Environment Canada Environnement Canada

Hydrometric Manual

Data Computations

Beta Version, 2012

Canada

Originating Authority: Water Survey of Canada
Weather and Environmental Monitoring Directorate
Issued under the authority of the Assistant Deputy Minister,
Meteorological Service of Canada

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Acknowledgments

This manual is a cooperative effort with contribution from many people. It reflects more than 3 years of research and development within Water Survey of Canada to adapt our 100 year legacy in computations to the prerogatives of on-the-fly data production. Many technologists, supervisors and managers provided expertise and ideas for the details of this manual. Two groups reporting to OMC-H were instrumental in the review and adoption of the new rules described here. These groups are the Network Operations Sub-Committee and the Data Control Sub-Committee. In particular, the following employees, listed in alphabetical order, must be acknowledged for their continued efforts and significant contributions to the development of these standards: Tom Arsenault, André Bouchard, Derek Elliott, Agnieska Fojt, Derek Forsbloom, Morie Gracey, Russ Gregory, Dave Harvey, Corey Hein, Scott Hill, Keith Hryciw, David Hutchinson, Dennis Lazowski, Lingling Liu, Patrick McCurry, Dave Moncur, Scott Palfreyman, Brian Pessah, François Rainville, Brian Russell, Alton Stead, Chris Thomson, Randy Wedel, James Wilcox, Jeff Woodward. Appreciation is also extended to the staff of Aquatic Informatics, especially Stuart Hamilton, who all provided continued support, advice and context for the integrated definition of procedures.

Record of Revisions

Version. No.	Date	Source	Description/Rational for Change
0	2012-12 -17	OMC-H / NetOps / DCS	Beta Version

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Foreword

Over the 100 years of Water Survey of Canada excellence, our data computations have been conducted using several different platforms. From the days of paper charts and rulers to the computer age, many procedures endured. There were important changes at times due to new capabilities and new user requirements. The current transition to a continuous data production approach, including real time display, has forced the adoption of such drastic changes. The current document outlines the procedures that allow continuity in our tradition of quality management while embracing the modernization of several elements in our computation systems.

Notes to Readers

This first edition is the Beta Version of Water Survey of Canada's new data computation procedures. During its expected short life, all users are expected to compile and report comments relative to its limitations or any opportunity for clarifications. These comments must be gathered by their supervisors and forwarded to local Data Control Sub-Committee members for consideration in the next release.

Purpose and Scope

The purpose of this document is to describe the standards to be used in the processing of surface water records. These standards are intended for use primarily by Water Survey of Canada, but may be of interest to partners or anyone using a continuous data production approach. The emphasis of the document relates to automated processing and analysis with a focus on systems used within Environment Canada, in particular the use of AQUARIUS, software developed by Aquatic Informatics. It also addresses manual interventions required throughout the process for adequate interpretation and quality control.

Terminology

Acquisition – Data is collected and provided to the processing stage.

Approval Status – Condition of data in the context of computation management, defined as Preliminary, Reviewed, Checked or Approved.

Approval Period – Dates over which a period of data is raised from a Provisional to Final state.

Approved – Approval status for data deemed to be the best that can be produced.

Automated Correction – Relates mostly to integrity checks which ensure that data is within realistic ranges specific to known and expected station conditions.

Carry Forward Correction – Synonym with Extrapolated Correction.

Checked – Approval status of data that was peer reviewed to confirm that all quality influences were factored in.

Comparison Data – Data used to validate decisions made in the production data cycle.

Contributed Data – Data provided by another agency and conforming to National Standards and HYDAT database requirements.

Data Revision – Changes made to previously published Final records.

Decode – Process of transforming information from one format to another.

Delivery and Dissemination – Final stage of data management in which approved hydrometric information is transferred into the national databases and made available to users.

Dependant Variable – Value that may change within the scope of a set of operations performed on a value which it depends on.

Derived Signal – Time series for a dependant variable.

Discharge Estimation Model – Mathematical representation of the expected relation between discharge and flow governing hydraulic or hydrological variables (e.g. stage-discharge curve)

Environmental Conditions – Information for a particular time on any weather and water quality parameters.

Estimating – Process of using assumptions valid for conditions that were observed over the period of interest.

Extrapolated Correction – Correction that is open ended and based on information known to be stable over the near future.

Extrapolation – Process of extending information known to be stable. It is not the process of predicting expected conditions

Extremes Recorded – Refers to the maximum and minimum of stage or discharge for the period of record.

Final – Publication status describing data confirmed to capture all observations, and meeting all standards.

Forecasting – Process of predicting expected conditions for a parameter in advance of proof.

HYDAT – National surface water database that provides published statistical records for active and discontinued hydrometric and sediment stations

Independent Variable – Information observed and not derived from other values, and often the basis to compute other values.

Integrity Checks – Verification against a system of physical properties to ensure that data is realistic for the collection site.

Level of Service – Depending on its priority, different levels of effort and resources can be assigned to a station to apply and automate the validation and interpretive work in the earliest stage of computation possible.

Notification – Message sent by the data computation system to operation staff to identify an event that occurred and which may require intervention.

Open Ended – Characteristic of conditions or an activity that has no identified end date

Peer Review – Redundant verification usually performed by someone different than the initial reviewer, to ensure that all standards and procedures were adequately met.

Portal – Web based information sharing system managed for Water Survey of Canada by Aquatic Informatics, commonly known as the Portal. It is used to report procedural, training or software/system problems called 'cases'.

Preliminary – Approval status for data submitted to automated and human interventions but for which all quality influences have not yet been factored in.

Production – Data is processed and transformed to produce the best available hydrometric information that conforms to national standards

Provisional – Publication status that describes best available but still evolving data.

Publication – Any means, temporary or permanent, by which data is made available to clients and users

Publication Status – Condition of data in the context of the quality available to clients and users, defined as Provisional or Final.

Raw Data – Time series and discrete values obtained via telemetry and field activities and not subjected to any correction.

Real-time Data – Data flowing directly from the station telemetry into the web publication services after being subjected to automated quality controls and models.

Reviewed – Approval status of data under evaluation to capture all factors influencing quality.

Sanity Check – Verification of data validity to rule out certain classes of obviously false results that may originate during acquisition, storage, retrieval or transfer.

Source Signal – Time series for an independent variable.

Station Health – Station equipment conditions which determine the ability to collect data that meet quality objectives.

Undefined – Non-standard approval status for data restricted from publication.

Working Signal – Time series containing the results of operations performed on source signals and surrogates to improve the final quality of the product it provides.

Training

Material to train on the use of AQUARIUS has been developed by Water Survey of Canada personnel. It is a simulation based on field and office scenarios understood to take place over a period of two years, but which can be performed in approximately 1 to 2 weeks. Each exercise introduces concepts related to the procedures and software applications with gradual complexity. The training manuals and associated data files required for the exercises are stored on our Portal (http://watersurvey.aquaticinformatics.com/). We recommend that you inquire with your local management about support available for data computation training.

1 Continuous Data Production

The origin of the current Continuous Data Production cycles can be traced back to the “Concept Paper on Automating Hydrometric Data Production and Quality Control”, presented to the Monitoring Operations Committee of Water Survey of Canada on June 6, 2002. The paper laid out a framework that has led to the development of the hydrometric workstation computer systems adopted in 2011.

Since September 2010, Water Survey of Canada has in parallel formally adopted a cycle of analysis and processing that allows production of real-time data. The best available data is continuously produced and published based on 4 cycles: Automated; Value Added; Final; and Revision (see Figure 1-1). These cycles mark a substantial departure from the calendar-year based production cycle. The focus of these processes is on a field-visit to field-visit production schedule and on unit value data production. Backward compatibility with daily aggregations and calendar year products can be derived from unit values on an as-needed basis.

1.1 Production Cycles

1.1.1 Automated

Provisional water level and discharge unit values are first automatically produced when ***Raw*** data is ingested via telemetry, QA/QC criteria, appropriate corrections and models are applied, and those provisional data are made instantaneously available for ***Publication*** to the web. This is the ***Real-time Data*** production phase.

1.1.2 Value Added

Provisional water level and discharge unit values are continuously improved and sent for ***Publication*** as information and knowledge is added through validation measurements, ingestion of logger flat files and human interpretation. The timing of value added efforts is defined by the ***Level of Service*** required at any station for any period of operation. Data values are likely to fluctuate during this preliminary phase. The continuous improvement process halts when no new information may further modify the interpretation or validation. The technologist then raises the data approval to ***Reviewed***, signalling the start of a peer review. When satisfied, the peer reviewer raises the data approval level to ***Checked***. The value added cycle ends when a supervisor raises the data status to ***Approved***, thus confirming that all relevant information for the complete interpretation of a period was assembled.

1.1.3 Final

When data has been approved, ***Final*** unit value data is published. The daily mean statistics will then also be produced for publication in ***HYDAT***. Peaks and extremes will continue to be validated and published annually.

1.1.4 Revision

Based on new information and the revision criteria, changes to final data may be required. The period of record that is identified for revisions is then demoted back to preliminary, returned to the production cycle and examined against the new information.

1.2 Level of Service

For data production in Real-Time, the level of service expected for any station, whether high or low, which defines the priority and intensity of staff intervention is based on Schedule C and D of the bilateral agreements. This level of service must also be clearly identified in HYDEX.

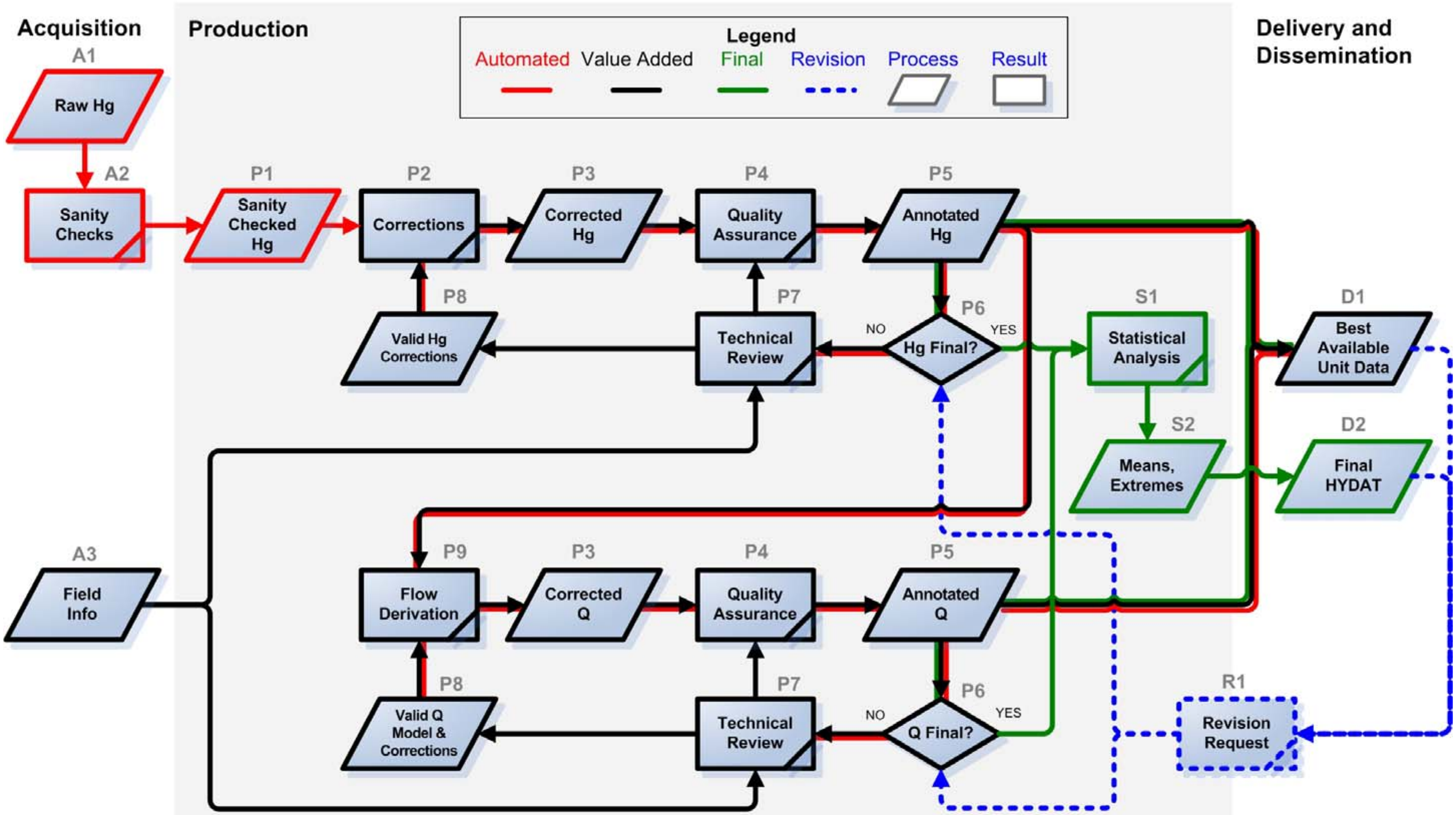


Figure 1-1: Continuous Data Production Cycle

1.3 Data Systems

1.3.1 Architecture

Data computation systems are managed at 4 different locations across Canada:

- HWS Primary Systems are located in Winnipeg, Manitoba;
- HWS DCP Primary Server and HWS Backup Systems are in Downsview, Ontario;
- AIPoll Server and HYDNOW Database are in Vancouver, British Columbia;
- Web Servers are located in Dorval.

This structure ensures an adequate redundancy and safety for the databases.

1.3.2 Problem Resolution

In general, when discovering a possible problem, the following basic items should first be confirmed:

- Correct equipment and communication parameters are referenced in HYDEX. Contact Data Control for assistance if necessary.
- Logger responds to call with HyperTerminal or has data transmitting properly to NESDIS
- SHEF codes are correct
- Datasets are properly configured in AQUARIUS.

Three types of system failures can occur for which operators may have to take actions:

1. Telemetry Data is not coming into AQUARIUS;
2. Telemetry Data is in AQUARIUS but there is no working signal for Stage or Discharge
3. Working signals are available but missing on the Real Time Web

1.3.2.1 Reporting problems via the Portal

Any problem must be reported via our web based information sharing system, managed for Water Survey of Canada by Aquatic Informatics, and commonly known as the AI ***Portal*** (http://watersurvey.aquaticinformatics.com/).
Any issue reported this way will be properly tracked, quickly prioritized and addressed by the most appropriate expertise. Issues reported this way may be related to training, procedural or software related problems.

To access this site, obtain a user name and password from your IT service desk.

To ensure the most adequate response, it is important that the case be properly documented. The case description should include:

1.3.2.2 Telemetry signal missing in AQUARIUS

There may be no Telemetry time-series at the station although it is equipped to transmit in this method. The cause of this problem must be identified and resolved.

1. First, confirm that transmissions did occur from the DCP. You can search for the DCP address online.
2. Then, ensure that the SHEF codes used are standard and adequate for the expected data.
3. Validate all information relative to the station acquisition in HYDEX, including, but not limited to, its DCP address, its time zone, phone number, etc.
4. For GOES stations, look at the station device and verify the DCP information.
5. For landline stations, look at the station device and confirm the modem model.
6. Then, validate the logger information such as model, effective dates, etc.
7. If the information contained in HYDEX was all correct, inform the area supervisor and the Data Control representative about the problem and decide if and how to report the problem in the Portal.
8. Minor Telemetry Issue: For problems affecting only one station, the technologist should enter a description of the situation directly into the Portal, sending a copy of the Portal case to the local Data Control representative for follow up.

9. Major Telemetry Issue: For problems affecting the acquisition at many stations, contact the local Data Control representative immediately. They will be responsible to enter a case into the Portal if required. Data Control may know about the issue or will report on the situation on behalf of the office.

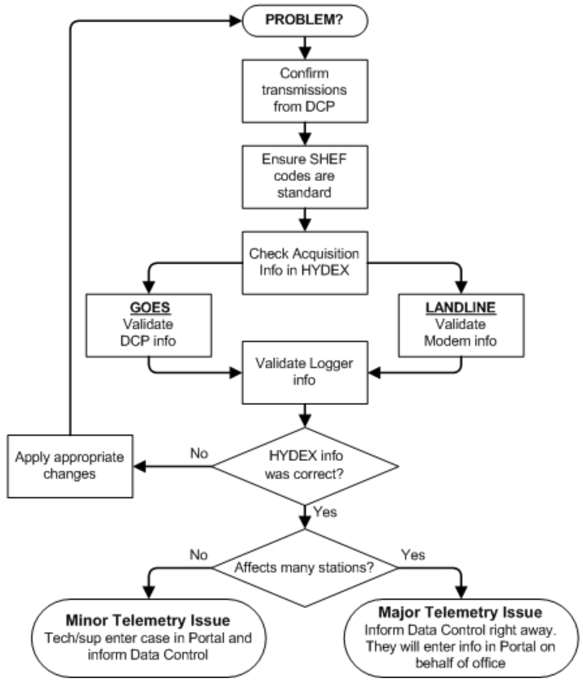


Figure 1-2: Telemetry Signal Missing in AQUARIUS

1.3.2.3 Working signal missing in AQUARIUS

Telemetry data is available in AQUARIUS but there is no Working signal resulting from it for either stage or discharge. The cause of this problem must be identified and resolved.

1. First, in the Location Manager, ensure that the Stage Working and Discharge Working time series do exist. The Stage Working should be set as a ‘composite’ type. Be sure to verify that the right time zone is used. The mixing rule applied in the Stage-Working must use Telemetry as the primary signal for that dataset.
2. Then, in Data Correction Toolbox, verify all corrections applied to the period of concern, to ensure that the Stage or Discharge Working is not deleted inadvertently (i.e., a Delete Region could be applied to current data).
3. If Stage Working is available but there is no Discharge Working signal, check the availability and adequacy of the model applied to derive data and its associated periods of applicability.
4. In some cases, discharge data may be derived using an alternative model not actually supported by AQUARIUS. The data may have to be brought in manually and will require the creation of specialized dataset to support it. In order to proceed, discuss the approved method with your supervisor.
5. If the above has been verified and the cause for the missing data still cannot be identified and corrected, the local supervisor must be notified and the issue discussed with Data Control.

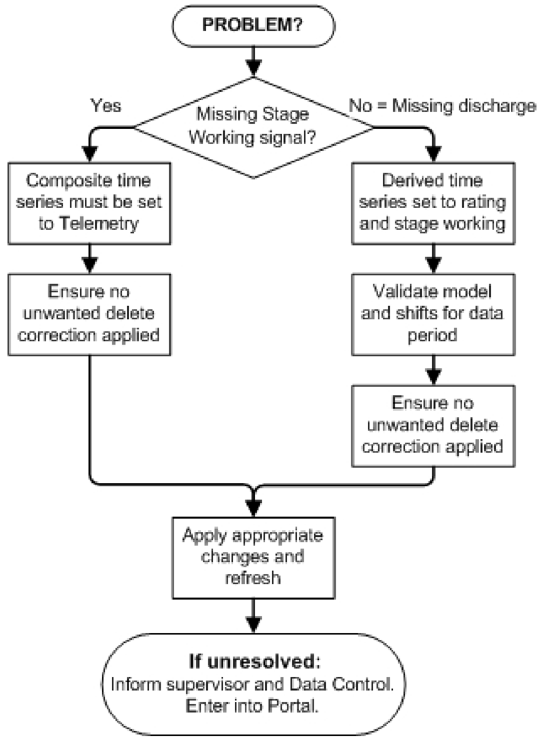


Figure 1-3: Working Signal Missing in AQUARIUS

1.3.2.4 Signal missing on Real-Time web

While all time series is available in AQUARIUS, there may be no display of information on the Real-Time web for clients and the public to view. Such display is part of our critical service and must be assured. The cause of this problem must be identified and resolved.

1. First, ensure that the Stage and Discharge Working signals exist within AQUARIUS.
2. In some cases, the ClearSCADA approval may have been unselected which prevents data from being published to the web. Ensure that the approval is turned on/selected (Data Correction toolbox).
3. Determine if the problem is only at one station, or if real-time data is missing for other stations as well.
4. Ensure that the parameter desired for display is available in the drop down menu. If it is not available, send a request to Data Control so that it is added.
5. If you are unable to resolve the issue, contact the local Data Control representative to report the issue.

Once the issue has been discussed with the Data Control representative, if deemed necessary, the technologist may enter the case into the Portal using “Web” as case type and copy the Data Control representative on it.

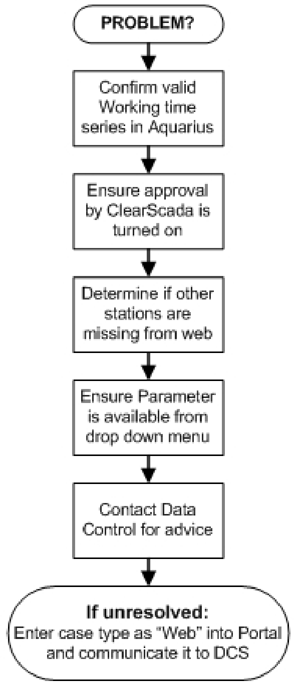


Figure 1-4: Signal missing on real-time web

2 Station Information

Items listed below represent information that must be entered into HYDEX at every station in order to provide a complete description of it. This information is obtained through the use of the Station Description report, the Station Inventory report and the Benchmark History report from AQUARIUS. Refer to HYDEX Administration for details on data entry.

In HYDEX

- Station Identification (name, number, province, operating office, time zone)
- Description of station location (seasonal access methods, local geographic reference features)
- Latitude and longitude (iIn decimal seconds, longitude should include a negative sign)
- Legal land description
- Operating responsibilities (responsible agency, period, type of station output)
- Station device description (logger, sensor, power supply, communication, elevation reference)
    - All device details (serial no, category, make, model, status)
    - Communication specific (GOES [ID, time slot and length, channel, LDR/HDR, antenna aim and azimuth] or Modem [phone #, baud rate])
- Datum used
- Drainage area
- Description of river channel (type of banks, bottom, etc.)
- Description of control (section or channel, natural or regulated)
- Description of measurement sections (location for low or high water, during ice cover, alternatives)
- Hydrological conditions (location of reservoirs, dams, weirs, peculiar and seasonal flow issues, etc.)
- Occupational health and safety considerations
- General remarks (station specific details, contacts, logistics, supplies)

Items listed below represent information that must be managed or stored within the Location Manager toolbox, in AQUARIUS.

In AQUARIUS

- List of benchmarks (primary, type, elevation, location relative to a local geographic feature)
- Pictures of control
- Sketch of local station layout showing north and scale, gauge, access roads, channel, intakes, benchmarks, WWG, flow direction, metering sections
- Topographic map showing hydrological features, north and scale

2.1 HYDEX Administration

The HYDEX system a relational database which contains metadata essential for computation processes supporting AQUARIUS. HYDEX was initially designed and adopted in 1969. The data base was created to track station information necessary for inventory tracking, operational and network management responsibilities. In 2005, HYDEX was significantly overhauled to enable the capture of historic changes in station metadata. HYDEX must be continuously updated. Overall administration of the database contents is administered by the data control supervisors in each region. The device, facility and site information maintenance is a responsibility assigned to each technologist validated and controlled by supervisors. A web interface accessible via the WSC' Intranet, provides the ability to update the following major elements.

Station Cost Arrangement
This element is updated by data control and contains funding, ownership and operator information about a station.

Station Device

Provides access to all devices (instrumentation) that is currently or has been used at a station. All fields for each device specified in this element must be completed as Aquarius uses this information to obtain data for the production process. This is a major responsibility of the technologist.

[Text on the following items to be added]
Station Facility
Station Images Upload
Station Information
Station Record Collection
Station Regulation
Station Tributary
Station Remarks/Descriptions

2.2 New Station

Do not create any dataset in AQUARIUS until its operational time zone has been configured in HYDEX.

1. Before a station is to become active in the field, create a new station in HYDEX and ensure that the HYDEX information requirements are complete. Once the station exists in HYDEX, it will be automatically created in AQUARIUS during the next HYDEX/AQUARIUS synchronization (hourly).
2. Request a UTC time offset for the new station to be added to HYDEX (the request goes to HYDEX Database Administrator). Once the time zone has been manually added in HYDEX, the "UTC offset" will propagate to AQUARIUS on the next HYDEX/AQUARIUS synchronization (hourly).
3. If telemetry is installed, ensure that logger and modem/GOES transmitter device information is populated in HYDEX. Once telemetry device information is completed in HYDEX, the updates will propagate to AQUARIUS on the next HYDEX/AQUARIUS synchronization (hourly)
4. Once all the steps above are completed, new AQUARIUS Telemetry datasets will be automatically created upon the first EnviroSCADA export of data to AQUARIUS.

2.3 Datum

An established elevation for every reference entered in AQUARIUS is required and must be documented against the Datum in use and listed in HYDEX.

All benchmarks, reference marks, reference points, gauge features and other permanent points that may be referenced to a datum should be included in the datum reference list. If a reference established elevation is modified due to a change of datum, a note regarding the change must be entered (e.g., Datum changed in 2008 from Assumed to GSC 1979). A review of historical level data in HYDAT should then be considered so that all levels are to the same Datum that is showing in HYDEX.

Datum references, such as wire weight gauges, do not usually have an established elevation documented on the Gauge History. However, if the gauge is stable, the first year of surveyed stability can be considered as the established elevation. Supervisors must review these values to determine if they are appropriate.

Be aware that Gauge Corrections must be applied to Stage Working time-series within the Data Correction Toolbox as well as to discrete values of stage resulting from station visit activities in the Field Visit Toolbox. More details are provided in the Data Correction section.

3 Acquisition

All Water Survey of Canada data that is essential for computation or publication must be captured in the AQUARIUS database and ultimately archived.

Contributed or other comparison data used in production do not reside within the Water Survey of Canada production systems. If any such data is used as the source of important interpretation and if there is any risk that these external data could be modified at a later date, the details on the version of the data used should be documented along with the completed computation. .

Climate data is obtained from the Meteorological Service of Canada network of stations. This data is not stored within the Water Survey of Canada production systems. It can be displayed along with other hydrometric data as surrogate by first choosing the station to be computed and then selecting the desired climate station in second.

3.1 Raw Data Time Series

Raw data is defined as time series obtained via telemetry or direct downloads that has not yet been subjected to any correction.

A time series obtained by Telemetry is the primary signal when available.

All Logger data loaded with Append Logger File in AQUARIUS must be done with interpolation type set to “Instantaneous Values” and approval level set to “Preliminary”.

As a signal is acquired or generated, it is then also automatically routed for display onto the web. Technologists have several methods to prevent or limit the information from going into publication. Refer to Controls on Data Publication for details.

Water level time series are composed of unit value data meant to represent instantaneous observations. The time interval between recorded unit values may be constant or variable. The programmable data logger allows the recording or sampling interval to be varied according to user-specified rules. The variable time interval can be based on the value of the parameter being recorded, the time length since the last recording, the rate of change of the parameter value being recorded, the value or rate of change of some other parameter, or some combination of these. The electronic processing system can accommodate either method of data recording: constant or variable time intervals.

Primary water level sensor data must be assigned HG as SHEF code within the station logger while secondary sensors are to be labelled HG2, HG3, and so on (Note: there is no HG1).

Refer to the list of WSC standard SHEF codes for further details.

The time system used in most field data-collection activities is based year round on local standard time, without making any change for daylight savings time. Data transmitted by telemetry requires the use of precise and well coordinated communication windows and thus has required the use of Coordinated Universal Time (UTC).

All data entry must be based on local standard time and be supplemented by information relative to the time zone that applies at the location.

3.2 Field Information

Field Information is defined as observations and measurements typically collected on Field Notes or in data acquisition software files.

Field information covers but is not limited to:

1. Stage
2. Discharge
3. Environmental conditions
4. Station health
5. Level surveys
6. Climate Data
7. Hydrometric Data; such as information from other locations

Indirect measurements, for example high and low water marks, can be entered as discrete values in the Field Visit Toolbox. The date and time corresponding to the event must then be estimated for the result to be entered. Detailed documentation relative to the nature of the value and its purpose must then be entered along with the information in the field visit, both globally for the entire Field Visit day, and specifically as an activity remark for the value itself.

The AQUARIUS database is not a repository for all of Water Survey files, but a computation database. As such, information captured on paper field notes is to be entered manually into the Field Visit Toolbox on an 'as required' basis, making sure that only data essential for computation will be available in the system. Also refer to Long Term Storage for details.

Paper field notes must be approved, scanned and filed on the Network Storage. They do not have to be stored in AQUARIUS.

3.2.1 Format, Precision and Significant Figures

The following standards are for the normal cases.

Date representation:
Year, month and day displaying all digits and followed by hour, minutes and seconds where required, displayed in 24h system.

Water level:
Observation: 0.002m
Computations and publications: 0.001m

Stream width:
Kilometres (km) to three significant figures but not more than one decimal place

Water velocity:
Metres per second (m/s) to three significant figures but not more than three decimal places

Cross-section area:
Square metres (m^2) expressed to three significant figures but not more than two decimal places

Water discharge:
Cubic metres per second (m^3/s) to three significant figures but not more than three decimal places

Water temperature:
Observations: 0.5°C

3.2.2 Datasets

Datasets are identified with the name of the variable they contain and a second label to identify their origin or purpose. This identifier is then followed by the station number (e.g. Stage.Logger@01AB003, Discharge.Working@05EA002).

It is recommended to enter a description of the dataset as this will help future operators sort through and use any available dataset during computation. It is good practice to add a comment in the DataSet Details displayed in the DataSets tab of the Location Manager.

The creation of new datasets should be limited to those approved by Data Control as required for standard computations.

Telemetry data handled by ClearSCADA will automatically create datasets to support these time series. Depending on the purpose of the station, other datasets will have to be manually created. For example, datasets for Stage Logger and Stage Working would be required at most stations. Note that Working time series is where any review and approval work is to take place, and is ultimately the source of any published data.

Some data may originate from sources outside of our standard Data Production cycle. In such case, the data may have to be brought in manually and will require the creation of specialized dataset to support it. If any alternative set is required, the need for them should first be approved by Data Control. Any dataset created will be seen along with all other sets and if not adequately planned could be a source of clutter and confusion. Standard datasets are usually defined for a station in relation to the list of data produced at this station. In particular, one should avoid creating datasets that will contain duplicates of other station data since this data could continue to evolve at the source and not be up to date in the copied version.

3.2.3 Long Term Storage

Technologists are responsible to ensure the permanent storage of raw data and field information via:

1. the upload of electronic files into AQUARIUS
2. the upload of electronic files on Network Storage
3. the archival of paper documents into Station Working File folders

3.2.3.1 Files Uploaded into AQUARIUS

Any data entered into AQUARIUS is saved and backed up automatically. Any file from which data is ingested and parsed into the Database via the Append Logger File toolbox or the Field Visit toolbox (e.g. HFC files) is also saved in its original format. All files saved in their original format can be retrieved if required.

When telemetry is complete and acceptable, the download and archiving of logger data is not mandatory. The decision to collect or not to collect the logger file during a visit is a risk managed on a site by site basis.

The availability and quality of telemetry data should be reviewed immediately prior to any station visit. If telemetry is poor at any station, the root cause for the problem must be identified and corrected and the logger data collected. If a review of the telemetry data shows that the time series is complete and adequate, any logger file collected does not have to be uploaded in AQUARIUS and only needs to be archived on the Network Storage. There is no national requirement to archive raw time series data (telemetry or logger files) locally when these were loaded into AQUARIUS.

At least one direct water level, its sampling time and a corresponding instantaneous logger value must be captured on Field Visit Notes (front sheet) as well as entered in AQUARIUS to support Sensor Reset Correction calculations.

When rapid changes in stage occur, the water level direct measurement should coincide with an archived logger reading. The peer reviewer should check that the time, date and stage value observed and written down on the Field Notes match values captured in AQUARIUS. Using logged data avoids possible live readings transcription errors, which cannot be checked otherwise. This also helps identify logger files loaded incorrectly, corrupt logger files, time zone confusion and date errors.

3.2.3.2 Files on Network Storage

The AQUARIUS database is meant to store data that is directly used in computation. However, it is not meant to function as the repository for all information gathered by Water Survey of Canada, such as ancillary measurement files, miscellaneous pictures, legal station documents, etc.

Every office must have access to space on a server properly maintained and backed up, and dedicated to the storage of station files. The information must be saved using standard naming conventions. It must be filed according to the standard directory structure.

The standard directory structure is as follows:

Final Records (transitional storage)
…\Office Name\Final Records\Station ID

Raw Data (logger files not uploaded, measurement files, etc.)
…\Office Name\Raw Data\Year

Miscellaneous Photos
…\Office Name\Photos\Station ID

Archived Records (locked)
…\Office Name\Archived Records\Station ID

Where:
Office Name is listed as per entries available in HYDEX
Station ID corresponds to the station alphanumerical identifier
Year is formatted as YYYY

With modern acquisition technologies, measurements are often composed of more than a single electronic file.

All files associated with a single measurement must always be kept together in a single folder for the information to be complete, and to make retrieval, transfer and copying of data easier to manage.

Any data file management must always be done in such a way as to preserve the integrity of the folder as a complete set of measurement information. It is the folder and all its content that represents the complete set of discharge measurement information. The folder is therefore named according to standard naming conventions.

Paper Field Notes remain the definitive information and must be easily accessible. Accordingly, all Field Notes must be scanned and saved on the Network Storage.

While not mandatory to store the scanned version of notes in AQUARIUS, it is considered good practice. The storage of notes should be done regularly but only once the data period to which the notes relate are finalized and approved.

3.2.3.3 Paper Documents

All paper Field Notes properly annotated and checked must be archived in the Station Work Files administered by each local office.

Copies of the Gauge History must be kept in the Station Work Files.

Any documentation pertaining to the station operation, such as access rights, environmental assessments, legal contracts should also be kept in the Station Work Files.

3.3 Deletions

The deletion of blatant errors in any time series must be managed within the Data Correction Toolbox, which allows a proper traceability of reasons for changes made.

No dataset is to be deleted by any technologist without prior approval by their Supervisor and Data Control representative. In particular, no raw data used in any computation must ever be deleted. No change is to be applied via the database administration functions for the purpose of deleting raw data.

Within the Field Visit Toolbox, if a blatant error is identified within any information entered, it can be deleted and re-entered in the Field Visit Toolbox only if this will not impact any future interpretation or computation work. There may be good reasons for invalid stage or discharge values to remain in AQUARIUS even when wrong. As an alternative to deletion, it is preferable to use Not Applicable (N/A) as ‘routing method’ and enter a remark beside the erroneous field. The Not Applicable routing tells AQUARIUS that the data should not be used anywhere but for display in the Field Visit Toolbox.

3.4 Sanity Checks and Discrete Value Corrections

Telemetry strings are sanity checked during decode and when data is exported from EnvironSCADA into AQUARIUS. Basic checks first remove nonsense and unworkable values. During the export, data is then submitted to Water Survey operations range checks, defined and controlled by Data Systems within the AQUARIUS manager.

Only simple corrections can be applied to Field Visit discrete values in AQUARIUS. If a more thorough editing of Field Visit data is required, it must be performed outside AQUARIUS, in the software initially used to collect the data. For example, in AQUARIUS, corrections may be required for errors in mean gauge heights, or for ADCP discharge measurements subject to a moving bed bias. Corrections that should be performed outside AQUARIUS are for example a current meter measurement where a panel width was wrongly entered and must be edited.

4 Corrections

The continuous data production system includes an automated level of corrections which uses production criteria defined and entered in a previous cycle. The automated level of production ends with the start of the Technical Review, where such production criteria are defined based on evidence (See Figure 1-1: Continuous Data Production Cycle). The Technical Review marks the start of the Value Added Level, which is a continuous cycle, performed until data is ready for final approval. A major element in this activity relates to Data Correction.

All corrections to time series must be applied within the Working signals.

Working signals are the single source of data dissemination and publication, and also the sole focus for any review and approval. While working in the Data Correction Toolbox, the data used is effectively offline until such time as it is saved back to the database via the output port.

Data displayed on the web is modified as soon as changes are saved in the Data Correction toolbox, over written with the latest changes applied.

4.1 Processing Priority

Technologists must ensure that every correction is assigned an adequate processing priority. The processing priority (priority stack) must be pre-processing, normal or post-processing. See Figure 2 below.

Within each priority stack, corrections are applied in the chronological order in which they were entered. For many corrections, this may be of little consequence since their effect often simply adds up linearly. For other corrections, the rank of application may be crucial and resulting effects cause errors hard to detect at a later stage (e.g. Amplification, Copy and Paste).

Beyond the processing priority that can be applied, a logical order in the application of corrections must be respected so that no mistake is introduced due to an out of sequence action. For example, data gaps should be filled in prior to applying any correction to time series. Gauge Correction should then be applied. Disregarded data and sensor resets should be applied last and only to normalized data.

The following sections provide details on the use of the three alternative processing priorities.

4.1.1 Pre-Processing

Apply a correction in Pre-Processing when it is meant to bring data to a common reference system, such as Gauge Corrections.

Time corrections should be applied in Pre-Processing and prior to any gauge corrections when the amount of the time correction required exceeds the sampling interval. (e.g. a time correction of 7 minutes applied to 5 minutes data)

Apply corrections introducing new data in the time series (e.g. Fill Data Gaps) in Pre-Processing when a complex array of corrections has already been applied over the area of interest (e.g. several Multi-Point Drift Corrections, Offset Corrections, etc). This way, already existing corrections will be properly applied to the newly inserted data as well.

4.1.2 Normal

Normal priority should be applied to most corrections.

4.1.3 Post-Processing

Apply corrections in Post-Processing when they are meant to validate final results with automated QA/QC measures. For example, a quality control automated correction (open-ended) could be applied in Post-Processing to delete any water level below the range considered dry at this station. In this case, all corrections would be applied prior to this reality check.

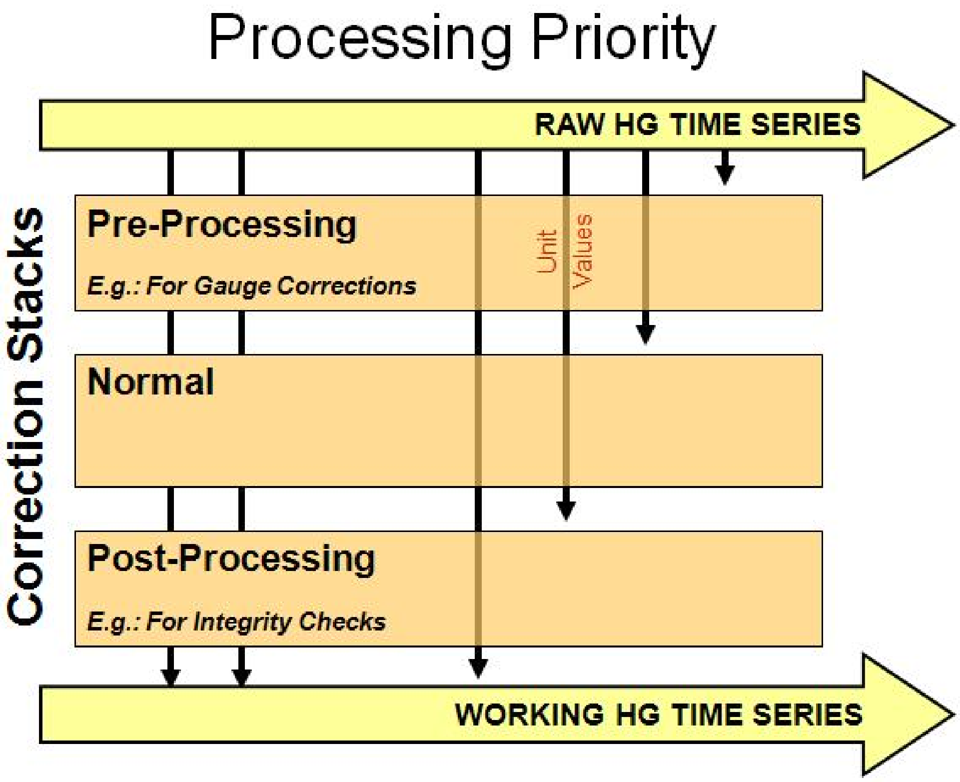


Figure 2: Data Correction Processing Priority

4.2 Projections

Projecting correction trends into the near future is an acceptable practice. Such projections can be done through the application of open ended corrections, or with corrections that have a fixed End Date set into the future (e.g. expected end of ice period).

All offsets, such as Sensor Reset Corrections or Gauge Corrections, can be applied as projections carried forward to a date just beyond the next scheduled visit.

Projections must be carefully monitored to identify limits in their application. Technologists must constantly determine if any correction should be improved and continue to apply or be terminated.

To ensure proper monitoring, any projected correction should be accompanied by a suitable notification.

For example, if an open ended Recession is applied, a notification triggered by rising temperature can inform the technologist when ice conditions are starting to change. Please refer to the section on otifications for more details.

As a minimum, using Set Note, it is important to annotate any period over which corrections are projected. These notes will later help to complete the appropriate validation of the initial interpretation and trend estimation (e.g. Set Note = "Stable gauge level was assumed. Validate during the next scheduled visit in June.")

During the automated production of provisional data, the technologist must also regularly evaluate time series to determine if the data should continue to be published while field validation is pending. Refer to *Controls on Data Publications* for more details.

4.3 Standardized Identification of Corrections

A description of every correction origin and purpose is automatically documented in AQUARIUS. This information specifically lists the time of creation, the author's identity as well as the characteristics defining the exact changes applied to the data.

The standard abbreviation SRC must be manually added to the automated remark of a correction used for Sensor Resets, and GC added for those used for Gauge Corrections. This help to quickly sort and review corrections used for those purposes.

Additional correction comments should be entered in capital letters to clearly identify that they were manually added, and be written in front of the text that was initially added automatically. Technologists are actually encouraged to add a comment describing the purpose and interpretation related to any of the corrections they will apply. Added comments can be as simple as a one word clue. For example, a comment associated with the deletion of invalid data caused by the purging of a line could simply say "PURGE". In particular, any period where more than 2 hours of data has been deleted should be annotated as described above to explain why it was done. The extra time spent on entering such information will make future data reviews more efficient.

In all cases, automated remarks describing correction details should not be altered nor deleted but only supplemented by technologists.

The following are two examples of annotations, one for a standardized correction type, and the other for a best practice situation.

Example 1:

"*SRC – Drift Correction with Calibration Drift value of -0.002m and Fouling Drift value of 0.000m*"
Here, SRC is a standard code added to identify a Sensor Reset Correction. It was added in capital letters before the automated description of the correction applied.

Example 2:

"*FLUSHED WELL – Delete Region*"
In this example, the text in capital letters and thus manually entered explains that a spike caused by the flushing of the stilling well was removed from the water level time series. The automated comment in lower case which corresponds to the Delete Region correction was left unchanged.

In addition to remarks added along with corrections, notes can be overlaid on corrected periods using the Set Note function within the Data Correction Toolbox. Such notes should be used to explain conditions that resulted in the selected interpretation and actions that were taken to fix the situation. These notes can also help to communicate and coordinate work among review teams.

Example 1:

A note states: "*Silting Orifice. Removed spikes*". The peer review and approval simply validate conclusions.

Example 2:

A note states: "*Possible ice effect. Need second opinion.*" The peer or supervisor may wish to provide an alternative interpretation or confirm conclusions prior to data approval.

4.4 Water Level Corrections

Any correction to water levels must be applied onto the Working time series. Water level corrections may be identified, developed or validated:

- As follow up to a Notification;
- Based on field information
- When back in office
- While still in the field (called in)
- As a result of reviewing time series features; or,
- As a result of interpretation which further refines the limits of previous projections

Water level data should be made as complete as possible, using all data sources and techniques available. If the water level working signal displays gaps, alternative source of water level data beside the primary signal should also be investigated to complete the information. Typically, this means that logger data will have to be used if telemetry failed. However, reasons for any missing data must ultimately be identified and addressed.

Gaps in water level time series for periods smaller than 120 minutes do not have to be filled. The need to complete these gaps must be assessed in relation to the impact they may have on the validity of daily statistics or any other products.

Different sensors may require different corrections relative to their Datum and the time series must therefore be carefully bridged together. When problems occur with the primary sensor feeding the Stage Working signal, the primary signal (HG) should not be switched to any secondary sensor (e.g. HG2) without adequate precautions.

When problems with the primary sensor are contained to past periods, secondary sensor data should be obtained from a Copy and Paste correction, which will provide good traceability and make adjustments easy. For real time operations, the working signal dataset mixing rules should be modified to use the secondary sensor, but then all ongoing corrections must be stopped, reviewed and reapplied starting at the time of the sensor change to make sure that data is properly bridged between sensors.

4.4.1 Gauge Corrections

Datum errors result from a change in the reference gauge which generally occurs over a long period of time. Datum errors are detected by running levels to the reference gauge, using stable benchmarks of known elevation. Based on this information, gauge datum corrections are then applied to recorded water level time series and field visit discrete measurements to make them consistent.

Datum errors should be carefully analyzed to determine the best method of correction. Very often, it cannot be determined when a datum error actually occurred, and the best method of correction is to prorate it uniformly throughout the period in question. If a specific time of occurrence can be defined, then the correction can be made starting at that time and carrying forward until datum is restored. The ability to detect, validate and apply datum error corrections is a driving factor in the speed at which approvals can be performed at any given station.

No approval period can be completed until the station datum error corrections have been properly validated and applied for that period.

Datum information must be routinely updated by the technologist, revised as required and reviewed at least twice a year. Results from Level Surveys, entered as a field activity result in the Field Visit Toolbox and displayed in the Location Manager Toolbox, must be considered by the technologist to determine if any gauge correction is required. If required, such gauge corrections must be applied manually in the Field Visit Toolbox on discrete water level measurements and on the water level working signal in Data Correction Toolbox. Gauge corrections must not be embedded into the logger.

Gauge corrections applied to the stage working time series will not automatically propagate to stage measurements obtained during field visits. These measurements must be corrected manually.

Gauge corrections with a departure greater than 0.003m are to be applied on the time series via the Data Correction Toolbox and in the Field Visit Toolbox for each visit covered during the impacted period, as defined by interpretation. It must be clear that the need for a correction is not defined by the departure between levelling results from visit to visit but the departure between the levelling results of a visit and the currently established elevations.

