Sys.resets))
    (Reset (Proj_Control))
  )
)

(@RULE= Turn_System_OFF
  (@LHS=
    (Is (Proj_Sys) ("OFF"))
  )
  (@HYPO= Proj_Control)
)

(@RULE= Assess_the_Quality_of_the_Curve_and_Store
  (@LHS=
    (Is (Quality) ("GOOD"))
  )
  (@HYPO= Qual_Check)
  (@RHS=
    (Do (TRUE) (Store_Crv))
  )
)

(@RULE= Assess_the_Quality_of_the_Curve_and_Continue
  (@LHS=
    (Is (Quality) ("NO GOOD"))
  )
  (@HYPO= Qual_Check)
  (@RHS=
    (Do (TRUE) (Flip))
  )
)

(@RULE= Retrieve_Data_Pairs
  (@LHS=
    (= (1) (1))
  )
  (@HYPO= Ret_DS)
  (@RHS=

```

```

        (Do (TRUE) (Make_Mod))
        (Reset (Set_Mod))
        (Do (Set_Mod) (Set_Mod))
    )
)

(@RULE= Sequential_Retrieve_of_Outliers
  @INFCAT=10;
  (@LHS=
    (Retrieve ("mark/scoupe") (@TYPE=ORACLE;@END="RELEASE";\
  @SLOTS=Dum_Out.id,Dum_Out.stage,Dum_Out.discharge;@FIELDS="ID","STAGE","DISCHARGE";\
  @QUERY="OUTLIERS WHERE ID BETWEEN @V(Stored.first) AND
  @V(Stored.Last)";@CURSOR=Cursor;))
    (>= (Cursor) (0))
  )
  (@HYPO= Ret_Outliers)
  (@RHS=
    (Reset (Dum_Mod))
    (Do (Dum_Mod) (Dum_Mod))
    (Do (ABS((Dum_Out.moddis-Dum_Out.discharge)/Dum_Out.moddis*100))
    (Dum_Out.perc))
    (Reset (Dum_Eval))
    (Do (Dum_Eval) (Dum_Eval))
    (Reset (Ret_Outliers))
  )
)

(@RULE= End_Sequential_Retrieve_of_Outliers
  (@LHS=
    (< (Cursor) (0))
  )
  (@HYPO= Ret_Outliers)
)

(@RULE= Set_model_to_2
  (@LHS=
    (Is (Mod_Set.temp) ("Model2"))
  )
  (@HYPO= Set_Mod)
  (@RHS=
    (Do (D_mod.modnum) (Mod2.modnum))
    (Do (D_mod.type) (Mod2.type))
    (Do (D_mod.texp) (Mod2.texp))
    (Do (D_mod.b0) (Mod2.b0))
    (Do (D_mod.b1) (Mod2.b1))
    (Do (D_mod.r2) (Mod2.r2))
    (Do (D_mod.see) (Mod2.see))
    (Do (D_mod.outliers) (Mod2.outliers))
    (Do (D_mod.wbe) (Mod2.wbe))
    (Do (D_mod.rae) (Mod2.rae))
    (Do (D_mod.ev) (Mod2.ev))
  )
)

```

```

        (Do      ("Comp_Mod") (Next_Step))
    )
)

(@RULE=      Set_model_to_1
  (@LHS=
    (Is      (Mod_Set.temp) ("Model1"))
  )
  (@HYPO=      Set_Mod)
  (@RHS=
    (Do      (D_mod.modnum)      (Mod1.modnum))
    (Do      (D_mod.type)      (Mod1.type))
    (Do      (D_mod.texp)      (Mod1.texp))
    (Do      (D_mod.b0)      (Mod1.b0))
    (Do      (D_mod.b1)      (Mod1.b1))
    (Do      (D_mod.r2)      (Mod1.r2))
    (Do      (D_mod.see)      (Mod1.see))
    (Do      (D_mod.outliers)      (Mod1.outliers))
    (Do      (D_mod.wbe)      (Mod1.wbe))
    (Do      (D_mod.rae)      (Mod1.rae))
    (Do      (D_mod.ev)      (Mod1.ev))
    (Do      (Data_Set.set2) (Data_Set.temp))
    (Do      ("Model2")      (Mod_Set.temp))
    (Do      (dummy.int+1) (dummy.int))
    (Do      ("Ret_DS")      (Next_Step))
  )
)

