United States Department of the Interior
U.S. GEOLOGICAL SURVEY
Reston, Virginia 20192

In Reply Refer To:
Mail Stop 415

February 23, 2017

Memorandum

OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM 2017.03

SUBJECT: Policy and guidance for shifting and check measurement practices when using the index-velocity method

The purpose of this memo is to provide policy and guidance on shifting and check measurement practices for index-velocity ratings. The index-velocity Techniques and Methods report TM3-A23 (Levesque and Oberg, 2012), Appendix 7, includes limited guidance on index-velocity shifts. This memo expands on that guidance by including additional information on shifting practices and applications. The memo provides (1) background information and motivation for the policy, (2) clarification on when to make check measurements, (3) information on when to shift, (4) justifications for the applications of shifts, (5) the method for applying shifts, and (6) links to additional tools and examples. A spreadsheet tool has been developed to help users of the index-velocity method implement the requirements described in this memo.

BACKGROUND

Application of shifts to stage-discharge ratings is a common method used by USGS to account for temporary changes in the hydraulic control that affect the stage-discharge ratings. TM3-A23, Appendix 7, provided limited guidance but did not present definitive, statistically-based methods for assessing rating uncertainty that would facilitate a decision whether or not to apply shifts to an index-velocity rating. Additionally, TM3-A23 disallowed the application of shifts to multiple linear regression (MLR) ratings, which has since been shown to be acceptable in limited circumstances. OSW has observed that shifting and check measurement practices for index-velocity ratings have been inconsistent across Water Science Centers, primarily due to incomplete guidance and a lack of tools for the rapid assessment and application of shifts, particularly where and when close observation of the channel and control would yield the most useful information and greatest insight - in the field, by the gage, at the time of the measurement.

SUMMARY OF POLICY

Discharge measurements made at index-velocity stations must be finalized on site, synchronized with velocity and stage data collected during the measurement, and compared to the rated discharge. Decisions on check discharge measurements and application of shifts must be made considering the uncertainties of the measurement (defined by the user at present and represented by error bars) and the index-velocity rating (represented by 95% prediction intervals). Check measurements are required during steady discharge when:

- The error bars of a measurement do not cross the rating and are completely outside the rating's prediction intervals, regardless of site observations; or
- The error bars of a measurement do not cross the rating, one of the error bars is outside the rating's prediction intervals, AND no physical cause for a shift can be documented.

A check measurement is *recommended,* but is not required, if a measurement lies within a poorly defined portion of the rating and the error bars of a measurement do not cross the rating. Check measurements often are not practical, and are not required, during periods of rapidly-varying discharge or stage.

Shifts to index-velocity ratings may be indicated if (1) the error bars of a measurement do not cross the rating, (2) at least one of the error bars is outside the rating's prediction intervals, and (3) there is a reasonable rationale for a shift. An observed change in flow conditions (not present during rating development) at the site or a departing trend in recent measurements from the rating are legitimate reasons for a shift. If indicated, shifts must be applied to the index-velocity rating and are defined by as many as three points. Shifts can be applied to simple linear, compound, and multiple linear index-velocity ratings. Shifts must be documented following policies in TM3A-23 and OSW Memo 2015.05. A spreadsheet tool is available to help users comply with policies in this memo to synchronize measurements in the field, compare measured and rated discharge, calculate rating uncertainty, and calculate and evaluate shifts.

WHEN TO SHIFT

The decision of when to apply a shift should be made with consideration for the uncertainties of both the discharge measurement and the rating.

Discharge Measurement Uncertainty

Quantifying the uncertainty of the discharge measurement (currently presented as the quality assigned to the measurement (excellent, good, fair, or poor) or some user-defined percent) is partially subjective but should be completed following guidance in Techniques and Methods reports TM3-A8 (Turnipseed and Sauer, 2010), TM3-A22 (Mueller and others, 2014), or the automatic computation provided in QRev (Mueller, 2016).