Gauge corrections are assumed equivalent to 0.000m and thus not applied when departure is smaller or equal to 0.003m.

Corrections below these departure limits should be applied only under extraordinary circumstances and for specific station needs. Beyond the use of any higher standard that may or may not be required at a given station, the most important directive is to adopt and abide to a consistent application of the datum error corrections. If required, higher standards must then be properly documented in the station work files to ensure their continued and uniform application through time.

4.4.2 Sensor Reset Corrections

Sensors may be subject to drifts or loss of calibration in their reported values. It is important to keep them in good synchronization with the value they monitor. Sensor reset corrections are used to rectify situations such as an orifice movement.

Sensor Reset corrections must be applied when a departure from the observed value greater than 0.003m has been detected.

4.5 Discharge Corrections

To properly control the application of corrections onto Discharge, technologists must understand how data production flows within AQUARIUS and acknowledge all dependencies. The most important dependency to recognize is that Discharge is based on Stage. If any change was introduced into Stage subsequent to the completion of Discharge corrections, the Discharge signal would have to be reviewed once again to make sure that the period impacted by the modifications is still valid.

Stage time series must be properly reviewed before the application of any correction onto the Discharge time series for the same period.

In line with this consideration, corrections applied to discharge data must be limited to features that cannot be addressed via water level corrections or models administered within the Rating Development Toolbox.

Correcting the Discharge time series for corrections 'missed' in the Stage time series is not acceptable.

Discharge corrections rely heavily on professional interpretation. To help review these changes, notes should accompany any correction applied to Discharge. Among other things, these notes should specify the method of interpretation (e.g., Hydrograph comparison), the reason for selecting the method over another, and any other detail that justifies the correction applied.

4.6 Best Practices

1. No change to any data should be made unless proper justification of assumptions can be provided and documented.

2. Percent Corrections, Set Interpolation Type and USGS Multi-point Drift Corrections should not be used for the correction of any Water Survey of Canada hydrometric data.

3. Amplification Corrections can be used for estimating data but should be annotated in details as it does not apply to all situations. This correction can be useful for defining a transition from zero flow to a trace flow. Equally, it is also useful for forcing discharge record to zero where a stage-discharge relationship does not apply, such as during backwater from beaver dams or ice. However, Amplification Corrections should not be used to recreate the effect of a shift as it will not generate equivalent data on peaks and lows as would be derived from a properly adjusted stage-discharge model.

4. Multi-Point Drift Corrections are used to apply linear drifting. Within Stage time series, this correction is often used to apply Gauge and Sensor Reset corrections. In Discharge Working, this correction can help refine estimated periods. Different interpolation methods can be selected (linear, cubic spline, polynomial). Linear is however the only recommended interpolation method to use for Gauge and Sensor Reset corrections between visits.

5. Revert to raw is nothing more than a new correction on the stack that undoes all of the underlying corrections. It does not impact on metadata mark-up and does not unwind the correction stack, or hence the audit trail. The primary use-case for this correction is to save time when blunders are made. The use of this correction can, arguably, provide a better audit trail relative to deleting many individual corrections. The primary risk is that it may make it 'look' like many corrections have been applied when in fact they no longer are.

6. Delete Specific Values allows a user to trim out a known specific value from a data set. For example, if a logger recorded invalid -9999 values, these can be removed and replaced with empty values. Users must however be cautioned that if another correction is later applied as pre-processing, a deleted value might reappear. As such, it is better to use Adjustable Trim corrections which can result in similar changes. Adjustable Trim Corrections delete values above or below lines defined by set values.

7. Fill Data Gaps is a correction that allows a user to fill sections of missing data in a dataset. The method of fill can be selected as copy and paste from a surrogate time series or as interpolation (linear, cubic spline, or polynomial). Using a Fill Data Gaps correction with interpolation actually results in the estimation of data and must be done to respect all related standards. In particular, estimation is generally not done on Stage time series. Estimated data must also be adequately graded. The use of this correction should therefore be restricted.

Fill Data Gaps must not be used to interpolate data other than Discharge nor be used for more than one single data gap at a time so proper grading can be applied.

8. Resample will modify data differently depending on the initial frequency of the time series. When using resample, it is not only the frequency that is important but also the start time. For example it may be desirable to have many data sets synchronized in time which is easy to do with resample. The raw data is always preserved so the correction is reversible regardless of whether you increase or reduce the frequency. There is a net ‘perceived’ loss of information if resample is used to reduce the dataset. In this situation, re-sampling is not an averaging function. There is interpolation when re-sampling is used to increase the number of points. This corresponds to an estimation which should be treated accordingly.

9. A Clock Drift Correction allows changes to original time stamps that drifted in a sensor deployed in the field. New start time and end time assigned via a Clock Drift Correction should correspond to the logger expected start and end time.

Clock Drift Corrections for anything less than 5 minutes must not to be applied in AQUARIUS but only in the logger, and be documented on Field Notes and in the station workbook. Also, do not overlay multiple Clock Drift Corrections as this may create loops difficult for the computation system to reconcile.

5 Rating Development

This section describes how to establish, adjust and administer stage discharge relationships at hydrometric stations. Theoretical details related to these procedures are available in Appendix A – Rating Theory.

5.1 Rating Development Strategy

5.1.1 Step 1: Pre-development

The first step prior to developing a stage-discharge relationship is to familiarize oneself with the gauging location and develop a working hypothesis about: (1) the complexity warranted to describe the rating relation; and (2) reasonable parameter ranges which describe each rating segment.

The technologist should review available cross-sectional surveys, photographs, gauge history, previously established rating curves and hydraulic models in order to develop a working hypothesis. In absence of a long gauging history, it is often best to formulate as simple a working hypothesis as possible about the rating relation. That is, a rating relation which is governed by a single control over the range of stage. The technologist should also determine the maximum stage range for which the rating model will be applied, stage range of transition zones (if applicable) between controls (e.g., bankfull stage), and effective point of zero flow if the rating relation is governed by section control.

5.1.2 Step 2: Review of discharge measurements

The second step in developing a stage-discharge relationship is to review all discharge measurements which will be used to derive the rating relation.

The technologist should compile and review as much information as possible regarding the measurements used to calibrate the rating relation. The following measurement attributes should be included:

- Measurement date
- Mean gauge height
- Discharge
- Control condition
- Measurement location
- Width
- Area
- Mean velocity
- Rate of change in Stage
- Technology used
- Measurement uncertainty (quantitative and/or qualitative)

The technologist should censor measurements made during variable backwater (e.g. ice or weed growth) or unsteady flow conditions for which the assumptions related to Manning's rating relation is invalid (See equation 6 in Appendix A – Rating Theory). The technologist should also censor measurements which are not representative of the current control condition. Measurements should be equally distributed over the range of recorded stage and of sufficient density to match the proposed complexity of the rating model. As a guideline, there should be at least 2 times the number of measurements as there are parameters defining the rating model unless other information can be provided to support the analysis.

The technologist must ensure that the mean gauge height is computed in a consistent method and to a common datum. It is useful to review the vertical datum history to ensure the technologist is interpreting historical measurements correctly. The technologist should ensure changes in technology and/or methodology over the measurement history do not confound interpretation of the applicable rating model. Historical measurements which are not used for defining the contemporary rating may still help guide the technologist in defining the complexity of the rating model and shape parameters.

The technologist should also review all measurements which have substantial influence on the shape of the rating relation. These are typically at the extremes (high and low end) of the rating relation. The “high leverage” observations should be reviewed to ensure they were conducted using standard procedures for the measurement method used. If the technologist notes that the standard procedures were not used, they may attempt to account for systematic bias due to the measurement method when fitting the rating model.

5.1.3 Step 3: Estimation of rating parameters

The third step in developing a stage-discharge relationship is to estimate the C, h_o, b parameters of the rating equation for each rating segment identified in the hypothesis.

Refer to the Equation Parameters section in the Appendix on Rating Theory for a description of these parameters. The definition of the rating equation, defined as $Q = C(H - h_o)^b$ involves: (1) identifying the stage range dominated by a single control; (2) adjusting the effective gauge height for zero flow to form a straight line between effective depth (H-h_o) and discharge in logarithmic space; and (3) fitting a straight line through measurements defining the rating segment by least squares or manual fit to estimate the remaining rating parameters (*C, b*).

Defining the stage range over which a single control dominates the rating relation can be difficult in the case of a compound control, especially when sparse and irregularly distributed measurements define the rating relation. Care must be taken not to include measurements which may be in transition between controls or representative of a different rating segment as inclusion will distort the estimation of the true value of the gauge height of zero flow. Review of cross-sectional surveys of the control reach will help to judge which measurements should be attributed to each control. There must remain sufficient measurement density in order that individual measurement uncertainty does not impact interpretation of the rating model.
At least six measurements should define any stage-discharge relationship segment.
If that is not achievable and there is no justifiable reason (e.g., channel surveys), it is advisable revisit the working hypothesis.

The effective gauge height estimated for each rating segment must be lower than the lowest point defining the rating segment otherwise the rating equation will be undefined.
If h_o is too low, the plot (Q vs. H-h_o) will appear concave up (Figure 1a). If h_o is too high, the plot (Q vs. H-h_o) will appear concave down (Figure 1b). Once the measurements plot as a straight line in log-space, then the other two rating parameters (C, b) can be estimated through least-squares regression or manual fit.

The resulting rating model should respect the underlying assumptions of regression as much as possible. That is: (1) the sample is representative of the underlying population being predicted; (2) the errors are random with a mean of zero; (3) mean gauge height is measured with no error; (4) the errors are uncorrelated; (5) the variance of the error is constant.

The residuals (deviance of measurements from predicted values) are a useful analysis to judge the goodness-of-fit of the rating model. Discharge residuals plotted by observed discharge, measurement date, or even calendar day of year can be informative of how well the rating model predicts the observed data (Figure 2). Residuals should be independent and identically distributed exhibiting no trend with time or increasing stage. Although residuals can be a useful tool for evaluating model fit, the technologist should exercise caution in interpreting the results. Trends in residuals may result from change in sampling strategies rather than a shift in control for example.

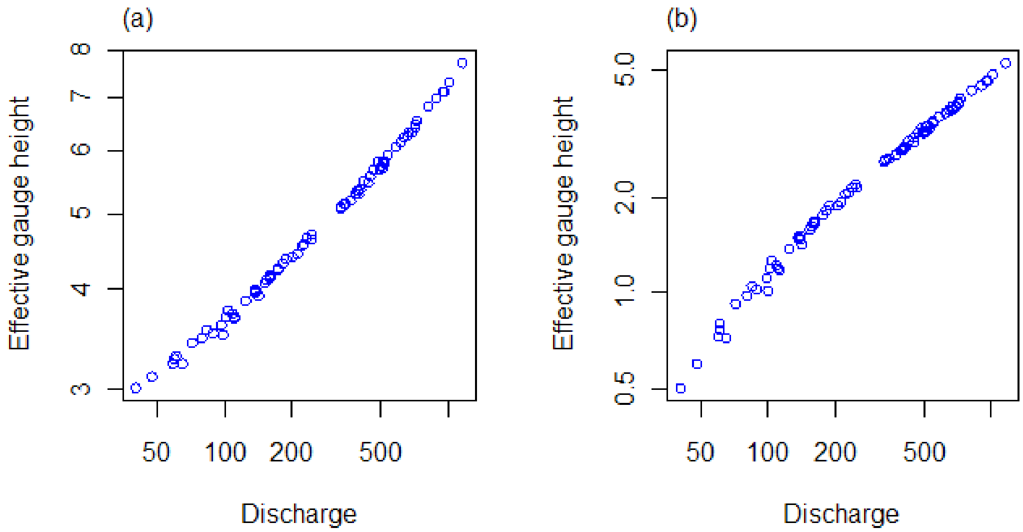


Figure 1 Adjustment of effective point of zero flow: (a) the value h_o is too low; (b) the value h_o is too high.

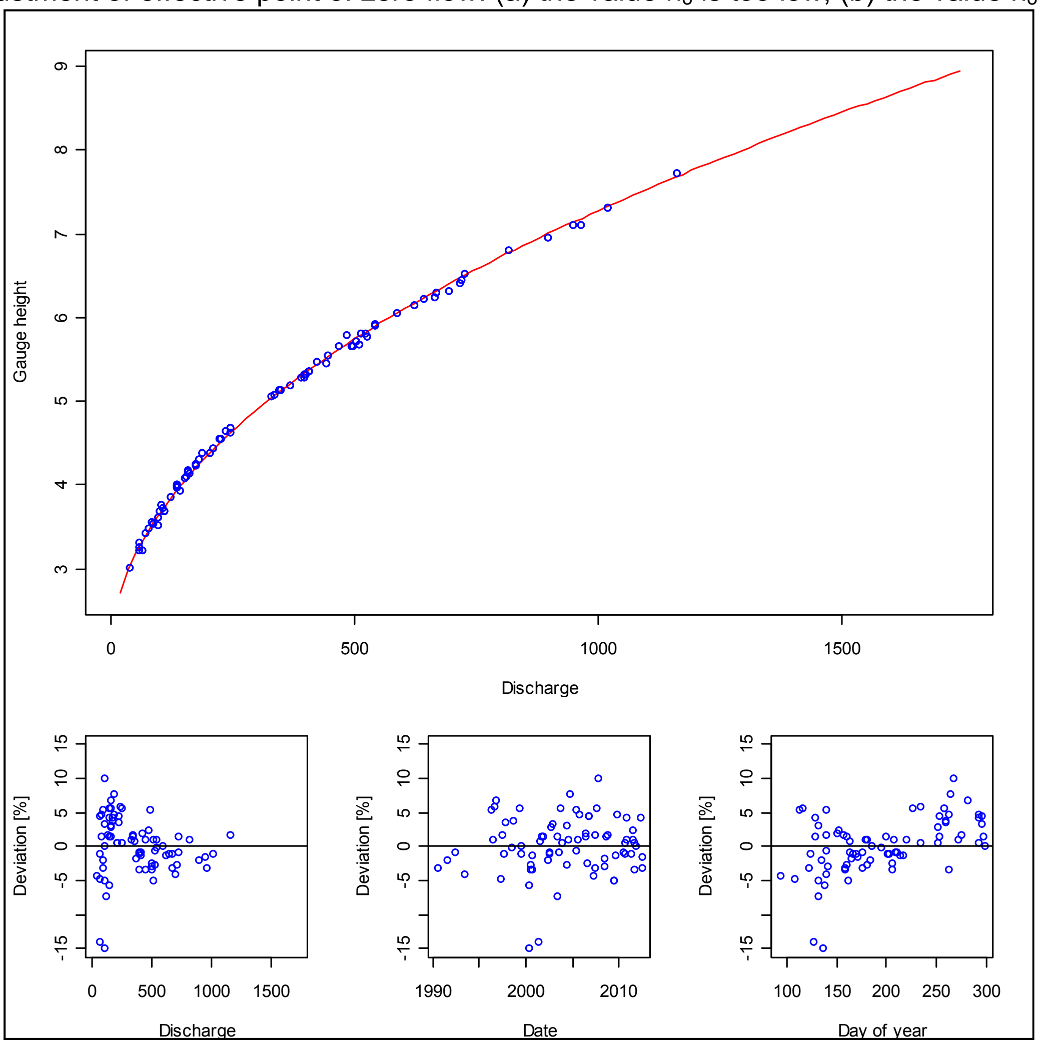


Figure 2 Example of rating relation with discharge residual plots by (a) discharge; (b) observation date; and (c) calendar day of year.

5.1.4 Step 4: Develop transitions between rating segments

The fourth step in developing a stage-discharge relationship is to define the transitions between rating segments.

When the rating relation incorporates more than one control, a transition between each segment corresponding to the controls will be required. Subjective interpolation is recommended to fit the rating relation over the transition zone. The level of complexity describing the rating relation through the transition zone should be directly related to available information.

5.1.5 Step 5: Develop rating extensions

The fifth step in developing a stage-discharge relationship is to adjust the range covered by it.

In most cases, the peak measured discharge will not coincide with the peak recorded stage value. This usually necessitates extension of the rating model. Uncertainty in the estimation of discharge for the curve extension is directly related to uncertainty in parameters of the rating relation.
For the upper end, the rating relation should not be extended beyond twice the highest measured discharge defining the rating relation. It must also not be allowed to go above bankfull.

The rating relation may be subject to further changes in control at extreme low flows, such as a local riffle or boulder nearby the stage sensing device.
In the lower end, the rating relation should not be extended below half the lowest measurement.

Subjective extrapolation of the high or low flow rating to account for changing control conditions may be necessary. Such extrapolation may then be subject to large uncertainty.
Sections of the stage-discharge relationship beyond the recommended minimum and maximum extrapolated range must be graded as Estimation.

It is not possible to plot zero in a logarithmic scale. Stage values actually dropping to the point of zero flow or beyond, such as stations with stagnant gauging pools when flow goes towards zero, would create mathematical impossibilities to represent their output.
Observations where the flow is below the detection limit (< 0.001 m^3/s) but have a detectable stage can be ascribed an arbitrary value less than the detection limit (set to 0.0001 m^3/s) for plotting in log scale.

Another method to handle very low flow is to estimate it based on D'Arcy's Law which predicts flow through saturated media:

$$Q = wks$$

where w is the effective width of the gauging pool; k is the saturated hydraulic conductivity based on the channel bed; and s is the channel slope

5.2 Review and Validation

As a general rule of thumb, there should be at least 2 times as many measurements as the degrees of freedom in the rating model. For a rating model with single control (three degrees of freedom), there should thus be at least six open water measurements used for calibration.

The rating model should not extend beyond 2 times the highest measured discharge while not being allowed to go above bankfull. The rating model should also not extend below half the lowest measured discharge.

Rating curve validation can become complicated by limited number of samples defining the range of observed stage and representative of the current control state and non-uniform measurement uncertainty. As explained before, examining plots of discharge residuals can offer insight to the stability of the control over the rating period or the suitability of the calibrated model to describe the true rating relation (Figure 2). Again, some caution must be taken when reviewing residuals plots to ensure that the pattern of residuals is not affected by the sampling program or non-uniform weighting of measurements during the calibration process.

The resulting rating model should respect the underlying assumptions of regression as much as possible. That is: (1) the sample is representative of the underlying population being predicted; (2) the errors are random with a mean of zero; (3) mean gauge height is measured with no error; (4) the errors are uncorrelated; (5) the variance of the error is constant.

Performing the peer review of a calibrated rating curve is an essential step.

1. Is the derived model based on sufficient information and justifiable assumptions?
    a. Does the model abide by the assumptions of regression?
        i. Errors are uncorrelated, exhibit no trend in magnitude or time
    b. Can model parameters be uniquely defined or could other values provide equally good fit to data?
    c. Are there alternate model structures (different number of segments) that cannot be ruled out?
2. Are the selected measurements appropriate and reflective of current control conditions?
    a. Should other “valid” measurements be included in the model development?
3. Does the rating curve model adequately cover the expected range of stage? If curve extrapolation is conducted, is the method appropriate?
    a. Was the method used for extrapolation appropriate?
    b. Can the extrapolated segments be independently confirmed with an alternate method?
    c. Are there sections of the rating that should be graded with an E?

5.3 Shifts

The validity of the stage-discharge relationship is verified every time technologists visit a station and obtain a referenced water level and discharge measurement. When the base rating is stable, measurements plot within 5% of the rating. However, many factors can affect the stage discharge relationship and require its adjustment. Examples are backwater due to beaver dams, weed growth or ice and scour or deposition in the channel. In those situations, shifts are then applied to the stage-discharge relationship. Shifts are temporary adjustments to base rating that apply until the cause for the change has receded or been confirmed as permanent and a new rating is developed.

When a specific shift is selected (highlighted) in the Shift Manager, right clicking on a measurement displayed in the time series graph will display information relative the difference between the measurement and the shifted curve using that shift. Looking at the Shift Error % column in the Field Visit Table will also display this same information for any measurement.

The application of a shift must be considered if a measurement is departing from the base rating by more than 5%. To decide whether a curve should be shifted or modified, technologists should also look at the current and previous year hydrographs to identify trends between the measurements and curve.

Some specific information on the conditions that may have induced change must then be gathered. The technologist tries to define a scenario about the intensity, range and duration of changes that affected the section and channel control, and their influence on the stage-discharge relationship.

a. What may have caused the measurement to plot off the curve?
b. How long has the condition likely affected the rating?
c. What sections of the rating are likely to be affected by the change?
d. Is the change stable or varying over time?

In addition, the following information can serves background for the interpretation of required changes:

- Current year and historical discharge measurements and their departures
- Shifts previously applied
- Temperature and precipitation data
- Historical hydrograph (station typical reaction to events)
- Comparison Hydrographs
- Pictures of control and channel conditions.

This information, to be documented, serves as justification for the design of the most appropriate shifting scenario for the rating model. A shift scenario can employ several different single point shifts or knee bend shifts. Once a justifiable scenario is developed, it is relatively easy to then apply the different ingredients required to reach the desired conclusions. The range over which the shift must apply to the base rating dictates the type of shift to be applied. Variations in the intensity of shifts over time are controlled via the way a period of application is assigned to the shift and will be described later in this document.

Example of Shift Scenario

In the scenario shown in the diagram below, a high water measurement on April 12 produced a shift of +0.054m. The May 9 measurement produced a shift of +0.037m. By using these two measurements to create a knee bend shift and applying it over the time period March 20 to June 4, certain assumptions are being made.

Diagram 6

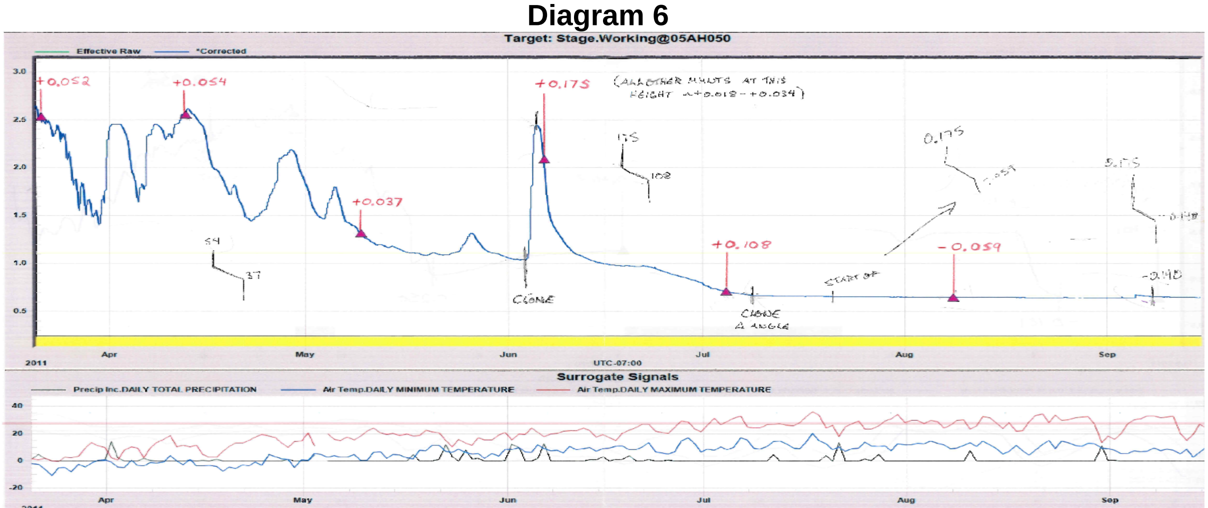


Diagram 7

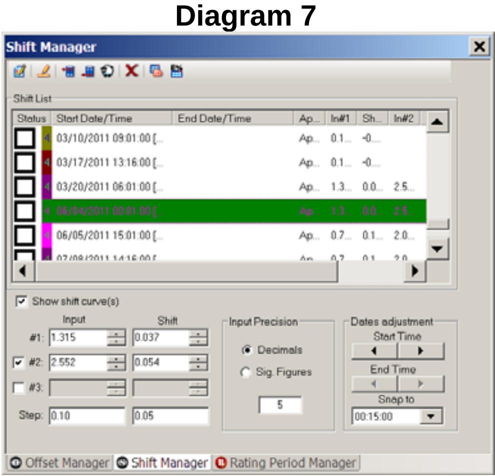


Diagram 8

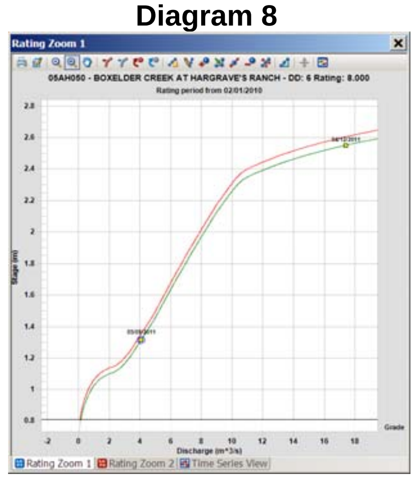
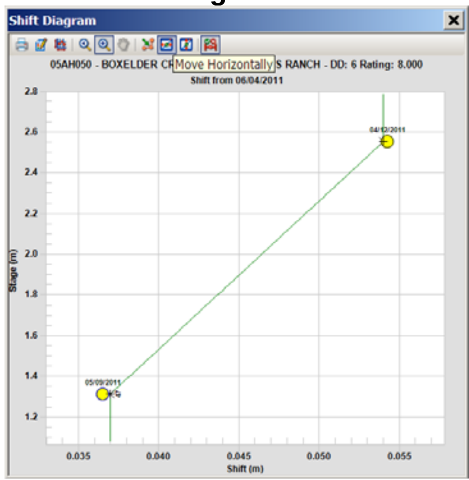


Diagram 9



1. The rating has changed; at a gauge height of 1.315m and lower there is a departure of +0.037m from the base rating and at a gauge height 2.552m and higher there is a departure of +0.057m. The shift is linearly distributed between two known points, as shown in Diagram 9.
2. Because the shift was applied between March 20 to June 4, these conditions are considered stable. There are two methods that can be used to maintain stable, consistent conditions (i.e. No shift blending). One method is to set an end date. The second method is to clone the March 20 shift and input a date of June 4 on the cloned shift. Either method produces the same results – stable shift between March 20 and June 4.
3. As the stage increases and decreases throughout this period, the software uses the shifted curve to obtain the discharge values. In this scenario, higher stages have a higher positive shift (i.e. +0.054m) and low stages have a lower positive shift (i.e. closer to +0.037m).

In referring to Diagram 6, June to August period, two knee bend shift are applied but the value on the bottom of the curve are the only values to change. This scenario makes the assumption that if the water level gets up to the upper end of the rating it will always have this shift of +0.175m but the lower end goes from +0.108m to -0.059m.

Diagram 10

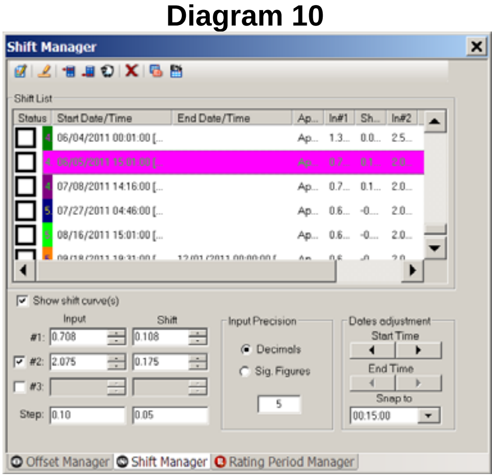


Diagram11

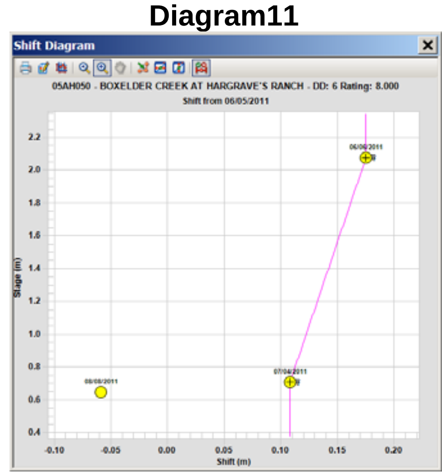


Diagram11

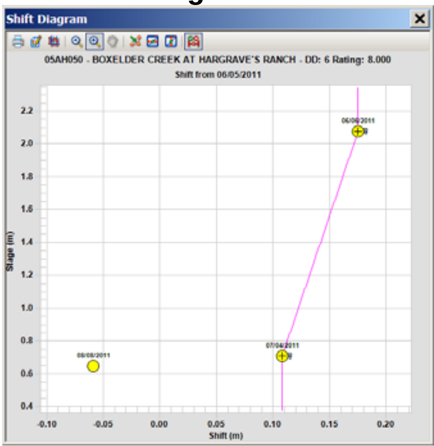
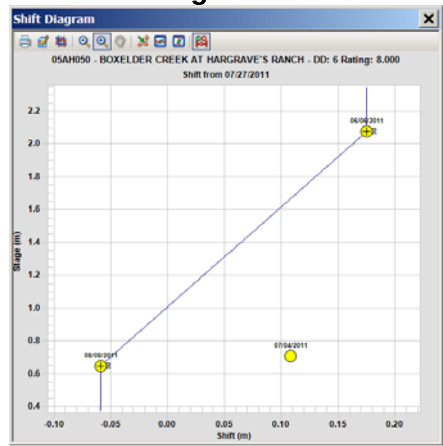


Diagram 13



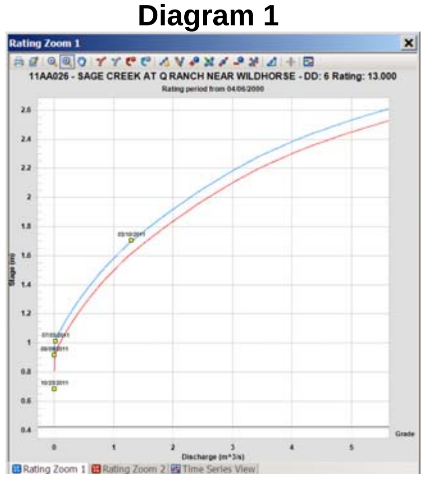
It's important to note that the technologist has to make a proper interpretation about the start and end of shifts. In the above example, the actual water level did not go back above 1.0m, towards the upper range of the rating and therefore the use of a knee bend shift was not necessary. Straight lining a series of one point shifts through this period would have given very similar results. However, it is important to understand that using a knee bend shift respected the assumptions made in the initial scenario and if the stage ever did go back up to that range, an adequate shift would have still been applied. This notion of implementing shifts justified by a solid scenario is especially important for the application of shifts during real time data production.

5.3.1 Shifts constant over the entire range of stage

When the departure from the base rating is assumed to be constant for the entire range of stage for the stage-discharge relationship, a single point shift must be applied. Such shifts require the input of only one value for a gauge height and one value for the discharge difference against the base rating (shift). The value of intensity, defined as 'shift' in the Shift Manager is derived from the field visit measurement and the interpretation of the presumed cause for the shift.

The value for stage (defined as the 'Input' in the Shift Manager) should be set to the assumed point of zero flow for the curve to be shifted (defined as 'Offset 1' in the Offset Manager). Entering such value will help approve shifts later in the production process by bringing all displayed values in their proper stage context.

Diagram 1



5.3.2 Shifts varying with Stage

When the departure from the base rating is assumed to vary with stage, affecting the various sections of the stage-discharge relationship differently, then a knee bend shift must be applied. Such shifts require the input of two sets of values for gauge height and discharge difference against the base rating (shift). The input of three sets of values to create a stage varying shift is rare but can be done. The values used to define the knee bend shift are derived from the field visit measurements as well as interpretation based on the presumed cause for the shift and the assumptions made for the different segments of the stage-discharge relationship.

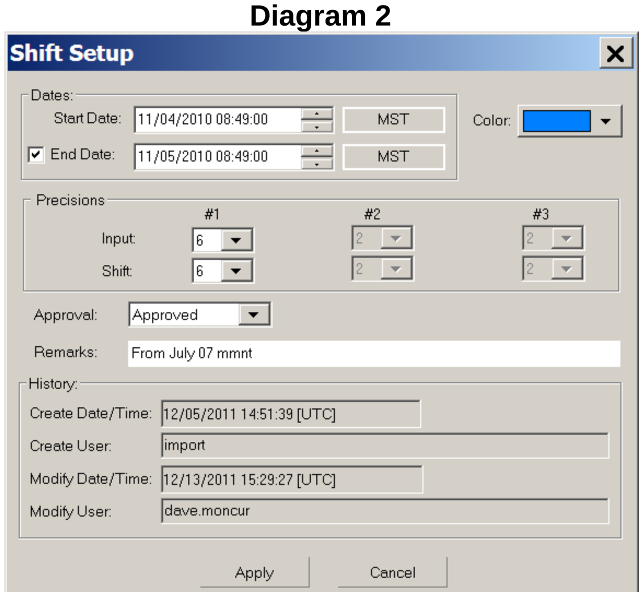
In general, there tends to be more stability on the upper end of the rating where the influence of channel control is predominant. It normally takes an extreme flow event to alter the channel geometry at higher stages. The lower end of ratings on the other hand is the portion typically defined by section controls and is more susceptible to scour or deposition. Typically, the lowest input value will be set to represent the highest shift intensity and the stage where a transition between a section control and a channel control occurs. The second and highest input value is then likely to correspond to the stage where the shift intensity is zero and merges back into the original curve. Defining the intensity of a required shift is generally derived from recent measurements but this intensity can also be based on historical observations, such as annual weed growth.

Knee Bend Shift should be preferred over One Point Shift whenever they are likely to represent the expected change to a rating at all possible stage. This way, the production of Q will adequately adapt to any condition in real time to produce the best provisional data possible.

5.3.3 Shift intensity pro-rated over time

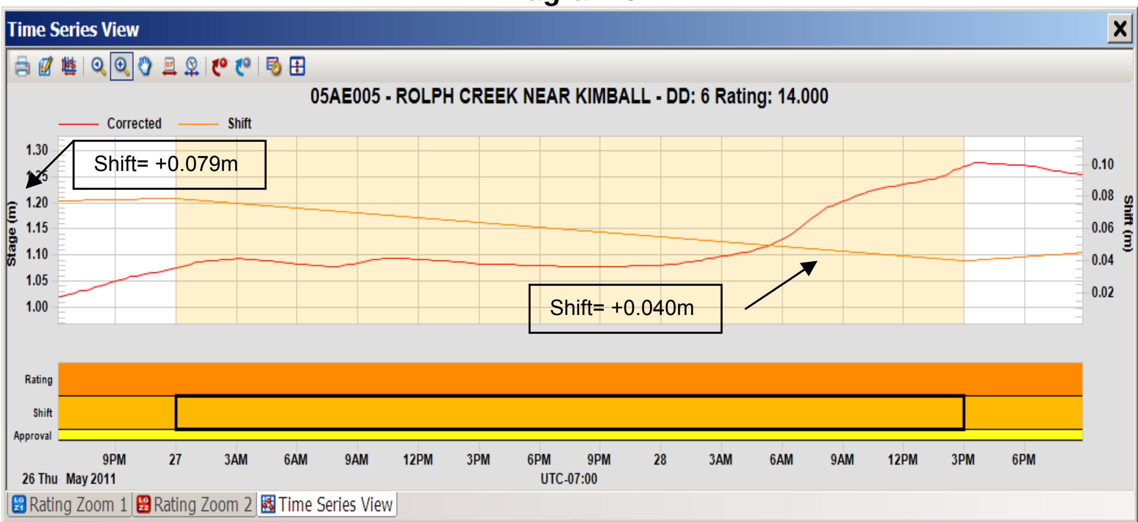
By either entering an “End Date” to any shift, the assumption is that the change to the rating is constant and stable over the defined time period.

Diagram 2



When the period of application for a shift is left open ended (No end date defined), the shift either (a) will remain constant indefinitely, or (b) will blend linearly into the subsequent shift over time (time based shift). A shift blends over time starting at its full intensity to gradually merge into the subsequent shift. In the Time Series, utilize the “Time Slider” function to get a graphical view of how the shift is being applied over time in the Shift Diagram. In the Stage time series view, you can also see a representation of how the shift varies over time as well. For example, in Diagrams 3 below, the intensity of the shift is graphically illustrated. It shows how two single point shifts (first one set to +0.079m, second one set to +0.040m) merge linearly over the time interval separating them. Here, the first shift was simply assigned no end date which told the system to gradually merge it into the value of the second shift. The same concept applies to knee bend shifts where the intensity of the shift may vary with stage for any given moment but will also merge linearly into the next shift if it is assigned no end date.

Diagram 3



5.4 Rating Development Methodology

Prior to developing the rating curve, the technologist will want to ensure that you the measurements to be used to define the rating were imported. *The steps below are used to create any rating segment.*

5.4.1 Pre-Curve Planning

The purpose of pre-curve planning procedures is to review historic and contemporary measurements to develop a working hypothesis about the nature of the rating model applicable for the gauging location.

1. Determine the stage range over which the rating relation is to be applied. The curve developed must at least include these extremes.
   - Within RDT, use the Time Series View and zoom in to identify the extremes (highs and lows) observed historically in HG.
   - Alternatively, determine these values within DCT or QuickView.
2. Determine the predicted point of zero flow.
   - Look at water levels associated with measurements in the Field Visit Table of RDT. Treat zero flow measurements with special attention, based on conditions at gauging reach. Be careful with observations from completely dry reaches as they may not be representative of the rating relationship.
   - Look at the lowest points in water level trace in DCT. This will provide an upper limit for the effective point of zero flow.
   - If possible, level survey the lowest point on the control during a field visit to provide further guidance to the identification of the point of zero flow.
   - Analyze old rating curves to identify points of zero flow used in the past.
   - Note that the point of zero flow will be further refined and confirmed when cycling through different offsets values during the development of rating segments.
3. Determine the zone of transition between the channel control and the flood plains.
4. Identify the elevations at which other possible influences on the control, such as changes in friction coefficient or geometry, may take effect between the upper and lower flow limits.
   - Analyze pictures of the control taken during visits at different water levels.

- Review level surveys conducted over the control cross-section. Alternatively, review discharge measurement cross-section profiles if these can be assumed similar to the control cross-section. Try walking on and around the control during visits, to understand where constrictions would be located as flow rises.

5. Develop a model working hypothesis.
   - List the expected number of control segments.
   - For each segment, describe the most likely:
     - Type
     - Shape
     - Stage range
6. Identify measurements that will best describe the current rating relation being modelled.
   - Censor measurements which do not reflect the current control condition.
     - Overlay previous curves to review where changes occurred and identify the dates for the last control altering events.
   - Censor measurements made during variable backwater (e.g., ice or weed growth) or unsteady flow conditions for which the rating relation is invalid.
   - Review high leverage measurements to ensure that they were conducted using standard procedures.
     - High leverage measurements are those likely having a substantial influence on the shape of the rating relationship. These are typically at the extremes (high and low end) of the relation.
     - If the hydrographer notes that standard procedures were not used, they may attempt to account for systematic bias due to the measurement method when fitting the rating model.
     - The hydrographer should also evaluate technologies and techniques used during the measurement program as they may confound the interpretation of the rating model. Knowledge of the location of measurement will help to group measurements taken at similar locations to analyse hydraulic geometry relations, if necessary.
7. Document all decisions made as supporting evidence.
   - Measurements to be selected or rejected
   - Pictures of control
   - Known physical changes applied to controls
   - Level surveys of control cross-section, transition zones and point of zero flow

5.4.2 Rating Curve Development

Any change to a rating curve model, such as the addition or modification of any rating point or offset, results in what is considered a new curve.

Always try to best fit the lowest control segment first and any higher range control features substantiated by field data next. Work from what is known towards where there is uncertainty or lack of information.

5.4.2.1 Initial Setup

1. Within Rating Development Toolbox, under the File section, select New.
   - Enter a Rating Number as per naming conventions.
2. In Setup
   - Select Rating.
     - Change the approval level to Preliminary.
     - Enter remarks relevant for the curve purpose.
   - Select Precision
     - Set it to 4 decimal places, which will help fine tune parameters during development.
3. Select measurements to be used to define the curve, as identified during the Pre-Curve Planning. Highlight only the measurements to be used over the period of interest as this will allow better scaling and reduce confusion.
   - In the Time Series View, zoom to the period applicable. Using the selection tools, turn on or off any measurement as desirable. Measurements not retained are grayed out.
   - Within the Field Visit Table, review the measurement list. Select or deselect any of them as desirable. The help with the selection, sort measurement by any feature listed in their associated columns.

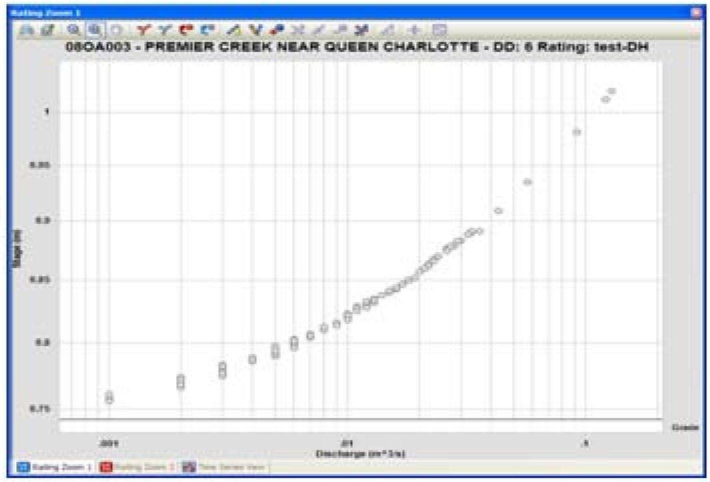
- You can color code measurements within the Field Visit Table to further help rating development decisions.
- Note that not all of the measurement information is transferred into the Field Visit Table. It is good practice to refer to the original field notes.

4. Within the Offset Manager
   - Enter a value slightly lower than the expected point of zero flow, as a starting point.
   - Ensure that the Plotting Offset Control is set to use Offset 1 as Single Plotting Offset.
   - Set the Offset Step to 0.010 for the initial adjustments. Reduce the steps later for fine tuning work.
5. Select Auto Scale in the overview window to zoom back to the data. Data will reappear in graphs. Alternatively, under Setup, turn the Automatic Rating Scale on, which will maintain the feature constantly active.

5.4.2.2 Section Control Fitting

The following procedures apply for the definition of new rating segments or the editing of existing ones. Controls are defined by a linear relationship between two rating points in log-log space and are characterized by a single offset.

1. Determine the best fit offset
   - In the Offset Manager, select Offset 1 which is typically understood as the point of zero flow.
   - Adjust the offset iteratively. Start to increase and decrease the offset value with the scroll button until all measurements fall along a straight line.
     - If the defined offset is greater than the best fit, then data will plot concave down. If the defined offset is smaller than the best fit, then data will plot concave up.
     - For finer detail, adjust the increment value (Offset Step) in the Offset Manager to 0.001.
     - Note that this method assumes a measurement sample that is a good representation of the control segment.



2. In Rating Zoom 1, place rating points at the extremities of the control segment.
   - Add a rating point below the lowest measurement and above the highest measurement thought to define the control segment under investigation.
     - Select the Add Rating Points from the Rating Zoom toolbar.
     - Select Move Rating Points from the toolbar to line up the rating developed with the selected measurements. Also influence the choices of rating point location based on the hypothesis defined during the pre-curve planning, taking into account the perceived transition zones.
     - Do not locate the upper rating point too far above the highest measurement considered to represent the control segment, as this will later help produce a smooth transition zone.

5.4.2.3 Upper Controls Fitting

The following procedures relate to control segments other than the section control. The Aquarius software will not allow users to develop more than 3 independent controls. Control segments are separated by transition zones, which can only be defined empirically.

1. Determine the best fit offset for the control segment being defined
   - In the Offset Manager, select Offset 2 or 3. Offsets related to channel controls do not correspond to any physical feature.
   - When selecting a second offset, a breakpoint is automatically created. Its location is defaulted on the lowest rating point. Breakpoints are defined to help display multiple relationships using different offsets in log-log space. Information above breakpoints will be displayed according to the second offset.

    - o To adjust the position of the breakpoint to correspond to a rating point below the stage range studied, select the up-down arrow in the breakpoint section and then hover the breakpoint line to drag it into position. Alternatively, use the scroll buttons in the Offset Manager.
    - o Breakpoints correspond to specific rating points. Rating points selected as breakpoints can no longer be moved during the definition of the control relationship. These rating points defined as breakpoints are greyed out within the Rating Table, which indicates that they cannot be modified.
    - o Breakpoint 1 is associated to Offset 2. Breakpoint 2 is associated to Offset 3.
  - Adjust the offset iteratively. Start to increase and decrease the offset value with the scroll button until all measurements fall along a straight line.
    - o If the defined offset is greater than the best fit, then data will plot concave down. If the defined offset is smaller than the best fit, then data will plot concave up.
    - o For finer detail, adjust the increment value (Offset Step) in the Offset Manager to 0.001.
    - o Note that this method assumes a measurement sample that is a good representation of the control segment.
    - o Note: If you wish to see all control segments plot in a straight line, select the 'multiple offset' option within the Offset Manager. Again, each section will be defined by the offset selected. Keep in mind that this is a display feature only. It might now represent the rating as a discontinuous line.
2. In Rating Zoom 1, place rating points at the extremities of the control segment being defined.
  - Define the range of the expected transition zone between control segment developed.
    - o Select the Add Rating Point in the toolbar and place a point near the upper end of the transition zone, where the next control is expected to start.
    - o As good practice, place another temporary rating point near the middle of the expected transition zone. Locate a breakpoint on this middle rating point. This will provide additional flexibility while developing the upper control section.
  - Add a rating above the highest measurement thought to define the control segment under investigation.
    - o Select the Add Rating Points from the Rating Zoom toolbar.
    - o Select Move Rating Points from the toolbar to line up the rating developed with the selected measurements. Also influence the choices of rating point location based on the hypothesis defined during the pre-curve planning, taking into account the perceived transition zones.
    - o Unless there are measurements to indicate otherwise, do not locate the rating points too far above or below the highest and lowest measurements considered to represent the control segment, as this will later help produce a smooth transition zone.