(@RULE=      Check_to_See_If_Slope_is_GOOD
  (@LHS=
    (>      (Stored.crvd)      (0))
  )
  (@HYPO=      Slope_Check)
  (@RHS=
    (Do      (TRUE)      (Retr_Prev_Crv))
    (Execute      ("echo @V(Fcrv.crvd) @V(Fcrv.type) @V(Fcrv.b0) @V(Fcrv.b1)
@V(Fcrv.texp) @V(Fcrv.r2) @V(Fcrv.first) @V(Fcrv.last) @V(Fcrv.maxs) > PROG/model.in")
    (@TYPE=EXE;))
    (Execute      ("echo @V(Mod1.crvd) @V(Mod1.type) @V(Mod1.b0) @V(Mod1.b1)
@V(Mod1.texp) @V(Mod1.r2) @V(MOD1.first) @V(Mod1.last) @V(Mod1.maxs) >> PROG/model.in")
    (@TYPE=EXE;))
    (Execute      ("PROG/curve_test")      (@TYPE=EXE;))
    (Reset      (Cursor))
    (Retrieve      ("PROG/qual.NXP")      (@TYPE=NXPD;@END="RELEASE";\
@SLOTS=Quality;@FIELDS="qual";@CURSOR=Cursor;))
    (Reset      (Qual_Check))
    (Do      (Qual_Check)      (Qual_Check))
  )
)

```

```

(@RULE=      Check_to_See_If_Slope_is_GOOD_B
  (@LHS=
    (=      (Stored.crvId)  (0))
  )
  (@HYPO=      Slope_Check)
  (@RHS=
    (Do      ("GOOD")      (Quality))
    (Reset   (Qual_Check))
    (Do      (Qual_Check)   (Qual_Check))
  )
)

(@RULE=      Start
  (@LHS=
    (=      (1)      (1))
  )
  (@HYPO=      Start)
  (@RHS=
    (Strategy
      (@PWTRUE=FALSE;@PWFALSE=FALSE;@PWNOTKNOWN=FALSE;\
      @PFACTIONS=FALSE;@PTGATES=FALSE;@EXHBWRD=FALSE;))
      (Do      ("ON") (Proj_Sys))
      (Execute  ("rm -f DATA/outlier.dat")      (@TYPE=EXE;))
      (Execute  ("rm -f DATA/crv*")      (@TYPE=EXE;))
      (Execute  ("rm -f DATA/data.lis")      (@TYPE=EXE;))
      (Execute  ("rm -f Tkb/best.txt")      (@TYPE=EXE;))
      (Execute  ("DATA/dataX")      (@TYPE=EXE;))
      (Reset   (Cursor))
      (Retrieve  ("mark/scoupe") (@TYPE=ORACLE;@END="RELEASE";\
      @SLOTS=Max.int;@FIELDS="MAX(ID)";@QUERY="PROJ_MSR_DATA";@CURSOR=Cursor;))
      (Do      (0)      (Iterations.counter))
      (Do      (Id.counter+1) (Id.counter))
      (Do      (Id.counter+6) (dummy.int))
      (Do      (Data_Set.set1) (Data_Set.temp))
      (Do      ("Model1")      (Mod_Set.temp))
      (Do      ("Ret_DS")      (Next_Step))
      (Do      (Proj_Control) (Proj_Control))
    )
  )

(@GLOBALS=
  @INHVALUP=FALSE;
  @INHVALDOWN=TRUE;
  @INHOBJUP=FALSE;
  @INHOBJDOWN=FALSE;
  @INHCLASSUP=FALSE;
  @INHCLASSDOWN=TRUE;
  @INHBREADTH=TRUE;
  @INHPARENT=FALSE;
  @PWTRUE=TRUE;
  @PWFALSE=TRUE;

```

```
@PWNOTKNOWN=TRUE;  
@EXHBWRD=FALSE;  
@PTGATES=TRUE;  
@PFACTIONS=TRUE;  
@SOURCESON=TRUE;  
@CACTIONSON=TRUE;  
@SUGLIST=Start;
```

)

```
#####  
#*      End of KB Code:  MOSDE.tkb      *  
######
```


APPENDIX C - Statistical Parameters

Appendix C defines the equations used to produce the statistical parameters used in the multiobjective Compromise Programming Routine, which evaluates the models generated in the MOSDE program.

R² Statistic

$$R^2 = \frac{SRR}{SEE + SRR} \quad (C.1)$$

where

SSR = sum of squares of residuals;
SEE = standard error of estimate;

$$SSR = \sum (D - D_p)^2 \quad (C.2)$$

where

D_p = mean value of the transformed discharge for the data set.

Standard Error of Estimate (SEE)

$$SEE = \left(\frac{SSE}{N-2} \right)^{1/2} \quad (C.3)$$

where

SSE = sum of squares error; and
N = number of data points.

The value of SSE is calculated according to:

$$SSE = \sum (D - D_m)^2 \quad (C.4)$$

where

$$\begin{aligned} D &= \text{measured discharge; and} \\ D_m &= \text{modelled discharge.} \end{aligned}$$

Number of Outliers (OUT)

An outlier is classified as a data point that has a measured value which differs from the calculated value by a given percentage. The allowable error is the percentage value, and was set to 20 percent for all analysis. The decision for allowable error is totally arbitrary at this time. Each outlier is calculated by:

$$ABS \left(\frac{D - D_m}{D_m} \right) * 100 > e_a \quad (C.5)$$

where

$$e_a = \text{allowable error.}$$

Water Balance Error (WBE)

$$WBE = \left| \sum_{t=1}^n D_{m,t} - \sum_{t=1}^n D_t \right| \quad (C.6)$$

Relative Absolute Error (RAE)

$$RAE = \frac{\left| \sum_{i=1}^n D_i - D_{m_i} \right|}{\sum_{i=1}^n D_i} \quad (C.7)$$

Explained Variance (EV)

$$EV = 1 - \frac{\sum_{i=1}^n \left[(D_i - D_{m_i}) - \bar{\epsilon} \right]^2}{\sum_{i=1}^n (D_i - D_{m_i})^2} \quad (C.8a)$$

where

$$\bar{\epsilon} = \frac{\sum_{i=1}^n (D_i - D_{m_i})}{n} \quad (C.8b)$$

Appendix D - Compromise Programming Routine

The following is a code listing of the Compromise Programming routine called Compro.for. It is utilized in the MOSDE (Chapter 5) as the evaluator of 63 separate SD models. It tries to find the optimal model as outlined in Section 5.2.3.