Prediction Intervals and Rating Uncertainty

Prediction intervals (see equations in Attachment A) can be used to describe rating uncertainty when using linear regression. They characterize the likelihood that a new rating validation measurement is consistent with conditions represented by the measurements used to develop or calibrate the rating. For example, by making some standard statistical assumptions, a new validation measurement made at an index-velocity streamgage has only a 5% chance of plotting outside the 95% prediction intervals developed for a rating IF conditions (such as velocity distribution and channel characteristics) that were present during the validation measurement were the same during measurements used in rating development. In other words, validation measurements that plot outside a rating's prediction intervals indicate that site conditions have likely changed substantially from the site conditions that predominated during rating development.

The use of 95% prediction intervals to describe index-velocity rating uncertainty is required. The intervals must be calculated and plotted with the rating during rating development.

Steps to Follow to Determine When to Shift

These steps must be followed to determine when a check measurement is needed and when a shift is justified for an index-velocity rating when making validation measurements (also see flowchart in Attachment B):

1. Process and finalize discharge measurements in the field in accordance with OSW Memo 2012.01. Synchronize index velocity and stage data with the discharge measurement times.
2. Calculate measured mean channel velocity (V_{mean_meas}) by dividing the measured discharge by the rated area from the stage-area rating at the standard cross section. Estimate the uncertainty of V_{mean_meas} using the quality rating of the discharge measurement. This means that the error bars for V_{mean_meas} are determined using the quality rating of the measurement (for example, excellent +/- 2 percent, good +/- 5 percent, fair +/- 8 percent, poor +/- 10 percent, or any user-defined uncertainty).
3. Compare V_{mean_meas} to the computed (also called rated) mean channel velocity (V_{mean_comp}).
4. If the V_{mean_comp} is within the rated uncertainty of V_{mean_meas} (scenario 1, fig. 1), shift analysis is complete and no further action is required. If the V_{mean_comp} is outside the rated accuracy of V_{mean_meas}, a shift may be indicated; continue following steps below.
5. Examine the uncertainty of the index-velocity rating using 95% prediction intervals (the intervals would already be calculated during rating development).
6. Plot the validation measurement's V_{mean_meas} on the rating to determine under which scenario the measurement lies (fig. 1):
   a. If the error bars on V_{mean_meas} do not cross the rating but both error bars are within the rating prediction intervals (Scenario 2, fig. 1), the measurement is within the uncertainty of the rating, and a shift is not indicated. Shift analysis is complete, and no further action is required.
   b. If the error bars of V_{mean_meas} do not cross the rating and one of the error bars is outside the rating prediction intervals, a shift may be indicated but should be further investigated (Scenarios 3 and 4, fig. 1). Proceed to step 7.
   c. If the error bars on V_{mean_meas} do not cross the rating and are completely outside rating prediction intervals, a shift is likely indicated (Scenario 5, fig. 1). Proceed to step 8.
7. Examine site conditions, previous field notes, and raw acoustic Doppler velocity meter (ADVM) data to determine if there is a condition or justification for a shift (see Justifications for Shifts section). Examine recent measurements to look for trends in departures from the rating.
8. A check measurement must be made following procedures in OSW Memo 2012.01 IF the measurement lies within Scenario 5 and is made during fairly steady discharge,

regardless of observations. A check measurement must be made if the measurement lies within Scenarios 3 or 4 AND a physical cause for a shift cannot be documented or recent measurements do not show a trend in departure from the rating. No check measurement is required for Scenarios 3 and 4 if a justification for a shift or trend in departure can be observed. A check measurement is still recommended if the measurement lies within a poorly defined portion of the rating. Check measurements often are not practical (and are not required) during periods of rapidly-varying discharge.

9. If a justification for a shift can be observed, or if a check measurement was made which confirmed the original measurement, apply a shift following guidance in the section "How to Shift".

Examples of shift assessments and applications are provided as Attachment C of this memo.