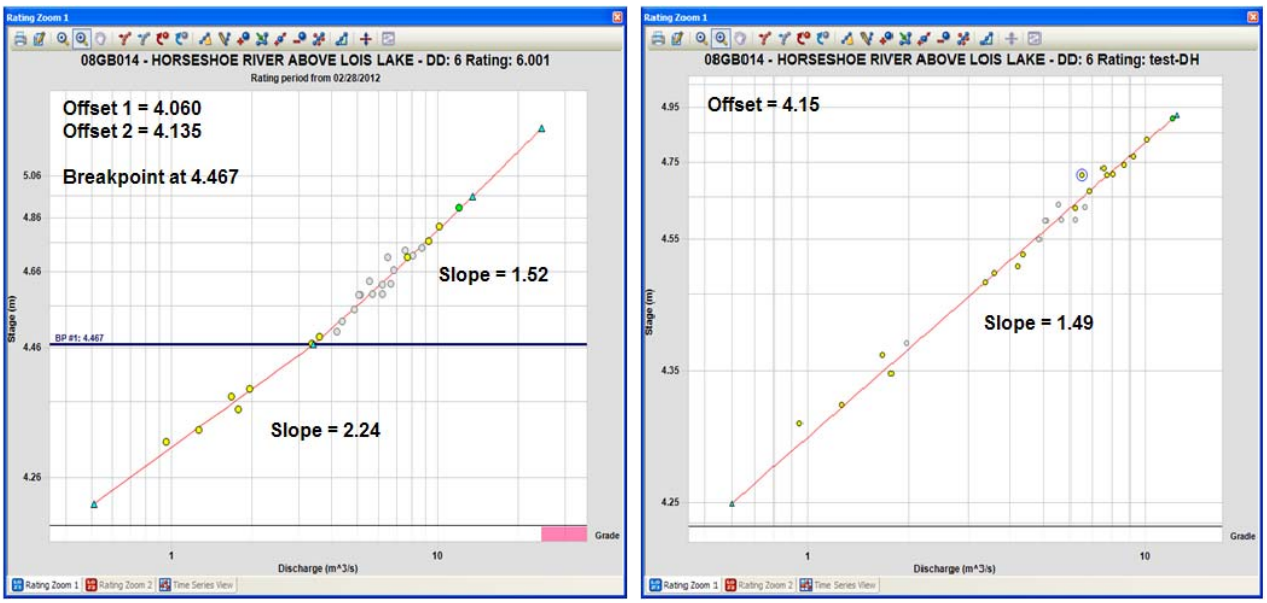
5.4.2.4 Transition Zones

1. Transition zones are stage ranges over which more than one control might be governing the rating relation. These regions are a mix of influences and cannot be calibrated but only estimated using multiple rating points to capture information provided by discharge measurements, interpretation from photographs of the control and channel reach, level surveys of control features and transition areas.
  - Blending is not desirable when no information to substantiate it or if an abrupt change in the control features is suspected at the transition.
    - o Ratings should not be over defined based on limited information. Breaks in curves indicate that more information is required for defining these zones.
    - o Blending should not be done for single controls, where this translates in the use of more than 2 rating points to account for deviations in the discharge measurement sample. Such deviation may show that the control is still ill defined, or that a shift is required.
  - Blending might be appropriate when there is no reason to expect an abrupt change between defined controls.
    - o Basic blending of controls is achieved by first making the zone as large as the uncertainty in available information permits. Transition zones should be defined as large as possible. This will help more smoothly join the well defined controls segments.

- o The simplest transition, using the fewest number of rating points possible should be defined. When there is little information, transition zones may require focused calibration field campaigns to help define them empirically.

5.4.2.5 Initial Review

1. Determine if the initial model hypothesis can be successfully applied
   - Verify if the number of control segments required to cover the entire range of stage is adequate.
     - o If the number of independent control segments separated by transition zones cannot be justified, as indicated by calibration discharge measurements, reduce the number of control segments accordingly. This translates in the deletion of rating points.
     - o If measurements do not fall in a straight line, a second offset might be required to account for the change in physics of the channel. Introduce more complexity by adding a segment. When working on the section control, this means lowering the position for the rating point down to the next suspected transition zone, effectively grouping a smaller number of measurement points in the lower section, and hopefully helping to more easily fitting data over a straight line.



Example of model misspecification leading to the development of multiple rating segments

   - Further investigate measurements selected that appear to be outliers
     - o Review procedures applied to determine if values could be suspect.
     - o Within the Field Visit Table, evaluate if the rating points and offset produce the best fit in Rating Errors for measurements selected.
     - o Try to obtain an even distribution of measurement positions around zero in the Shift Diagram.
     - o Note that the Shift Diagram displays values for the independent variable (i.e. Stage) and not the dependant one (i.e. discharge). Proportions are thus not maintained between the lower and upper values. The diagram can only be used as guidance to ensure a balanced distribution of results, but not for adjusting the intensity of errors across the range of values.
   - Review the rating curve equation in the Rating Table to confirm that the Slope is within the physical range for the type of control considered.
   - If any change to the initial hypothesis are warranted
     - o Review the documented hypothesis.
     - o Return to step 1 until satisfied.

5.4.2.6 Documentation

1. Document information that served as basis for the rating developed

- Final hypothesis
- Range of influence for each of control segment defined
- Curve specific comments can be added in the remarks field under rating set-up. These should be limited in scope and should be descriptive of the curve (i.e. Rating #2 coincides with Rating #1 at and above 1.0M.)

5.4.3 Extension of Curves

Extensions are required when the range of stage initially used to define a curve is exceeded.

To create an extension, first clone the curve and assign it a new number as it will be a new curve once approved.

- Remember that if a curve must be extended beyond the accepted limits (relative to highest and lowest measurements), the range beyond those limits must be graded with an E for Estimation.
- It is recommended that extrapolations be defined based on at least 1 supporting independent flow estimation method to corroborate the extension.

5.4.3.1 High End Extensions

Any historical measurement in the upper end of a rating should be weighted positively when developing a rating.

1. Do perform an upper end extension, select the Extend Rating Line icon. This adds a black rating point at the upper end of the rating curve.
   - Click and drag the point up to the stage and discharge range desired for the extension.
     - As long as it is shaded black, the extension rating point will only move on a straight line defined by the previous control segment in log-log space. If the control geometry and channel rugosity remain fairly constant, then a straight-line extrapolation is reasonable.
     - As previously mentioned, the extension should not exceed twice the value of the highest measured discharge without appropriate grading.
2. Once satisfied by the extension, delete the rating point which was previously the upper limit for the highest segment.

5.4.3.2 Low End Extensions

Curves cannot be extended all the way to zero. Rating points cannot be located right at the point of zero flow. A value slightly higher (Q=0.0001 recommended) should be used when Discharge must be derived below detection limits. An automated correction can then be applied to the Discharge time series to set it to zero if required.

- In the lower reaches, remember that curves cannot be extended below half the value of the lowest measured discharge without appropriate grading.
- The lowest zones must be flagged and reviewed to confirm any actually equal to zero or below detection.
- The offset for the section control segment should be slightly higher or equal to the point of zero flow if this information is available.
- To expand the rating
  - First note the equation for the lowest control segment from the rating table.
  - Using Insert Above in the Rating Table, enter a new rating point.
  - Compute the new rating point coordinates using the section control equation noted.
    - If working with an estimate of the desired stage, compute the expected discharge as [C*(Stage-Offset)^Slope]
    - If working with an estimate of discharge, compute the expected stage as [Offset+(Discharge/C)^-Slope]
  - Enter the new rating point coordinates.
  - Once satisfied by the extension, delete the previous lowest rating point if the extended area is considered to be still part of the pure section control.

- If there is evidence that the section control no longer applies in the lowest stage, then consider the area near zero flow as a transition zone. The previous lowest rating point must then not be deleted. Rating points defining the transition zone are then adjusted to represent information available. The transition zone remains bounded by rating points at the upper and lower end, understanding that the lower point cannot be on zero since the software does not allow it (Q=0.0001 recommended).
  - DRY periods of records must be managed with overrides applied onto the Working-Discharge Time-Series. Stage data may vary within the gauge pool while Discharge is either below detection or zero for dry spells.

5.4.4 Rating Period

Technologists creating new ratings are responsible to recommend a start date (for the Rating Period) to their supervisor based on the hydrologic features which triggered the need for the new curves.

- The period of applicability of a new curve must be left blank until enough measurements have been collected to define the curve and for the supervisor to be satisfied with the results for the purpose of provisional publication of discharge data.

New Rating Periods must be defined for and aligned with each Approval Period. A single curve thus will have multiple periods. When any period is approved, the period of data becomes locked, which prevents changes to approved data.

- If the approval level is increased for a rating period (e.g. from Reviewed to Checked), all shifts affected during that rating period are increased as well, thus saving the time that would be required to individual change the approval of each shift.
- If the Period of a newly established rating extends back into the area of a shift used for the transition to the new model, the shift turns red in the shift manager, indicating that they are no longer within the Period of applicability of the previous curve on which they applied, and will no longer be applied in that region.
  - If required, new shifts used to account for subsequent control changes must then be developed in association with the new curve, to ensure a smooth transition in conditions modeled.
- To set the period of applicability:
  - Define the rating curve start date and time
  - Open the Rating Manager
  - Select the Curve in the rating list
  - Select the Rating Period section
  - Adjust the start date and time (If necessary the end time)
  - Add remarks
  - Select Apply
  - Once the rating curve has a period of applicability, it will show up on the time series view in the Rating Development toolbox.
  - Verify the possible presence of a jump in the derived data caused by the change of curve. A tolerable threshold for such jump between values from the new and the previous model is 5%. Overrides can be used to adjust transitions when the change of curve has to be applied at this period but the value is exceeded.
    - Overlay the previous curve
    - Investigate the start date to identify the stage range
    - Identify if there are important differences in the curve outputs for this stage range
    - Within DCT, look at Working Discharge at the time of transition to detect any jump
    - If a jump exists, explore a different transition date or apply a shift to blend the transition
      - If you need to adjust the start or end time of the rating curve, select the Adjust Date icon. Select the rating bar in the time series view and moving it to the desired date. Enter a more precise time by adjusting the time step in the Rating Period Manager or type a value in the Rating Period section.

5.4.5 Shift Application

- To shift a curve:
  - Select the measurements that will define your shift (See step 1 in rating curve development).
  - Open the Shift Manager
    - Insert a shift below
    - Select a start date for the shift (fine tuning the time/dates can be done later if necessary).
    - Select an end date for the shift (fine tuning the time/dates can be done later if necessary).
    - Note that if no end date is specified for the shift created (open ended), it will be pro-rated into the next applicable shift. This is also valid for zero shifts.
  - Select Apply (The shift now appears in the time series view).
  - In the Shift Manager:
    - Adjust the Input and Shift Value.
      - The input value is the stage at which the shift will take effect, moving away from the curve. The shift value is the intensity of shift that will apply/move away from the curve. This information can be either typed in or adjusted graphically in the shift diagram.
      - Understanding the section control and the type of shift being used is very important.
    - Select input value #1 and enter a water level at the point that you believe the bottom of your shift curve will be applied (carried constant). The amount of shift can be left at zero.
    - Select input value #2 and enter a water level value where the shift will end and the rating curve will be applicable.
  - In the Shift Diagram:
    - Select Rescale to get a full view of the measurement(s).
    - Select the Move Rating Points.
    - Select the low point of reference of your shift (represented by an X on the zero line of your shift diagram).
    - Pull this “X” away from the zero line in the shift diagram to the measurement(s) that you are shifting. This point should be located at a position where your shift will be carried forward with a constant shift.
      - The upper “X” on the shift diagram represents where the shift blends back into the rating curve. The location of the lower”X” represents the location where the shift becomes fully applied. The line between both “X’s” represents the gradual transition away from the rating curve, for that particular water level. Below the lower “X” the shift is constant. This style of shift I known as a knee bend shift.
  - Select the measurement(s) to display the percent shift away from the curve.
  - Adjust the start/end time for the shift if necessary. Again, if no end date is selected it will pro-rate into the next applicable shift.

5.4.6 Validation

It is recommended to first clone a curve to be validated so that no change is inadvertently introduced in technician’s original work.

5.4.6.1 Data Compilation

- Identify the stage range
  - observed gauge height range
  - predicted range extremes
- Identify unique controls features
  - Number
  - Type and characteristics
  - Transition zones
- Review the measurement sample selection
  - Only select measurements defining the current control
  - Censor backwater measurements

    - Review high leverage measurements against standard procedures
    - Review measurement history for last channel forming event
- Overlay previously valid curves
- Identify pictures relevant to the rating development

5.4.6.2 Review

- Why was a curve change required?
- Is the working hypothesis valid?
- For the number of control segments expected, are there enough measurement points to develop or modify a model?
- Are transition zone range and position adequately defined?
- Do curve parameters such as slope correspond to values expected?
- What are the least certain sections?
- Could the model be simpler?
- Is the supporting evidence properly documented?
    - Documented selection of curve defining measurements
    - Pictures of control
    - Physical changes and maintenance on control
    - Complete measurements metadata (e.g., outside Vs inside gauge)
    - Channel cross-section survey, including transition elevations

6 Estimation

Estimation techniques were initially documented as part of the Methods for Estimation of Hydrometric Data, by D.W. Kirk and L.H. Heinze, 1984. It initially dealt with the estimation of daily water levels and discharges for short periods under open-water conditions when basic field data are missing.

This material has been adapted to cover instantaneous and daily products, as well as cover ice affected conditions. Estimation of maximum instantaneous values is also covered, but not monthly or annual mean data. There may be some overlap with other procedures or interpretation of the stage-discharge relation during unstable conditions such as backwater from ice effects, weeds, beaver activity or shifting during floods (silting and scouring).

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

Water levels are collected on a continuous basis at most gauging stations for a specific period of operation, e.g. year-round, standard period, irrigation period, low-water period, high-water period, etc. and for a specific purpose or purposes. Field programs are set up for each station before the year begins to achieve the objectives in accordance with the station operation schedule. However, the actual field data that were collected are sometimes incomplete; record loss occurs and it becomes necessary to apply methods of estimation to produce a continuous record suitable for publication.

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

6.1 Reasons for Estimating Data

It is not the purpose of this chapter to suggest on how to resolve the problems which led to the need for data estimation in the first place. However, data estimation is usually required:

1. because of missing or invalid water level records, or
2. during periods when the stage-discharge relation is very unstable or indeterminate.

6.1.1 Water Level Record Loss

The following are some causes of water level record loss:

- Missing or invalid gauge readings for stations not equipped with a recording gauge.
- Recorder malfunctions for various reasons, such as power outage.
- Sensor problems (e.g. shaft encoder or pressure sensor) owing to freezing or silting, entangled float, dry well (stream still flowing), etc.

6.1.2 Undefined Stage-Discharge Relation

Record loss may occur even when complete water level records are available, but insufficient discharge measurements were obtained to define the stage-discharge relation accurately.

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

6.2 When to Estimate

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

6.2.1 Estimation Factors

In essence, before a period of data is estimated, the following points pertinent to the station should be considered when estimating periods of missing record or during periods of an unstable stage discharge relationship.

6.2.1.1 Data Requirements

- The length of the estimation period will have a direct influence on the confidence level of the estimated data. Longer estimated periods will have less confidence associated with them than shorter periods of data estimation.
- Data estimations should only cover the period of the operation schedule of the station.
- The primary purpose of the station will have a direct effect on what types of estimations are performed on the data. The frequency of data within data estimations should be considered as discussed later in this section.

6.2.1.2 Hydrology

- The physical characteristics of the basin upstream and downstream of the estimated station data. Soil type, slope, land use may influence shape of the hydrograph.
- The amplitude of fluctuation of the hydrologic regime. Greater fluctuations in water level and discharge will be more difficult to estimate and frequency of the estimated data should be taken into consideration.
- The consistency of the general shape of the hydrograph whether it be water level or discharge. Comparison of historical records with similar meteorological and antecedent conditions will aid in the estimation.
- High water marks within close proximity of the gauging station.
- Comparison stations. Stations within or adjacent to the station to be estimated should be a major consideration depending on the spatial distance between stations and the homogeneity of basin characteristic such as regulation, land use, and tributary contribution differences and timing of these contributions.

6.2.1.3 Human Activities

- The degree and frequency of regulation. If the estimated period is within a known regulation period are regulation records available to assist in the estimation.
- Urban influences can greatly influence the shape of the water level and discharge hydrograph. Consideration of runoff from storm sewers, the urban heat island effect, snow melting machinery and the use of roadway de-icing chemicals are a few of the factors that can influence the estimation.
- Supplementary data from on-site cameras, local observations or possibly data or observations from other agencies can be incorporated into the data estimation.

6.2.1.4 Meteorology

- Air temperature. Air temperature can have a direct effect on snowmelt which can contribute runoff through the estimation period. It should also be a consideration towards the formation of ice cover or causing upstream tributaries to "shut off". The influence of evaporation when estimating water levels on lake or reservoir stations is greatly enhanced with warmer air temperatures.
- Water temperature. Water temperature can be used during discharge estimations during periods of freeze up and breakup. The formation of frazil and anchor ice is dependent on water being super cooled which may be reflected in the water temperature record. Questionable periods of ice effect may be confirmed or dismissed based on water temperature records.
- Precipitation. Precipitation is a major direct contributor to the shape of the water level and discharge hydrograph. If available, consideration should be given to rainfall intensity, duration and directional distribution. Snow course data will also aid in the estimation process when considering water equivalent of the snow pack and or the capacity to absorb/repel rainfall events
- Wind direction and speed. This data can aid in the estimation of water level on a lake or reservoir especially if the water body is prone to surge events.
- Cloud cover. Cloud cover is to be considered when estimating an urban based station. The duration and intensity of sunshine can act as a catalyst for snow melting chemicals that may otherwise be dormant on cloudy days and where temperatures and generally equal.
- When considering meteorological data from other sources other than the station to be estimated, it is important to realize that considerable spatial variation can occur between stations. The timing, intensity and directional trend of meteorological events should be considered for the estimation.

6.3 Real Time Estimation

After consideration of these items, it may become apparent that a reasonable estimate can be produced using one or more methods. An approved estimation strategy should be documented in the station management plan of each station.

Discharge data should be estimated on the fly at any station whenever the level of efforts and expertise required is aligned with management and client requirements, as defined in the station management plan (refer to figure 1). Provisional data, including estimated data, shall be made available to the public unless:

- It is outside of the station's period of operation, or
- The data quality is deemed too poor to represent a reasonable estimate of true conditions.

Technologists must set up automated corrections) to apply the minimum quality thresholds and help manage provisional data according to station conditions and user expectations documented in the station management plan. Station management must also include a series of station specific notifications to alert technologists of any problem in a timely fashion. The following should be considered:

4. max/min water level alarms – tech/sup/client services
5. Water level range alarms – tech, client services (Client services on behalf of DFO, Power corp, etc) (E.g. between 3.400 and 3.500, a mmnt is needed or between those values triggers a response on a water use license)
6. Change of stage/flatline – tech, flood forecasters
7. Percentage of data removed – tech (notice that Auto QA/QC is removing certain % of data)
8. Metadata/Station Health/Meteorological alarms (air and water temperature, precipitation, etc). Parameters such as VB <12, Precip values > X, Signal Strength < X should be establish to give a 24/7 monitoring of station health.

Automated checks on data integrity do not preclude the need to review data manually as often as the station conditions require and station management plan dictates.

Discharge data can be estimated at any frequency between one value per day and that of the rate initially used for the logging of sampled data that will provide sufficient confidence in estimates produced.

If there are periods of highly questionable data, technologists with their supervisor's approval have the ability to remove these periods from publication until a time where their adequate estimation is assured possible. If estimation cannot be done with any level of confidence, then the record must not be published and no estimate must be made available.

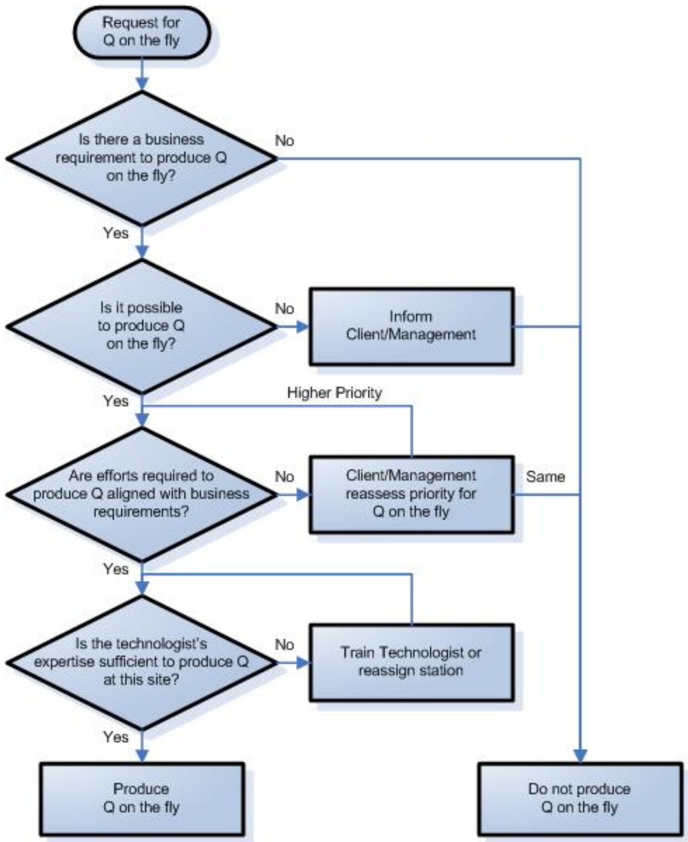


Figure 1: Determination of when to produce Q on the fly

6.4 Grades

Below is a list of the grades available within Aquarius and how they affect the use of symbols on the data set.

A. - 2 – UNUSABLE

The unusable grade can be used to select periods of water level that should not be used for water level publication. The unusable grade will delete the water level data when the mean daily water level is calculated for the twelve month per page report but does not remove the data from the data set. All symbols are automatically attached to the daily mean values whether it be an E or an A, Since the data is not deleted from the water level data set, the unusable water level data is used to calculate the discharge working data set and is available for correction/estimation. The ability to see the deleted water level represented in the discharge data set enables the estimator to see possible trends that may be present in the unusable water level. This may act as a guide that would not be present if the water level data was deleted in the water level data set. The grade period that was selected in the water level data set automatically is transferred to the discharge data set. Before the discharge data set is finalized, the grade period must be changed to “estimated” and not left as “unusable”, otherwise the estimated data will not show up in the twelve month report.

B. 0 – UNDEFINED
C. 10 – ICE
D. 20 – ESTIMATED
E. 30 – PARTIAL DAY
F. 40 – DRY
G. 50 – REVISED

Some discretion is required whether it is appropriate to assign the symbol "E" even if shift or backwater corrections are applied. This may occur during shifting conditions (silting or scouring) especially during flood events, channel improvement (construction), tidal effect or tributaries, or if there is a "significant" extension of the stage-discharge relation at either the low-water or high-water range.

The symbol "B" is to be used instead of the symbol "E" during ice conditions. Record loss may also occur during ice breakup or freeze-up or during intermittent ice cover and therefore it may be difficult to determine whether the symbol "B" or "E" applies. The method of estimation may overlap with "winter flow computations." Without any background data to fall back on, it becomes subjective as to what and when you should grade the estimation period with an E or a B. If there is any doubt about whether there is ice, data is graded with an E. Only days where it is 100% sure that there was ice are graded with B.

It is imperative that any estimated data be immediately graded as such. Adequate remarks should also accompany data to explain the estimated method used and the nature of the values (e.g. Aggregate versus Instantaneous). Data users should regularly be reminded to base their decisions on confirmed interpretation and reviewed information only.

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

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

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

The symbol “B” should be employed whenever data are computed by means of any of the estimation methods during periods of winter ice backwater effects.

6.5 Data Frequency within Estimation Periods

The collection of water level data is now fully automated and digital. This change has produced high frequency data. While traditional methods of corrections and estimation remain similar as in the past, the ability to apply them is now enhanced with advances in computer programs. This is both an opportunity and a challenge when work must be applied to "unit value" rather than daily aggregates.

The Technologist must decide at what scale data should be estimated between unit value instantaneous data or daily aggregates. These two perspectives are now products in their own right and must thus be treated as such. The estimation of water level and discharge using unit value data sets allows for complex and detailed correction. Generally, unit value estimation over a short period of time, especially over periods less than a day, can produce a more accurate estimate than estimating daily mean values. However, unit value estimation on rivers with high daily fluctuations may not accurately represent the general trend that is produced by daily mean values. It should also be noted that generally as the period of estimation increases the accuracy of unit value estimations decreases substantially.

Datasets can be estimated in the original frequency or be converted to daily mean data, but the nature of the resulting data (instantaneous or aggregate) must be tracked and documented. So, while it is at the discretion of the technician and supervisor to decide on the best approach to produce the data, it is essential to document the nature of the data produced in great details so users know what to expect for every period of any dataset.

Unit value time series must be annotated in details to explain if estimated data was produced to mimic instantaneous observations, or to capture general trends showed by daily means. This documentation of the work is meant to ensure that users know the nature of any data they will use.

6.6 Method Selection Guide

The various factors that should be considered when selecting the appropriate method of estimation are summarized in this section. Any supplementary information such as meteorological data, will improve the estimates. It should be noted that data estimations do not necessarily rely on one method of computation and that several methods may be incorporated into the estimated period. Particular methods may be better suited than others based on stream flow and basin characteristics as well as the type of data that requires estimation. More detailed explanations and procedures are given in other sections.

6.6.1 Methods Comparisons

Method	Merits	Limitations
Interpolation	Requires recorded data only at beginning and end of period.	Suitable for periods with static conditions
Interpretation	Can be used for various types of recorder malfunction and some forms of backwater conditions	Should be used with caution for fluctuating data.
Hydrograph comparison	Can be used for any portion of the hydrograph	Requires data from one or more stations with similar basin characteristics
Recession constant	Reliable for "natural flow" streams during recession periods; Can describe recession in mathematical terms;	Requires historical data to establish shape of recession.
Curve-fitting	Useful for dense networks and as a check on data estimated by other methods.	Requires historical data; must be carried out by computer.
Mathematical models	Best fit estimation based on comparative stations or the station historical data	Computer model must usually be developed specifically for each individual basin.
Secondary sensor	Best suited method if available	Hydrologic conditions may vary between the primary and secondary sensor

6.6.2 Stream Flow Characteristics

Below is a table that shows where the various methods can be used based on various stream flow characteristics.

Streamflow Characteristic	Interpolation	Interpretation	Hydrograph comparison	Recession constant	Curve Fitting	Mathematical Models	Secondary sensor
Regulated	X	X	X		X	X	X
Natural flow	X	X	X	X	X	X	X
High daily fluctuation			X		X	X	X
Low daily fluctuation		X	X	X	X	X	X
Rising limb		X	X		X	X	X
Peak segment		X	X		X	X	X
Recession limb		X	X	X	X	X	X
Static conditions	X	X	X	X	X	X	X

6.6.3 Basin Characteristics

Below is a table that shows where the various methods can be used based on various basin characteristics.

Basin Characteristic	Interpolation	Trace interpretation	Hydrograph comparison	Recession constant	Mathematical Models	Secondary sensor
Small basin	X	X	X		X	X
Large basin	X	X	X	X	X	X
Sparse network	X	X	X	X	X	X
Dense network	X	X	X	X	X	X

6.6.4 Data Considerations

Below is a table that shows where the various methods can be used based on various data considerations.

Data consideration	Interpolation	Trace interpretation	Hydrograph comparison	Recession constant	Mathematical Models	Secondary sensor
Manual gauge readings missing	X		X	X	X	
Recorder malfunction	X	X	X	X	X	X
Backwater during open water		X	X		X	
Backwater during ice cover	X	X	X	X	X	
Stage-discharge problem		X	X		X	
Short period - 10 days or less	X	X	X	X	X	X
Long Period -10 days	X	X	X	X	X	X
Data available for other stations	X	X	X	X	X	
Maximum/minimum instantaneous values missing		X	X			
Water level only to be estimated	X	X	X		X	X
Historical data missing			X	X	X	X

6.7 Methods Description

6.7.1 Interpolation

A simple method of estimating data is by interpolation. This method can be used reliably where the water level or discharge has remained relatively uniform or has increased or decreased at a steady rate. It is imperative that nearby meteorological records for the estimated period are consulted to confirm static conditions such as precipitation for discharge estimates and wind speed and direction for water level estimates. Comparison with other hydrometric stations from within or adjacent basins can be consulted to confirm or deny static conditions and thus the use of this method. This method is usually more applicable under natural flow conditions or where the regulation pattern is known (such as a good record of reservoir water levels).

Example 1: Water level receding after freshet

(June 1 22:00) 15 minute values logged to that point

(June 1 22:00 to June 2 06:00) Interpolation over 8 hours using data re-sampled over 15 minute values and straight line Recession which reacts like a straight line interpolation for short periods..

(June 2 6:00) 15 minute values logged from then on

Example 2: Water level receding after freshet

(June 1 12:00) 15 minute values logged to that point

(June 1 12:00 to June 5 08:00) Interpolated over 92 hours using data re-sampled over daily values, due to expected uncertainty, and a straight line Recession

(June 5 8:00) 15 minute values logged from then on

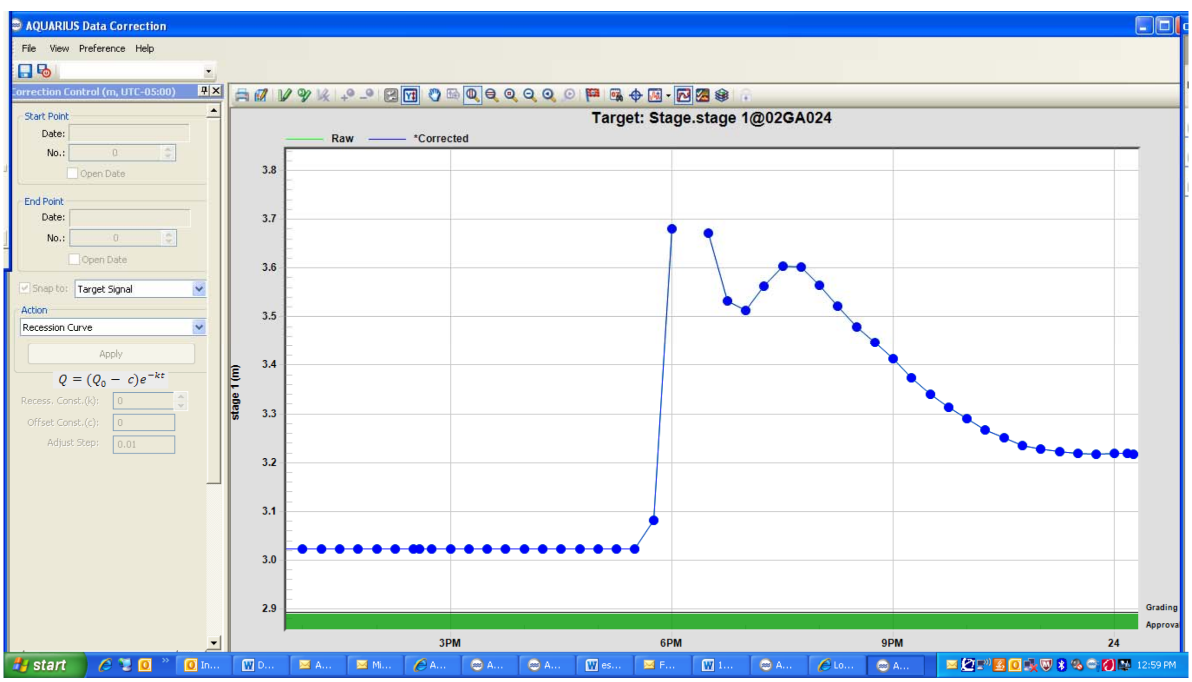
Missing data are computed by determining the difference between the known values before and after the missing period, dividing this value by the desired increment, and adding this value as a constant to each day. This is done with automations available in the Data Correction Toolbox.

6.7.2 Interpretation

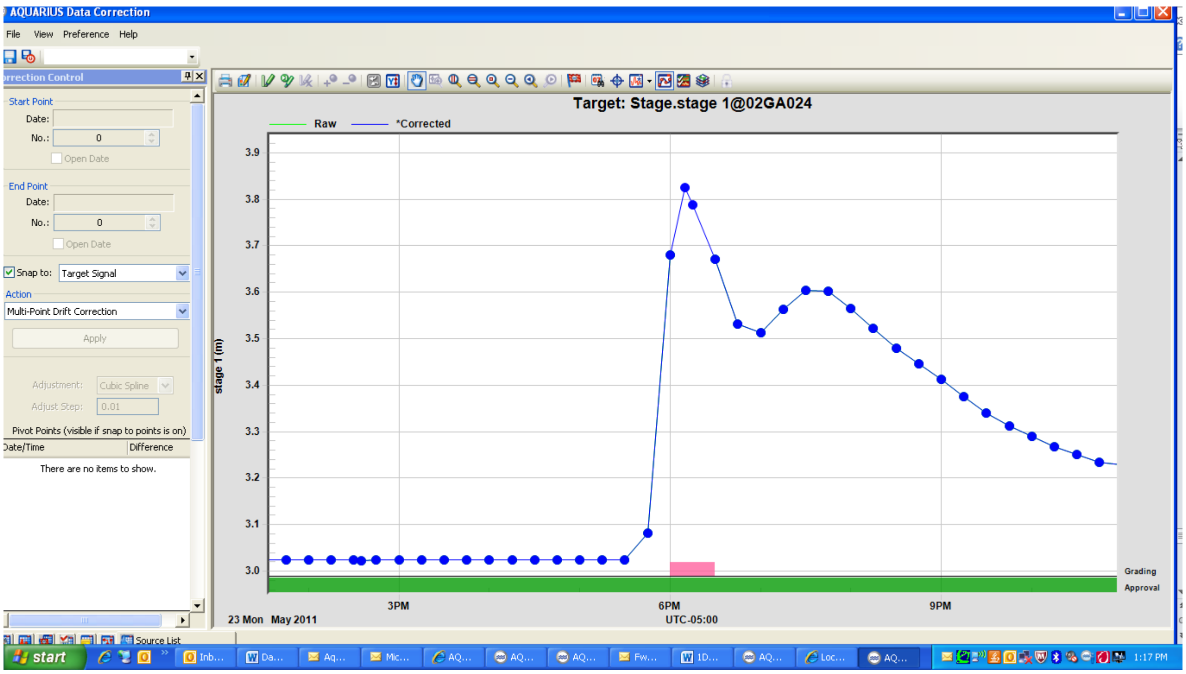
Water level record loss usually occurs because of recorder malfunction or sensor problems. Additional field information such as high-water marks, meteorological data or observations by local residents improves estimates.

6.7.2.1 Maximum instantaneous Water Level

The maximum instantaneous water level can at times be estimated from high water marks, observed readings, other physical identifiers, imperfect or incomplete recorder trace.



In this case a power outage caused the recorder to miss the maximum instantaneous reading. The levelling of high water marks produced a maximum instantaneous water level of 3.820m.

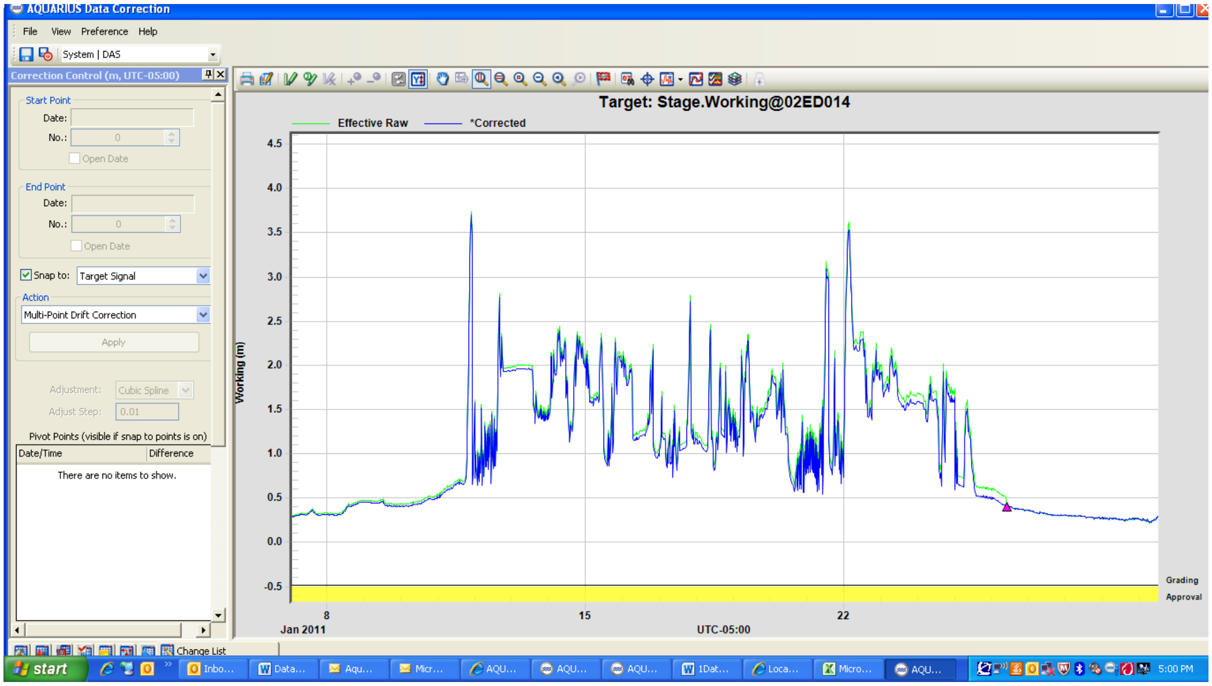


An estimate was produced through interpretation and the record completed to fill in the missing data.

6.7.2.2 Pressure Gauge Problems

Problems associated with pressure sensors are probably the most serious because it often is not obvious that the water level trace is invalid, e.g. during slow gas leakage. Also during intermittent malfunctioning, it is not clear which specific portion of the dataset does indeed represent the true water level. The symbol "A" should be used where the water level trace is estimated, and in fact in some cases, it would be more appropriate to use the symbol "E". Missing, incomplete or questionable water level records can be estimated or confirmed by the hydrograph comparison method.

The diagram below illustrates periods when ice had compacted over the orifice and thus creating false water levels. It is not obvious as to what sections may represent proper water level and that which represent false readings other than the extreme values. Interpretation of the record would be nearly impossible and other methods of estimation would have to be applied to this period. Because the length of this period is large, estimation of water level may not be possible with any degree of accuracy.

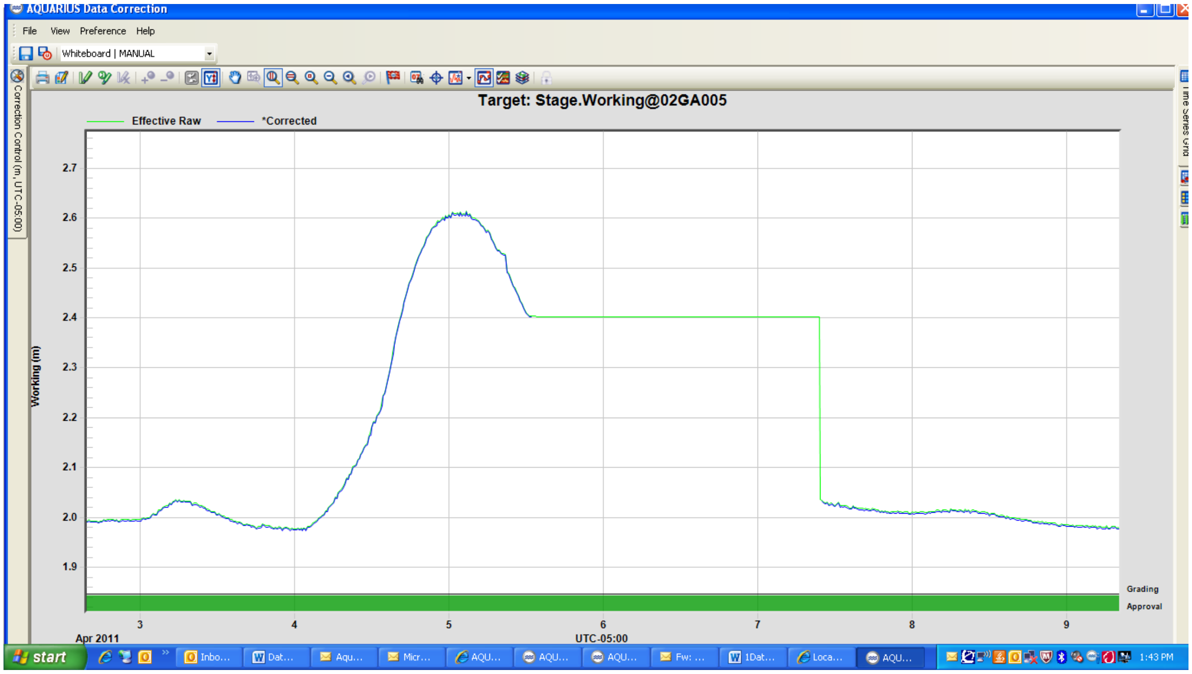


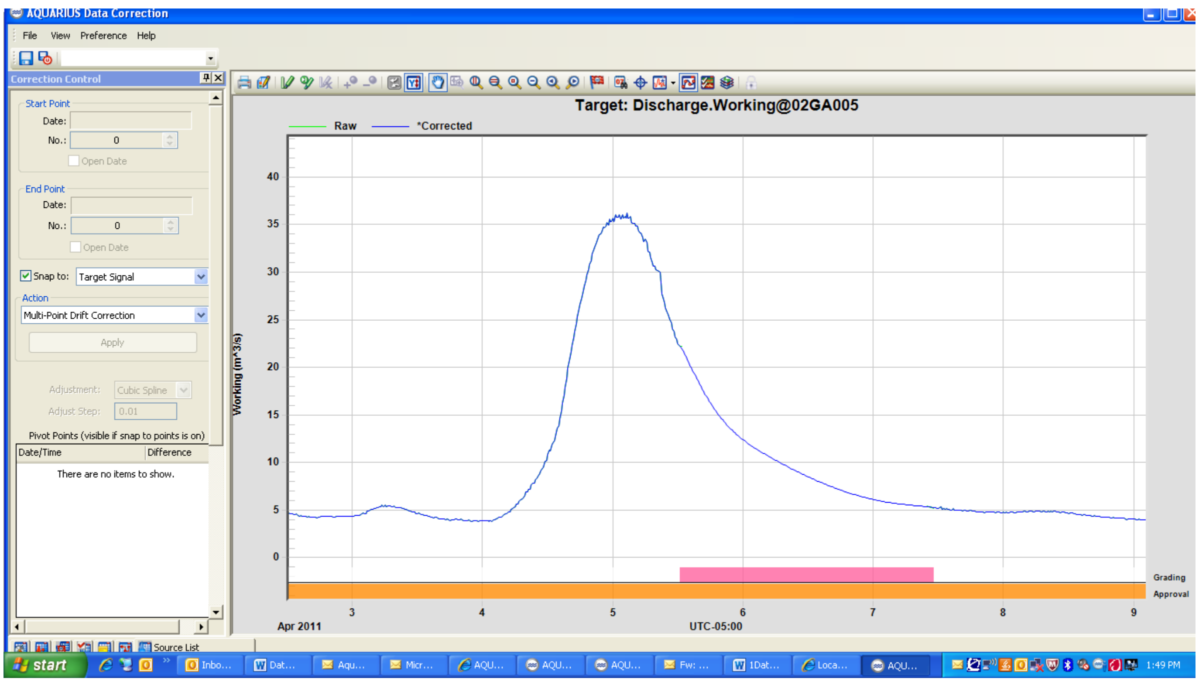
6.7.2.3   Stilling Well Problems

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

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

Here is an example of a float system that became hung up. The erroneous water level was removed but not estimated as it was not an operational requirement. A discharge estimate was performed using interpretative techniques.





6.7.3 Hydrograph Comparison

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

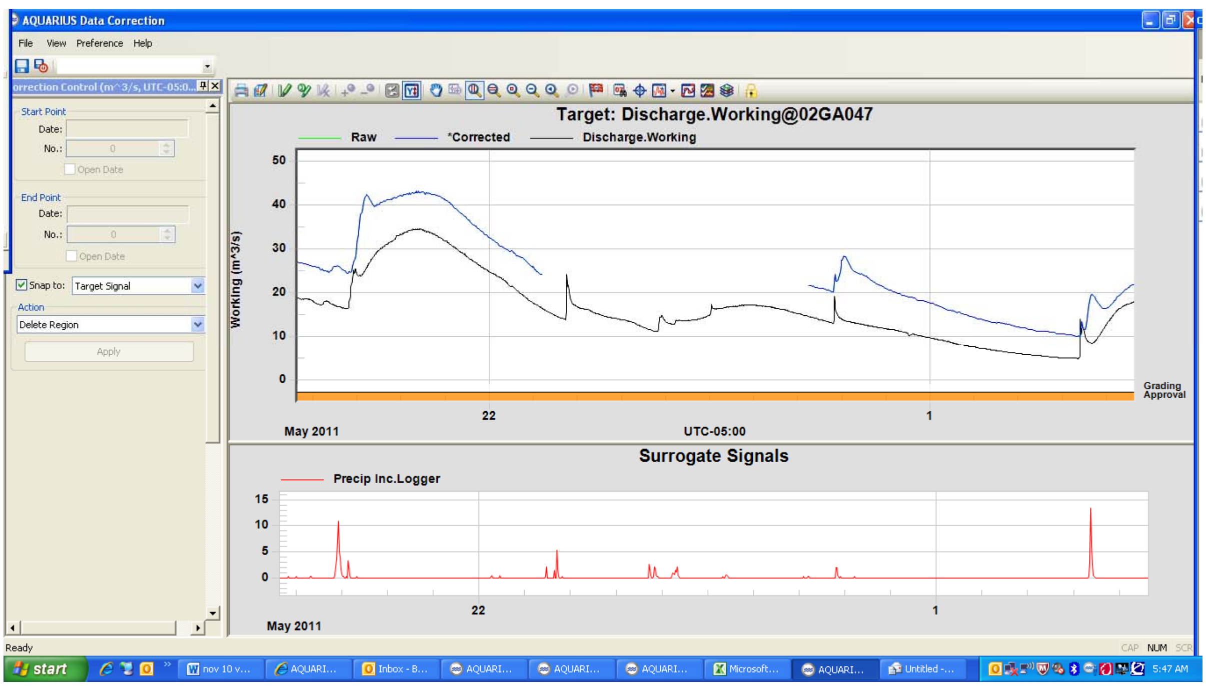
It is desirable that hydrograph comparisons be made with more than a single reference station. The comparisons will differ from each other to some degree with the greatest weight being given to the results obtained from reference hydrographs

- that show the closest fit with the target hydrograph;
- on the same stream as the target station; and
- for stations whose drainage areas approximate that of the target station.