```

C*****
C*
C*   Program: Compro.for
C*
C*   This fortran program evaluates 63 sets of generated statistics for
C*   evaluation by the multiobjective Compromise Routine. The output is
C*   the "optimal" model based on the compromise.
C*
C*   Input:      compro.dat
C*
C*   Output:     compro.izl - standard output list
C*               compro.NXP - Nexpert Object database formatted output
C*
C*****

      DIMENSION V(63,63),VMAX(63),S(63),IS(63),W(63),VMIN(63)
      DOUBLE PRECISION V,VMAX,S,W,WMAX,SUM,VMIN,BOB
C
      OPEN(UNIT=5,FILE='compro.dat')
      OPEN(UNIT=7,FILE='compro.izl')
      OPEN(UNIT=8,FILE='compro.NXP')
      READ (5,*) KR,NO
1      FORMAT(12I6)
      READ (5,*) P
      WRITE (7,4)NO,KR,P
4      FORMAT(////8X,'MULTIOBJECTIVE COMPROMISE PROGRAMMING'
1 //8X,'NUMBER OF ALTERNATIVES = ',I3//8X,'NUMBER OF CRITERIA =
',
3 I3//8X,'COEFFICIENT P = ',F6.1//
4 8X,'INPUT MATRIX'//)

```

```

2   FORMAT(12F6.0)
   WRITE(7,5) (K,K=1,KR)
5   FORMAT(8X,'CR:',12I6)
   DO 10 N=1,NO
   READ (5,*) (V(K,N),K=1,KR)
   WRITE(7,6) N,(V(K,N),K=1,KR)
6   FORMAT(8X,'ALT',I2,(12F6.1))
10  CONTINUE
   READ (5,*) (W(K),K=1,KR)
   WRITE(7,7) (W(K),K=1,KR)
7   FORMAT(//8X,'WEIGHTING COEFFICIENTS'//
1   13X,12F6.1//)
C
   WMAX=-1E+25
   DO 11 K=1,KR
   IF (W(K).GT.WMAX) WMAX=W(K)
   VMAX(K)=-1E+25
   VMIN(K)=1E+25
   DO 12 N=1,NO
   IF (V(K,N).GT.VMAX(K)) VMAX(K)=V(K,N)
   IF (V(K,N).LT.VMIN(K)) VMIN(K)=V(K,N)
12  CONTINUE
11  CONTINUE
   DO 13 N=1,NO
   SUM=0.
   IF (P.GE.100.) GO TO 20
   DO 14 K=1,KR
   IF((VMAX(K)-VMIN(K)).EQ.0)THEN
     BOB=1.0E-25
   ELSE
     BOB=(VMAX(K)-VMIN(K))
   ENDIF
   SUM=SUM+((VMAX(K)-V(K,N))/BOB*W(K)/WMAX)**P
14  CONTINUE
   S(N)=SUM**(1/P)
   GO TO 21
20  CONTINUE
   DO 15 K=1,KR
   IF((VMAX(K)-VMIN(K)).EQ.0)THEN
     BOB=1.0E-25
   ELSE
     BOB=(VMAX(K)-VMIN(K))
   ENDIF
   SN=(VMAX(K)-V(K,N))/BOB*W(K)/WMAX

```

```

        IF (SUM.LT.SN) SUM=SN
15      CONTINUE
        S(N)=SUM
21      CONTINUE
13      CONTINUE
        WRITE (7,8)
8        FORMAT(//,8X,'FINAL TABLE'/8X,'ALT          L(ALT)          RANK'/)
        DO 16 N=1,NO
        IS(N)=1
        DO 17 M=1,NO
        IF (S(N).GT.S(M)) IS(N)=IS(N)+1
17      CONTINUE
        WRITE (7,3) N,S(N),IS(N)
3        FORMAT(7X,I4,F9.3,I6)
16      CONTINUE
C
        DO 23 I=1, NO
        IF(IS(I).EQ.1)THEN
        WRITE(8,169) I
        ENDIF
23      CONTINUE
169     FORMAT('  altl',/, '*****',/,4x,i2,'l',/, '*****')
        STOP
        END

```