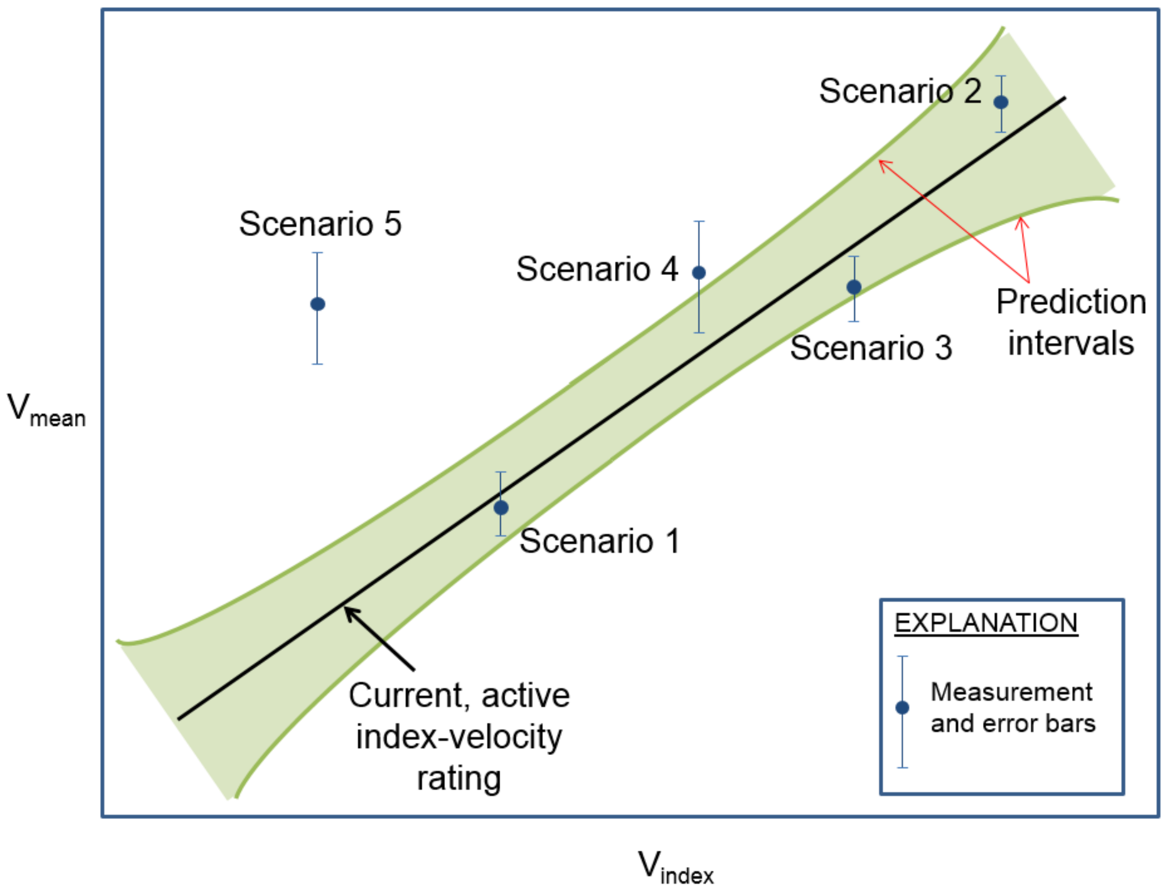

Figure 1. Example index-velocity rating with prediction intervals, validation measurements, and velocity shift scenarios.

JUSTIFICATIONS FOR SHIFTS

Justifications for shifts fall into three major categories: 1) changes in velocity distribution in the ADVM-measured cross section, 2) changes in area at the standard cross section, and 3) unforeseen changes to the ADVM. Justification categories 1) and 2) can be caused by vegetation growth, debris, partial ice cover, scour, or fill. Justification category 3) can be caused by a change in the ADVM's orientation, an obstruction in one or both ADVM beams within the measurement volume, a beam failure, or a change to the ADVM measurement volume resulting from transducer biofouling or low backscattering conditions. Reasonable attempts must be made to visually observe and document conditions that would justify a shift. A trend in measurements departing from the rating may indicate that a permanent rating change to either the index-velocity or stage-area rating (or both), rather than a temporary shift, is needed. In this case, it is acceptable to continue a shift until a new rating or ratings can be developed. According to TM3-A23, a minimum of 10 measurements per independent variable over a wide range of stream conditions is recommended before a new rating can be developed.