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

Consideration must be given to all the estimation factors stated previously as well as the contribution and timing of tributary flow. Meteorological and hydrometric factors will be the most readily available and often the factors that are of greatest influence during the hydrograph comparison process. If the flow is regulated, any diversions to or from the system or the effect of storage must also be a consideration.

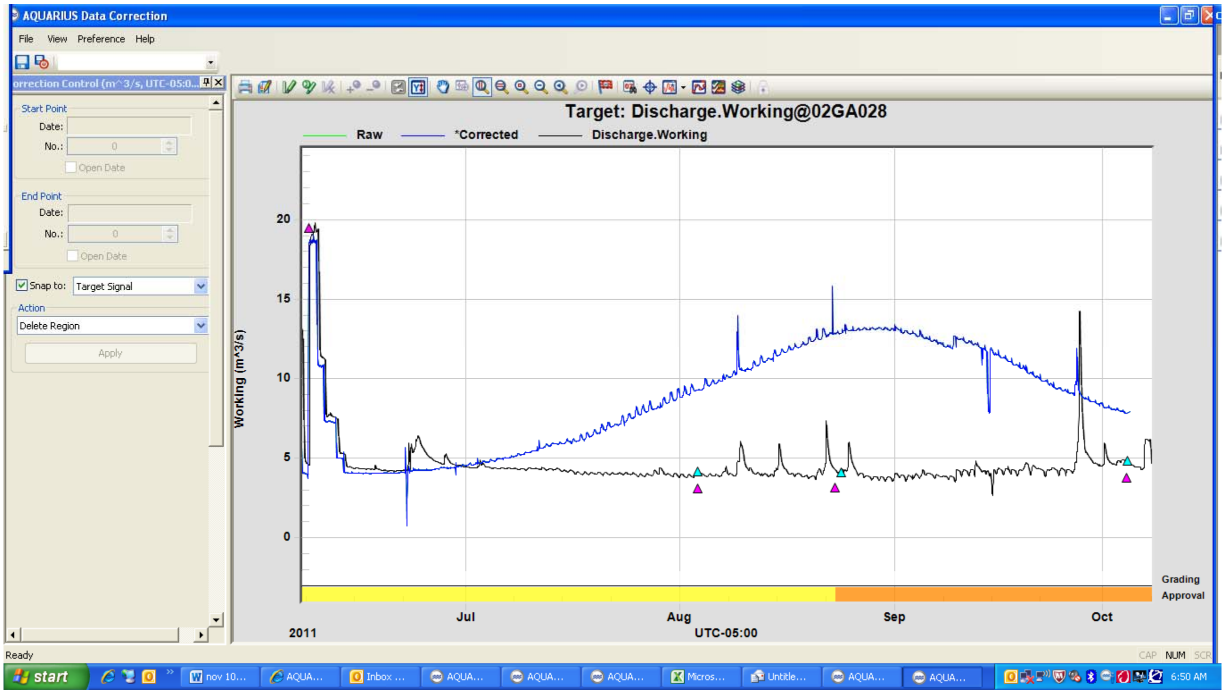
An understanding of the time lags at various stages for stations in the same or adjacent basins is important. To adjust comparison basins for time lags, a step by step process is described later in this chapter that can be used to time lag the comparative hydrographs to put them into “sync” with the target hydrograph that requires estimation. Knowledge of the regional and basin characteristics is also required when selecting stations which are comparable.



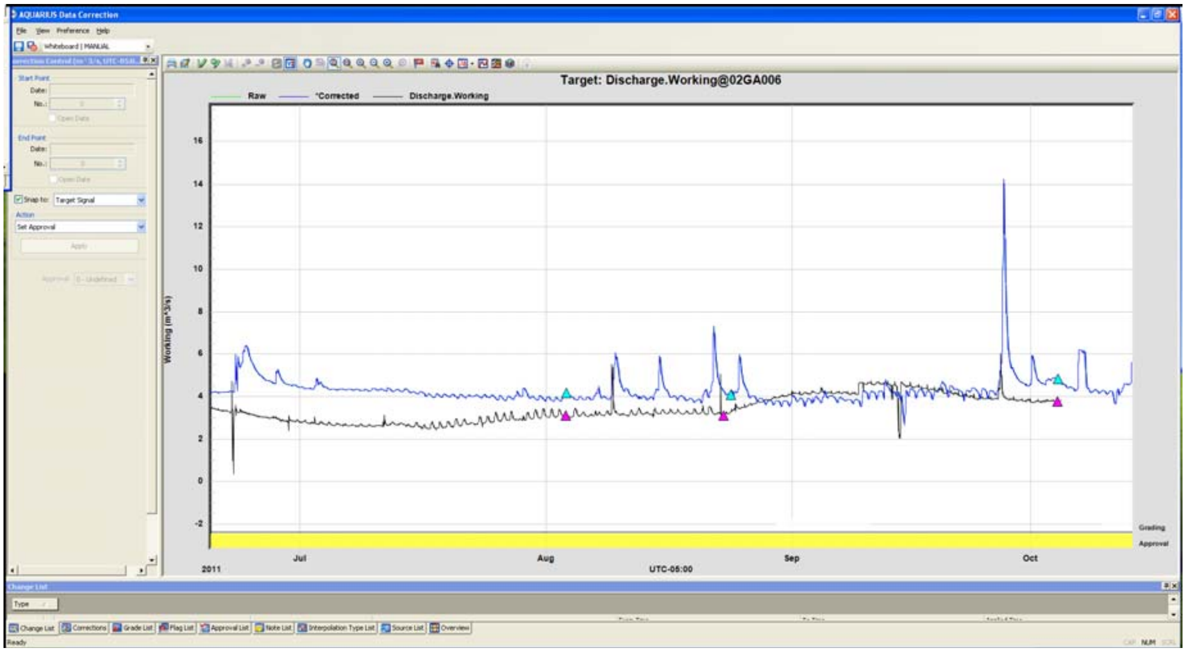
In the example above a station has a period of missing record due to a logging malfunction. In order to estimate the missing period, the hydrograph from an upstream station and precipitation data were considered as the predominant factors to be used for the estimation. The estimator can clearly determine that there is a good relationship between the upstream and downstream discharge hydrographs both of which are influenced by precipitation events. In this scenario a direct copy and paste correction will not produce an accurate estimation. Upon further examination, consideration will have to be given to the lag time between the stations. It should also be noted and considered during the estimation that the upstream station is located within an urban centre which produces a more pronounced effect to the hydrograph during precipitation events.

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

Below is an example of a comparison of between an upstream and downstream station that clearly shows that the upstream station is affected by weed growth during the summer period. Measurements have been taken and appropriate shifts will be applied to the data set.



Shifts were applied based on the measurements taken. The hydrographs are then compared again to verify the effect of the shifts as shown below. The hydrograph comparison revels that the shifts produced a better general relationship but requires further refined shifting. Further estimated shifts may become too complex to produce accurate discharges and at such time some form of estimation procedures need to be applied for the affected period. In this particular case, the outlet of a dam is immediately upstream of the target station and discharge records should be consulted for further estimation purposes.



6.7.4 Recession constant

The shape of the falling (recession) limb of a hydrograph can be described mathematically by a simple equation with one constant. This recession constant is unique to a specific watershed under similar flow conditions and its value can be used either to gain an understanding of the flow processes (hydrograph separation into various components) or to estimate the falling hydrograph when the discharge along any point of the falling hydrograph is known.

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

Equation 7a
A general mathematical equation for the recession limb is:

$$Q2 = \mathrm{Q}1^{K\Delta t}$$

where Q2 - discharge at time t2
Q1 = discharge at time t1
K - recession constant (<1)
Δt = elapsed time interval (t2-t1)

Equation 7b
Rearranging the equation, the recession constant can be obtained as follows:

$$\mathrm{K} = \{\frac{Q2}{Q1}\}^{\frac{1}{\Delta t}}$$

Equation 7a will produce a straight line on semi logarithmic scale.

Because the recession constant is generally not consistent throughout the entire range of discharges or for all seasons the recession curve should be broken into short segments for various discharge ranges.

6.7.4.1 Short Periods

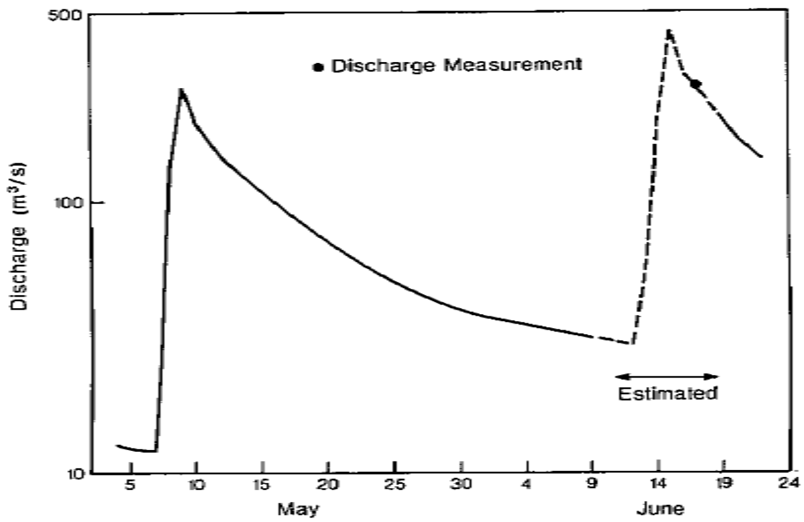


Figure 8. Recession constant method.

Estimated period June 10–19

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

June 13–14 estimated by hydrograph comparison.

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

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

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

Date	Recorded (m^3/s)	Calculated K	K Used	Estimated (m^3/s)	Notes
June 1	36.8				
2	36.2	0.98(1)			(1) $K = \frac{36.2}{36.8} = 0.98$
3	35.4	0.98			
4	34.5	0.97			(2) The average "K" calculated for the recession of June 01-09 is for the continuing recession to the start of rain on June 13.
5	34.0	0.99			
6	**33.4**	0.98			
7	32.6	0.98			(3) 31.1 x 0.98 = 30.5 m^3/s
8	32.0	0.98			
9	31.1	0.97			
10			0.98(2)	30.5E(3)	(4) The "K" values for the recession from the peak on June 15 come from another period of record (May 4-12) with similar flow conditions.
11			0.98	29.9E	
12			0.98	29.3E	
13	heavy rains		rising limb	55.0E(7)	
14	heavy rains		rising limb	200 E(7)	(5) The June 16 flow is estimated "backwards" from the flow on June 17: 268 ÷ 0.87 = 308
15				428 E(6)	
16			0.72(4)	308 E(5)	(6) The June 15 flow is estimated "backwards" from the flow on June 16: 308 ÷ 0.72 = 428
17	268 A		0.87	268 A	
18		0.87(8)	0.87	233 E(9)	
19		0.87	0.87	203 E	
20	177	0.87	0.87		(7) The discharges for the rising limb (June 13-14) cannot be defined by recession constants and must be defined by another method (e.g. hydrograph comparison).
21	157	0.89			
22	143	0.91			
May 4	12.9				
5	12.3	0.95			
6	12.1	0.98			(8) $K = \{\frac{177}{268}\}^{\frac{1}{3}} = 0.87$
7	12.2	1.02			
8	131	>1 rain			(9) 268 x 0.87 = 233
9	266	>1 rain			
10	191	0.72(4)			
11	168	0.88			
12	146	0.87			

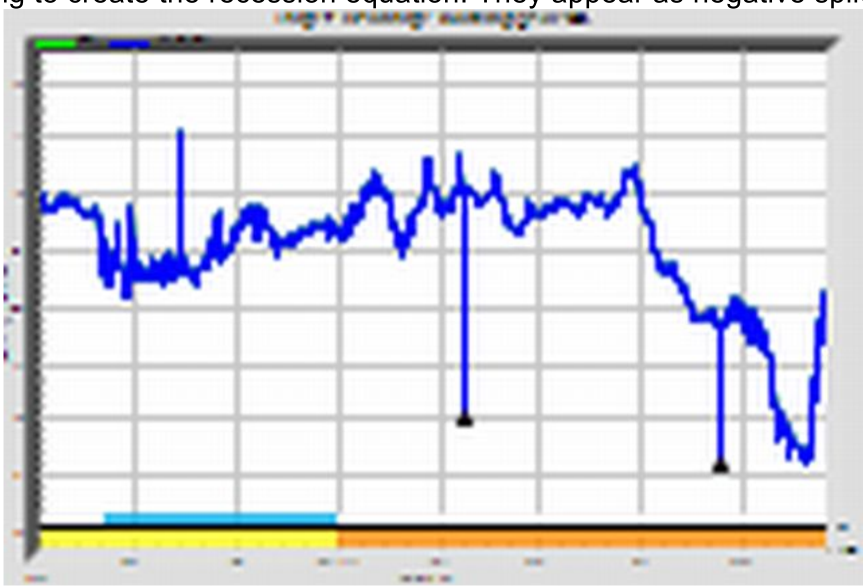
6.7.4.2 Long Periods

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

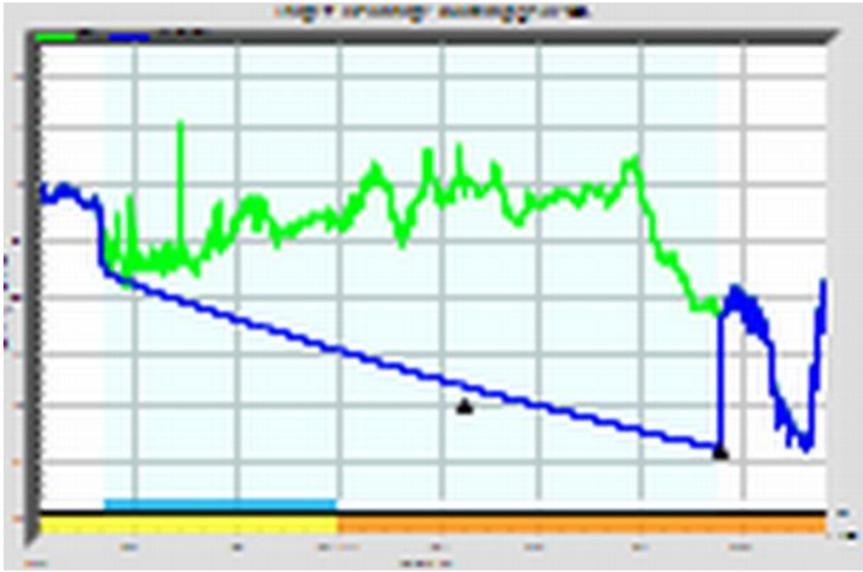
A recession curve may also be developed by plotting values of Q2 against Q1 some fixed time "t" later. Normally, a curve indicating a gradual change in the value of "K" will result. This curve approaches a 45° line as Q approaches zero. The recession curve for the Churchill River above Otter Rapids is illustrated in Figure 9. This method may be used to construct recessions for base flow or direct runoff. For base flow recession, data should be selected from periods several days after the peak of a flood so that it is reasonably certain that no direct runoff is included. After the base flow recession has been established, it can be projected back under the hydrograph immediately following a flood peak and the difference between projected base flow and the total hydrograph used to develop a direct runoff recession curve. The base flow curve should be drawn to envelop the plotted data on the right because such a curve represents the slowest recession (high K). Conversely, data for the direct runoff recession are enclosed on the left.

Example
The recession trend is broken into two sections. (Normally this case would require three sections, but the difference in the recession constant between the first day of ice conditions and the first measurement, and the first measurement and the second measurement was minimal.)

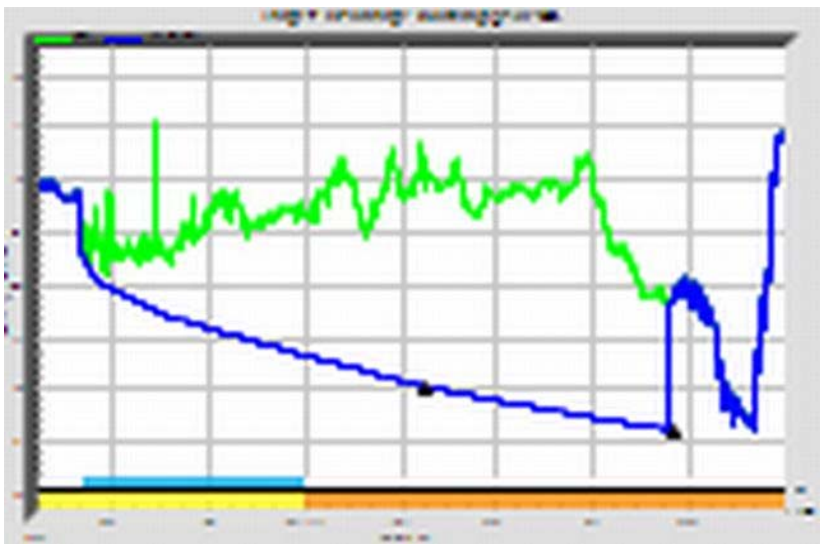
1. Measured discharge values were manually entered into the discharge working time-series, thereby given something to create the recession equation. They appear as negative spikes in the graph.



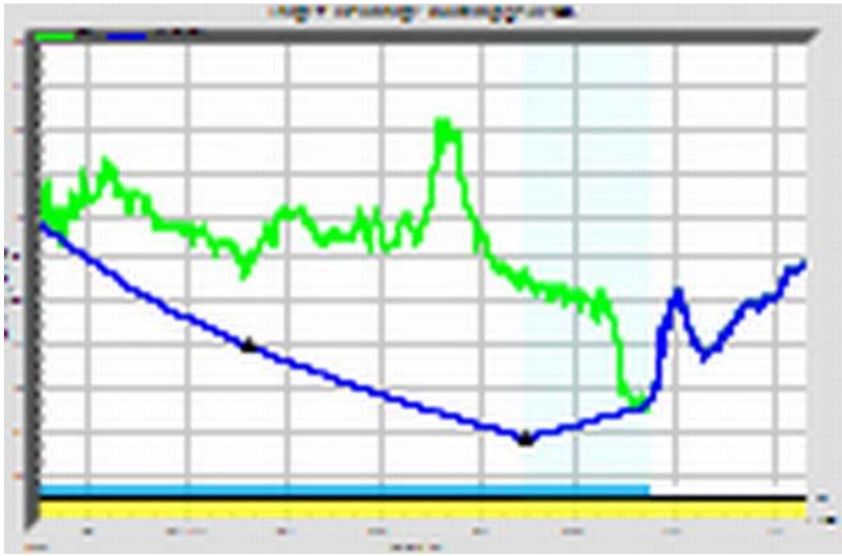
2. A recession trend was drawn to the second measurement. (Alternatively, this could have been draw to the first measurement, then a second equation from the first measurement to the second measurement)



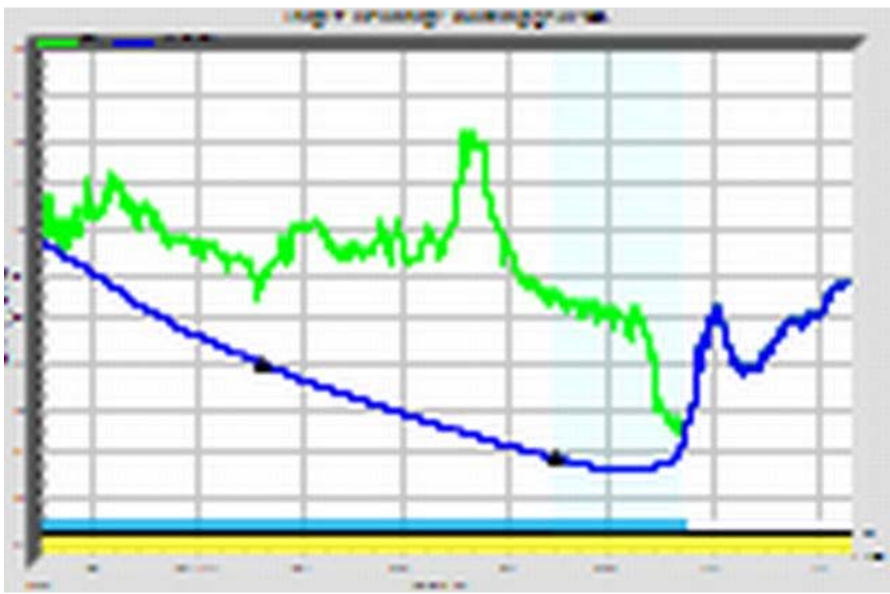
The recession line was adjusted down to intersect the first winter measurement value.



3. A recession constant was draw from the last measurement to the rising limb of the hydrograph at the point of open water conditions. Note: It may be necessary to break this portion into smaller portions, especially if the peak of the hydrograph is under backwater conditions.



4. The rising limb of the hydrograph is adjusted to reflect the flow conditions in freshet at the station.



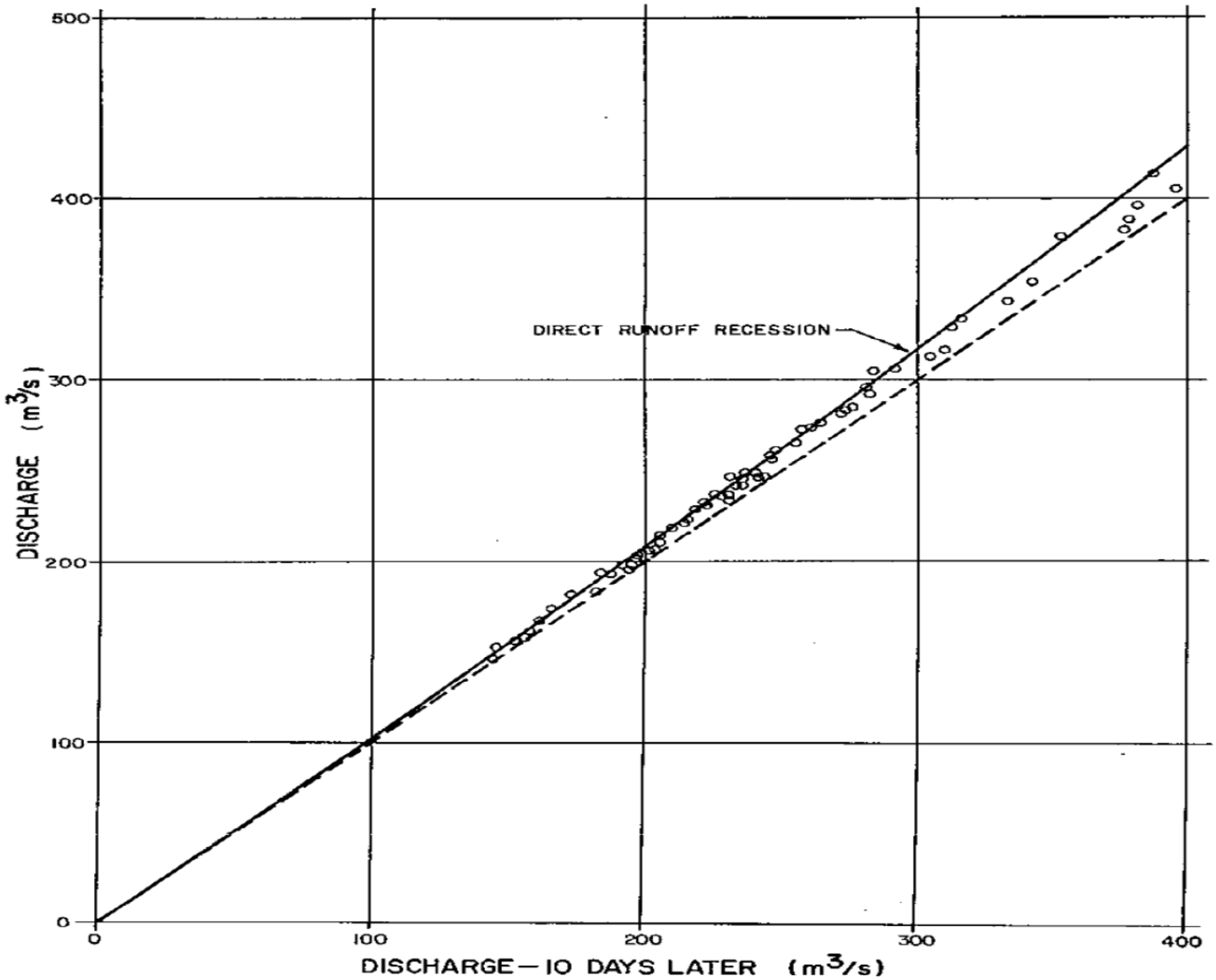


Figure 9. Recession curve for Churchill River above Otter Rapids.

6.7.4.3 Procedures

6.7.4.3.1 First Method

- Select period (unselect 'snap to' if there is no data in this period or if forecasting a recession trend into the future)
- Resample the period to 1440 which is a daily value, interpolation type set to "none" as you don't need actual values in the dataset, just time stamps - this will now give you data points, albeit with empty values or a straight line from the last value.
- Manually enter the value for the last data point in your recession trend in the "time series" grid that you want to shoot to.
- Select the same time period again, making sure the end of the selected period includes your manually entered last value (so the recession curve has something to draw to)
- Apply the recession trend tool as a Post-processing application.
- Adjust the recession trend using the Multi-point drift correction. You will likely find it easier to adjust (especially during freshet) in smaller time sections. Use Post processing on these corrections.
- Look at the end result in "QuickView" with the display set to semi-log display. Note that adjusting the result to a satisfactory level of confidence may require trial and errors.

6.7.4.3.2 Second Method

- Select period (unselect the 'snap to' if there is not data there or you are forecasting a recession trend into the future)
- Resample the period to 1440 which is a daily value, interpolation type set to "Linear" this will give you a straight line from the last value
- **Difference from first method:** Using the multipoint correction, adjust your end point down to about the range you want the end to be (give or take)

- Manually enter the value for the last data point in your recession trend in the "time series" grid to the exact value that you want to shoot to.
- Select the same time period again, making sure the end of the selected period includes your manually entered last value (so the recession curve has something to draw to)
- Apply the recession trend tool as a Post-processing application.
- Adjust the recession trend using the Multi-point drift correction if needed. You will likely find it easier to adjust (especially during freshet) in smaller time sections. Use Post processing on these corrections.
- Look at the end result in "QuickView" with the display set to semi-log display. Note that adjusting the result to a satisfactory level of confidence may require trial and errors.

6.8 Mathematical Methods

Several mathematical methods were studied by Water Resources Survey over the years to determine their suitability for estimating missing data. Some of these methods require models based on historical data. Such models are usually unique to a specific river basin and are applicable only when calibrated. Advances in computing power the availability of such resources have at times made these accessible to operations. More detailed information will be provided by the Data Control Section (Ottawa) as these procedures are developed and standardized nationally.

6.8.1 Curve fitting

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

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

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

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

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

6.8.2 Summation Program

A summation/statistical program were developed within Water Survey of Canada, Ontario Region, for use in a dense network of gauging stations within the Saugeen River basin in southern Ontario. The program output permitted the comparison of:

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

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

6.8.3 Flow-Routing Methods

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

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

6.8.4 SAP2

The stream flow accounting program was developed to compare mean daily discharge between basins and ultimately providing comparison values that could be imported into a data set that had missing record. The program was capable of applying a factor to daily mean discharge based on drainage area ratios and allowed daily time lags to the data sets. Stream flow accounting was also available to aid in the estimation of missing periods of record.

6.8.5 Secondary Sensor

[information to be added]

6.9 Estimation Methodology

6.9.1 Display of Shifted and Unshifted Discharge

- Display of shifted and unshifted Q to guide the estimation of discharge under ice
  - Steps are:
    1. First create a stage-discharge relationship called unshifted.
    2. Open the base rating in RDT.
    3. Go to the rating table and use the export to .csv button
    4. Open the new rating (unshifted version) and import as .csv
    5. Then, create a Dataset for Discharge which you call Unshifted and link it to the Hg working and the unshifted rating
    6. Open Discharge.Working, showing corrected and raw Q, and Discharge.Unshifted as surrogate which can be overlaied to show unshifted Q.

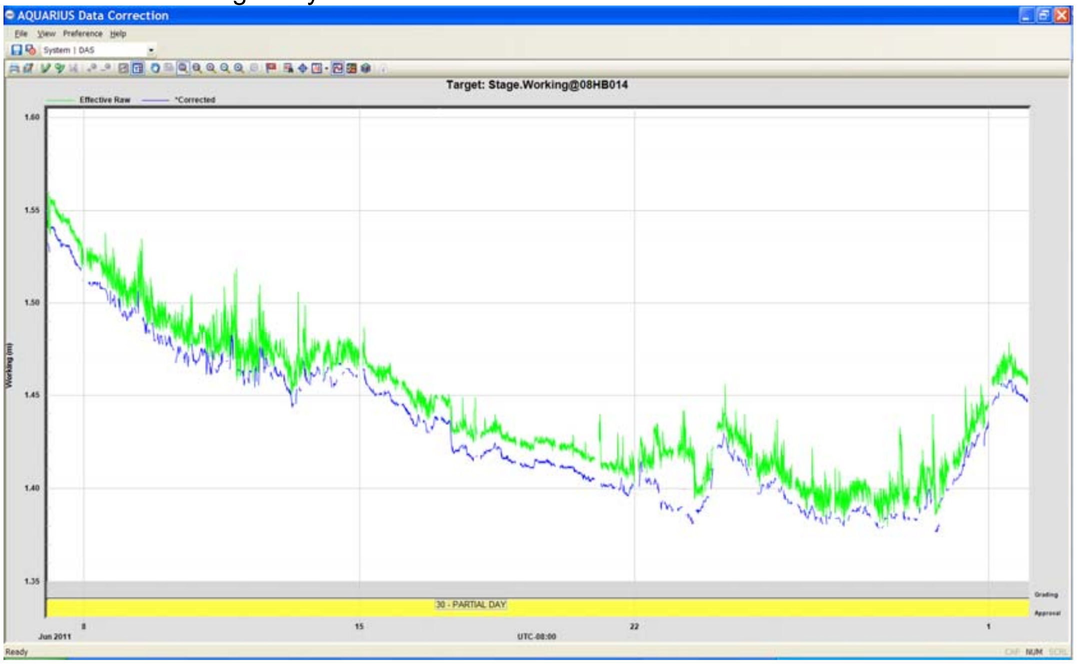
6.9.2 Display of Discharge in Semi-log Plot:

  - Run recessions in current display and at same time have QuickView open which has semi-log. Staff saves and reloads to look at interim steps as work progresses.
  - Compare in Data Correction previous year's trends. Approved data helps see how the trends may apply to current year. This is to train in new perception of tool.
  - Highlight previous years recession trends to capture the constants and see if some information can be adapted as general rule for the winter recession (stats)
- Comment from Morie: would be interesting to have ability to overlay years… This may either be an enhancement (to be listed in Portal) or is an item that could be developed in the Whiteboard.
- Comment from Derek: first doing rough draft by segregating periods of open water to ice cover, ice cover period, ice period to open water. Then you will finalize data by doing overall review of trace without regards to any transition. This helps to hard enter the points where the trace must go through

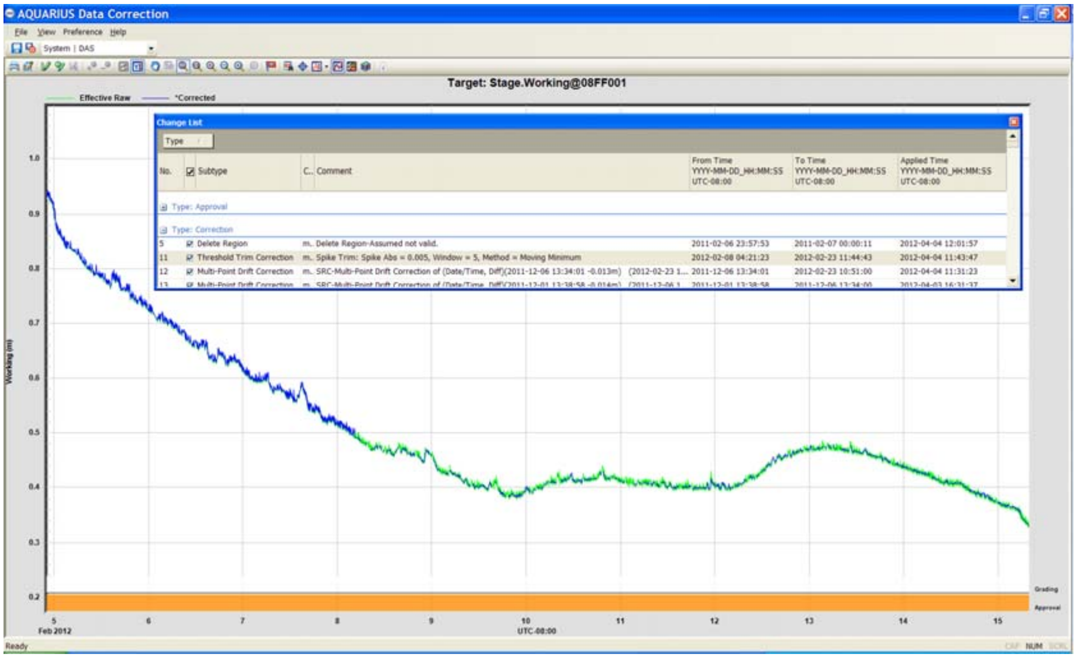
and only interpolate between the hard values measured (line going through dots)

6.9.3 Correction of Silty Trace

Example of silty trace that can be salvaged.
Situation where the derived discharge may be "E" due to non confidence in the result.



Trace Edited creating partial days ("A")



Showing the transitions from uncorrected to data corrected for silting. Depending on the degree of silting and confidence in the values the corresponding discharge may be flagged as "E".

6.9.4 Use Surrogate Signal from Other Station

Objective:
To estimate missing time series flow from a target station with a surrogate station flow data set using Springboard.

Overview:
Springboard does not allow clock drift corrections for discharge in data correction but does allow it in stage. If you want to use a nearby station to estimate flows within Springboard you need to set up a time lagged stage signal to feed a composite discharge signal. By doing so, no original integrity in original data sets will be compromised.

Definitions:
Target station – The station that has missing record and is the “target” for requiring data from a nearby station
Surrogate station – The station that has a complete data set and reflects similar flow characteristics that would be useful for estimating the “target” station upstream, downstream or in an adjacent watershed.

Step 1 Analysis by overlaying discharge signals
Determine the best surrogate station which compares reasonably in discharge working against the station with missing record (target station) and determine the associated lag time. How?

1. Select any number of stations in springboard that you would like to use for analysis with the target station. Determine the best flow signature available from any available surrogate stations by overlaying the discharge working signals together in data correction and select a manageable region to view in some detail. (see Figure 1)
2. Once the best surrogate has been determined; isolate it with the target and determine the time lag. Select the cross hair tool and determine a likely lag time by viewing similar peaks (or valleys) and record the difference then close data correction. Another option to determine the time lag is to mark region for 2 peaks and note the time difference in start and end times. (see Figure 2)

Figure 1

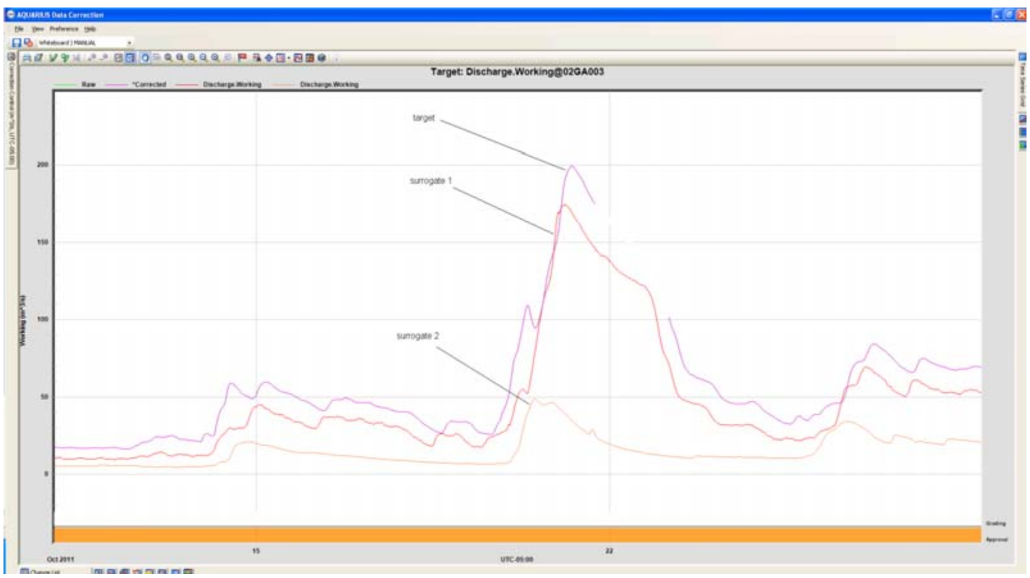
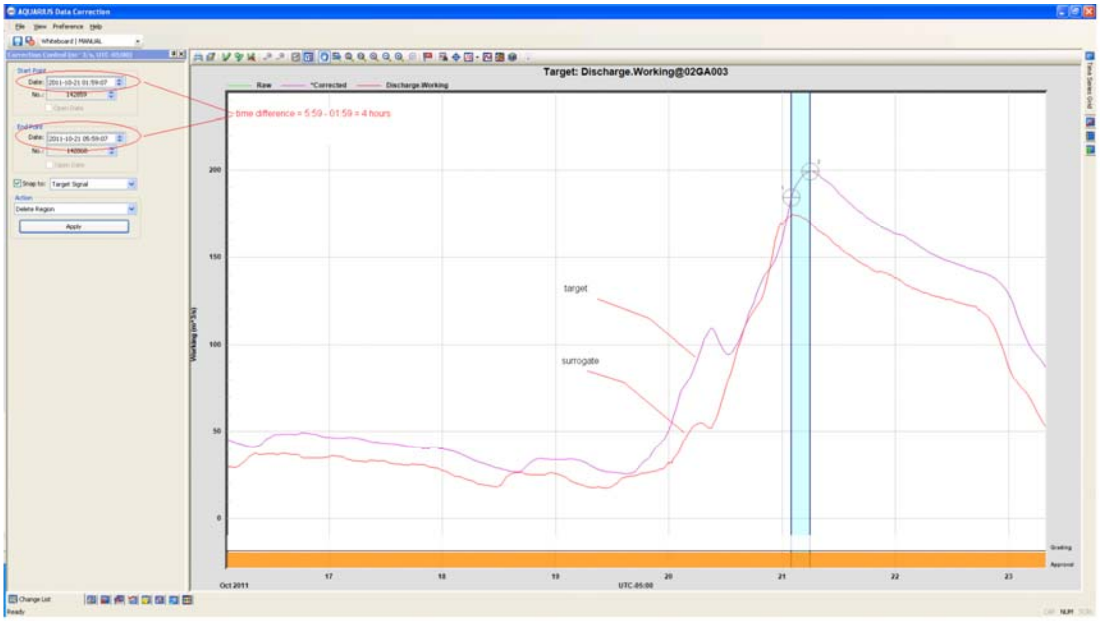


Figure 2



Step 2 (see figure 3) create a new stage data set first

Select surrogate station in springboard and then select location manager:

1. Select Data Sets tab and add new time series
2. Select Type = Basic
3. Label = “Time Lag”
4. Description = ‘surrogate data set with time lag for estimating target station 02GAXXX’
5. Time Zone = default
6. Parameter = Stage
7. Units = m
8. Gap tolerance = 121
9. Save

Step 3 (see figure 3) create another new data set for discharge

1. Select Data Sets tab and add new time series
2. Select Type = composite
3. Label = ‘Time Lag’
4. Description = ‘surrogate data set with time lag for estimating target station 02GAXXX’….(station with missing record or target)
5. Time zone = default
6. Units = m3/s
7. Gap tolerance = 121
8. Configure derived rating curve = stage-discharge.rating curve (surrogate)
   =stage.Time Lag (surrogate)
9. Save and go back to Data Sets

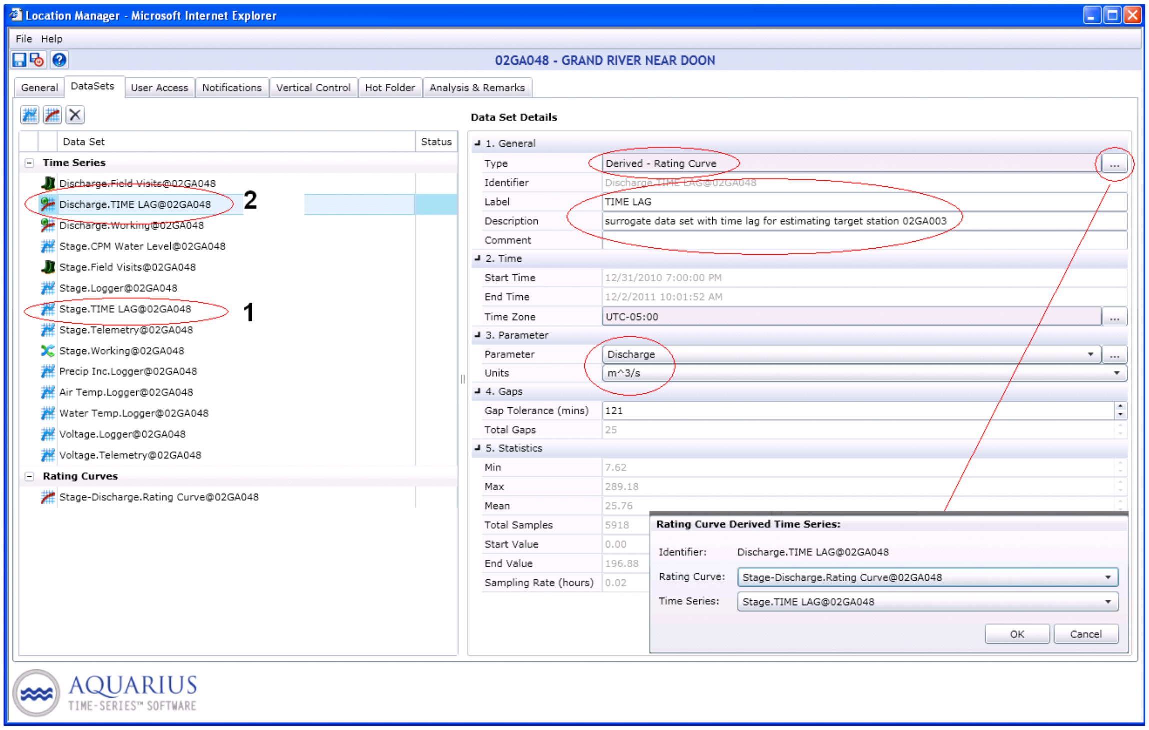


Figure 3

Step 4

Populate the new time lag stage data set

1. Go to location manager and append some generic logger or telemetry data for the surrogate station to give Stage.TIME LAG data set something to start with and allow it to be opened.

Step 5

Overlay the target and TIME LAG discharge data sets in data correction

2. Open the Stage.working (first) and the Stage.TIME LAG (second) signals together in data correction for the surrogate station. Highlight a region or as much time as needed for the missing target data you will be working with later and copy/paste Stage.working into Stage.TIME LAG. At this point you can highlight the entire region and apply a clock drift of what was determined earlier; in this case 4 hours and save.
3. Now you will finally be able to work with the discharge signals overlaying the target and the time shifted surrogate signal. (See Figure 4) Select the target station (02GA003) and surrogate station (02GA048) in Springboard. Highlight the target Discharge.working (first) and then the Discharge.TIME LAG (second). Overlay the 2 signals and zoom to the missing period in the target. Highlight the missing region and copy/paste the data from the surrogate. Apply multi point drift corrections to make the new data agree with the target.
4. Save and Exit after rechecking your time lag.