HOW TO SHIFT

Changes in the standard cross section can result in changes to the index-velocity rating because V_{mean} is calculated using rated area at the standard cross section. While shifts may be caused by changes in the channel at either the standard cross section or the location of the ADVM, or both, applying the shift to the index-velocity rating is computationally comprehensive because both velocity and area are represented in the rating. As a result, shifts must be applied only to the index-velocity rating, and not to the stage-area rating.

Shifts to index-velocity ratings can be defined by as many as three points. Shift magnitudes and input points must be determined based on the site's hydraulic conditions, the scatter of measurements about the rating, and any previously applied shifts. Shift curves should generally tie back into the rating; however, open-ended shifts could be justified for some conditions including semi-permanent velocity changes (such as due to partial ice cover, channel blockage, or ADVM beam obstruction). A shift based on vegetation growth will not typically result in an open-ended shift.

The optimum shift for a single measurement for a simple linear regression (SLR) or SLR segments of a compound rating is calculated using equation 1:

$$Optimum\ shift\ = \frac{(V_{mean_{meas}} - rating\ intercept)}{rating\ slope} - V_{index} \tag{1}$$

Where $V_{mean_{meas}}$ is the measured mean channel velocity

V_{index} is the average synchronized index velocity during the measurement

The optimum shift for a single measurement for an MLR rating with terms V_{index} and V_{index}* stage is calculated using equation 2:

$$Optimum\ shift\ = \frac{(V_{mean_{meas}} - rating\ intercept)}{rating\ slope1 + (rating\ slope2 * stage)} - V_{index} \tag{2}$$

Where:

rating slope1 is the regression coefficient on the V_{index} term

rating slope2 is the regression coefficient on the V_{index}*stage term
stage is the average synchronized stage during the measurement

Shifts to MLR ratings are allowed but should be applied with extreme caution because the shift is being applied to two terms in the rating equation. These shifts should be applied only to periods having similar stages and velocities represented by the measurement(s) used to define the shifts.

When shifts are applied, more frequent than normal measurements must be made at index-velocity sites to verify shifts and define the range of conditions over which shifts are valid. In particular, care must be taken to make enough measurements at sites with MLR ratings to verify shifts over a range of stage and velocity because of the inclusion of two variables in the rating. Additionally, shifts can be applied to sites influenced by a daily tidal signal ONLY if measurements have been made over the full range of the tidal cycle to adequately define the shift curve.

CONSIDERATIONS FOR AQUARIUS

Due to current (winter 2017) limitations in the USGS AQUARIUS database, shifts must be applied differently to SLR and MLR ratings. Shifts to SLR ratings are applied as true shifts to the index-velocity rating, but shifts to MLR ratings must be applied as corrections to the index-velocity data. Displaying velocity data on NWISWeb is problematic because of these corrections. USGS prohibits changing a correct input parameter (for example, stage) just to get the correct output parameter (for example, discharge, in the case of a stage-discharge relationship) as stated in OSW Memo 2005.07. For MLR ratings, the application of a data correction to represent a shift would result in a change to the index-velocity data in Aquarius. As a result, raw index-velocity data at streamgages with shifts applied to MLR ratings must not be displayed to the public on NWISWeb unless a separate "pass-through" velocity parameter is created in AQUARIUS to hold the shifted (corrected) index-velocity data, which is then used to calculate discharge. In this case, only the raw "uncorrected" index-velocity data, but not the "pass through" velocity data, can be displayed on NWISWeb.

A tip sheet is provided as Attachment D of this memo with procedures for entering velocity shifts and, where needed for MLR ratings, creating a "pass-through" velocity parameter in the USGS Aquarius database.