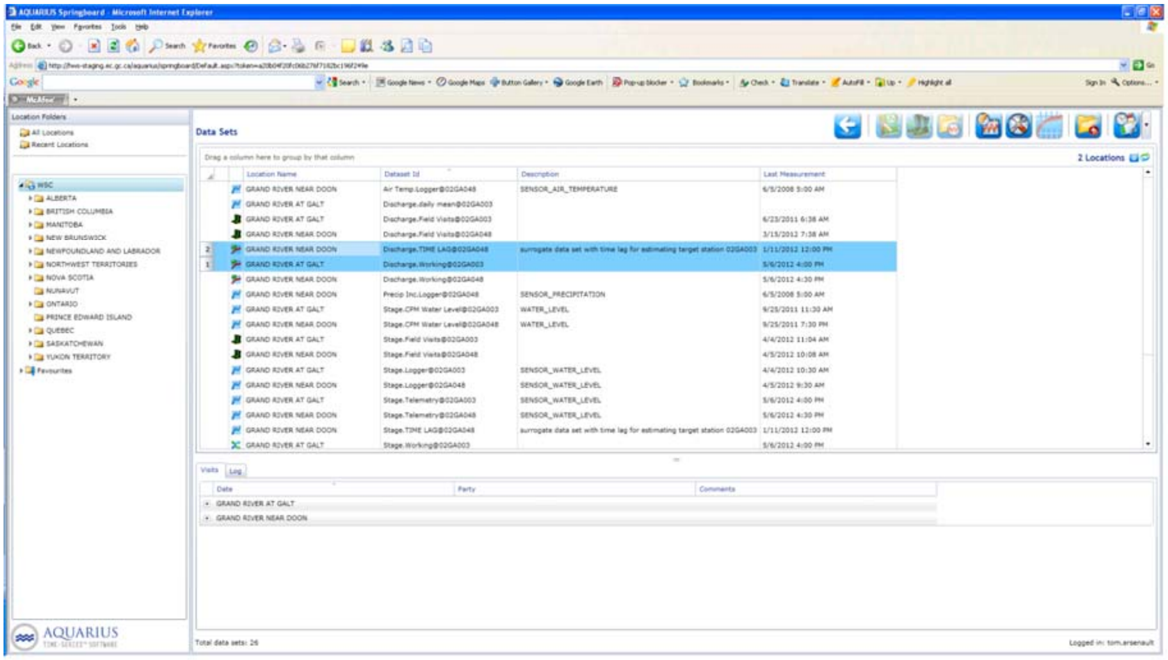


Figure 4

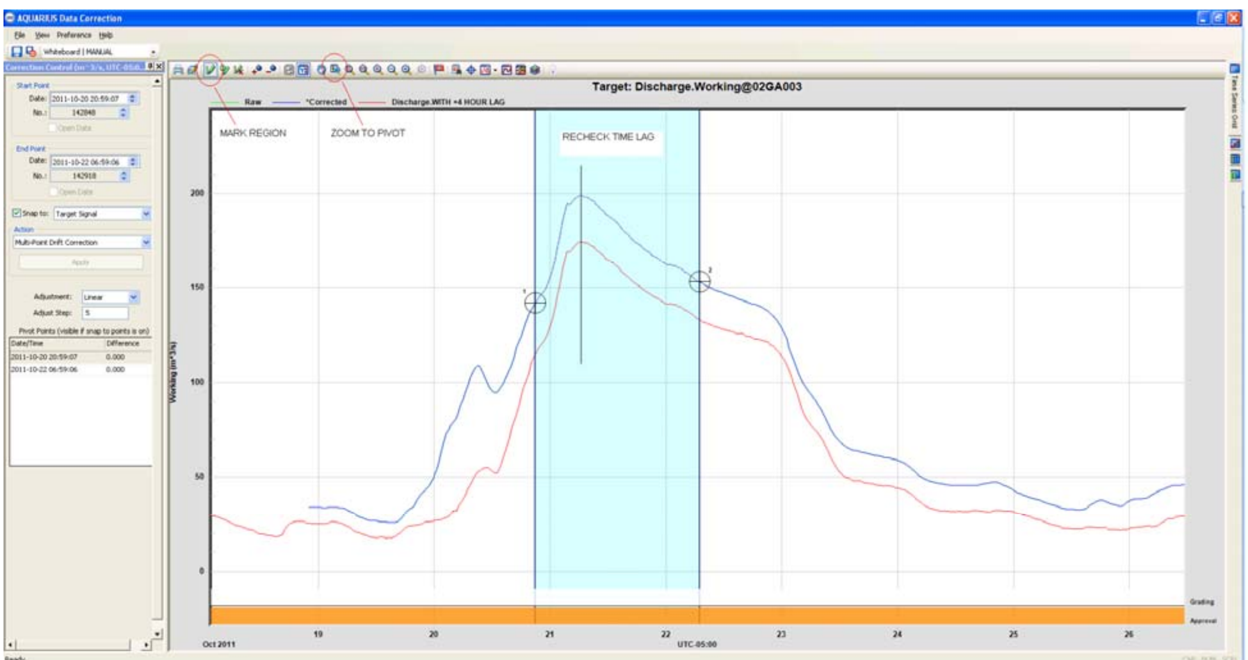


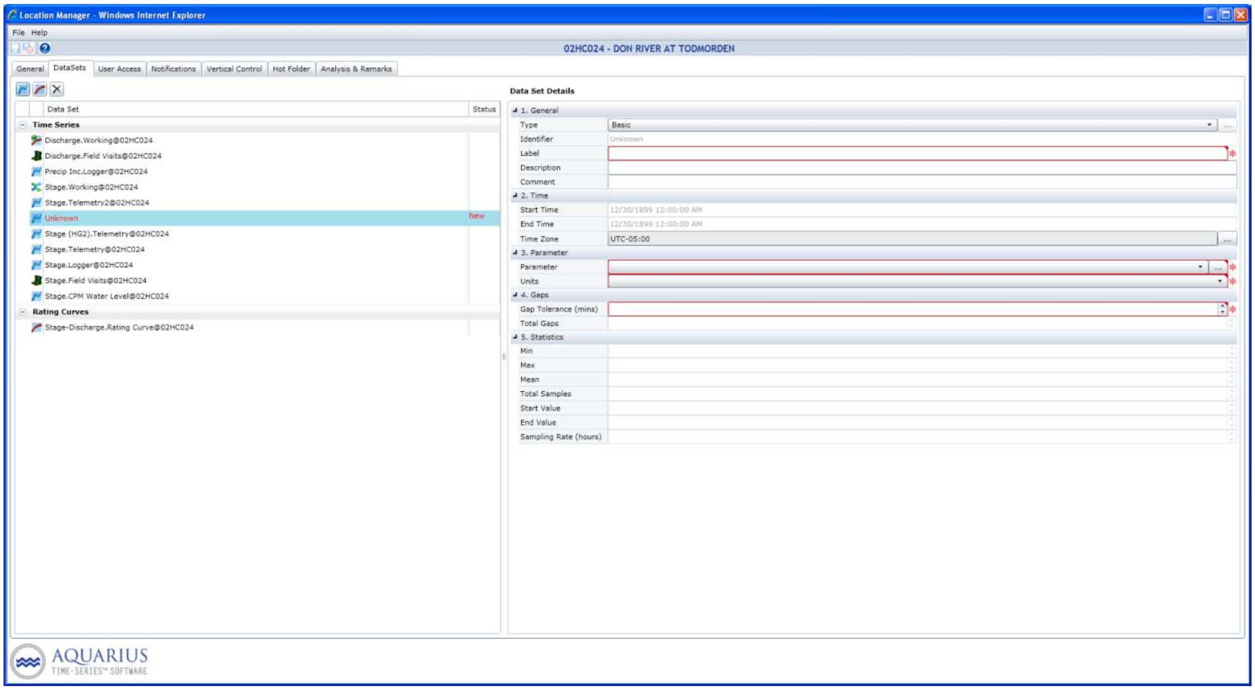
Figure 5

6.9.4.1 Daily mean discharge dataset

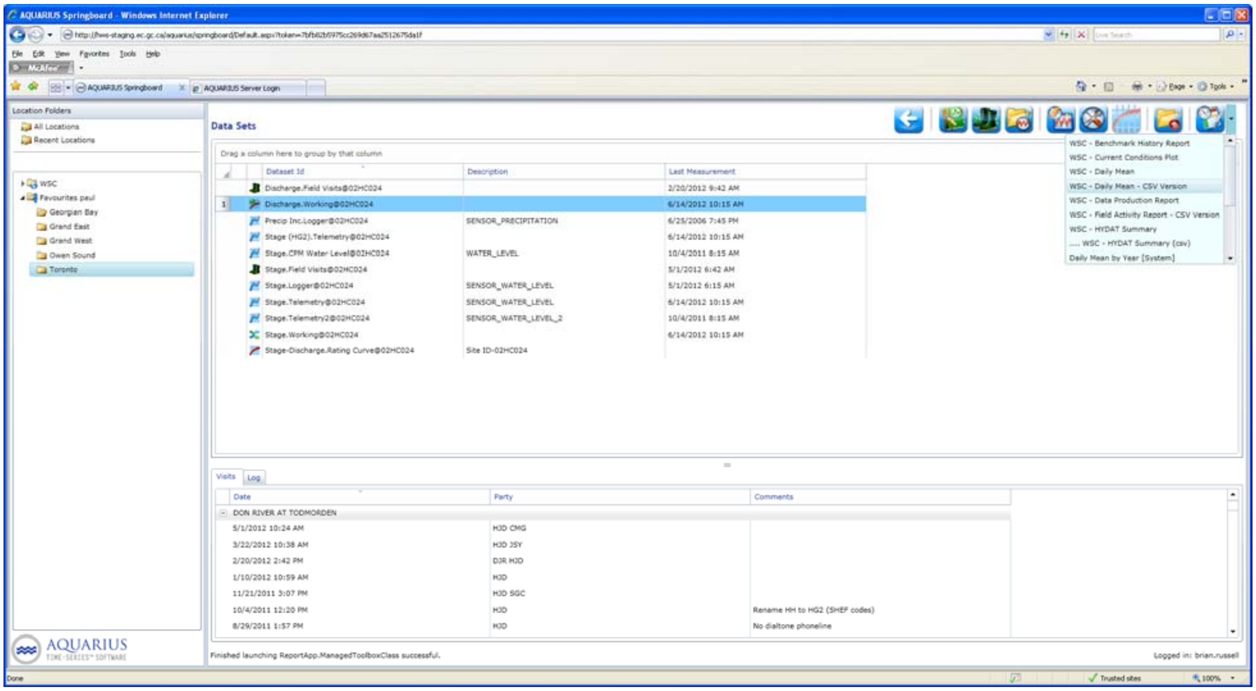
Data Estimation document – Creating a Daily Mean Data Set

An important tool for data estimation is to be able to see how the unit value data plots as a daily mean value for either corrected or uncorrected discharge data. Below are the steps to follow to create the daily mean data set.

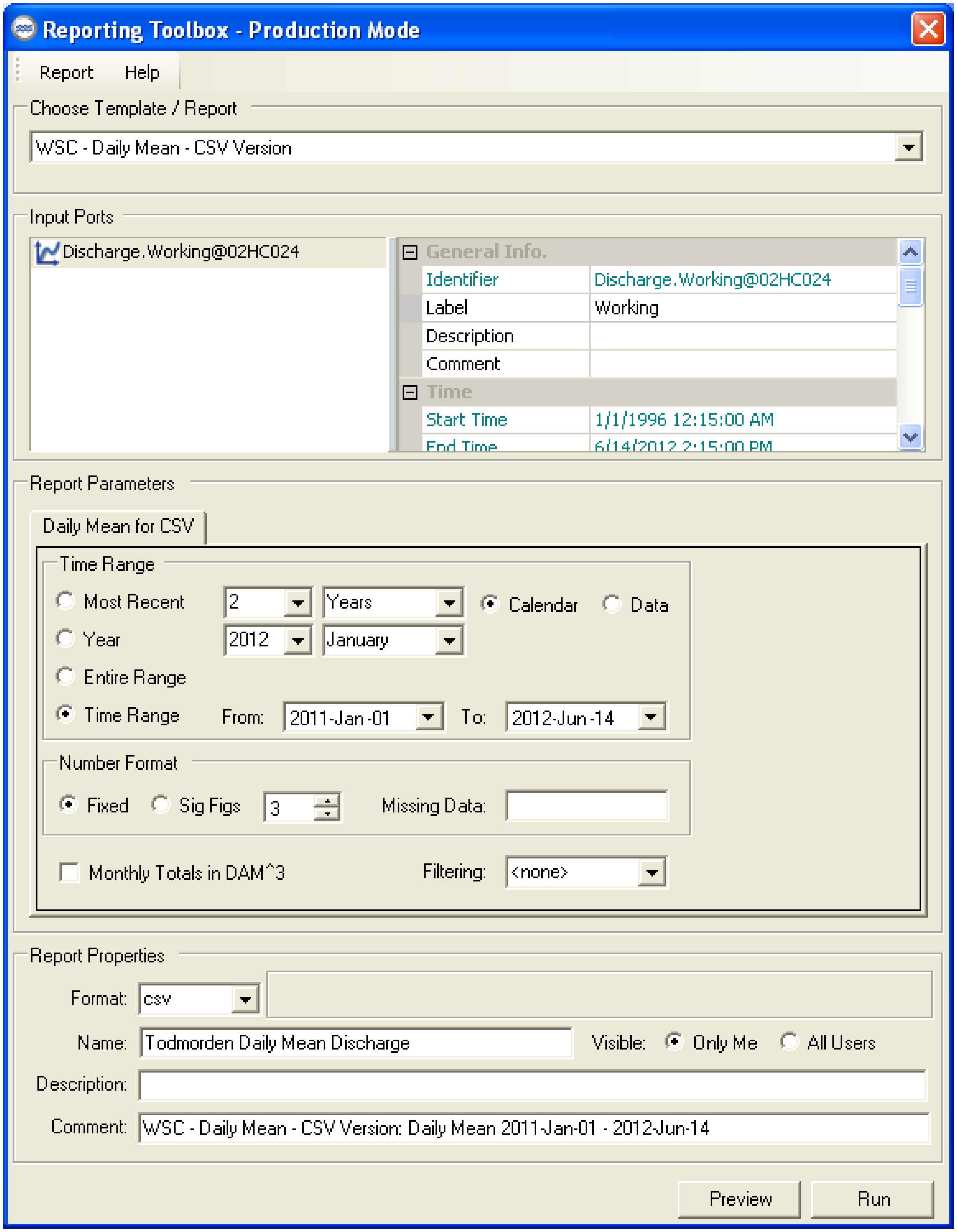
1. Select the station from the Aquarius dashboard.
2. Open Location Manager and select the Data Sets Tab



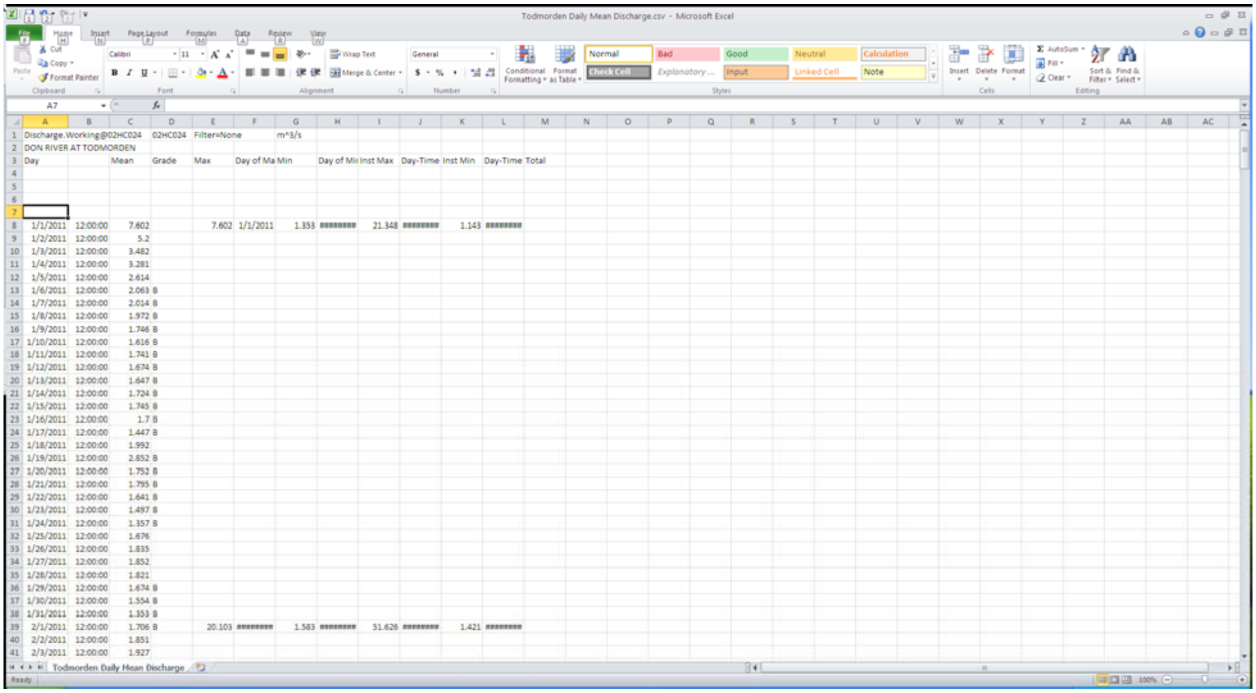
3. Select the New Time Series Icon and fill in the required parameters
   - Label- “Daily Mean Corrected” if corrections have already been applied or “Daily Mean Uncorrected” if no corrections have been applied to the data set.
   - Parameter – Discharge
   - Gap Tolerence – 1442 seems to work fine
4. Save and exit from Location Manager
5. The data set you want to view has now been created so now you need to fill the data set with the desired data
6. Select the station from the Aquarius dashboard.
7. Select the “Go To Data Sets” icon.
8. Once you get to the Data Set page select Discharge Working.
9. Go to the reports tab pull down menu and select “WSC – Daily Mean – CSV Version”.



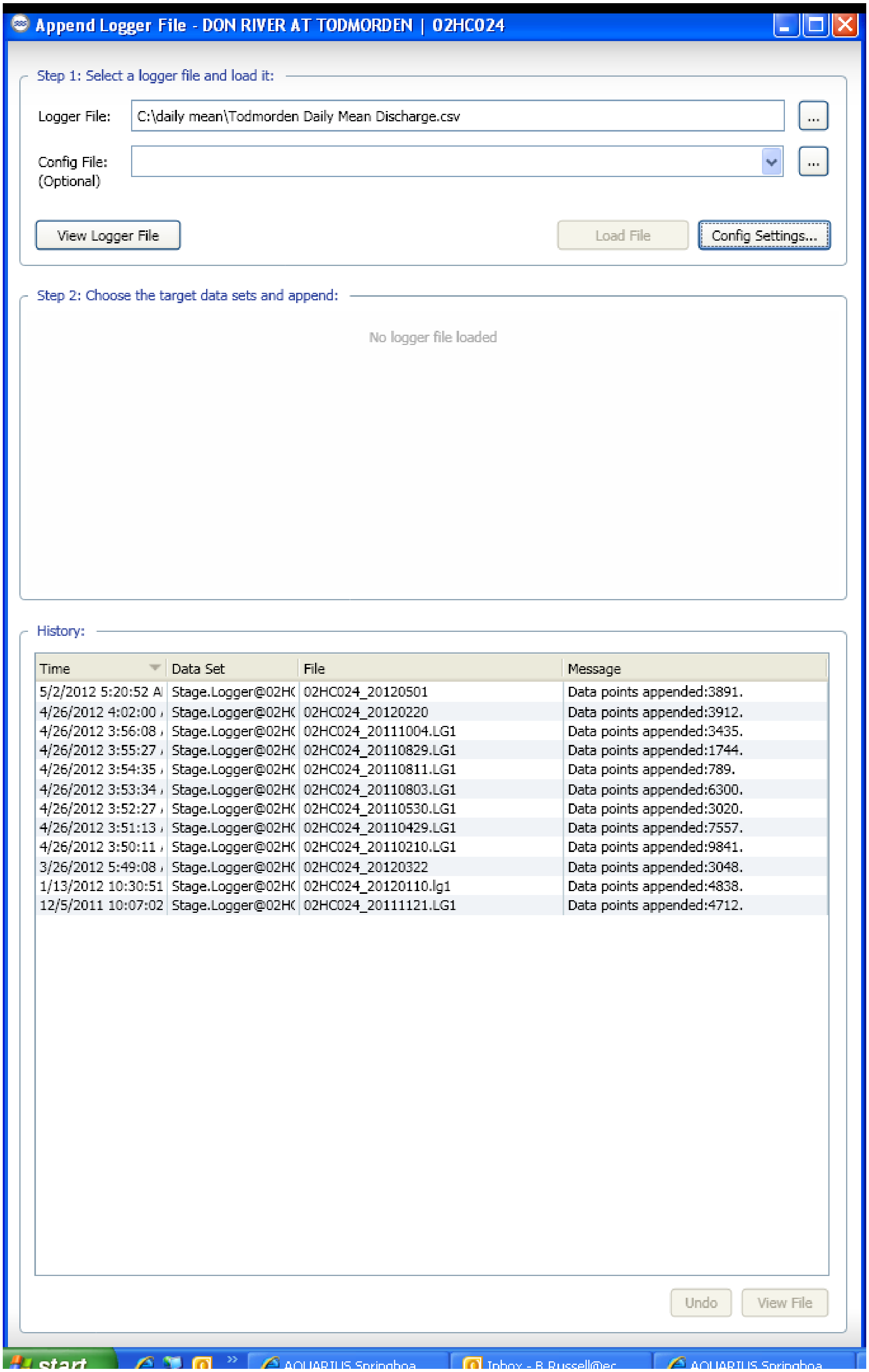
10. From the Reporting Toolbox – Production Mode select:
    - Time Range (example shows Jan 01 2011 to the present)
    - Report Properties select csv in the format pull down menu (this is not a default and must be selected) and Name
    - Select **<u>Run</u>** and not Preview.



11. Aquarius will run some scripts and then ask that the file be saved. Make sure you know where it is being saved and the File name that you want
12. The data set has been created and at this point you have to do some editing of the file to get Aquarius to accept it.
13. Open the data set that was just saved in the report section.
14. Insert a column between column A and B and fill with a time stamp (use 12:00:00)
15. Insert 3 rows above the first row of data. This is required when setting up the data set to append as the header row seems to be attached to the first row of data. Otherwise you will lose the first data row.

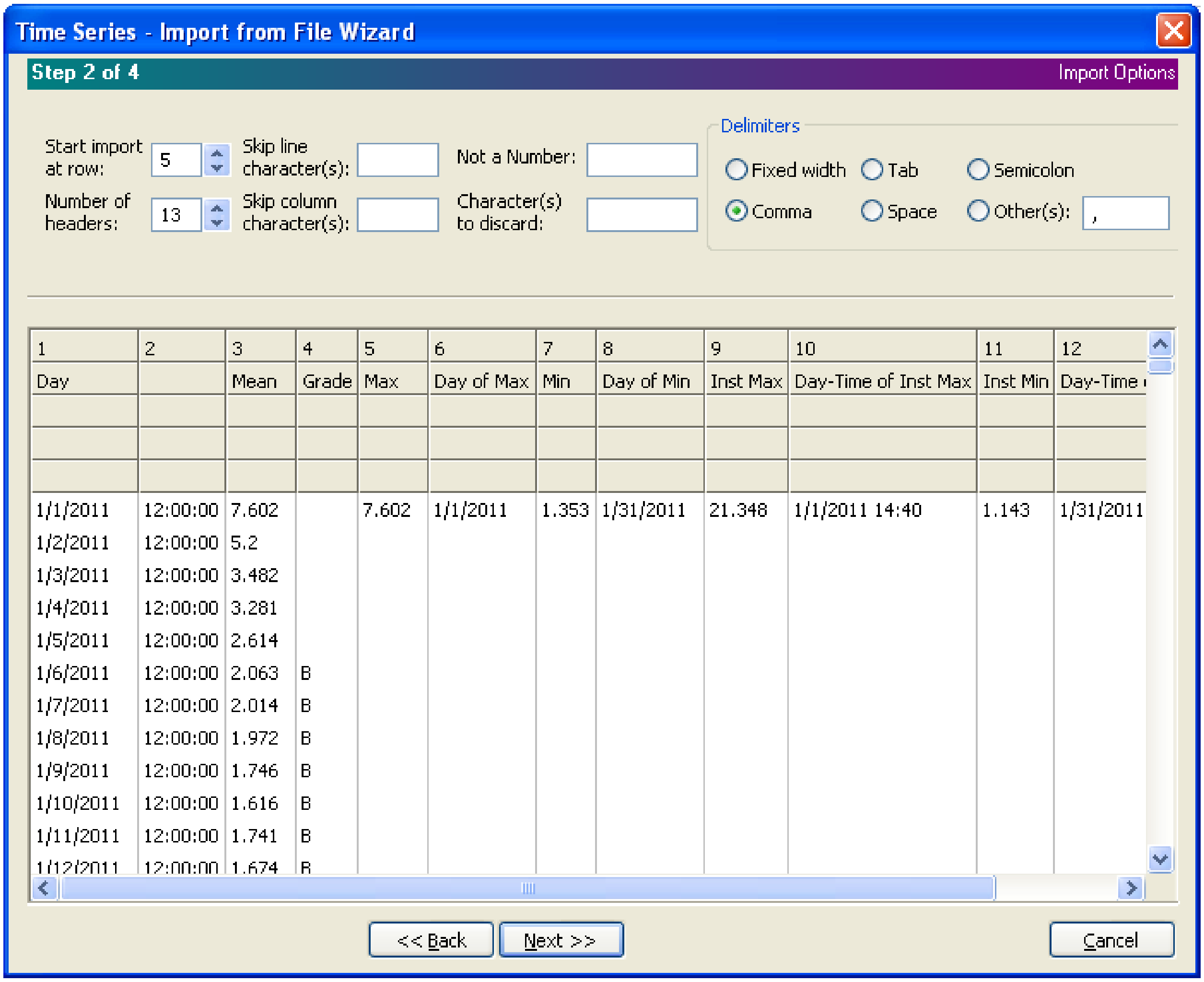


16. Save file. Answer yes to all dialog boxes
17. From the dashboard in Aquarius open the APPEND LOGGER FILE by clicking the appropriate icon
18. From the Append Logger File box:
    - Select logger file
    - Go to Config Settings…which takes you to the Time Series – Import from File Wizard box

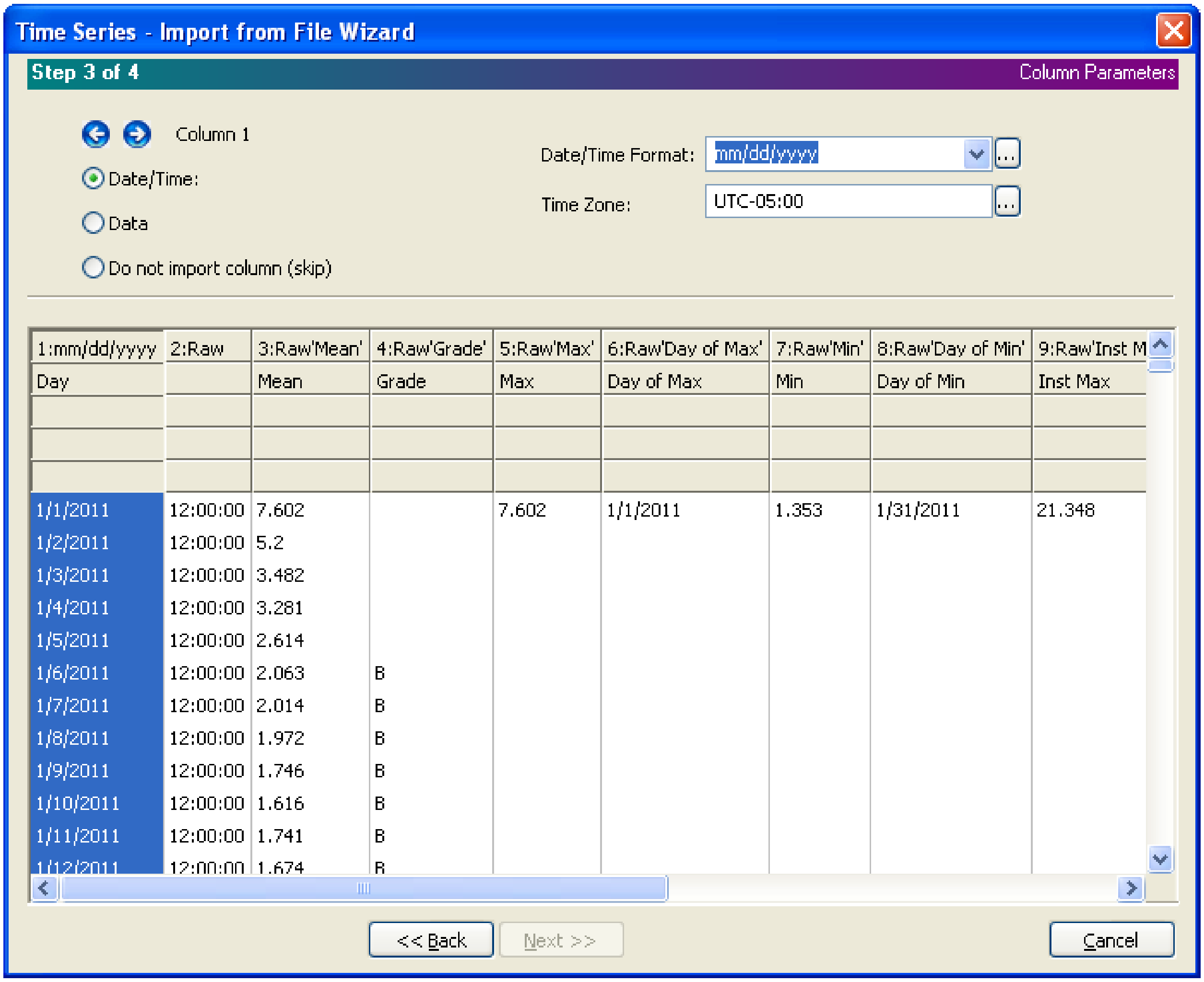


19. From the Time Series – Import from File Wizard box:
    - Select Text File from the Time Series drop down menu (default)
    - Select Next>>

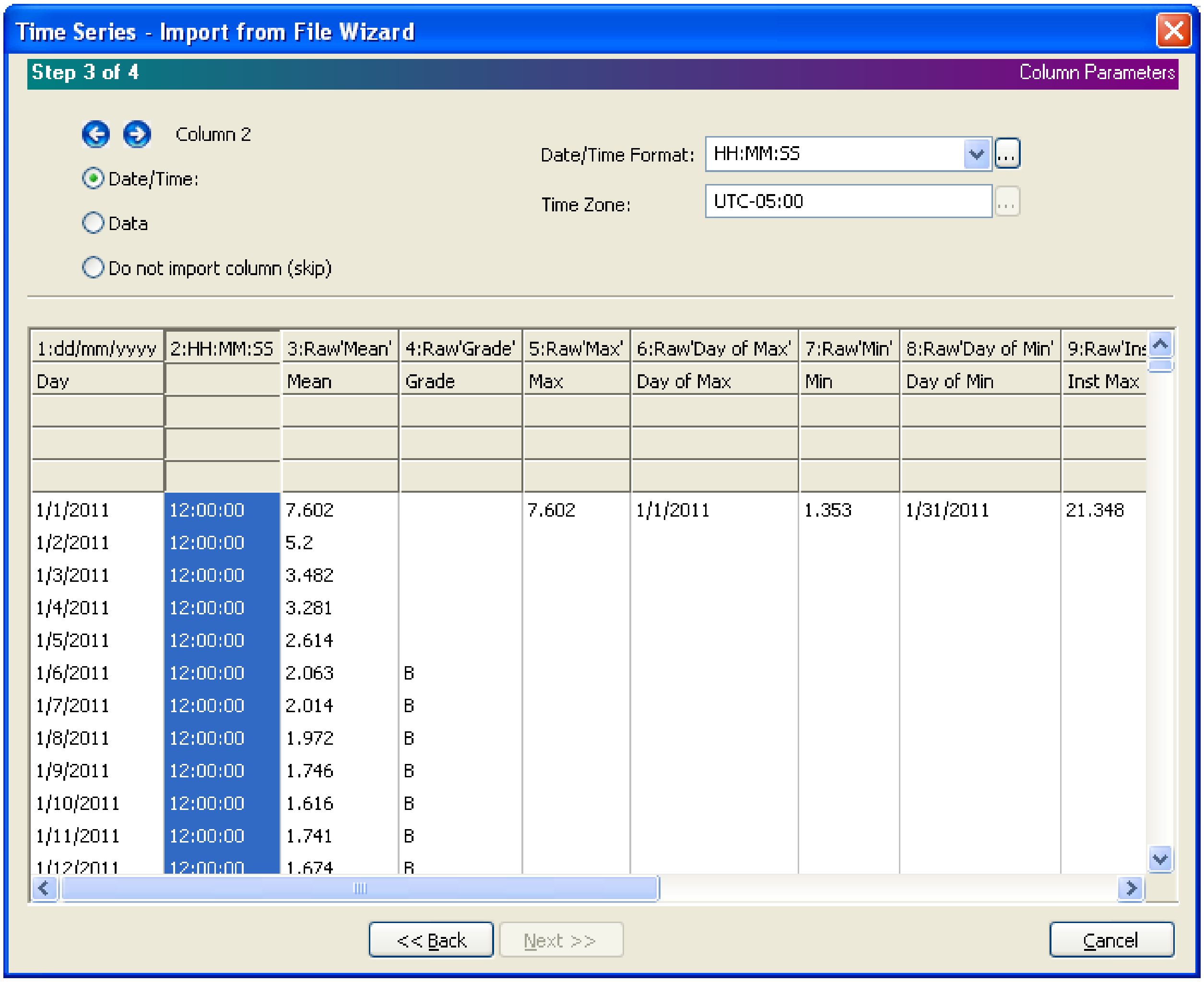
- Here is where you define the fields that you want to import (step 2 of 4)
  - Number of headers box – type in 13
  - Start import at row: toggle down to appropriate row (5)
  - Select Next>>



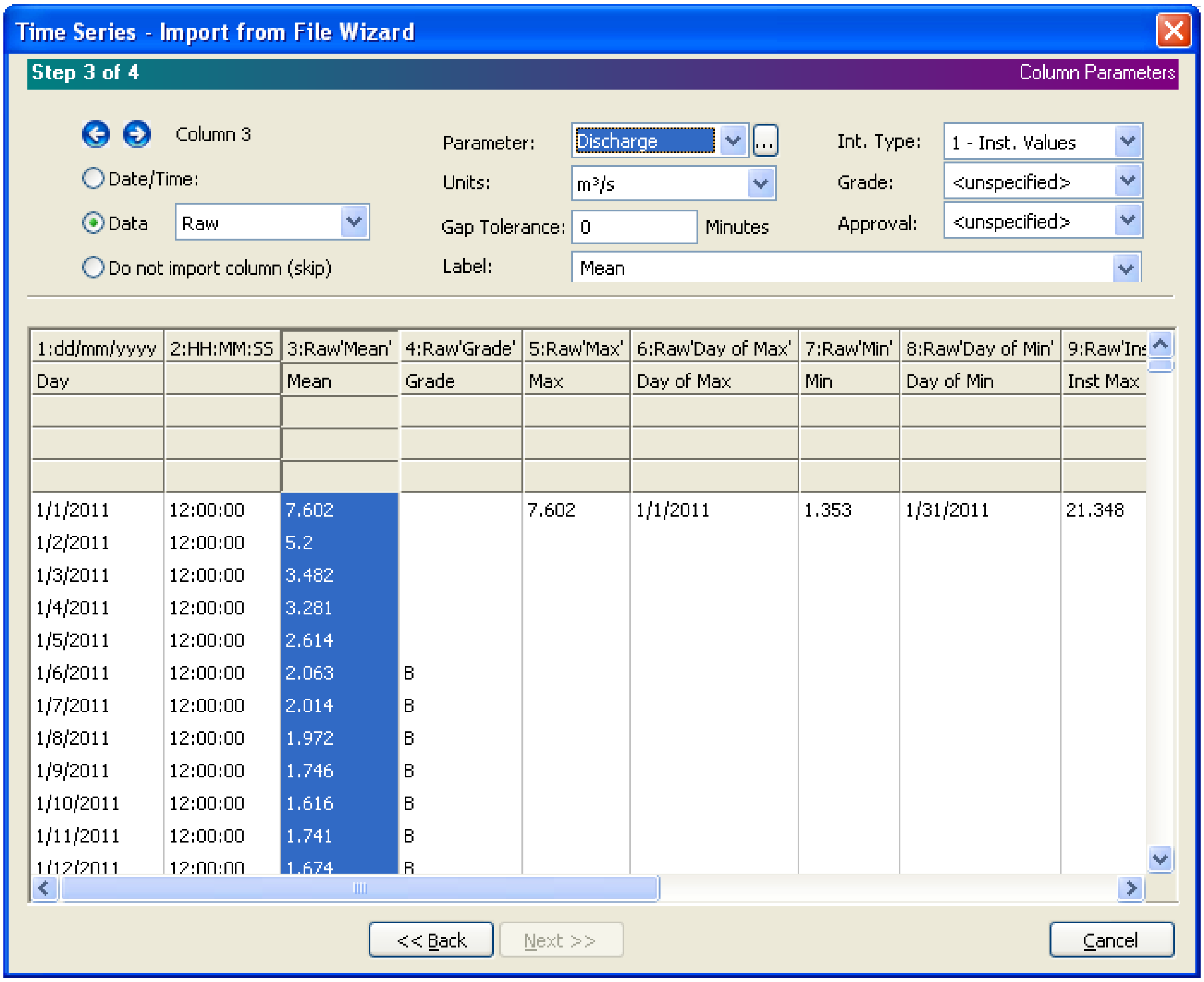
- Here is where you define what to import by column
  - From column 1
    - Select Data/Time: option
    - From Date/Time drop down menu select proper date format (mm/dd/yyyy)



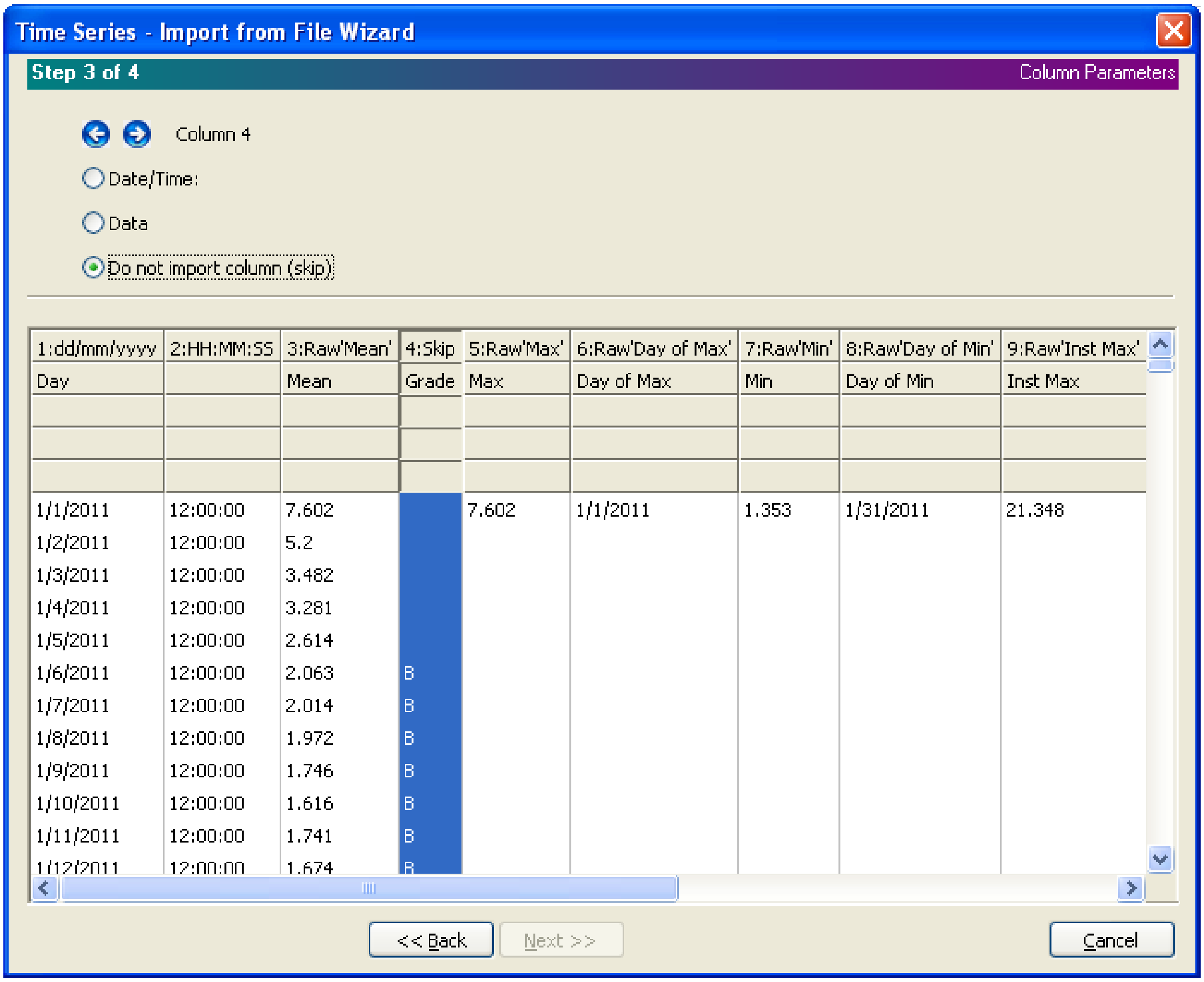
- o From column 2 (select right arrow to get you to column 2)
    - Select Data/Time: option
    - From Date/Time drop down menu select proper time format (HH:MM:SS)



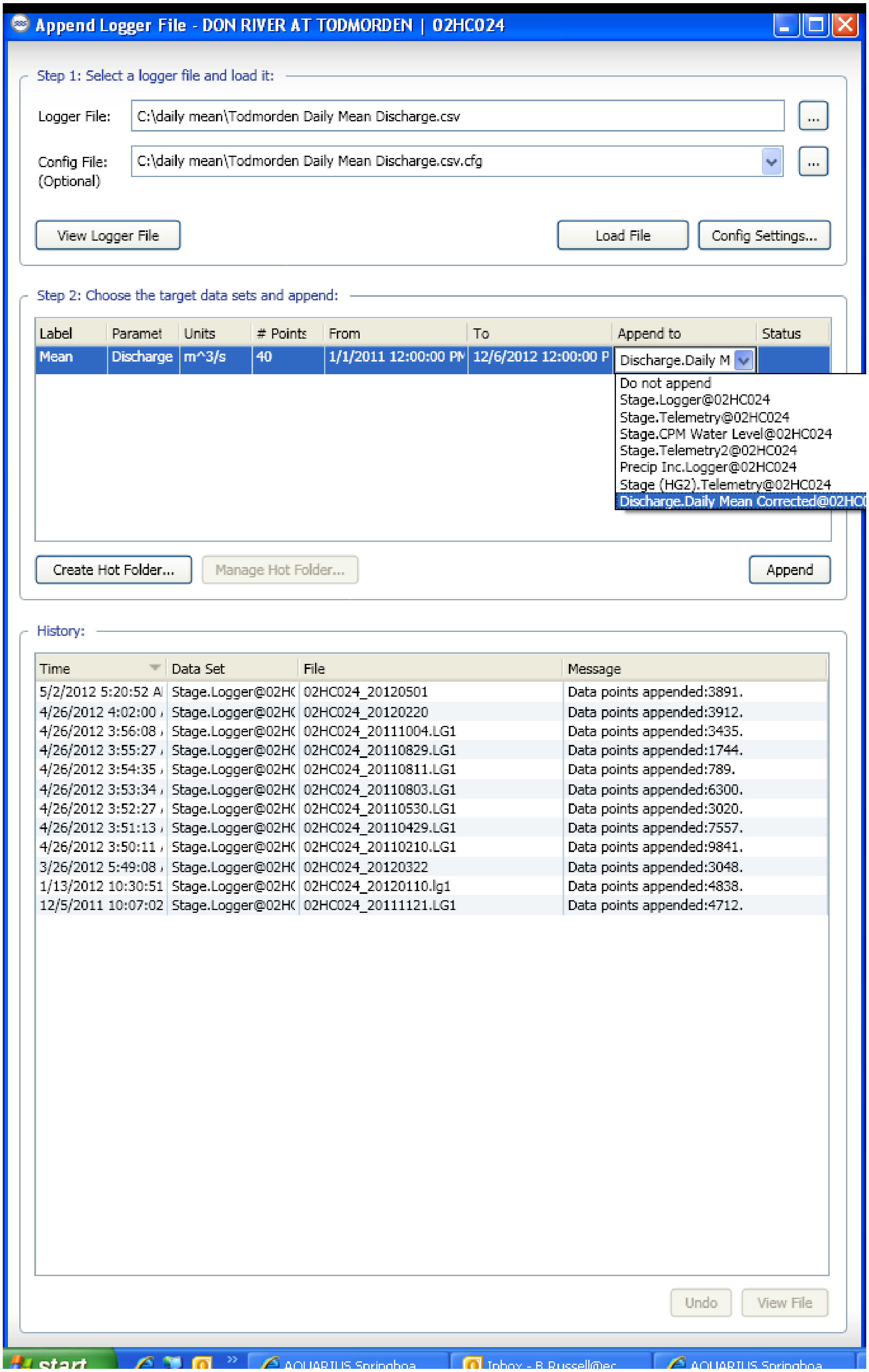
- o From column 3
  - Select Data option (leave as raw on drop down menu)
  - Select Parameter: (discharge from drop down menu)
  - Leave all other fields the same



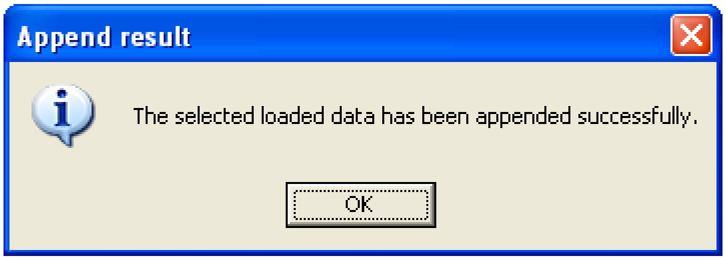
- o From column 4 to 13
    - Select Do not import column (skip)



- Once complete the Next>> button should be active and selected (sometimes the Next>> button is still greyed out so you have to go back and make sure you have made the right selections. It may take some fiddling but eventually the Next>> button becomes usable).
- Step 4 allows you to save this configuration so you can use it for other daily mean discharge imports (Config file). Select Finish button
- You may get an Invalid warning but all is OK
- You are now back in the Append Logger File where in Step 2 you select the appropriate data set (Discharge. Daily Mean Corrected).



- Select Append button
- A dialog box will appear saying the data has been appended successfully.



- The data set is now ready for use.