TOOL FOR EVALUATING AND CALCULATING SHIFTS

OSW has developed a spreadsheet tool for synchronizing velocity and stage data with discharge measurements, comparing rated and measured mean channel velocities, and calculating and evaluating shifts in the field and office. QRev or SVMobile files for validation measurements can be imported with this tool. The tool then imports rating information, calculates error bars for each validation measurement and prediction intervals for the rating, and produces plots to help the user assess whether shifting can be justified based on measurement and rating uncertainty.

OSW plans to update Appendix 7 in TM3A-23 to include the guidance in this memo as well as additional shifting examples. Anyone wishing a printed copy of TM3A-23 should contact Annette Goode (agoode@usgs.gov). Any questions on index-velocity shifting practices should be directed to Kevin Oberg (kaoberg@usgs.gov) or Molly Wood (mswood@usgs.gov).

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Distribution: All WMA Employees

ATTACHMENTS

A. Equations for Calculating Prediction Intervals as Referenced in OSW Memo 2017.03
B. Flowchart Illustrating Steps to Follow to Determine When to Shift
C. Examples of Shift Assessments
   Example #1: Bogus River (SLR rating; unidirectional flow; shift scenarios 1 and 5; negative shift due to vegetation in channel)
   Example #2: Granite Creek (SLR rating; unidirectional flow; shift scenarios 1, 4, and 5; positive shift due to changing velocity distribution from upstream landslides)
   Example #3: D&R Canal (compound rating; bidirectional flow; shift scenarios 2, 3, 5; positive shifts due to vegetation obstructing ADVM beams)
D. Tip Sheet for Entering Velocity Shifts in the USGS Aquarius Database

REFERENCES

Levesque, V.A., and Oberg, K.A., 2012, Computing discharge using the index velocity method: U.S. Geological Survey Techniques and Methods 3-A23, 148 p., http://pubs.usgs.gov/tm/3a23/.

Mueller, D.S., 2016, QRev - Software for computation and quality assurance of acoustic Doppler current profiler moving-boat streamflow measurements-Technical manual for version 2.8: U.S. Geological Survey Open-File Report 2016-1068, 79 p., http://dx.doi.org/10.3133/ofr20161068.

Mueller, D.S., Wagner, C.R., Rehmel, M.S., Oberg, K.A,, and Rainville, Francois, 2013, Measuring discharge with acoustic Doppler current profilers from a moving boat (ver. 2.0, December 2013): U.S. Geological Survey Techniques and Methods, book 3, chap. A22, 95 p., http://dx.doi.org/10.3133/tm3A22.

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p., https://pubs.usgs.gov/tm/tm3-a8/.

Attachment A. Equations for Calculating Prediction Intervals as Referenced in OSW Memo 2017.03

The uncertainty of a simple linear regression (SLR) index-velocity rating must be described using prediction intervals (eq. 1) as defined in Helsel and Hirsch (2008):

$$\hat{y} - ts\sqrt{1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{SS_x}}, \hat{y} + ts\sqrt{1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{SS_x}} \quad (1)$$

Where:

- t is the two-tailed t statistic for a specified α in the prediction interval calculation $(1-\alpha/2) * 100\%$ (for example, 0.05/2 = 0.025 for a 95% prediction interval), with n - 2 degrees of freedom;
- s is the standard error of estimate;
- n is the number of measurements used to define the index-velocity rating;,
- x_0 is the index velocity obtained from the ADVM;
- $\bar{x}$ is the mean of all the index velocities (for measurements used to define the rating);
- SS_x is the sum of squares of the index velocities used in the rating (determined from regression analysis); and
- $\hat{y}$ is the rated mean channel velocity.