6.10 Streamflow Hydrographs Theory

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

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

6.10.1 Hydrograph Characteristics

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

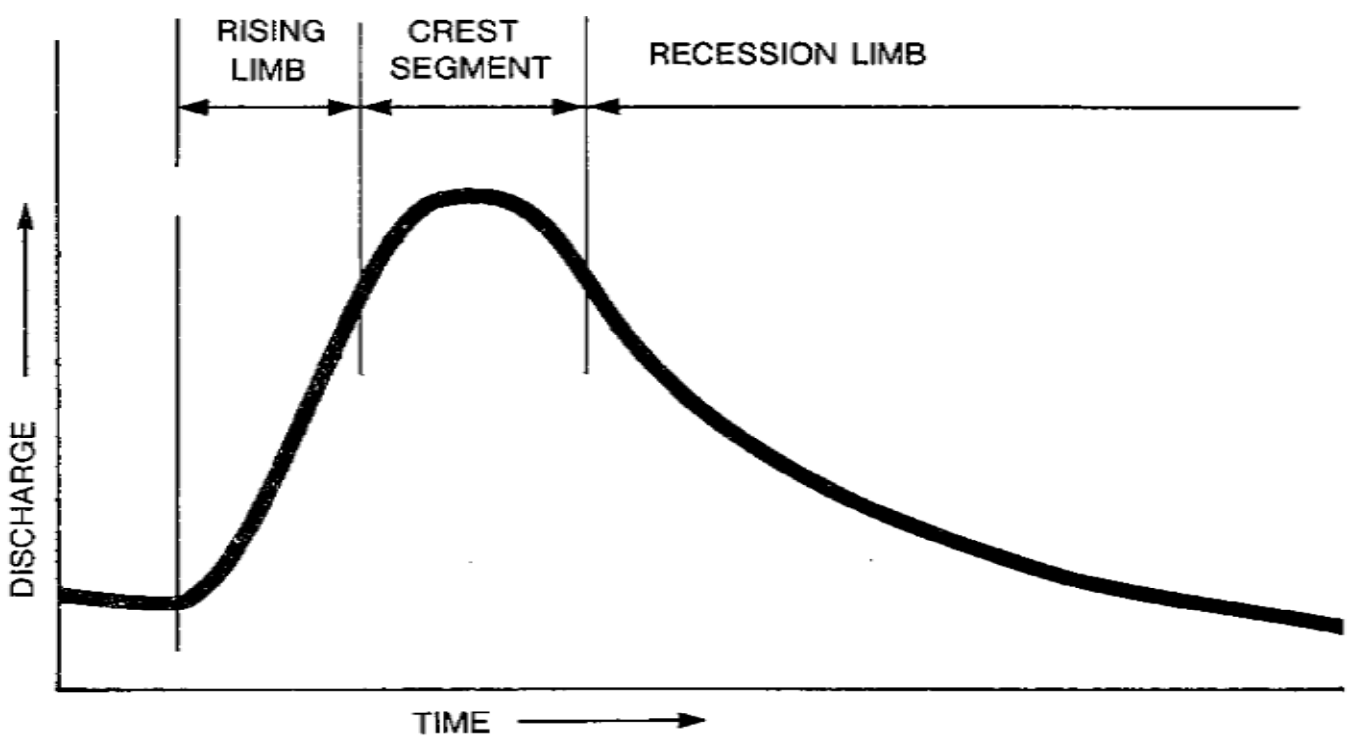


Figure A-1. Elements of a typical hydrograph.

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

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

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

6.10.1.1 Factors Affecting Hydrograph Shape

6.10.1.1.1 Climatic Factors

6.10.1.1.1.1 Precipitation intensity and duration

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

6.10.1.1.1.2 Distribution of precipitation

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

6.10.1.1.1.3 Direction of storm movement

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

6.10.1.1.1.4 Type of precipitation, type of storm, temperature

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

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

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

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

6.10.1.1.1.5 Antecedent conditions

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

6.10.1.1.2 Topographical and Geological Factors

6.10.1.1.2.1 Drainage area size and shape:

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

6.10.1.1.2.2 Distribution of the drainage system

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

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

6.10.1.1.2.3 Slope of the main channel

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

6.10.1.1.2.4 Slope of the effective drainage basin

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

6.10.1.1.2.5 Pondage

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

6.10.1.1.2.6 Geological factors

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

6.10.1.1.3 Stream flow Regulation

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

6.10.1.1.4 Storage

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

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

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

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

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

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

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

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

7 Quality Assurance

7.1 Automated QAQC Measures

Automated QAQC Measures are actions based on integrity criteria defined specifically for each station. They are the first corrections applied, during the automated phase. These actions can be categorized into two groups: a) corrections, and b) notifications.

7.1.1 Integrity Criteria

Integrity criteria are the driver of any automated QAQC measure. They are designed using knowledge of specific local conditions to help identify situations that may require email notification, the flagging of data, automated corrections or manual interventions.

Technologists are responsible to identify, configure and maintain QAQC data integrity criteria at their stations. Integrity criteria must be specifically designed to monitor Station Health and Hydrometric Conditions at a station.

Station Health criteria must include:

- Maximum allowed gap in telemetry
- Battery voltage lower limit.
- Spikes
- Percentage of data deleted automatically

Hydrometric Conditions criteria must include:

- Maximum in expected data range
- Minimum in expected data range
- Maximum rate of change, and
- Maximum length of flat line periods
- Data in range of interest (e.g. values where calibration visits may be required)

Integrity criteria values must be based on conditions specific to each station. When no significant record is available yet, criteria can be approximated using general stream size and reactivity, as listed in table 2. However, these values must be improved once actual knowledge of the station is available. They should preferably be based on conditions experienced at the station during at least the past 5 years of record. The past record is surveyed to determine the 20 greatest values for the highest peaks, the lowest troughs, differences between consecutive unit values, and the time periods during which there was no change in the record. Based on these samples, a statistical analysis is performed by the technologist to establish a suitable threshold for every integrity criterion. This analysis and its results are documented in the station work files.

Integrity criteria should be refined as experience with the station behaviour and hydrometric conditions improve. They should be regularly revised, at least once a year, and preferably before every change of water regime. Criteria other than those listed in table 2 may also be considered. For example, Nitrogen pressure set to be triggered at values < 300 pds could also be used as a notification although it is not listed. Some stations may have tipping bucket alarms or signal strengths set up as well. Of course, each station and its accessibility/visit frequency would imply different values for proactive maintenance. The exploration of alternative criteria that can further contribute to the technologist’s interpretive and planning abilities must be encouraged.

Table 2: Generic Integrity Criteria by River Type – For Initial Approximation

River Type:	Description	Small Reactive	Medium	Large Stable
	Peak	< 100 cms	100 – 1000 cms	> 1000 cms
Station Health				
Maximum allowed gap in telemetry*		>24 hours*	>24 hours	>24 hours
Battery voltage lower limit.		12 V	12 V	12 V
Spikes		0.004-0.007m last 8hrs	0.004-0.007m last 8hrs	0.002-0.004m last 8-24hrs.
% of data deleted automatically		>10% within last day	>10% within last day	>10% within last day
Hydrometric Conditions				
Maximum expected in data range**		To be defined	To be defined	To be defined
Minimum expected in data range		To be defined	To be defined	To be defined
Data in range of interest		To be defined	To be defined	To be defined
Maximum rate of change		3m per day	2m per day	1m per day
Maximum length of flat line periods		0.007m within last day	0.002m within last day	0.002m within last day

*A gap in telemetry should represent at least 3 consecutive attempts to obtain data.
** Make sure the upper limit takes into account potential flood events.

7.1.2 Automated Corrections

Automated corrections should be biased against the deletion of potentially valid data as much as can be predicted. However, corrections should cleanse signals from simple and localized errors or prevent the dissemination of blunders and unrealistic values. In particular, data out of a station reality range should be deleted for real time displays until such time where it can be validated manually.

Any data not meeting the expected integrity criteria of a station should be deleted or flagged. Any data identified as spikes, data above the maximum rate of change, or that is likely part of a flat line period could also be automatically deleted or be only flagged to later help focus review efforts and manual validation. Technologists do not need to set any email notifications for such issue. They can be informed by a % of data deleted criteria in case too many values were ever removed, in order to rectify the automated criteria that may have caused too aggressive a deletion. The use of flags and notifications is explained later.

Automated QAQC measures must be configured as Post-Processing corrections. Prior to any automated QAQC measures, data must be modified to properly fall within expected hydrometric conditions for the station.

For example, data should be properly submitted to gauge datum changes and sensor resets. Considerations should also be given to any special chronological order of application that may be required within the Post-Processing priority stack itself.

7.1.3 Notifications

Notifications may take the form of emails sent automatically to responsible staff, or flags assigned to specific data points within a time series during the automated cycle and later addressed during data review. Flags help focus the data review, and thus enhance the review efficiency. Notifications are used by the automated computation system to inform technologists, supervisors and data control about station health issues and hydrometric data features that may require immediate attention. Notifications should be configured for all those criteria defined in the previous section. Notifications may also be custom designed for needs specific to the station operation, such as information required by the technologist to address special client requirements.

The technologists are responsible for managing notifications from their assigned station. Continuous data production implies the need for a prompt response to any emailed notification. It also implies the need for enhanced team coordination. As such, technologist must make sure that their notifications are forwarded to other member of their work team whenever they will not be available to respond.

While in the field or on leave, the technologist primarily responsible to manage a station must forward the email notifications to the person assigned as back up in the team for that station.

The information on station health can greatly assist supervisors in managing their portion of the hydrometric network.

Supervisors should be copied on email notifications configured to deal with Station Health issues.

Data Control, in coordination with the technologist and supervisor, may directly enter new notifications or edit existing ones if and when they judge it necessary. However, they do not need to be included in the distribution list themselves except if they request or make such change to the notification parameters.

Notifications are for internal use only. Clients and partners are not to be included on notification email distribution lists.

Refer to the Integrity Criteria listed in Table 2 for guidance on the review of notifications and flags of interest. Any notification or flag should also be accompanied by a comment describing the selected time of start, its objectives and the criteria calibration method and history.

Notifications and flags must be reviewed and updated at least once a year, preferably before every change of water regime, as conditions and knowledge (integrity criteria) of the station evolves.

7.1.3.1 Email Messages

The content of emailed notifications is configured within the Location Manager Toolbox. Each message should be carefully titled to provide a clear idea about the information it contains.

The content of a notification email message must explain which integrity criteria were exceeded and what actions are expected from the technologist in charge.

Suggestions for titles and core messages are listed below:

Title: HIGH WATER
Message: The Maximum expected in data range threshold has been topped and the station is considered to be in Priority 1 condition (flood stage). A discharge measurement may be required at this station.

Title: GAP IN RATING
Message: The range of stage that has been reached is in a section where the stage discharge rating curve is ill defined. The station is considered to be in a Priority 2 condition. It should be investigated if possible before conditions change.

Title: NO DATA
Message: The threshold for ClearSCADA attempts to update telemetry data has been exceeded. Data is no longer coming into the working dataset.

Title: LOW WATER
Message: The threshold has been broken at the low end of the stage discharge curve. The station is considered a Priority 2 likely to persist until a precipitation event. It should be investigated if possible before conditions change.

Title: LOW BATTERY
Message: The minimum threshold for battery voltage has been exceeded. The station should be monitored and investigated before power issues result in a loss of data.

7.2 Manual Data Approval

The Approval Status of data computation elements relate to the condition of data in the context of computation management. This status, internal to Water Survey of Canada, must be raised through 5 different levels as approvals proceed. These levels are defined as follows:

- **(0) Undefined:**
  Approval status for data restricted from publication.

- **(1) Preliminary:**
  Approval status for data submitted to automated and human interventions but for which all quality influences have not yet been factored in.

- **(2) Reviewed:**
  Approval status of data thought to have captured all factors influencing quality.

- **(3) Checked:**
  Approval status of data that was peer reviewed to confirm that all quality influences were factored in.

- **(4) Approved:**
  Approval status for data deemed the best that can be produced.

Approval levels should always evolve from Preliminary to Approved. Data approval levels should not be downgraded.

Data must not be changed or downgraded when Approved. Any correction of previously Approved data corresponds to a Data Revision which must abide to Data Review criteria and procedures.

7.2.1 Frequency of Approval Periods

While performing data approval, remember that the purpose of Provisional data (Preliminary, Reviewed and Checked) is to serve as guidance to data users, for occasions when the timing of data is more important than its accuracy while Final data (Approved) is meant to serve for the purpose of long term statistics and is based on confirmed information and solid justification.

The ability to complete data approvals depends on 3 conditions required to confirm data validity: 1) Confirmed reference gauge stability; 2) Completed validation of field results and Stage time series; 3) Completed validation of estimation models and methods; 4) Completed validation of the derived discharge time series.

Data approval should be performed at least on a bi-annual cycle, with periods of final approval completed on dates defined by each district.

Approval periods must not include parts of days. They must be set to start or finish on the last full day at midnight and not on the actual time of a visit.

Seasonal stations may only operate for 8 months but must still have a total of 12 months of approved period.

The entire calendar year of a station must be approved, regardless of the station operating period.

Approvals must not be performed at a frequency so high as to risk triggering the need for data revisions.

7.2.2 Approval Sequence

Once data are approved, they are locked and can no longer be modified by technologists. However, until this final level is reached, dependencies between various data types must be adequately understood to ensure that data is not modified inadvertently while completing the computation process.

Any valid data approval sequence must integrate inter-dependencies, start with the review of independent variables, of models, and move towards the review of information derived from these.

Approvals should be completed as per the following specific hierarchy:

1. Gauge History
2. Field Visits
3. Stage Working time-series
4. Rating Curves
5. Shifts
6. Discharge Working time-series
7. Period of applicability for Rating Curves

The Data Production Report is a tool which can help track the progress of data computations and approvals against these items. It can be used for checkers and approvers to coordinate their work with the responsible technologist.

7.2.2.1 Gauge History

Technologists must confirm the gauge stability using level checks or historical reviews. In exceptional cases where proof of gauge stability is evident, approval could be completed in advance of a gauge level check. For example, it may be possible to carry forward a gauge correction for a seasonal station to the end of the operating period. Technologists are then required to specifically document digressions from the stricter monitoring of gauge stability in the station files that were approved by their supervisor.

Gauge stability must be confirmed prior to the final approval of any period.

If a Gauge History shows periods of instability, an increase in the frequency of approval will require a proportional increase in the frequency of gauge level checks. Final data can be based exclusively on extrapolation of known information only if a solid justification is documented.

7.2.2.2 Field Visits

The approval level of Field Visits must be at least raised to Checked, after their peer review. Field Visits do not have to be Approved.

Review the values entered for any field visit activity to make sure that they mirror information initially captured in Field Notes. Information is transferred directly from the Field Visit Toolbox to other computation elements in AQUARIUS. So reviewing this information first will circumvent the need to review it anywhere else later.

Stage: Check the observed values, their associated time, and the application of any gauge correction. Ensure the values in the ‘Result’ fields are correct.

Discharge: Ccheck the observed values, their assigned mean time, mean gauge height and related discharge corrections (e.g. correction of discharge for moving bed bias, or side channel measurement). Also check that any required gauge correction was properly applied to the mean gauge height here as well. Ensure values in the 'Result' fields are correct.

Check that values were properly dispatched to other computation elements in AQUARIUS. For example, mean gauge heights must only be available in the Rating Development Toolbox as it is not a discrete observation but an aggregated value that cannot be used to calibrate the stage time series.

Verify discharge measurement details if any doubt exists about the proper application of associated standard field procedures, or as spot check verifications for such measurement. The verification may have to be performed outside AQUARIUS, using the original acquisition software for their review as well.

Technologists should keep visit results clean of any unnecessary data. They should also keep track of changes to field data on the original field notes. These notes should be scanned and saved on the Network Storage only once they have been adequately reviewed and data for their period has been approved. This can be done on a regular schedule and for many stations at once.

7.2.2.3 Stage Working Time-Series

Unit value time series proceed through all Approval Levels, up to Approved. During the Automated phase of data production, Stage time series entering AQUARIUS are automatically raised to Preliminary when handled by ClearSCADA and subjected to sanity checks.

Check the Stage Working time series for any unexplained anomaly. Within the Change List in the Data Correction Toolbox, check whether all corrections were justified and properly documented. Standard comments must accompany every correction for which specific tracking requirements have been defined. Verify that no valid data was identified or treated as if it was incorrect.

Check that all data periods requiring a symbol have been graded. In the Data Gap List, identify any missing period greater than 120 minutes and determine whether more efforts should have been made to complete it or even if it requires estimation.

Final water level time series can include gaps. Water level data can only be estimated at lake stations over periods no greater than 10 days.

Once the time-series approval has been raised, include relevant information in the Station Analysis.

7.2.2.4 Rating Curves

Rating curves are first created at the Preliminary level and evolve through all approval levels independent of other modelling components, and as fast as design and calibration information is available and allows validation.

Curves can be validated and approved while not implemented. It is when a Rating Period is assigned to a curve that it becomes active for that period. Transitions between models should be defined before any such activation. This decision is done in coordination between the supervisor and technologist.

Once the curve is approved, thoroughly document how the new curve was derived and any important interpretation and validation information on the Station Analysis. The approved rating curve information could also be printed and archived as part of the documentation of approvals (backup to compensate for gaps in audit trail and locking of the Rating Development Toolbox).

7.2.2.5 Shifts

Shifts are first created at the Preliminary level and then evolve through all Approval Levels. However, their approval level must always be equal to or lower than the Rating curve and Rating Period on which they depend.

Once the Rating Period approval level is raised, any shift within that period is automatically raised to the same level of approval.

If the end date of a Rating Period is entered, a new open ended Rating Period must be have been created before any other open ended shift can be entered and thus support real time data production.

7.2.2.6 Discharge Working Time-Series

Discharge time series proceed through all Approval Levels, up to Approved. These time series must not be set automatically to any level other than Preliminary when first derived via the active model. Higher approval levels must be manually assigned by the technologists and supervisors during the Value Added and Final phases of production.

The approval level of Discharge time series is first set to the lowest common denominator among that of all derivation components, namely the Stage time series, the rating curve, its rating period and any associated shift.

Check the Discharge working time series for any unexplained anomaly. Within the Change List in the Data Correction Toolbox, check whether all override corrections were justified and properly documented. While standard comments must accompany every correction for which specific tracking requirements was defined, best practices dictate that interpretation relative to any correction should be described. Verify that no valid data was identified or treated as if it was incorrect.

No correction must be applied in discharge to mitigate errors originating from the Stage time series.

Validate estimated periods in the Discharge working time series using QuickView to display data in a semi-log plot if useful. While making reference to gaps in the Stage time series, check that all estimated periods were properly graded. Raise the time-series approval. Include relevant information in the Station Analysis.

7.2.2.7 Rating Period

The approval level for any Rating Period can be set to any value up to that of the Rating Curve on which it will apply. Note however that Stage-Discharge relationships are used by the computation system to derive Discharge data as soon as they are assigned a Rating Period.

A Rating Curve should not be assigned any Rating Period when data should not be produced from it.

As previously stated, the approval level of Discharge time series is first set to the lowest common denominator among that of all derivation components, namely the water level time series, the rating curve, its period of applicability and any associated shift.

The approval level of a Rating Period must remain at Preliminary during all open ended periods. It must be approved only once an Approval Period is completed. This ensures that Discharge data is first created at the Preliminary level and because, in real time production, there are always doubts about a curve applicability against current conditions.

To complete an Approval Period, Technologists must assign open ended Rating Periods an end date that corresponds to this Approval Period. The approval level for the closed Rating Period can then be set to Reviewed. The technologist then assigns a new Rating Period to the curve that will be used during the next Approval Period, making sure dates do not create undesired gaps in the resulting Discharge. The new Rating Period, which is open ended, is then set to Preliminary. Relevant information must be included in the Station Analysis.

Rating Periods correspond with Approval Periods. Every time an Approval Period ends, the current model Rating Period must also be closed and a new one be assigned to the curve used during the next Approval Period, making sure data production remains seamless.

7.3 General Responsibilities

Data approval is a team responsibility coordinated between the Technologist assigned as primary responsible for a station, Technologists identified to provide assistance for production at the station and for the peer review of its results, their Supervisor and Data Control representative. Each team member is responsible to communicate with their team mates to ensure that the next phase in data approval will be addressed in a timely manner.

To help track the progress of data approval, teams must use the most recently approved Computation Checklist form.

7.3.1 Technologists

Technologists are first responsible for the timely review of all computed data at the stations they operate. They ensure the compliance of their data computation to all adopted standards..

Technologists must document any inadvertent or intentional deviation from expectations as to why the non-compliance occurred and what impact it may have on data. Non-compliances should be recorded as a note spanning the period and as an approval comment in the Station Analysis. Reference to any relevant Corrective and Preventative Action Report (CPAR) should also be included.

Technologists are responsible to verify that the version of any contributed data obtained is in compliance with the contributing agencies Quality Management System and respects the National Hydrometric Program's requirements.

Technologists are responsible to review field activity information while still in the field where corrective measures can be implemented when necessary. Field information, such as a discharge measurement, therefore enters AQUARIUS at the Reviewed approval level. Field measurements thought to deviate significantly from standard procedures must not be assigned an approval level higher than Preliminary if they are entered into AQUARIUS. Comments associated with the field visit should then clearly indicate why the measurement is kept at a lower approval status. These measurement should also not be routed to any toolbox if they are considered invalid. These measurements are then available for inspection but cannot be used for rating development or data corrections.

Technologists are responsible for the general completion of a Station Analysis for every period approved.

7.3.2 Peer Reviewer

Peer Reviewers are Technologists assigned to ensure that all processes and information required for the computation of data are complete and available. They are not expected to validate interpretation or add to the Station Analysis.

Peer Reviewers check that the data entered for all Field Visit is correct and they then raise the field information approval level to Checked.

Peer Reviewers inspect data for any missed correction opportunities. They check if all data has been properly graded with proper comments and justifications. They may decide to enter some corrections on the fly (e.g. minor editing of a mean gauge height), but they normally provide notes back to the responsible Technologist for them to apply appropriate corrective actions.

7.3.3 Approving Supervisor

Supervisors have the responsibility to approve all data, validating its compliance to all adopted standards. As such, they are provided with administrative rights allowing them to modify all approval levels for all data types. Supervisors review time series correction histories and spot check discrete data to ensure overall compliance with procedures. Supervisors focus on validating interpretation throughout the station data computation.

Supervisors are responsible to approve closed Periods of Applicability in conjunction with approving the Stage and Discharge time series once they have confirmed that the computation is complete. This is an important step which triggers the production of HYDAT aggregate data.

Supervisors may decide to enter some corrections themselves (e.g. minor editing of a mean gauge height), but they normally provide notes back to the Technologist for them to apply appropriate corrective actions.

Supervisors direct and approve Technologists efforts in setting up automated processes. They monitor results, the time and effort spent on management of automated processes. They therefore validate Notifications used and verify that they are properly updated. Recommendations are then provided to the technologist and tracked in the Station Analysis along with all other publication remarks for which they are also responsible. Supervisors archive the final Station Analysis document version into the Network Storage once data is approved.

7.3.4 Data Control

Data Control representatives are lead for the Quality Management System within their assigned area. The main responsibility of Data Control is to advise on various aspects of the data collection, computation, publication, file naming and file storing procedures according to adopted standards and guidelines. Data Control must also ensure that new computation software guidelines are understood by all staff, implemented and audited at least once a year. Data Control ensure that the following tasks are completed for each Approval Period:

- Upload to HYDAT and validate on HYDAT the peaks and extremes for each complete publication period.
- Ensure that all applicable publication and/or historic remarks are entered for each calendar year by reviewing the remarks during the validation process. The entries are made in HYDEX and should be entered by the Hydrometric supervisor as all publication remarks must be approved.
- Ensure that any provisional or final data products in addition to HYDAT data, are properly generated and named according to the National File Naming convention.
- Manage the creation and distribution of various products and ensure that the appropriate tools/reports are used within Aquarius. (Certain reports within Aquarius should not be used as the reports may not generate properly or do not meet the needs of the Cost Share partners or other external users).
- Within each district/region, each Data control supervisor should define what the standard process is for the creation and distribution of various products ie. define how provisional daily data will be created and which format will be used.
- Any exported files or reports must be archived at least once a year (ie. Benchmark History Report, Station Analysis and HYDAT Summary.

- Provide guidance and oversee any data revisions that are required. Extreme caution should be taken when revising migrated data (ie. prior to 2011/2012 implementation). Data revisions must be thoroughly documented and any relevant files must be added to the archives.
- Conduct annual audits of the office computations and hydrometric monitoring stations. Results of the audits should be communicated with all staff and actions should be taken to address any non compliance (in coordination with Hydrometric supervisors and Area Heads).
- The display of all provisional data products such as real time Discharge on the web must be closely monitored by Data Control. In some cases, Data Control may have direct involvement in creating and publishing some of these products. In other cases, Data Control will provide guidance in managing them.

8 Documentation

Complete documentation is needed to:

- Aid in the review and approval of hydrometric computations;
- Ensure availability of supporting information critical to forensic review of approved computations should the data ever be called into question.

Documentation must include:

- Completion of forms, checklists and summaries maintained outside of AQUARIUS;
- Completion of remarks, comment boxes, and use of flags, grading levels and symbols maintained within the AQUARIUS application.

The web-based user interface called AQUARIUS Springboard provides protected access to Water Survey of Canada data and the tools required for its production. The Springboard user interface gives one-click access to common data production tasks such as updating a rating curve, editing a time series, running a report, uploading a logger file, importing a gauging measurement, etc. In particular, this interface keeps a precise log of all activities performed on any data by any employee.

The AQUARIUS Whiteboard interface is an alternative to the Springboard for the production of data when non-standard methods are required. The Whiteboard enables the creation of processing steps from a variety of tools and routing data between them according to custom requirements. As a standalone tool, it can write results directly back into the database. However, it leaves little trace of the author and production methods applied. When activated within the Springboard however, writing to database is disabled. Results can only be saved locally and be imported into the database via the Springboard, along with proper traceability. Although non-standard data production cannot then be automated, this safeguards the database integrity.

Due to the traceability and standardized nature of any activity performed on hydrometric data within the Springboard environment, the Springboard is to be used as the primary interface for data production within Water Survey of Canada. Whiteboard is to be used by technologists for data production only when activated within the Springboard. The use of any other method of data production, such as using the Whiteboard in standalone mode for automated production, must be carefully documented, justified and approved by management.

8.1 Grades

The Set Grade action allows the user to apply symbols to sections of data for highlighting potential uncertainties. Grades propagate and aggregate. The lowest grade wins. Grades do not affect publication to the web. They also cannot overlap. Grades are used in AQUARIUS both to mark data as well as to control how the data is used in calculations. Grades are defined as:

- **(-2) Unusable:**
  Record is entirely unreliable and not for use in any calculations or totals, including daily mean reports.

- **(0) Undefined:**
  Applies to any trace deemed outside acceptable quality limits but in which trends could be used for estimating discharge. It will not show up as data in daily mean reports.

- **(10) B – Ice Conditions:**
  Use this symbol to indicate that ice conditions in the stream have altered the open water stage-discharge relationship. This symbol will not be used for water level data. However, if it is required for specific stations an appropriate explanation should be given in the Station analysis form. This symbol applies to instantaneous unit values and daily aggregates.

- **(20) E – Estimated:**
  Use this symbol during open-water periods for discharge records or all year for water level records, whenever they were determined by some indirect method such as interpolation, significant high-water extension, comparison with other streams or by correlation with meteorological data. This symbol is used only when there is no usable measured data available for the day or missing period. If desired, the method or estimation may be given in a suitable remark. Do not use this symbol for discharges during ice periods. This symbol applies to instantaneous unit values and daily aggregates.

- **(30) A – Partial Day:**
  Use this symbol during open-water periods for discharge or water level records to identify days with gaps of greater than 120 minutes in the data string and/or those days missing data not significant enough to warrant estimation and the use of the 'E' symbol. The 'A' symbol indicates that the daily mean associated with it, is interpreted to be congruent with a daily mean calculated from a complete string of data and that it be consistent with the trends shown by adjacent data. Do not use this symbol for discharges during ice periods. This symbol does not apply to instantaneous unit values.

- **(40) D – Dry:**
  Use this symbol to indicate that the stream or lake is 'dry' or that there is no water at the gauge. This symbol is used for water levels only. This symbol does not apply to instantaneous unit values.

The grade 'A' is assigned automatically. The grades 'B', 'E' are applied manually and must be accompanied by a comment justifying the use of the grade. The grade 'B' has precedence over the grade 'E', which has precedence over the grade 'A', which has precedence over the grade 'D'. Grades are applied to the working signal only. Grades must be shown on graphs of unit values time-series for the working signals and accompany the data in their tabular forms. Printouts for daily discharges and water levels must show a symbol for each day where applicable. The grade is shown to the right of the daily discharge figure in reports. This grade will not be displayed in any monthly or annual summary of aggregated data. The grade is to be shown for extreme value reporting where applicable. Use of grade in reports must be accompanied by an appropriate reference in a legend, i.e. B – Ice conditions.

8.2 Deletions

Many places allow users to change permanently the existence or nature of data and these possibilities must be controlled.

- The deletion of station lists in "My Location" folders is possible. All metadata can be edited or deleted. HYDEX synchs should repair most of it if inadvertently lost. Rule sets (notifications) can be deleted

- Remarks, Datasets, Datasets associated metadata can but should not be deleted. Rating points and curve defining information should not be deleted. Corrections should not be deleted.

8.3 Approvals

All interpretive work and related decisions must be documented. The version of data which does not reside in AQUARIUS but which was used in computation suffice as documentation. All changes in approval status should be completed with a comment indicating any departure from expectations, interpretation of the significance of any departures from expectations on the quality of the data, and opportunities for improvement. The use of the most recently adopted Computation Checklist is mandatory to track the approval of data.

A review of documentation requirements in the data computational process identified several fields/reports that must be manually generated and archived because of limitations in both the AQUARIUS and HYDEX software. The documentation is required for operational field support; to facilitate the computation checking and approval processes; and to support requirements of the quality management system. Note that this list is non-exhaustive and that other documentation may be maintained as required. All documentation must be securely archived according to approved naming and filing conventions and be version controlled. Completed documentation must be accessible by whoever requires it and can reside in either digital or hard-copy formats.

8.4 Water Survey Reports

A variety of reports and documents can be generated to support hydrometric data computations at Water Survey of Canada. All of these reports and documents are identified here, indicating where they are created, and describing their specific use.

8.4.1 External Reports

Reports created outside AQUARIUS for data computation process, data requests, station management.

8.4.1.1 Station Analysis

Created for each Approval Period following requirements listed in the Station Analysis template. Information is captured from AQUARIUS Station Remarks; field notes; publication summaries showing missing and estimated data, peaks, and extremes. Purpose of the document is to record all pertinent activities, interpretations, and factors influencing the computed results. Also contains qualitative or logistical commentary that contributes to the Station Management Plan.

8.4.1.2 Computational Checklist

Created for each Approval Period following requirements listed in the Computational Checklist form. This document is used by the data computer to ensure all steps in the computational process have been completed.

8.4.1.3 Operational Reports

Usually created for Third Party clients as an operational summary of hydrometric activities covering specified periods. These usually include a description of annual activities with reference to stage and discharge quality and collection status; state of stage/discharge curve development; issues associated with the hydrometric program

8.4.1.4 Non-standard/unpublished data and information

This includes summaries of historic high resolution data-sets (CompuMod hourly's, VAX SAV sets) ice thickness and water temperature data derived from historic paper measurement notes, transcribed digital historic water level data from discharge stations

8.4.1.5 Station Management Plan

This document defines the requirements for general station operation, and includes station visit schedules and access logistics, Life Cycle Management requirements, station activities requirements including measurements and general maintenance.

8.4.2 Internal HWS Reports

Reports generated within AQUARIUS.

8.4.2.1 Benchmark History Report

This document replaces the manually generated and updated Gauge History form and contains a record of location, elevation, and names of all benchmarks at a station including the reference elevation datum. The primary purpose of the BMH is to document results of elevation checks (level circuits) of all benchmarks relative to an identified master control benchmark, which is assumed to be the most stable vertical control at that location.

8.4.2.2 Current Conditions Plot

This report automatically plots the latest water level received via telemetry on the current S-Q curve, and provides a corresponding discharge value and all transmitted parameters in a tabular summary

8.4.2.3 Daily Mean

This report provides a 12 month-per-page summary of the daily mean values of the time series parameter selected and summarizes the mean, max and min for each month. The max mean daily values are bolded in the daily data set for each month. The min mean values are also identified in the daily data set but are underlined. The monthly mean and the instantaneous unit values are tabulated at the bottom of each month's data and are identified with the day they occurred and a time stamp corresponding to the time of observation.

8.4.2.4 Daily Mean – CSV Version

This report is essentially the same as the Daily Mean report although it is presented in a three column date/data/grade format suitable for viewing/manipulating in a spreadsheet. The mean/max/min information is presented in individual cells along the rows of the first day of each month.

8.4.2.5 Data Production Report

This report displays the approval status of Stage Working, Level Survey, Discharge Working, Discharge Measurement, and Rating Curve. Approval Status are identified as Undefined, Preliminary, Reviewed, Checked, Approved, and Unspecified.

8.4.2.6 Field Activity Report – CSV Version

This report summarizes station visit information derived from Field Note information entered into HWS, and includes Station ID, Station Location Name, Date of Visit, Activity Type, Mean Time, Time Zone, Stage Value (Mean Gauge Height), Unit of measure for stage, Discharge Value, Unit of measure of Discharge, Rating Curve #, Shift from Base Curve, Control Condition, Activity Remarks, and Location Remarks

8.4.2.7 HYDAT Summary

This report shows the approved daily mean Water Level and Discharge data, and the approved minimum and maximum Peaks and Extremes that are ready for upload to HYDAT. It serves as 'receipt' of confirmation for data actually uploaded to HYDAT and is used by DCS to verify data prior to the upload.

8.4.2.8 Daily Mean by Year

This report shows the daily mean value of the selected active telemetry or logger Time Series Parameter from the Data Set ID field and is grouped by year – similar to the "Daily Mean 12 month-per –page summary"

8.4.2.9 Hourly Mean by Month

This report shows the hourly mean value of the selected active telemetry or logger Time Series Parameter from the Data Set ID field and is grouped by month.

8.4.2.10 Hourly Mean by Week

This report shows the hourly mean value of the selected active telemetry or logger Time Series Parameter from the Data Set ID field and is grouped by week.

8.4.2.11 Monthly Mean by Decade

This report shows the monthly mean value of the selected active telemetry or logger Time Series Parameter from the Data Set ID field and is grouped by decade.

8.4.2.12 Rating Curve

The display shows either the current rating curve or the rating curve used for a selected date. Stage-Discharge rating Curve must be selected in the Data Set ID field in order for the curve to be displayed.

9 Products, Delivery and Dissemination

Water Survey of Canada publishes instantaneous unit values and statistical products for Water Level and Discharge. The ultimate approbation to publish these products is defined and administered for each station under the Hydrometric Agreements.

The 4 levels of approval of any data, defined as Preliminary, Reviewed, Checked and Approved, set the publication status. This publication status qualifies the quality, the type of products as well as the methods used to make these available to clients and users. The 2 levels of publication are themselves defined as Provisional and Final.

9.1 Standard Products

[Text not yet available]

9.1.1 Standard Calculations

[Text not yet available]

9.1.1.1 Statistical Analysis

When enough data is available, statistical computation is performed over set period. Statistics produced are made available as standard HYDAT products. First instance of peak should be used, statistics (mean) should not be calculated for partial month

9.1.2 Cost Recovery

The Water Survey of Canada policy on charging for data and information requests states that all existing WSC data products and information will be made available for free to anyone using either of the following two access methods:

- by remotely accessing WSC data and information holdings via the WSC Internet Website;
- by personally accessing WSC data and information holdings from a WSC office

All requests made for customized data products (including curves) and information from clients outside of Environment Canada, and which are subsequently filled by WSC personnel, will result in charges being assessed as a minimum of one hour charge at the rate of the current top step of the EG-5 times the Treasury Board tier 3 adjustment factor of 3.3, with charges to continue at that rate for any additional hours or portion there-of, until the data request is complete. Isolated Posting Allowances to be included for all requests answered by personnel in Northwest Territories, Nunavut and Yukon.

9.2 Real Time Web

The best available unit value time series produced in a continuous cycle are made available, published to the web, on the fly.

Data displayed must be managed to evolve only one way, from “Provisional” to “Final”.

Datum transformation must be the very first change applied to any data. Transformation must take place upstream of the computation process, as this is the most secure way of dealing with Datum changes.

Data must be processed and published within the same Datum.

9.3 HYDEX

[Text not yet available.]

9.4 HYDAT

Final Data as Aggregations, Peaks and Extremes are published to the Web via HYDAT standard products. HYDAT produces annual info using the results of monthly statistics. Annual peaks are generated on the basis of monthly peaks. The first instance of the peak should be used for annual data.

Providing the data for periods prior to 2011 from AQUARIUS would result in slightly different results than the final and approved computation performed initially and thus result in potential discrepancies. Note that not all requested data is in HYDAT (measurements, cross sections, rating curves, hourly, 15 minute data, water temperature, etc.)

All official requests for data prior to 2011 (CompuMod Migration) must be fulfilled via HYDAT. Statistics can be produced on demand through the workstation but are always considered preliminary. HYDAT is the final reference in case of discrepancy between statistical data products. HYDAT is the only source of official and final data and statistics.

If any data point is missing within the time series used to determine a peak over any period, the result need to be validated.

9.5 Controls on Publication

This section explains how to manage data publication within and outside operating periods. It describes how to remove parts of time series from publication. It also describes how to control the display of data on the web.

9.5.1 Removal of Data outside Operating Periods

Agreements dictate when data is to be produced at any station. Some stations operate for part of the year only, and controls are thus required to limit the publication of data. While what is known as 'shoulder data' must not be published, this data which is outside operating periods must still be accessible by technologists to monitor their station.

- Station operators must set a Delete Region correction over the period outside of operations to prevent non-publishable periods from progressing to the web or HYDAT.
    - Such a correction can be established for dates set in the future.
- To troubleshoot data acquisition during periods outside of operations, technologists can review the raw telemetry signal.
    - Raw telemetry is available within AQUARIUS or via Current Conditions reports delivered by automated notifications.
- To progress to HYDAT, data at any station must be approved. Approval Periods must cover the entire year, including deleted periods outside operations.
    - The Delete Correction allows this final approval to take place over the entire year while preventing the publication of real-time data outside the operating period.
    - Failing to approve any period would leave data unlocked, and at risk of being changed.

9.5.2 Removal of Data within Operating Periods

There are 4 general scenarios for which data within operating periods should not be published:

1. Invalid time-series data
2. Questionable time-series data
3. Invalid parameter

4. Discontinued publication

Justification for non-publication must be captured in the station documentation.

9.5.2.1 Invalid Time-series Data

Under certain station conditions, quality record cannot be obtained, therefore producing misleading data. Simply make use of a Delete Region correction once the data invalidity has been confirmed. Data will be removed permanently from corrected production system time series and the web.

9.5.2.2 Questionable Time-series Data

Under certain station conditions, quality record cannot be obtained, therefore producing misleading data. Records must then be removed from the web until it is possible to better determine quality. Decisions to stop web displays must be validated by supervisors and Data Control. Set the Approval Level of any questionable data period to ‘Undefined’ or ‘Unspecified’. Web systems will then filter such data. Dates for such undefined approval levels can be set ahead into the future. Data remains available for review and enhancement within AQUARIUS, with the intent that the data will be either validated or deleted before approval is complete. Once data can be displayed again, its approval level simply has to be reset to a value other than ‘Undefined’ or ‘Unspecified’. A standard web message (Appendix A) explaining why information is missing could be developed and posted if desirable for ensuring clear communication with users. Data Control is responsible for setting up such communication messages for users.

9.5.2.3 Invalid Parameter

Data Control must be informed of the need to disable website displays for any parameter. Data Control has privileges to modify display options. A standard message (Appendix A) explaining the situation could also be developed and posted if desirable for ensuring clear communication with users.

9.5.2.4 Discontinued Publication

Data Control must be informed of the need to discontinue the publication. Data Control has privileges to entirely stop web publications. A standard alert message (Appendix A) must also be posted.

Data Control Sub-committee members have administrative rights for the water office web site, in addition to management responsibilities for HYDEX and HYDAT databases and processes.

Guidance on Water Office web administration functionalities is provided as a separate procedure specific to those responsibilities.

9.5.3 Standard Web Alert Messages

The following standard messages are displayed on the web when publication stops. It helps manage client expectations and indicates the reasons for the disruption.

English	Français
This station is down for construction.	Station hors service pour construction.
Operational from (Start Date) to (End Date). Any data outside this period is not published.	Opérationnel du (Date début) au (Date fin). Toute donnée hors période n'est pas publié.
A failure (Date) of (What) has impacted real-time data delivery for much of the hydrometric network. Work is underway to restore service by (Date).	La livraison en temps réel des données provenant du réseau hydrométrique est interrompue depuis (Date) suite à (Pourquoi). Les travaux sont en cours pour rétablir le service au plus tard le (Date).
Other messages to be defined. *Share any need with DCS*	*Autres messages à définir.* *Identifiez les besoins avec DCS.*

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Appendix A: Procedural Highlights

The following text is an attempt at providing the most important aspects of the data computation procedures. Readers should be aware that partial information can in no way replace a thorough read through the details outlined in the entire manual and may in some cases represent a risk of misunderstanding when taken out of context. As such, it should be understood as a way to find information related to an issue of interest, in ways similar to the table of content presented at the beginning. Readers are strongly encouraged to always refer to the sections from which these elements of text were extracted.

This first edition is the Beta Version of Water Survey of Canada's new data computation procedures. During its expected short life, all users are expected to compile and report comments relative to its limitations or any opportunity for clarifications. These comments must be gathered by their supervisors and forwarded to local Data Control Sub-Committee members for consideration in the next release. 11

2 Station Information 20

2.2 New Station 21

Do not create any dataset in AQUARIUS until its operational time zone has been configured in HYDEX. 21

2.3 Datum 21

An established elevation for every reference entered in AQUARIUS is required and must be documented against the Datum in use and listed in HYDEX. 21

3 Acquisition 22

3.1 Raw Data Time Series 22

A time series obtained by Telemetry is the primary signal when available. 22

All Logger data loaded with Append Logger File in AQUARIUS must be done with interpolation type set to "Instantaneous Values" and approval level set to "Preliminary". 22

Primary water level sensor data must be assigned HG as SHEF code within the station logger while secondary sensors are to be labelled HG2, HG3, and so on (Note: there is no HG1). 22

All data entry must be based on local standard time and be supplemented by information relative to the time zone that applies at the location. 22

3.2 Field Information 23

Paper field notes must be approved, scanned and filed on the Network Storage. They do not have to be stored in AQUARIUS. 23

The creation of new datasets should be limited to those approved by Data Control as required for standard computations. 24

When telemetry is complete and acceptable, the download and archiving of logger data is not mandatory. The decision to collect or not to collect the logger file during a visit is a risk managed on a site by site basis. 24

At least one direct water level, its sampling time and a corresponding instantaneous logger value must be captured on Field Visit Notes (front sheet) as well as entered in AQUARIUS to support Sensor Reset Correction calculations. 25

Every office must have access to space on a server properly maintained and backed up, and dedicated to the storage of station files. The information must be saved using standard naming conventions. It must be filed according to the standard directory structure. 25

All files associated with a single measurement must always be kept together in a single folder for the information to be complete, and to make retrieval, transfer and copying of data easier to manage. 25

Paper Field Notes remain the definitive information and must be easily accessible. Accordingly, all Field Notes must be scanned and saved on the Network Storage. 25

3.3 Deletions 26

No dataset is to be deleted by any technologist without prior approval by their Supervisor and Data Control representative. In particular, no raw data used in any computation must ever be deleted. No change is to be applied via the database administration functions for the purpose of deleting raw data. 26

4 Corrections 27

All corrections to time series must be applied within the Working signals. 27

Data displayed on the web is modified as soon as changes are saved in the Data Correction toolbox, over written with the latest changes applied. 27

4.2 Projections *28*

All offsets, such as Sensor Reset Corrections or Gauge Corrections, can be applied as projections carried forward to a date just beyond the next scheduled visit. 28

To ensure proper monitoring, any projected correction should be accompanied by a suitable notification. 28

4.3 Standardized Identification of Corrections *29*

The standard abbreviation SRC must be manually added to the automated remark of a correction used for Sensor Resets, and GC added for those used for Gauge Corrections. This help to quickly sort and review corrections used for those purposes. 29

In all cases, automated remarks describing correction details should not be altered nor deleted but only supplemented by technologists. 29

4.4 Water Level Corrections *30*

Gaps in water level time series for periods smaller than 120 minutes do not have to be filled. The need to complete these gaps must be assessed in relation to the impact they may have on the validity of daily statistics or any other products. 30

When problems with the primary sensor are contained to past periods, secondary sensor data should be obtained from a Copy and Paste correction, which will provide good traceability and make adjustments easy. For real time operations, the working signal dataset mixing rules should be modified to use the secondary sensor, but then all ongoing corrections must be stopped, reviewed and reapplied starting at the time of the sensor change to make sure that data is properly bridged between sensors. 30

No approval period can be completed until the station datum error corrections have been properly validated and applied for that period. 31

Gauge corrections applied to the stage working time series will not automatically propagate to stage measurements obtained during field visits. These measurements must be corrected manually. 31

Gauge corrections are assumed equivalent to 0.000m and thus not applied when departure is smaller or equal to 0.003m. 31

Sensor Reset corrections must be applied when a departure from the observed value greater than 0.003m has been detected. 31

4.5 Discharge Corrections *31*

Stage time series must be properly reviewed before the application of any correction onto the Discharge time series for the same period. 31

Correcting the Discharge time series for corrections 'missed' in the Stage time series is not acceptable. 32

4.6 Best Practices *32*

Fill Data Gaps must not be used to interpolate data other than Discharge nor be used for more than one single data gap at a time so proper grading can be applied. 32

Clock Drift Corrections for anything less than 5 minutes must not to be applied in AQUARIUS but only in the logger, and be documented on Field Notes and in the station workbook. Also, do not overlay multiple Clock Drift Corrections as this may create loops difficult for the computation system to reconcile. 33

5 Rating Development 34

5.1 Rating Development Strategy *34*

The first step prior to developing a stage-discharge relationship is to familiarize oneself with the gauging location and develop a working hypothesis about: (1) the complexity warranted to describe the rating relation; and (2) reasonable parameter ranges which describe each rating segment. 34

The second step in developing a stage-discharge relationship is to review all discharge measurements which will be used to derive the rating relation. 34

The third step in developing a stage-discharge relationship is to estimate the C, h_o, b parameters of the rating equation for each rating segment identified in the hypothesis. 35

At least six measurements should define any stage-discharge relationship segment. 35

The effective gauge height estimated for each rating segment must be lower than the lowest point defining the rating segment otherwise the rating equation will be undefined. 35

The resulting rating model should respect the underlying assumptions of regression as much as possible. That is: (1) the sample is representative of the underlying population being predicted; (2) the errors are random with a mean of zero; (3) mean gauge height is measured with no error; (4) the errors are uncorrelated; (5) the variance of the error is constant. 35

The fourth step in developing a stage-discharge relationship is to define the transitions between rating segments. 37

The fifth step in developing a stage-discharge relationship is to adjust the range covered by it. 37

For the upper end, the rating relation should not be extended beyond twice the highest measured discharge defining the rating relation. It must also not be allowed to go above bankfull. 37
In the lower end, the rating relation should not be extended below half the lowest measurement. 37
Sections of the stage-discharge relationship beyond the recommended minimum and maximum extrapolated range must be graded as Estimation. 37
Observations where the flow is below the detection limit (< 0.001 m^3/s) but have a detectable stage can be ascribed an arbitrary value less than the detection limit (set to 0.0001 m^3/s) for plotting in log scale. 37

5.2 Review and Validation *37*
The resulting rating model should respect the underlying assumptions of regression as much as possible. That is: (1) the sample is representative of the underlying population being predicted; (2) the errors are random with a mean of zero; (3) mean gauge height is measured with no error; (4) the errors are uncorrelated; (5) the variance of the error is constant. 38

5.3 Shifts *38*
The application of a shift must be considered if a measurement is departing from the base rating by more than 5%. To decide whether a curve should be shifted or modified, technologists should also look at the current and previous year hydrographs to identify trends between the measurements and curve. 38
The value for stage (defined as the 'Input' in the Shift Manager) should be set to the assumed point of zero flow for the curve to be shifted (defined as 'Offset 1' in the Offset Manager). Entering such value will help approve shifts later in the production process by bringing all displayed values in their proper stage context. 41
Knee Bend Shift should be preferred over One Point Shift whenever they are likely to represent the expected change to a rating at all possible stage. This way, the production of Q will adequately adapt to any condition in real time to produce the best provisional data possible. 42

5.4 Rating Development Methodology *43*
Any change to a rating curve model, such as the addition or modification of any rating point or offset, results in what is considered a new curve. 44
To create an extension, first clone the curve and assign it a new number as it will be a new curve once approved. 49
Curves cannot be extended all the way to zero. Rating points cannot be located right at the point of zero flow. A value slightly higher (Q=0.0001 recommended) should be used when Discharge must be derived below detection limits. An automated correction can then be applied to the Discharge time series to set it to zero if required. 49
Technologists creating new ratings are responsible to recommend a start date (for the Rating Period) to their supervisor based on the hydrologic features which triggered the need for the new curves. 50
New Rating Periods must be defined for and aligned with each Approval Period. A single curve thus will have multiple periods. When any period is approved, the period of data becomes locked, which prevents changes to approved data. 50

6 Estimation **53**

6.5 Data Frequency within Estimation Periods *58*
Unit value time series must be annotated in details to explain if estimated data was produced to mimic instantaneous observations, or to capture general trends showed by daily means. This documentation of the work is meant to ensure that users know the nature of any data they will use. 58

7 Quality Assurance **95**

7.1 Automated QAQC Measures *95*
Technologists are responsible to identify, configure and maintain QAQC data integrity criteria at their stations. Integrity criteria must be specifically designed to monitor Station Health and Hydrometric Conditions at a station. 95
Automated QAQC measures must be configured as Post-Processing corrections. Prior to any automated QAQC measures, data must be modified to properly fall within expected hydrometric conditions for the station. 96
While in the field or on leave, the technologist primarily responsible to manage a station must forward the email notifications to the person assigned as back up in the team for that station. 97
Supervisors should be copied on email notifications configured to deal with Station Health issues. 97
Notifications are for internal use only. Clients and partners are not to be included on notification email distribution lists. 97
Notifications and flags must be reviewed and updated at least once a year, preferably before every change of water regime, as conditions and knowledge (integrity criteria) of the station evolves. 97
The content of a notification email message must explain which integrity criteria were exceeded and what actions are expected from the technologist in charge. 97

7.2 Manual Data Approval *98*

Data must not be changed or downgraded when Approved. Any correction of previously Approved data corresponds to a Data Revision which must abide to Data Review criteria and procedures. ... 98
The ability to complete data approvals depends on 3 conditions required to confirm data validity: 1) Confirmed reference gauge stability; 2) Completed validation of field results and Stage time series; 3) Completed validation of estimation models and methods; 4) Completed validation of the derived discharge time series. ... 98
Approval periods must not include parts of days. They must be set to start or finish on the last full day at midnight and not on the actual time of a visit. ... 98
The entire calendar year of a station must be approved, regardless of the station operating period. ... 99
Any valid data approval sequence must integrate inter-dependencies, start with the review of independent variables, of models, and move towards the review of information derived from these. ... 99
Gauge stability must be confirmed prior to the final approval of any period. ... 99
If a Gauge History shows periods of instability, an increase in the frequency of approval will require a proportional increase in the frequency of gauge level checks. Final data can be based exclusively on extrapolation of known information only if a solid justification is documented. ... 99
The approval level of Field Visits must be at least raised to Checked, after their peer review. Field Visits do not have to be Approved. ... 99
Final water level time series can include gaps. Water level data can only be estimated at lake stations over periods no greater than 10 days. ... 100
Curves can be validated and approved while not implemented. It is when a Rating Period is assigned to a curve that it becomes active for that period. Transitions between models should be defined before any such activation. This decision is done in coordination between the supervisor and technologist. ... 100
If the end date of a Rating Period is entered, a new open ended Rating Period must be have been created before any other open ended shift can be entered and thus support real time data production. ... 101
The approval level of Discharge time series is first set to the lowest common denominator among that of all derivation components, namely the Stage time series, the rating curve, its rating period and any associated shift. ... 101
No correction must be applied in discharge to mitigate errors originating from the Stage time series. ... 101
A Rating Curve should not be assigned any Rating Period when data should not be produced from it. ... 101
The approval level of a Rating Period must remain at Preliminary during all open ended periods. It must be approved only once an Approval Period is completed. This ensures that Discharge data is first created at the Preliminary level and because, in real time production, there are always doubts about a curve applicability against current conditions. ... 101
Rating Periods correspond with Approval Periods. Every time an Approval Period ends, the current model Rating Period must also be closed and a new one be assigned to the curve used during the next Approval Period, making sure data production remains seamless. ... 102

7.3 General Responsibilities ... *102*

To help track the progress of data approval, teams must use the most recently approved Computation Checklist form. ... 102
Technologists must document any inadvertent or intentional deviation from expectations as to why the non-compliance occurred and what impact it may have on data. Non-compliances should be recorded as a note spanning the period and as an approval comment in the Station Analysis. Reference to any relevant Corrective and Preventative Action Report (CPAR) should also be included. ... 102
Peer Reviewers are Technologists assigned to ensure that all processes and information required for the computation of data are complete and available. They are not expected to validate interpretation or add to the Station Analysis. ... 102
Supervisors are responsible to approve closed Periods of Applicability in conjunction with approving the Stage and Discharge time series once they have confirmed that the computation is complete. This is an important step which triggers the production of HYDAT aggregate data. ... 103

8 Documentation ... **105**

Due to the traceability and standardized nature of any activity performed on hydrometric data within the Springboard environment, the Springboard is to be used as the primary interface for data production within Water Survey of Canada. Whiteboard is to be used by technologists for data production only when activated within the Springboard. The use of any other method of data production, such as using the Whiteboard in standalone mode for automated production, must be carefully documented, justified and approved by management. ... 105

9 Products, Delivery and Dissemination ... **109**

9.2 Real Time Web ... *109*

Data displayed must be managed to evolve only one way, from “Provisional” to “Final”. ... 109
Data must be processed and published within the same Datum. ... 109

9.4 HYDAT *110*
All official requests for data prior to 2011 (CompuMod Migration) must be fulfilled via HYDAT. Statistics can be produced on demand through the workstation but are always considered preliminary. HYDAT is the final reference in case of discrepancy between statistical data products. HYDAT is the only source of official and final data and statistics. 110

9.5 Controls on Publication *110*
Data Control Sub-committee members have administrative rights for the water office web site, in addition to management responsibilities for HYDEX and HYDAT databases and processes. 111

Appendix A: Rating Theory

Stream discharge integrates all hydrological processes and storages upstream of a particular point in time and space. It is one of the most widely measured quantities in the hydrological cycle. Since it is prohibitively expensive to monitor stream discharge continuously, the most common approach is to continuously measure stream stage (water level) and apply a transfer function, known commonly as a rating curve or stage-discharge relation, to derive a continuous discharge time-series. Local reach characteristics dictate the applicability of this method to explain variations in discharge as a function of stage alone. In instances of variable backwater and unsteady flow, more complex gauging methods and techniques for deriving discharge are required.

This document serves as a basic manual to describe the basic theory and procedures for fitting simple rating curves; where a unique relation between stage and discharge exists. It describes the basic classification of flow, rating development and extrapolation, as well as procedures and best practices for developing rating relations within the Aquarius Hydrometric Workstation.

Flow in open channels

Classification

Flow in open channels may be classified according to its steadiness and uniformity. Under steady flow conditions, observations of velocity and depth are unchanging over time. Uniform flow conditions mean that the velocity and depth do not vary with distance down the channel such that flow lines are parallel to the channel bed and free water surface. Under uniform flow conditions, the pressure distribution everywhere in the flow is hydrostatic and depends purely on depth beneath the free water surface. Under non-uniform flow conditions, flow lines converge or diverge inducing local acceleration/deceleration of flow. Hydrostatic conditions no longer apply under these circumstances.

Natural channels typically exhibit some unsteadiness and non-uniform flow conditions. The uniqueness of the stage-discharge relation is usually an indicator of how well the chosen reach reasonably approximates steady uniform flow conditions. Unfortunately, it may be difficult to unravel the nature or cause of a non-unique rating relation. Changes in boundary friction, slope, width, wetted perimeter, and velocity may form a non-unique relation between stage and discharge for a given reach.

Controls

The relation between stage and discharge for open channel flows is typically controlled by channel conditions downstream which cause backwater effects to propagate upstream to the point of stage measurement. The velocity (V) with which a wave travels in open water is proportional to the depth of water such that

$$V = \sqrt{gh} \tag{1}$$

where g is the gravitational constant. The Froude number (Fr) is a dimensionless ratio between water velocity and wave velocity:

$$Fr = \frac{V}{\sqrt{gh}} \tag{2}$$

Flows with Froude numbers greater than one are classified as super-critical and flow disturbances from downstream do not propagate upstream. In fact the control on water levels for super-critical flows will be upstream of the point of stage measurement and should be avoided as a gauging location.

Flows with Froude numbers less than 1 are classified as sub-critical and allow disturbances to propagate upstream. Under sub-critical flow conditions, the cumulative influences of downstream disturbances upon a recorded water level are collectively known as the “control”. In some cases, the control can be a bedrock sill, riffle or channel narrowing which results in critical flow conditions. The critical flow feature prevents further downstream disturbances from propagating upstream and affecting measured water levels. Under these instances, the control is termed “section control”.

“Channel control” is used to describe reach conditions where water levels are controlled by roughness, slope, and geometry of the channel downstream. In some cases, a compound control exists which exhibit a section control at low stages which drowns out to become channel control at higher stages. In other cases, a gauging site may have a section control defining the lower section and a different section control defining the higher range of rating.

In order for the control to be optimal for a hydrometric gauging site, it must be both stable through time and sensitive to changes in flow. Stability of the control may be affected by variable backwater, aquatic vegetation, unsteady flow, or mobile bed. At many gauging sites, these effects are unavoidable. More complex rating models or increased sampling are required to document changes in control and are not discussed in this procedures document.

Total Energy of Flow

For hydrostatic conditions, the total energy or head (H) of a vertical column of water can be expressed as

$$H = y + z + \frac{V^2}{2g} \tag{3}$$

where z is the height of the channel bed above a datum, y is the depth of water, V is the mean velocity, and g is the gravitational constant. Equation (1) is commonly known as the Bernoulli equation and represents total energy of a fluid as the sum of potential (depth) and kinetic (velocity) energy (head). A fluid may therefore have different proportions of velocity and pressure energy (head) for a given total energy (head). As flows approach critical flow, the proportion of total energy attributable to velocity approaches 1/3. Gauging reaches with significant velocity head can adversely impact the established rating relation; especially if the stage measurement device is not representative of total head.

Equation Parameters

Simplified approximations for open channel flow, such as Manning’s equation (Eq. 4), assume steady uniform flow conditions:

$$Q = \frac{1}{n} A R^{2/3} s^{1/2} \tag{4}$$

where n is the Manning’s roughness coefficient, A is cross-sectional flow area, R is the hydraulic radius (flow area divided by wetted perimeter), and s is the slope of the energy grade line. The Manning equation can be thought of as the product of two terms: (1) roughness and energy gradient (n, s); and (2) channel geometry (A, R). Significant changes in these terms with discharge will ultimately impact the rating relation.

If we assume steady uniform flow (i.e., energy grade and roughness are constant), power-law channel (ie., width is a power function of effective flow depth), and hydraulic radius is reasonably approximated by effective flow depth, discharge in open channels can be expressed purely as a function of effective flow depth (h):

$$Q = ch^x \tag{5}$$

where c and x are empirical parameters. This is the basic form of the rating relation. Since hydrometric gauges record water level and not effective flow depth, an offset is incorporated to correct stage readings to effective flow depth:

$$Q = C\left(H - h_o\right)^b \tag{6}$$

where Q is discharge, h is gauge height, h_o is the effective gauge height of zero flow, and C and b are calibrated parameters. The term H-h_o is the effective depth of water (hydraulic head) above the control. The term “effective gauge height” is used since zero flow may never actually be observed at the gauging section. This is particularly relevant where no definable critical flow feature (i.e., section control) is controlling the stage-discharge relation (e.g., large rivers).

The solution to equation 6 requires the estimation of two calibrated parameters (C, b) for section controlled gauging locations. In cases where h_o cannot be precisely defined, it too must be established through calibration. For gauging locations with compound controls, each rating segment governed by a unique control must be calibrated separately. As the number of unique controls governing the rating relation increases, so do the number of parameters identifying the rating relation (on the order of 4n-1, where n is the number of rating segments). Typical gauging sites should not have more than three rating segments defining the rating relation (e.g., section, channel, floodplain control).

As the number of parameters of a model increases, so does the likelihood of parameter interaction – where different combinations of parameter values can effectively give a similar result or “goodness of fit” to observations. This results in a high degree of uncertainty in estimating the true parameter value. When extrapolating the rating relation outside of the observed range (low or high stages) may result in unrealistic predictions of discharge. There are a number of factors which can contribute to uncertainty in estimating the true parameter values of the rating equation. These include:

1. non-uniform sampling of stage/discharge over the observed stage range and through time
2. limited sample size
3. non-uniform measurement uncertainty
4. change in the underlying rating relation
5. incorrect model structure

One strategy to reduce parameter uncertainty is to define reasonable ranges for parameter values before hand. Observation of systematic control changes, longitudinal and cross-sectional channel surveys can be helpful in identifying realistic parameter values and giving more credibility to the derived rating.

There is some guidance on the estimation of rating exponent (b) based on geometry of the control (Table 1). While these values can be used as guidance, there can be a number of reasons why the calibrated value may deviate from a theoretical value. Firstly, channel shapes are rarely regular and symmetrical, making it difficult to determine which ideal geometry may best represent surveyed conditions. Secondly, if velocity or pressure head (which contributes to effective depth above the control) varies non-linearly with observed stage, it can contribute to a significantly higher calibrated exponent than based on geometry alone. These conditions may be present where velocity head is significant within the gauging reach (as presented in the previous section).

Table 1: Suggested values for rating exponent based on control geometry

Shape	Value of exponent (b)
Rectangular	1.3 to 1.8

Parabolic	1.7 to 2.3
Triangular	2.5 to 3.0

The most common approach to calibrating the rating relation is to work in logarithmic space and use linear regression techniques to fit the rating relation. Taking the logarithms on both sides of the rating equation results in a linear equation in log-space of the form:

$$\log(Q) = \log(C) + b\log(H - h_o) \qquad (7)$$

where the rating exponent (b) is the slope of the line in log space and the logarithm of the rating coefficient (C) is the offset.

The procedure for calibrating a rating relation for a gauging location is (1) pre-calibration; (2) review of discharge measurements; (3) estimate parameters for each rating segment; (4) develop transitions between rating segments; and (5) develop extensions to the rating relation to estimate discharges outside the observed range used to calibrate the rating relation. The next section describes each of these steps in more detail. Section X describes procedures for validating a rating relation.

10 Appendix B: Migration and Legacy Information

Pre-2011 data migrated from CompuMod to AQUARIUS was brought into AQUARIUS for the purpose of historical reference only. No correction is expected to be applied on this data, except if a data revision is required.

Metadata

If a migrated station establishment or construction date is unknown, 1900-01-01 is to be used. For the established elevation, use the elevation that is at the top of the Gauge History. If this elevation is significantly different from the 2010 and 2011 elevations, this should be investigated further or reviewed with the assigned supervisor. In some cases, the established elevation might be documented in a previous datum. In that case, it should not be used. In other cases it may be an unstable benchmark that needs to be addressed. If there was a datum change, use the elevation that was approved the first year of the current datum. If the Master has changed since the station was established, the Master (Primary Active) should be the Master that was approved in 2010. If a BM was destroyed prior to 2011, you do not have to enter it. If you have not levelled in a BM in a few years due to inaccessibility, keep it as active as it may be used again in the future. You can copy and paste your written description from your Gauge History by using "Ctl C" and "Ctl V" (the right mouse click feature for copy and paste does not work in AQUARIUS).

Datasets

2011 measurements migrated from CompuMod have their mean gauge height also entered as a single discrete water level. Technologists, in conjunction with their supervisor, should discuss if the discrete water is applicable for use in determining SRC within the stage.working time series. If it is not an appropriate discrete value for determining SRC's then additional entries using the actual collected discrete values are required. Regional practice dictates that Discharge/MGH will come through together as a single activity with the same mean time and no secondary information such as width, velocity, start/end times. These values are drawn from CompuMod database and if they weren't entered, they won't be here. Since this is partial information, you have the option of leaving it if it is correct, but if corrections are required you will need to upload the measurement file which has the secondary info. You may also upload all measurement files if you choose, duplicates migrated from CompuMod will have to be reloaded.
There will also be a Stage activity, but these are only copies of the MGH values for time and stage value. Since these will be incorrect, we will need to delete the Stage value activity with the Xboot icon. It will then be necessary to add individual stage values and logger reading values through the New then Manual Data Entry icon, then dispatch these to the time series.

Data Correction

Use caution while copy and pasting over migrated data, as the corrections may be applied twice (once in migration and once in AQUARIUS).
All imported gauge corrections had to be changed from offset corrections to drift corrections (double-check)

Shifts

Migrated open ended zero shifts should be assigned a closing date so they do not ever merge into any shift applied during current operations. Since some of these zero shifts were created a while back, their merging could generate an error that would be hard to identify or track to its origin.

Reports

No daily means report generated from approved migrated data (data approved prior to 2011) shall be distributed without evidence that it respects results published within HYDAT. Before the distribution of any daily means report for migrated data, a check against HYDAT must be done. If data does not match HYDAT, it must not be distributed. The data in question must then be scrutinized to identify the cause and a potential need for data revision.

Appendix C: Rating Development Case Studies

Beaver Bank River near Kinsac

Pre-Curve Planning

Rating Development Objective

Replace the migrated CompuMod (arithmetic) with one developed with the new approach available with the Rating Development Toolbox in Aquarius (log-log).

Observed and Predicted Control Features

- Stage Range information about the recorded data was easily obtained with “Select Statistics Period” in Quick View Toolbox (Figure. 1).
    - Lowest water level ever recorded was 0.070m in September 2001
    - Highest water level ever recorded was 2.566m in March 2003
    - A survey of the gauging pool and downstream cross sections has been completed.
    - In 2010 the Point of Zero Flow was surveyed as 0.034m.
    - At low flows the river meanders along the bed rock bottom.
    - As the section control drowns out the water enters the overbank where there is vegetation comprised of trees and grass.

Table 1: Observed Control Feature Elevations (m)

Lowest Record	.070
Highest Record	2.566
Zero Flow	0.034

Working Hypothesis

- The control is irregular bedrock. At medium to high flows the section control is submerged. The river overflows the banks into the riparian zone.
- At extreme low flows the river is confined to the low line areas of the river flow around large rocks.
- At medium to high stages the control is the down stream channel features.

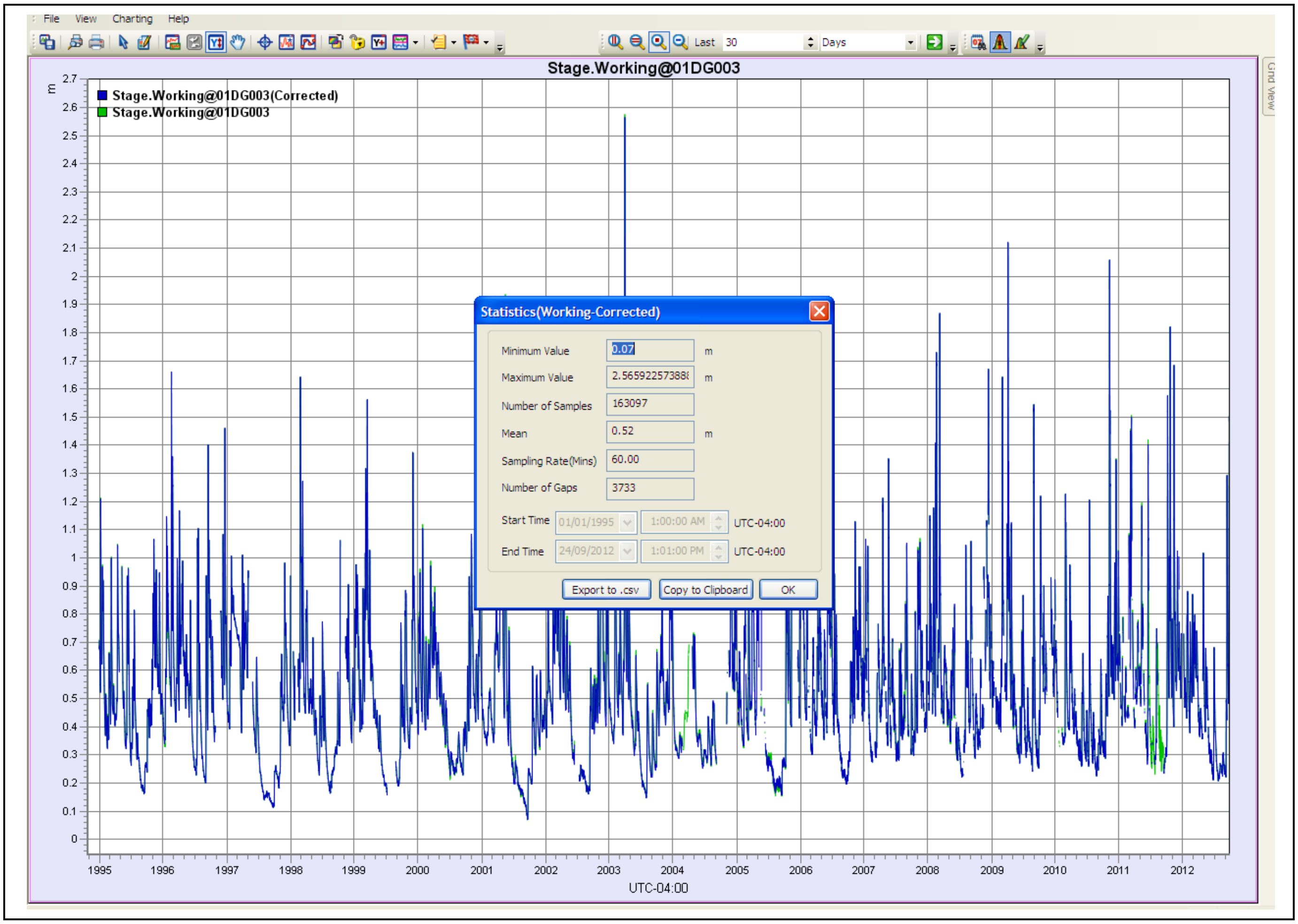


Figure 1: Identification of recorded water level extremes using the Quick View Toolbox

Figure 2: Profile of gauging pool and control. Look upstream towards gauge. (HG = 0.686m)

Figure 3: >100m Down Stream of the gauge. Gauge height of 0.266m

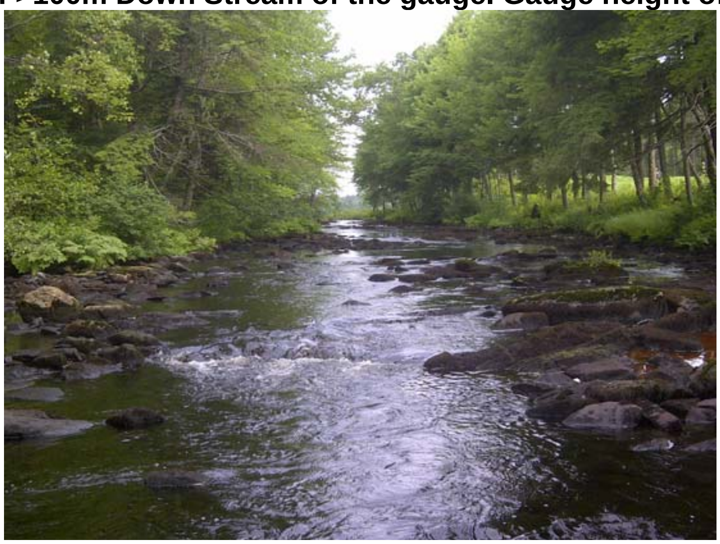


Figure 4: Cross section of gauging pool. Referenced to existing datum, water level 0.686m.

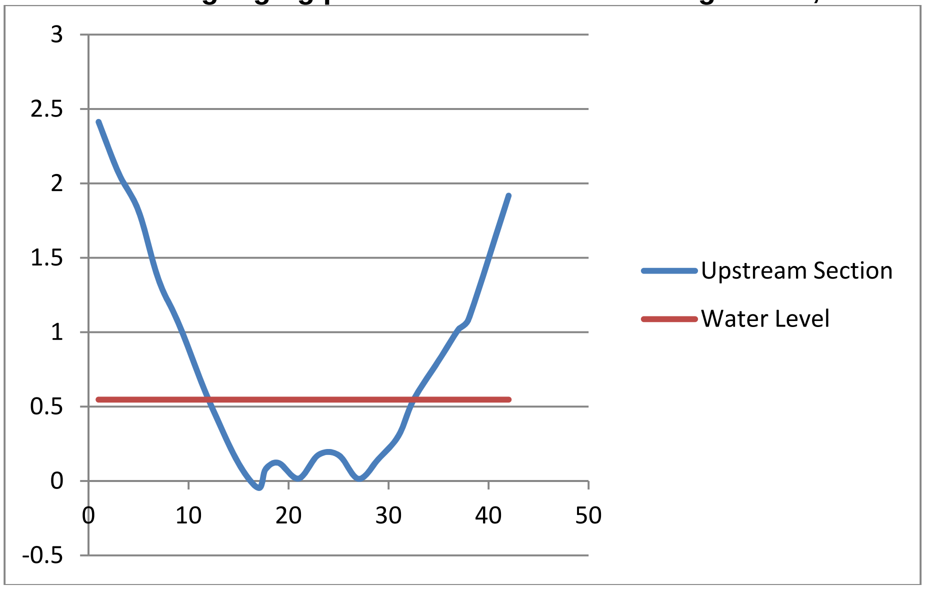
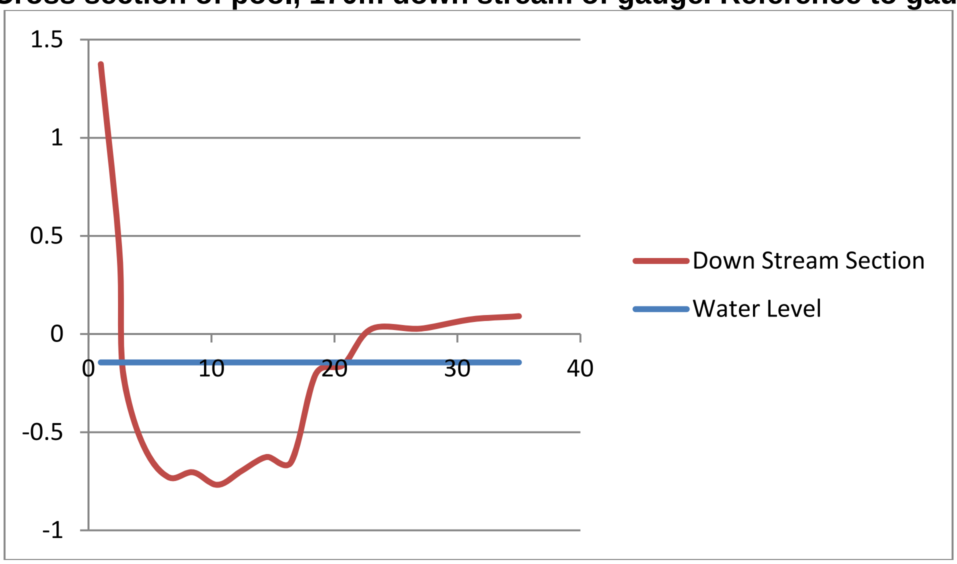


Figure 5: Cross section of pool, 170m down stream of gauge. Reference to gauge datum.



Rating Curve Development and Analysis

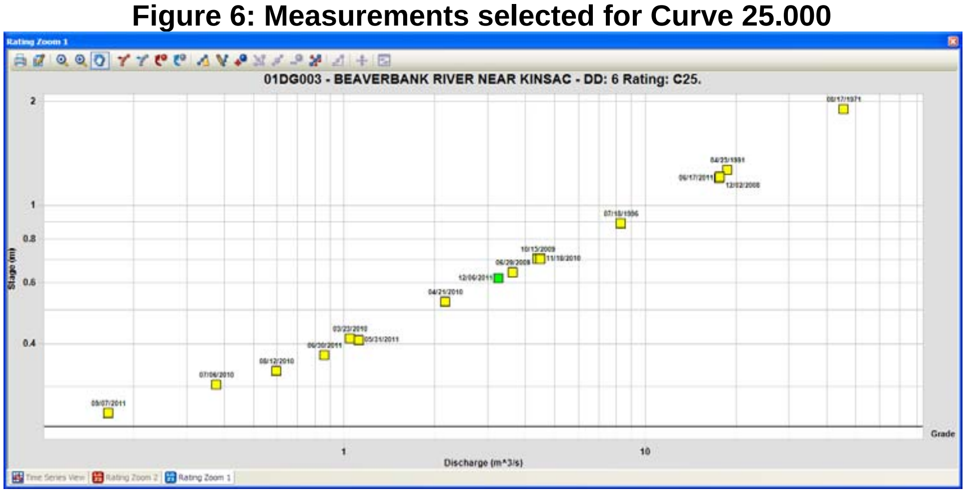
- The new curve is numbered 25.000.
- All measurements on previous curve were selected and used as guidance for new curve along with the current years measurements.
- The historical highest and low measurements were selected, in this case only used as guidance.
- This station is at the outflow of a lake is typically gets little back water.
- In the summer there is little backwater due to weed and algae.
- There is a high velocity head at medium to high stages.

Table 1: Measurements Selected

Date/Time YYYY-MM-DD HH:MM:SS	Stage m	Discharge m^3/s	R Error %
1971-08-17 12:00:00 [UTC-04:00]	1.9	45.6	-15.8
1991-04-23 09:30:00 [UTC-04:00]	1.267	18.7	-6.86
2008-12-02 12:27:00 [UTC-04:00]	1.212	17.7	-1.79
2011-06-17 09:35:00 [UTC-04:00]	1.2	17.6	0.292
1996-07-18 09:30:00 [UTC-04:00]	0.891	8.3	-0.26
2004-04-21 08:21:00 [UTC-04:00]	0.779	6.19	4.81
2000-04-11 12:00:00 [UTC-04:00]	0.733	5.18	2.46
2002-05-01 12:27:00 [UTC-04:00]	0.713	4.73	0.551
2010-11-18 10:52:00 [UTC-04:00]	0.704	4.49	-1.45
2009-10-15 08:52:00 [UTC-04:00]	0.703	4.39	-3.22
1997-04-17 09:05:00 [UTC-04:00]	0.702	4.67	3.33
2009-06-29 13:00:00 [UTC-04:00]	0.641	3.62	1.4
2011-12-06 11:36:14 [UTC-04:00]	0.617	3.25	0.835
2010-04-21 10:50:00 [UTC-04:00]	0.527	2.16	1.82
2003-08-07 09:49:00 [UTC-04:00]	0.494	1.87	4.68
2010-03-23 10:50:00 [UTC-04:00]	0.414	1.05	-4.74
2011-05-31 08:30:00 [UTC-04:00]	0.41	1.12	4.91
2011-06-30 10:00:00 [UTC-04:00]	0.37	0.86	-3.19
2010-08-12 12:59:00 [UTC-04:00]	0.334	0.595	3.37
2010-07-06 10:02:00 [UTC-04:00]	0.305	0.377	-3.34
2011-09-07 10:28:00 [UTC-04:00]	0.252	0.165	-2.67
2005-08-31 12:26:00 [UTC-04:00]	0.198	0.004	-93

*****NOTE***Red indicated measurements deselected**

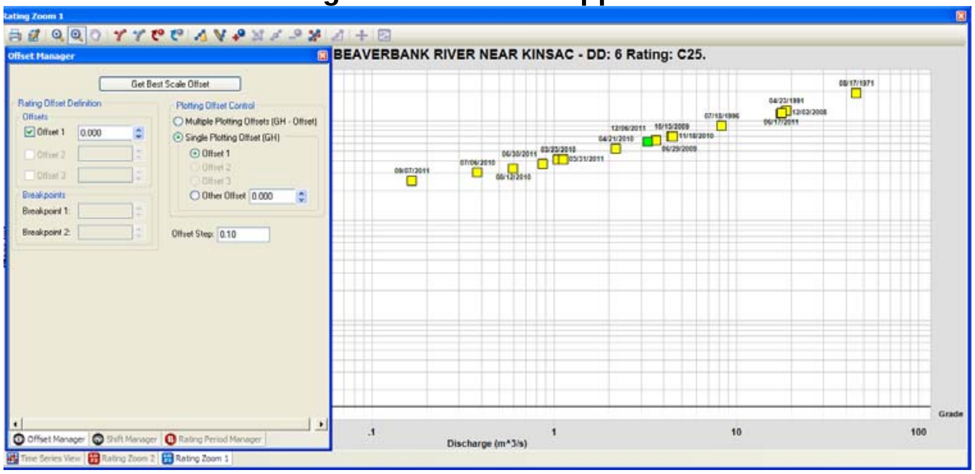
Figure 6: Measurements selected for Curve 25.000



Section Control

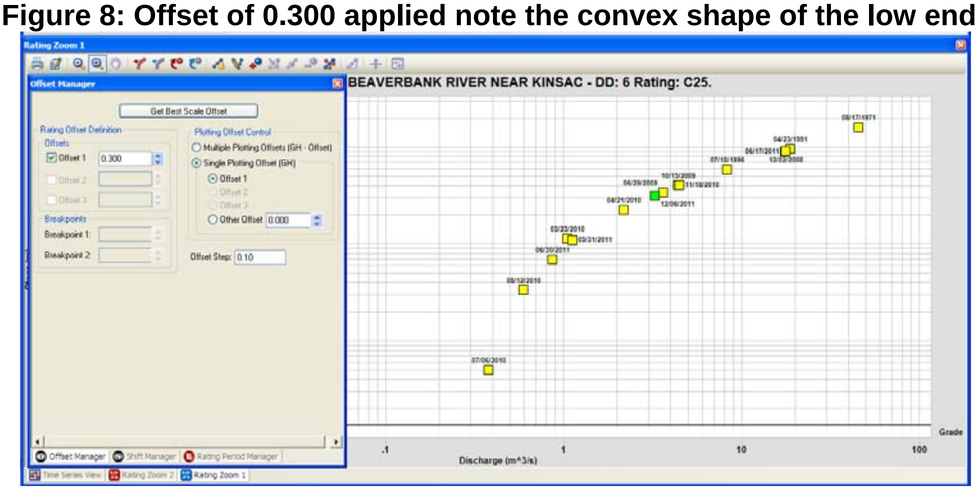
- Since there is very little concavity of the measurements and it is an assumed datum it is a good speculation that the offset or point of zero flow will be relatively low.

Figure 7: No offset applied.



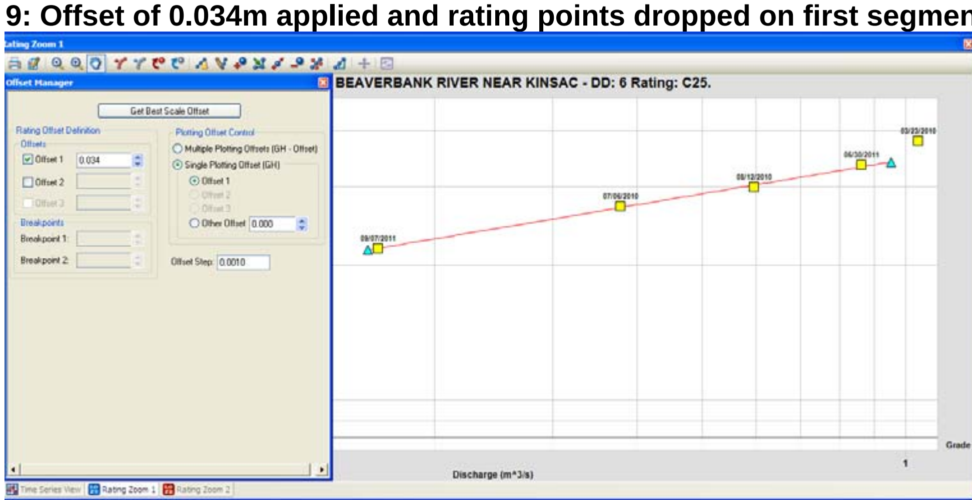
- As the offset is adjusted it is becomes clear that the offset for the low end of the curve is between 0.000 and 0.300 due to the convex shape of the measurements. See Figures 5 and 6.

Figure 8: Offset of 0.300 applied note the convex shape of the low end.



- By iterating the offset it was determined the low end (Section control offset was 0.010m) See Figure 7.

Figure 9: Offset of 0.034m applied and rating points dropped on first segment of curve.



- The alignment of the 03/23/2010 measurement indicates there is a break point between this measurement and the 06/30/2011 measurement. Between the two segments there is a transitional zone. This area at times does not follow the typically trends and measurements are required to properly calibrate the model.

Channel Control

- As the offset for the second segment is adjusted it is becomes clear that the offset for the low end of the curve is between 0.000 and 0.300 due to the convex shape of the measurements. See Figure 8 and 9.

Figure 10: No offset applied to the second segment.

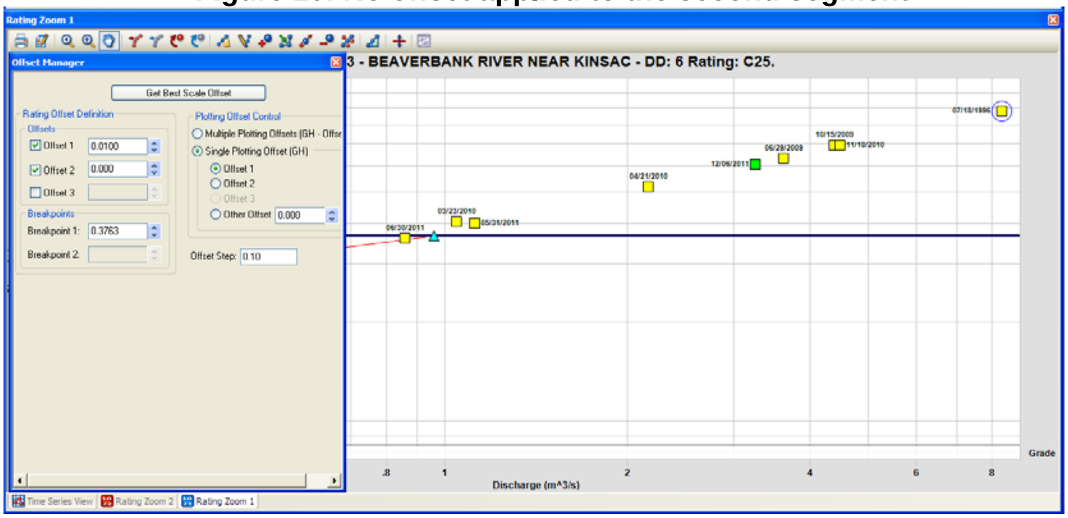
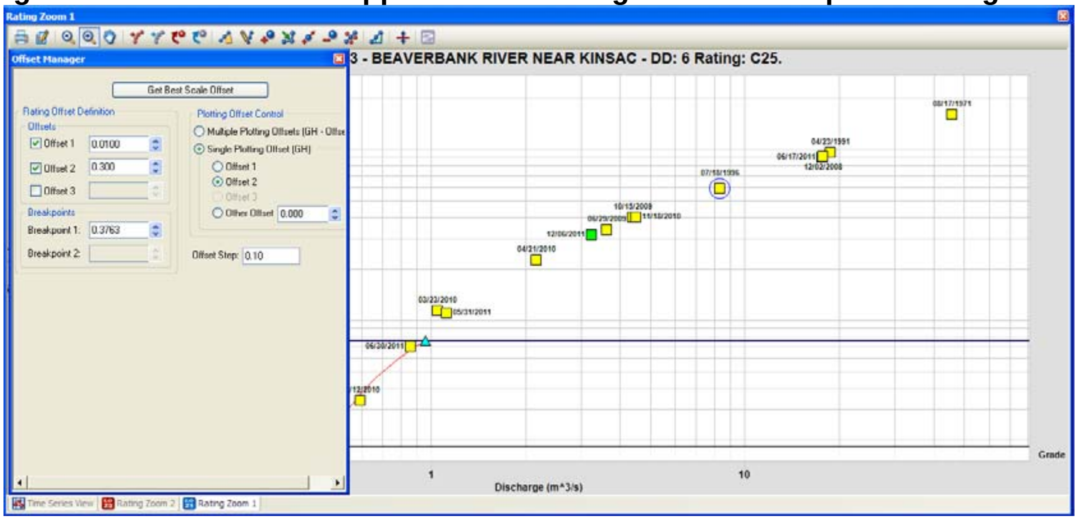


Figure 11: Offset of 0.300 applied note the slight convex shape of the high end.



- By iterating the offset it was determined the second segment (Channel control) offset was 0.050m) See Figure 10.

Figure 12: Offset of 0.050m applied and rating points dropped on second segment of curve

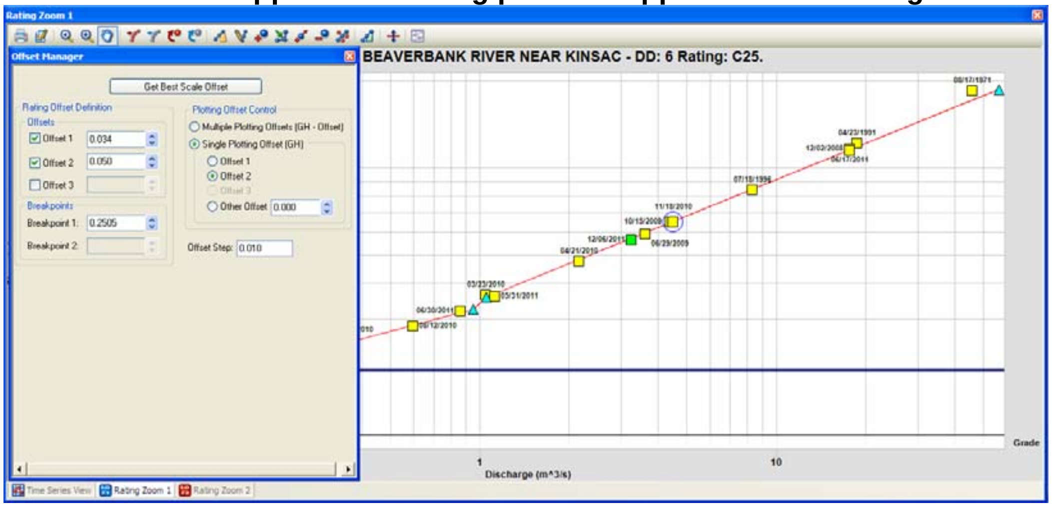


Figure 13: Rating table with equations for each segment.

Rating Table

Stage	Discharge	Offset	Slope	Equation
m	m^3/s	m		
0.07	0.000171321492	0.03400	-----	-----
0.3731	0.9201	0.03400	3.82949	X = 57.86821 *
0.3958	0.9716	0.03400	0.84051	X = 2.28349 * (Y-0.03400)^0.84051
2.1091	70.5065	0.05000	2.40141	X = 12.44403 *

- To extend the high end, the extend rating button was used. This function maintains the properties of the segment (Slope and Coefficient).
- If rating points were not dropped at a low enough water level a low end extension must be done. To do this simply insert the historical low water level the rating equation found in the rating table and solve for Q, see Figure 11. Once computed the water level and computed discharge were entered in the rating table.
- The rating table can be used as a secondary check. Ensure that the offset for each segment stays the same or increases. Check the slope of each segment with the control geometry to see if this matches the working hypothesis.
- For this river the first segment has a slope of 3.7 and an offset of 0.034 see Figure 12. The slope compares with a flood plain/braided. As stated in the working hypotheses the river flows between the bed rock and large rocks. Therefore, on a micro scale the river behaves as a braded channel at these low stages, refer to Figure 3. The second segment has a slope of 2.35 and a larger offset of 0.0500m. The slope of this segment falls in between triangular and parabolic control shape. Refer to Figure 4, even though the survey was completed at gauging pool it gives an indication of the channel geometry.
- The coefficient for the lower segment is high at 57.9 and 12.4. As observed in Figure 12 again at the low stages the river is consider to be rough. Below is the stage discharge equation:

$$Q = \beta * (H\text{-}PZF)^{a+b+c}$$

Where:
B = all the information about the channel characteristics
(Channel slope, roughness, channel complexity)
PZF = Is the point of zero flow over the control. In cases of channel control this may not be clear defined and is considered an effective point of zero flow.

a = Is the area as a function of head.
b = Is the relation of specific weigh of water as a function of head.
c = Is the velocity head.

The average roughness for this river at low stages is 0.468 and at the higher stages the average roughness is 0.085. This results in the roughness being 4.17 times greater at the lower stage. When comparing this with the coefficient of the two segments 57.9 and 12.4 the lower coefficient is 4.67 times greater. This values are very close and validating the large coefficient for the lower segment.

Conclusion and Recommendation

- Little statistical weight was given to the historical 1971 high measurement, due to a more recent lower high flow measurement. With more statistical weight given to the recent lower measurement high flow measurement, discharges of 100% of this measurement must be flagged as an estimate.
- All pre existing measurements were used in the development of the log-log curve. However the high end has been refined to reflect the 2011 measurement.
- Since all previous measurements were used, it suggests that there was little if any curve change. Referring to Figure 14 both curve 24 and 25 are very similar below 10m^3/s. Beyond this point the refinement occurs.

Figure 14: Curve 24 and 25. Blue 24/Red 25

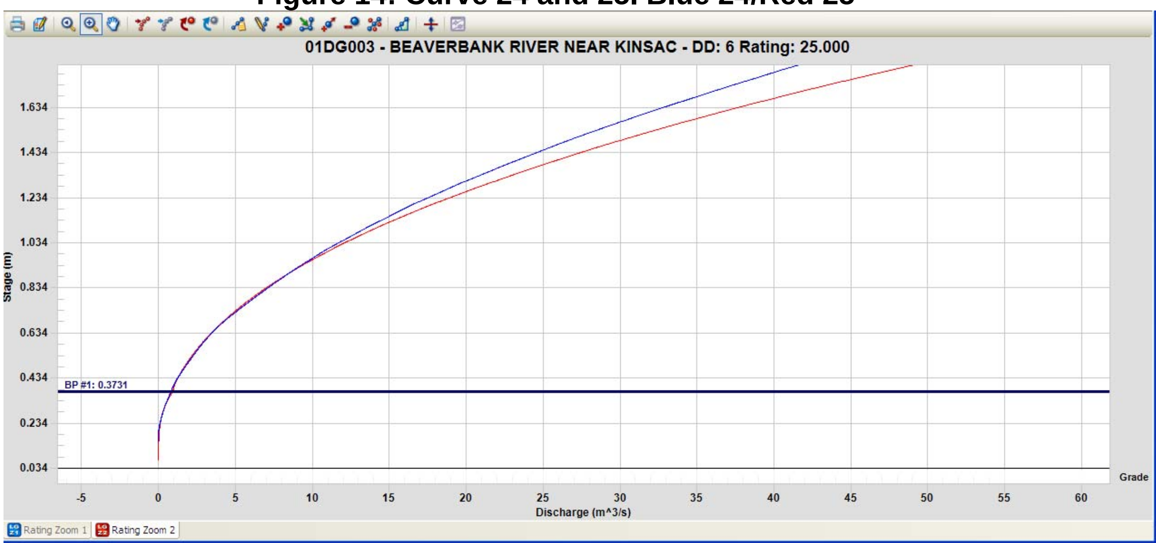


Figure 15: Aerial image of river.

Note: 170 is upstream cross section. 0 is downstream cross section.

Elk River near Natal

Station Description

Overview

Elk River near Natal (08NK016) is located in the south eastern British Columbia and is a headwater catchment to the Columbia River basin. The station has been in operation from 1950 to present (62 years of record) and drains a total upstream watershed area of 1840 square kilometres. Hydrology of the basin is snowmelt-dominated, with annual maximum and minimum flows typically occurring in the months of June and January - March respectively (Figure 1).

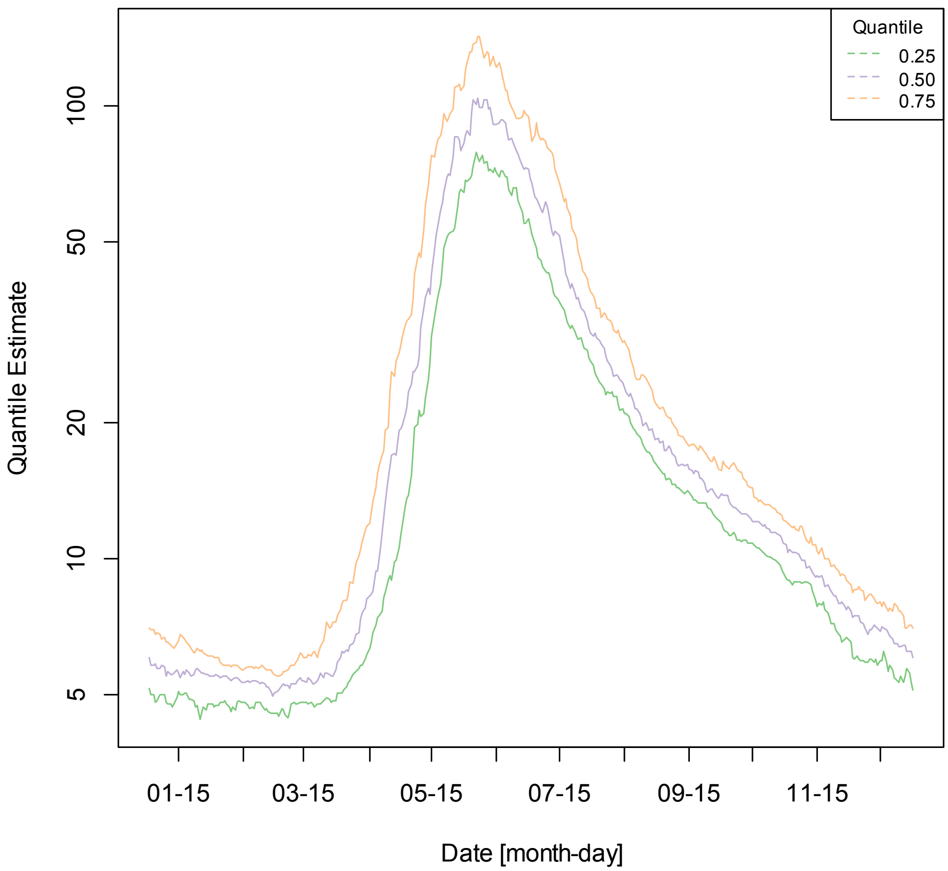


Figure 1 Lower (25th), Median (50th), and Upper (75th) quantile estimates based on historical mean daily flow record

Historical Range of Stage/Discharge

Table 1: The top 10 highest/top 2 lowest[1] historical maximum/minimum instantaneous published discharges

Date/Time	Discharge	Flag
1995/06/07 12:40:00	436	
1974/06/18 08:30:00	340	
1996/06/09 18:50:00	296	
2002/06/17 23:30:00	238	
1986/05/29 16:13:00	229	
1981/05/27 15:00:00	220	
1990/05/31 08:38:00	195	
1982/06/14 09:15:00	188	
2007/06/06 14:15:00	180	
1998/06/01 13:51:00	177	
2000/12/12 00:00:00	4.9	B
1999/02/10 00:00:00	3.86	B

Being a snowmelt-dominated streamflow regime, it is quite easy to coordinate the measurement program to coincide with the highest recorded stage. During the 2012 year, for example, maximum recorded stage was 1.55 m on June 7, 2012. Technicians visited the site on June 8 2012 and made a discharge measurement corresponding to a mean gauge height of 1.454 metres.

The current approved rating is Table Number 30 valid from the period February 5, 2007 to present. It is an arithmetic rating developed in CompuMod and valid for the stage range from 0.17 to 2.00 metres. The contemporary record (January 2012 to present) is still in reviewed or preliminary approval level. The range of stage which the rating must accommodate is 0.195 to 1.55 metres.

Control Condition

The gauging location is governed by a riffle located approximately 30 metres downstream from the gauge (Figure 2a). At higher flows, a side channel on left bank becomes activated nearby the control although the section control remains more or less intact (Figure 2b). The cableway is located at the gauging location. Above gauge height of approximately 2.0 m, the channel will go overbank and become floodplain dominated. Survey of the riffle control on September 20, 2012 estimated the lowest elevation to be approximately -0.283 metres.

[1] Only two years of observation for annual minimum instantaneous series are available

Figure 2 View looking downstream at control conditions (a) September 20,2012 MGH = 0.406 m; and (b) June 8, 2012 MGH = 1.454 m. Red arrows locate large woody debris at bar apex for reference between photos.

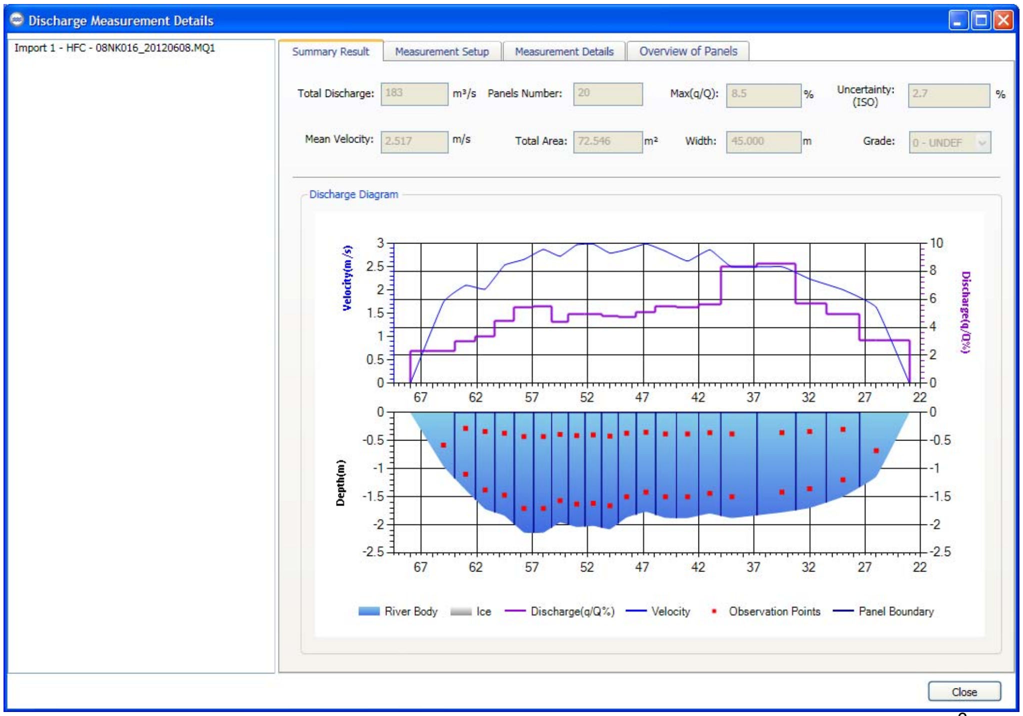


Figure 3 Cross-sectional profile of June 8, 2012 measurement (183 m^3/s)

Working Hypothesis

Based on the geometry of the channel, two controls appear to be in place. For stages less than 2.0 metres, the rating relation is controlled by the downstream riffle (section control). No observations in the recent gauging record are available for overbank conditions; however above gauge heights of 2.0 metres the channel expands into the floodplain. A working hypothesis would be that a single rating relation is dominant over the range of stage from (approx) 0 – 2.0 metres. We expect that high water events may re-work the riffle forming the rating control. We would expect this to impact the low end of the rating only. No significant overbank floods have occurred in the past two decades which would potentially re-arrange the riffle and cause a major change to the rating relation.

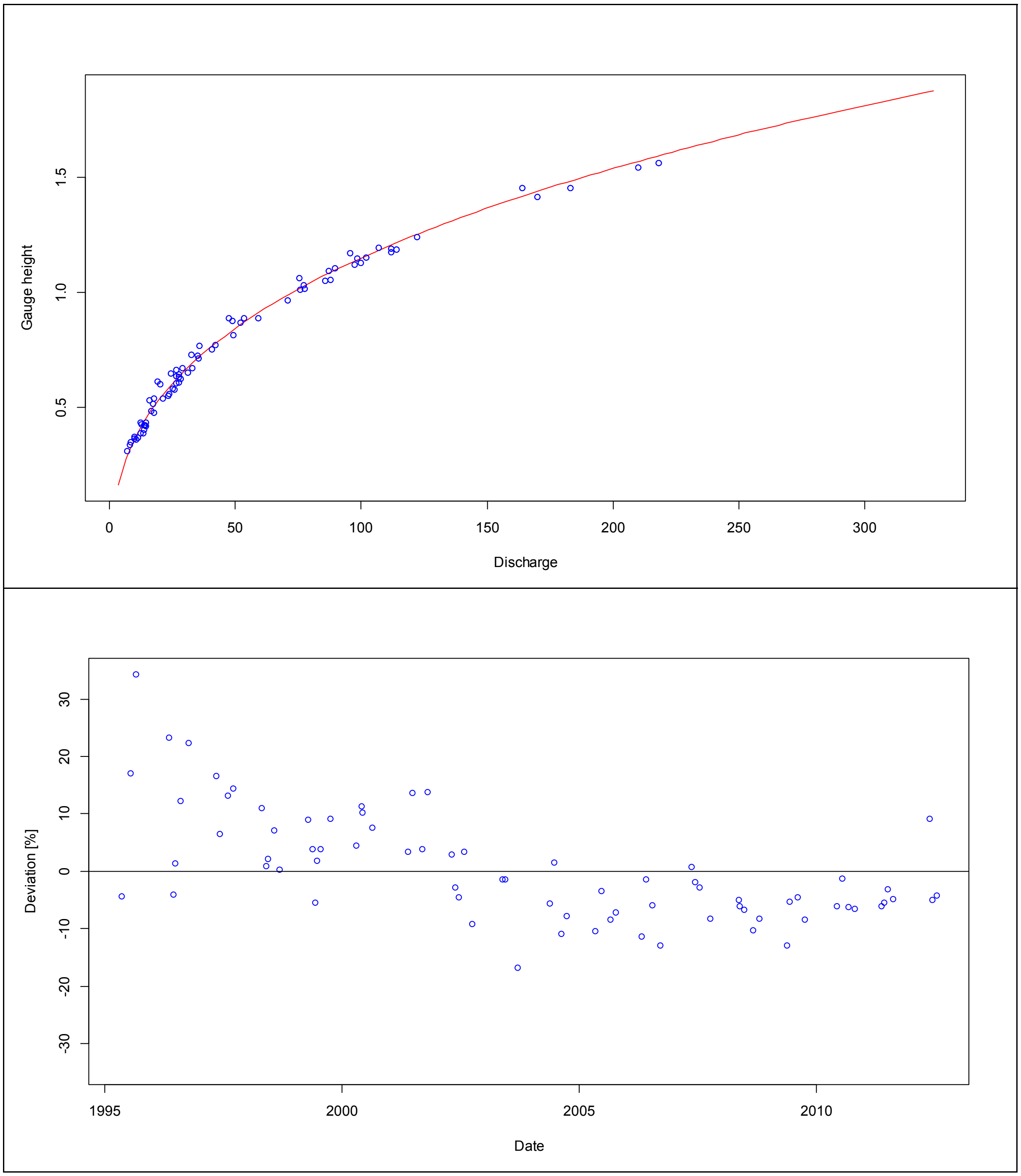
A survey of the downstream section control (riffle) on September 20, 2012 measured -0.218 m on the left bank and -0.283 m mid-river. The point of zero flow should be at, or less than -0.283 metres.

Measurement Selection

Since historic measurements may have limited description of the control condition (i.e., open or ice affected), a simple rule based on day of year can be applied to determine which measurements could be considered open water. In this station case, all measurements made after calendar day 100 (ca. April 10) and less than calendar day 300 (ca. October 25) were considered open water. For measurements available since 1995, this resulted in 77 considered to be open water.

A preliminary rating relation was fit to all open water measurements available since 1995 (Figure 4a). Figure 4b illustrates a plot of the discharge residuals to the fitted rating. There appears to be a systematic shift in the pattern of the residuals before and after the freshet in 2002-2003. A flow of 220 m^3/s was recorded on June 18, 2002 which caused a shift in the section control (Figure 5). Considering this fact, measurements after this high water event were only considered in developing the contemporary rating curve.

A total of 43 open water measurements made since the 2002 high water event were used to develop the contemporary rating curve. Plots of Area versus Stage and Mean Velocity versus Stage were compiled to evaluate the consistency of measurements, as well as develop relations which could be used to verify curve extrapolation (Figure 6). It is clear that one measurement made on May 16, 2012 plots significantly off the Stage-Area relation. This measurement was conducted from the cableway using standard Price AA current meter. Plots of cross-sections at the cableway indicate that this measurement has significantly less depth than other measurements made before and after the May 16th measurement (Figure 7). It appears that the technician did not incorporate the distance of the meter above the sounding weight in the depth computation[2]. Review of the HFC note indicates that this was in fact the error made. Without careful review of the measurement, it could have been interpreted as a temporary shift in control. This would have led to a period of computed flows which were substantially lower than reality. For the sake of brevity in this assignment, the May 16th measurement was censored from further analysis. However, the depths could have been adjusted to incorporate the distance of the meter above bottom of sounding weight and re-compute the discharge.



[2] The status of the measurement at the time of publication of this report was "Checked"

Figure 4 (a) Plot of the rating relation based on all open water measurements since 1995; (b) Plot of the discharge residuals as a function of measurement date.

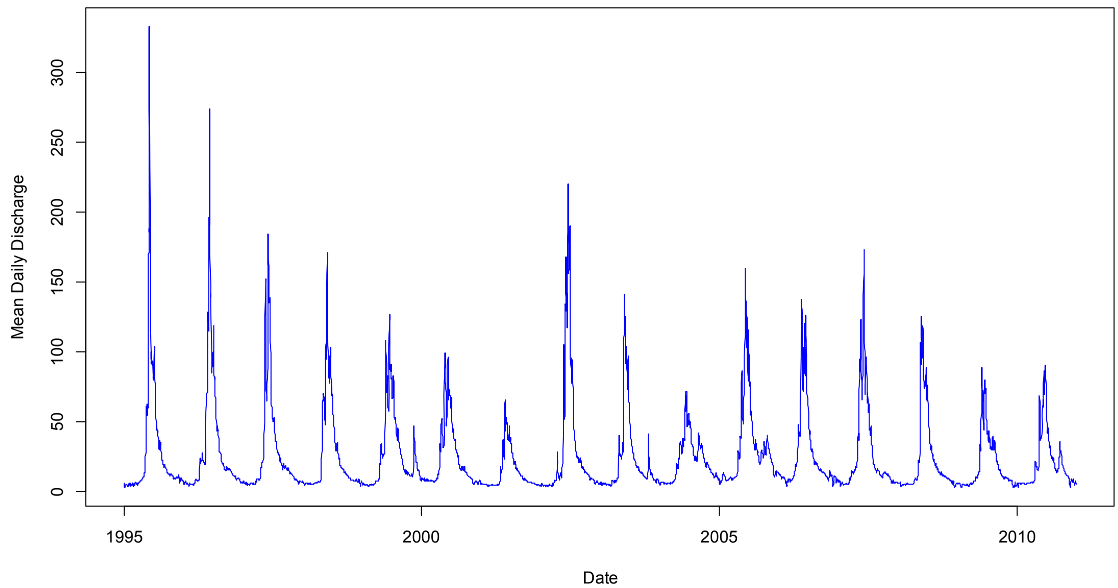


Figure 5 Historical published mean daily discharges 1995 to present

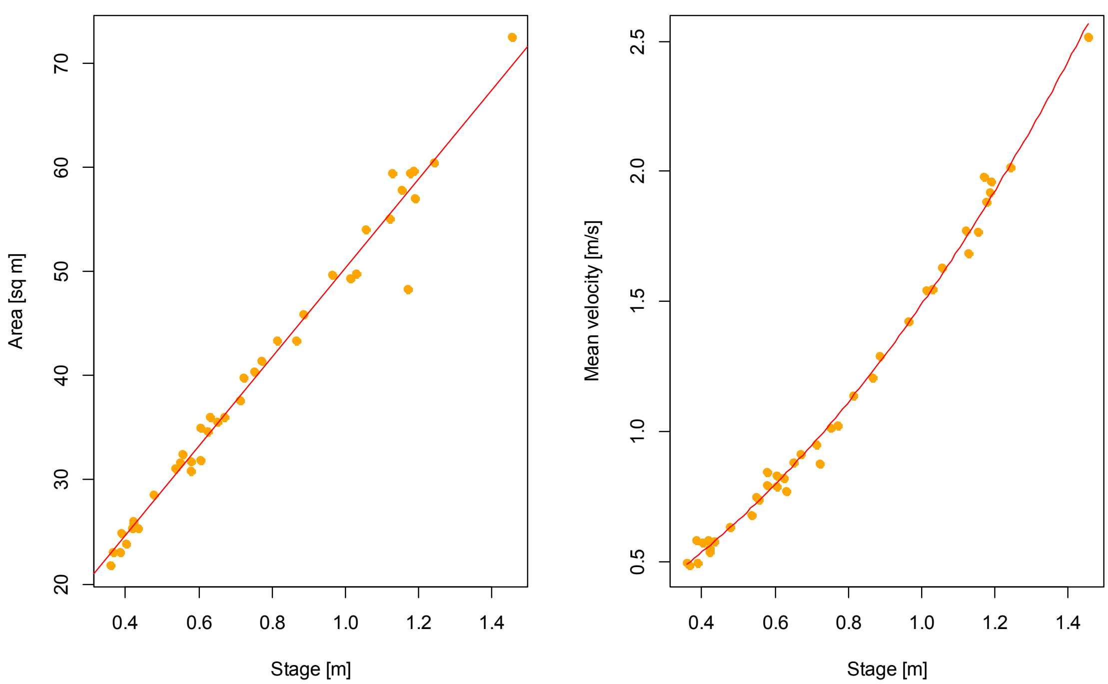


Figure 6 Plots of (a) Area vs. Stage; (b) Mean velocity vs. Stage

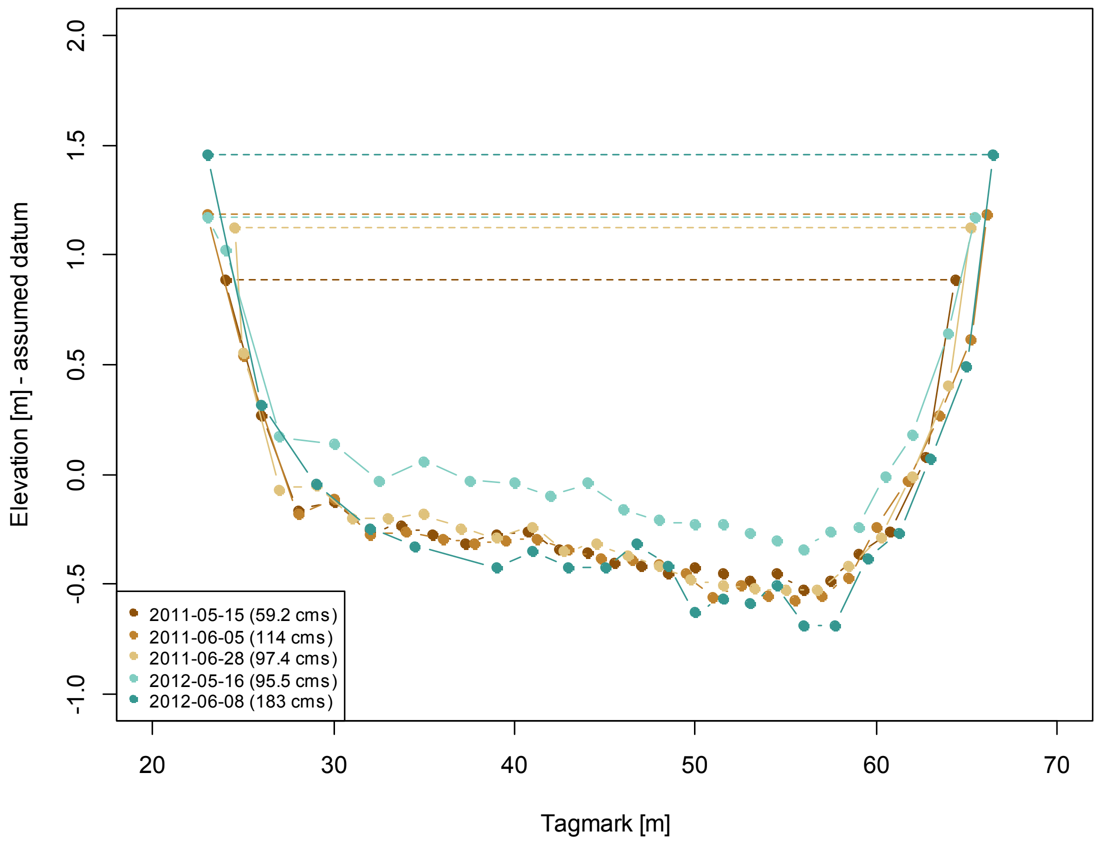


Figure 7 Cross-sectional profiles of recent discharge measurements made at the cableway

Rating Development

For the studied station, a total of 48 measurements were used to develop the rating curve. This includes (1) all measurements since June 18, 2002 (except May 16, 2012 described in the last section), (2) historic measurements which exceed approximately 100 m^3/s; and (3) recent mid-winter measurements which the control condition is explicitly know as being open water (over-riding the assumed November – April “ice” rule).

The first step was to adjust the offset in order to fit a straight line between total head (H-offset) and discharge (Q) in log-log space. Figure 8 illustrates that the default Offset1 value is too high based on the shape of the rating. The Offset1 value was adjusted downward iteratively until a straight line was attained (Figure 9). Rating points at the bottom and top end of the measurements were adjusted such that the distribution of points in the shift diagram exhibited little or no trend. A final curve was established with the following equation:

$$Q = 32.251 \cdot (H + 0.335)^{2.934} \quad (1)$$

The rating offset (-0.335 m) is slightly lower than the surveyed elevation (-0.283 m), but is in the ballpark considering that the channel bed is comprised of large cobbles. The rating exponent is higher than would be expected based on the control geometry. However, the number of measurements used to derive the rating relation trumps a fit based on control geometry alone. Of the 48 measurements, four plot greater than or equal to +/-5% off the calibrated curve (Figure 10). The residuals do not exhibit any trend with date and discharge and exhibit constant variance (homoscedasticity).

Discharge residuals above 120 m^3/s appear to be positively biased (i.e., observed flows are greater than the rating curve would predict). This may be indicative of an increase in channel conveyance due to the activation of the left bank side channel at higher flows. While this alternate hypothesis may be a more valid representation of the rating model at higher flows, it was not invoked for the following reasons: (1) the calibrated model fits the existing measurements within +/-5% criterion using a single control; (2) the stage at which the side channel activated is currently unknown; and (3) there are limited number of samples to define the rating segment.

At the low end of the rating curve, the March 20, 2012 measurement plots approximately 5.5% to the left (backwater) of the calibrated curve. This measurement plots marginally outside the normal confidence limits. If necessary, shifts could be used to better describe a short-term adjustment of the control conditions.

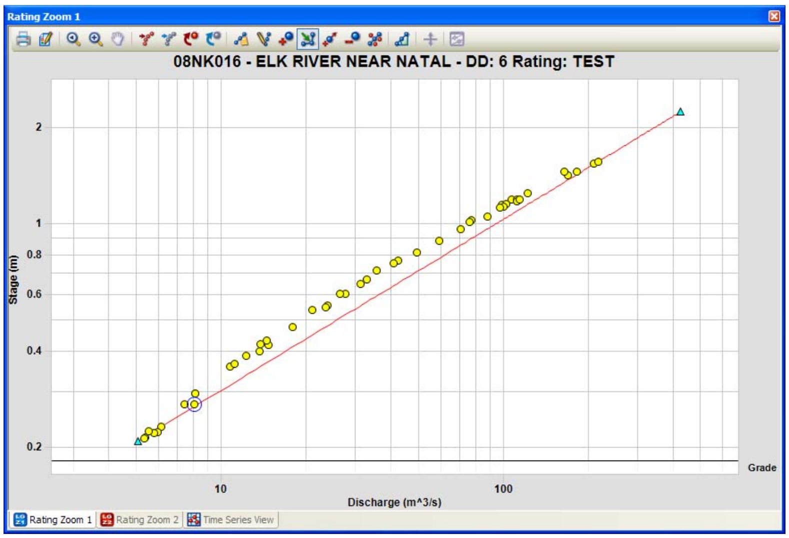


Figure 8 Concave down plot using offset1 equal to 0.0 m indicating that the offset is too high

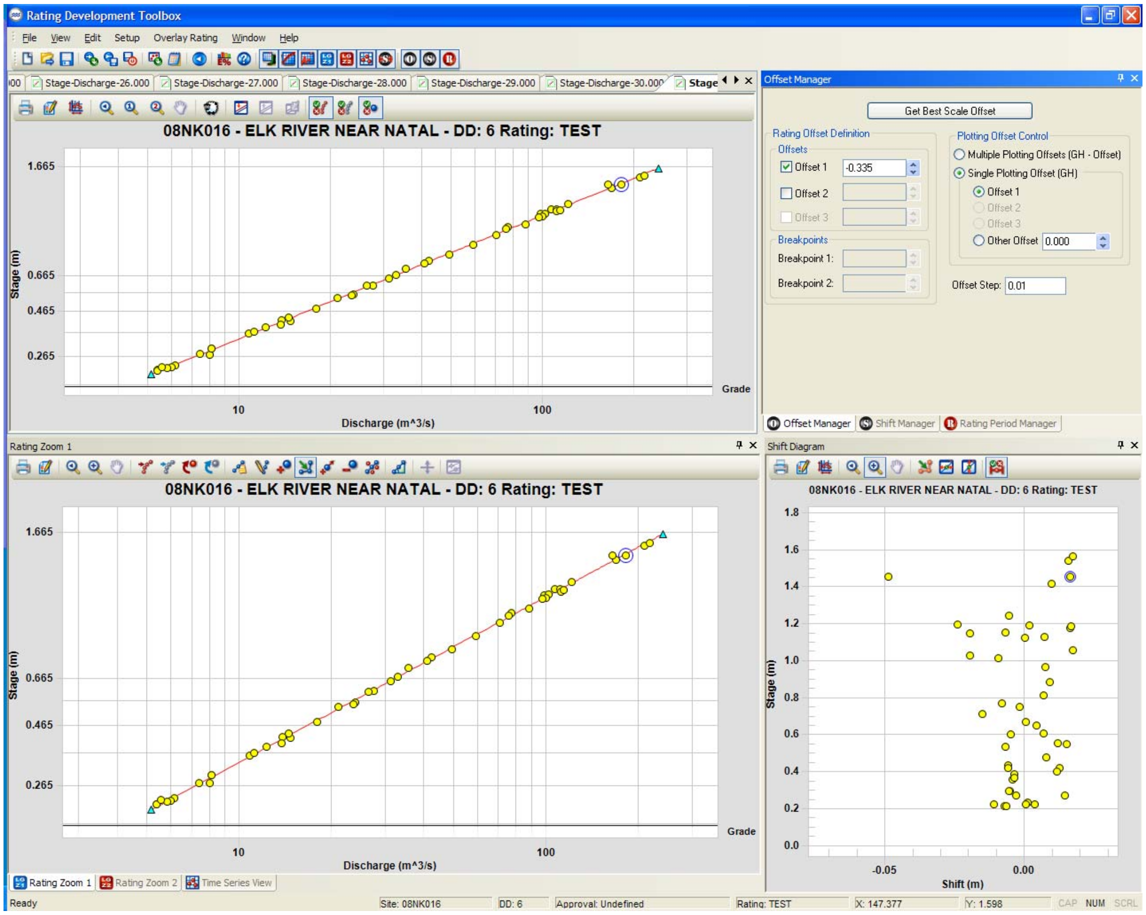
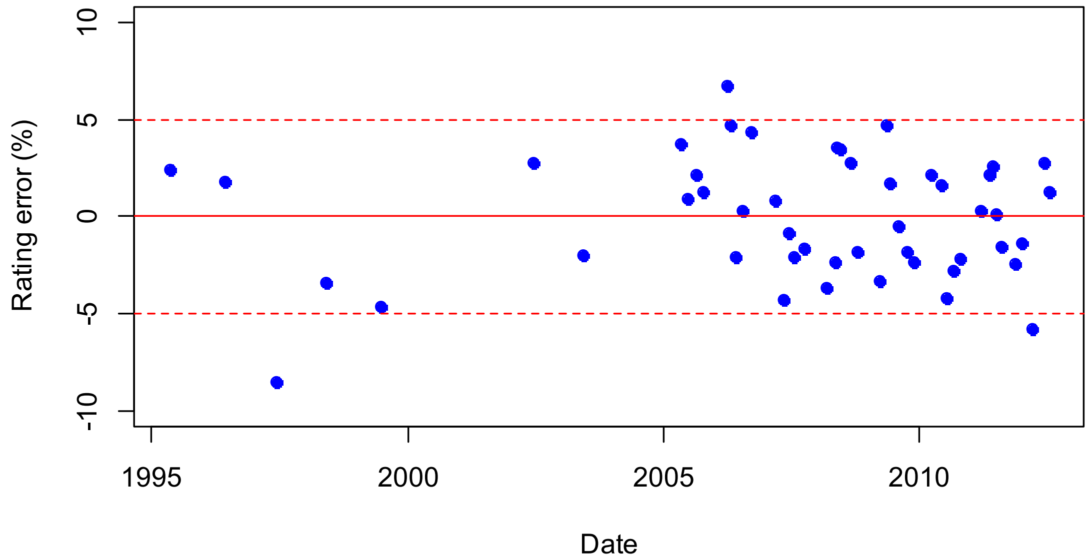


Figure 9 Final calibrated rating relation for Elk River at Natal



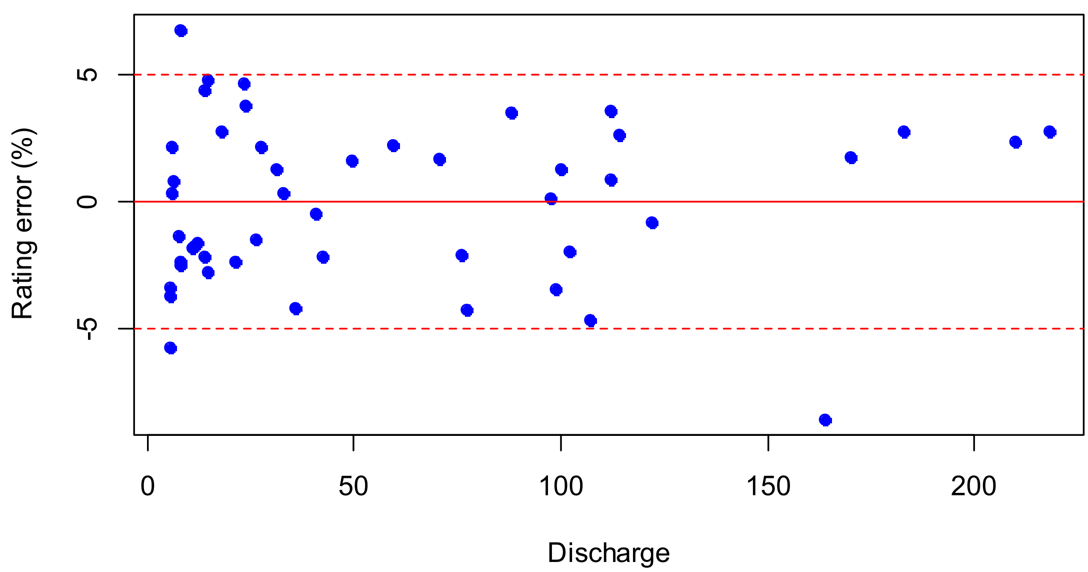


Figure 10 Plots of rating residuals by measurement date (top); and by observed discharge (bottom)

Rating Extrapolation

Based on the working hypothesis that floodplain control exists above a gauge height of approximately 2.0 metres, any extrapolation beyond this stage should be done with extreme caution. Therefore, the top end of the curve should not exceed 2.0 metres gauge height. This represents approximately 1.8 times extrapolation from the highest observed measurement (June 18, 2002 – 218 m^3/s).

At the low end, the rating must predict discharges to a minimum of 0.195 metres gauge height. Given that the historical range can vary down to 0.170 metres and that shifts may be used to manage temporary changes in control, it was decided to extend the rating curve down to 0.165 metres. This will give sufficient flexibility to the hydrographer for applying shifts to the low end of the rating as required.

Figure 11 illustrates the rating curve with lower and upper curve extensions.

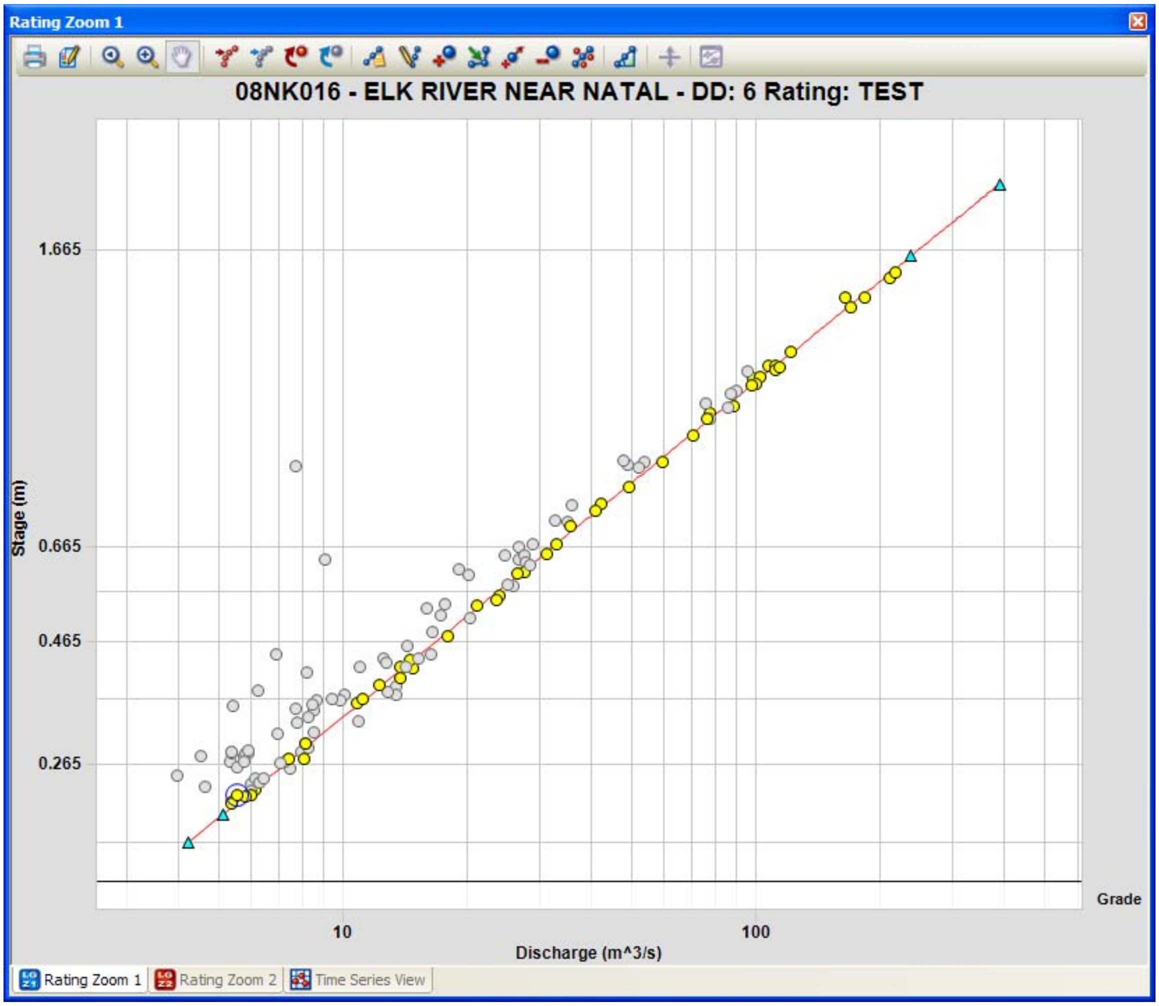
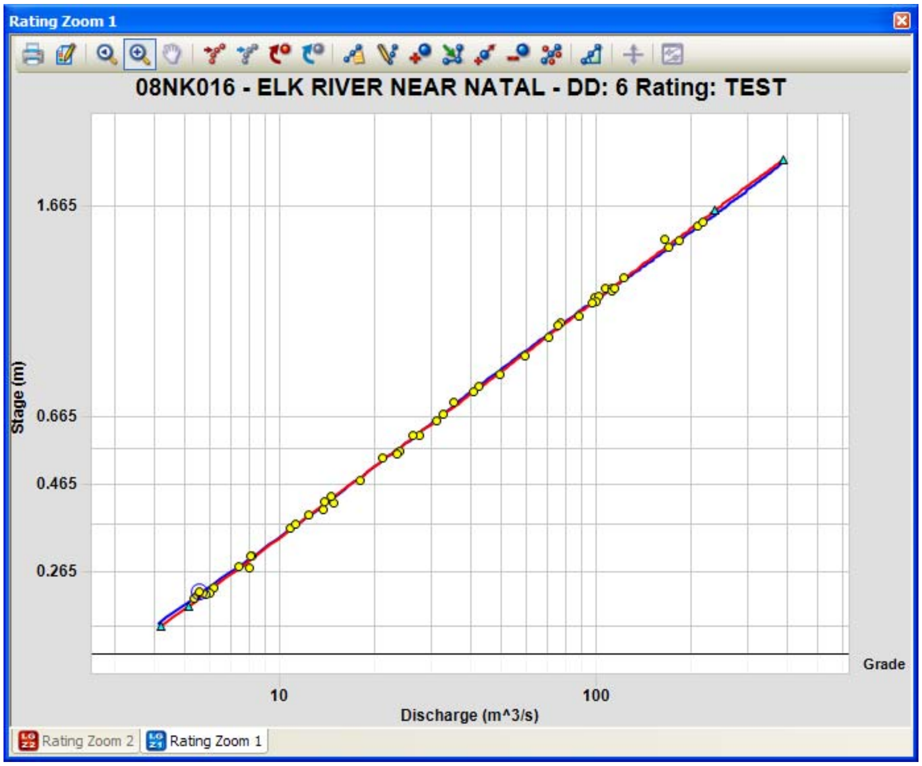
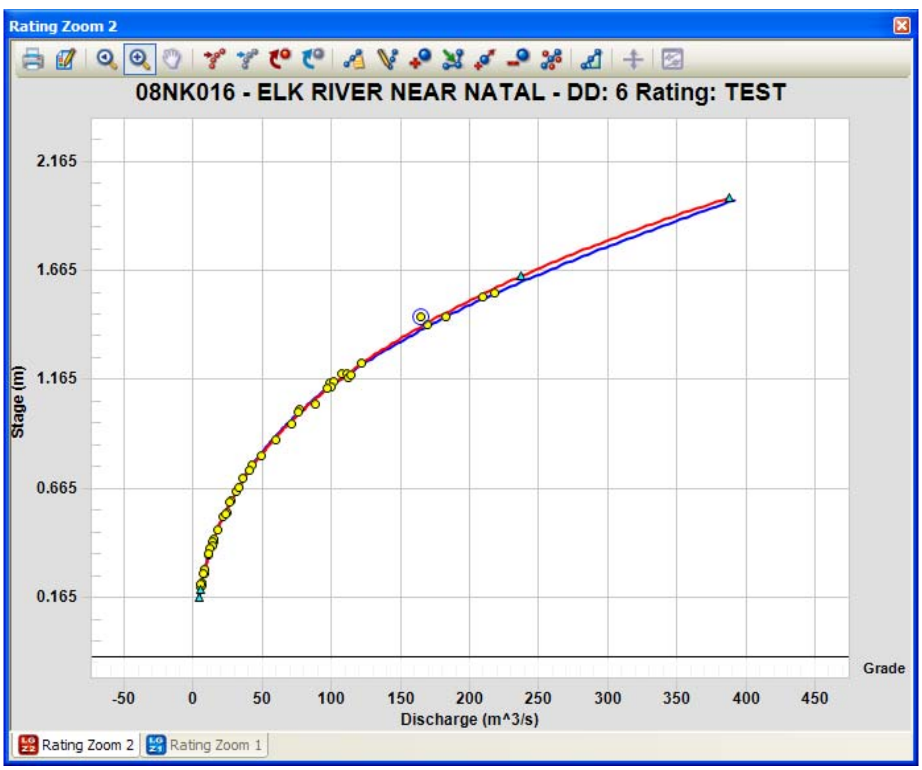


Figure 11 Base rating curve with low and high flow extrapolation segments

Rating Validation

Figure 12 illustrates the current rating to the currently approved curve (Number 30) in both log-log and arithmetic space. The approved curve more closely fits four of the upper end measurements (greater than 150 m3/s) at the expense of fitting to the high measurement


Rating Zoom 1
08NK016 - ELK RIVER NEAR NATAL - DD: 6 Rating: TEST
Stage (m)
1.665
0.665
0.465
0.265
Grade
10
100
Discharge (m^3/s)
Rating Zoom 2
Rating Zoom 1


Rating Zoom 2
08NK016 - ELK RIVER NEAR NATAL - DD: 6 Rating: TEST
Stage (m)
2.165
1.665
1.165
0.665
0.165
Grade
-50
0
50
100
150
200
250
300
350
400
450
Discharge (m^3/s)
Rating Zoom 2
Rating Zoom 1

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