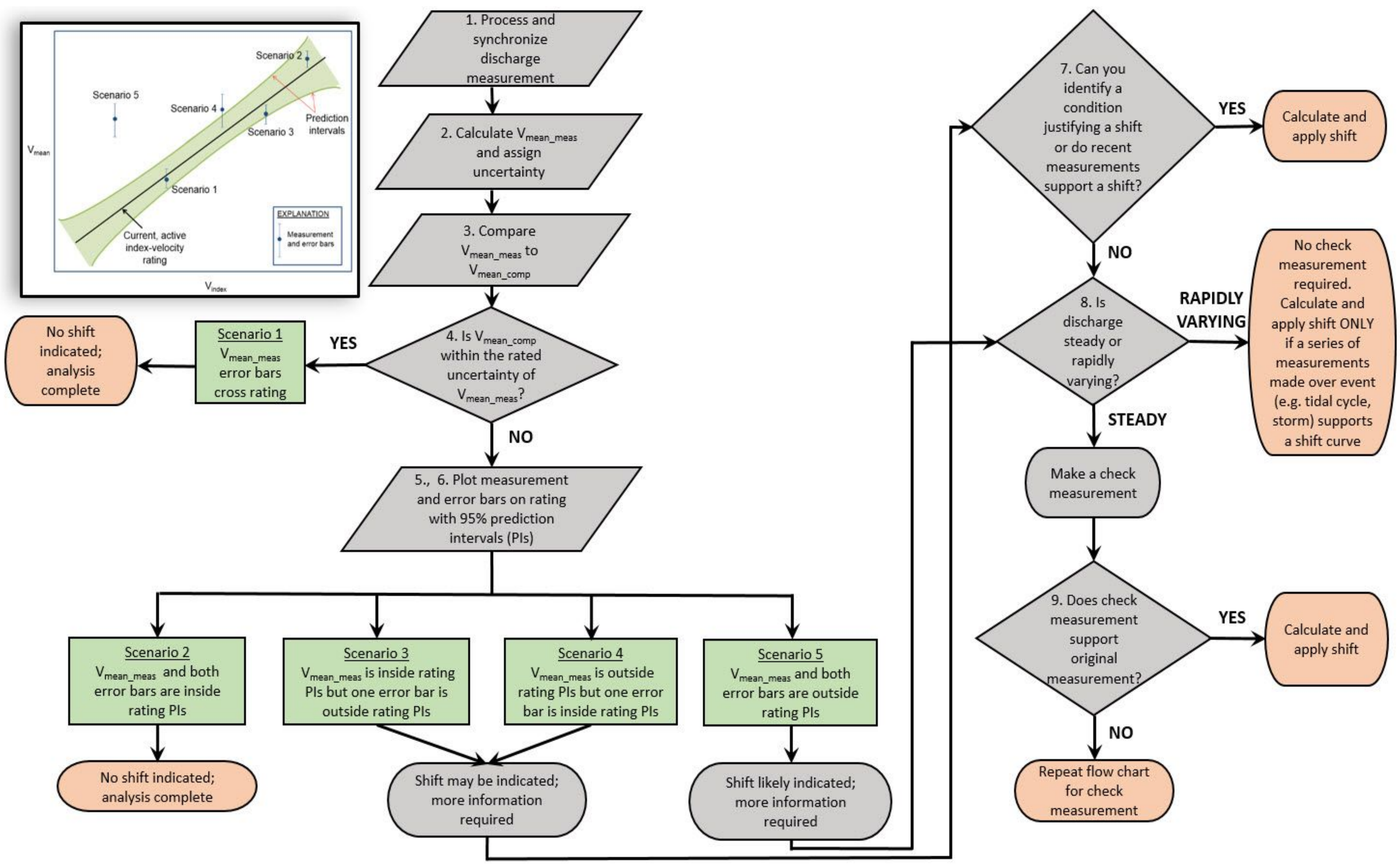
The uncertainty of a multiple linear regression (MLR) index-velocity rating can best be calculated using a variance-covariance matrix, which is difficult to calculate using current spreadsheet tools in use for index-velocity rating development. The following simplified approach (eq. 2) provides a rough approximation to prediction intervals (Helsel and Hirsch, 2008) and is required for use with MLR ratings until further notice:

$$\hat{y} - ts, \hat{y} + ts \quad (2)$$

REFERENCE

Helsel, D.R., and Hirsch, R.M., 2012, Statistical methods in water resources: U.S. Geological Survey Techniques of Water Resources Investigations 4-A3, 522 p., http://pubs.usgs.gov/twri/twri4a3.

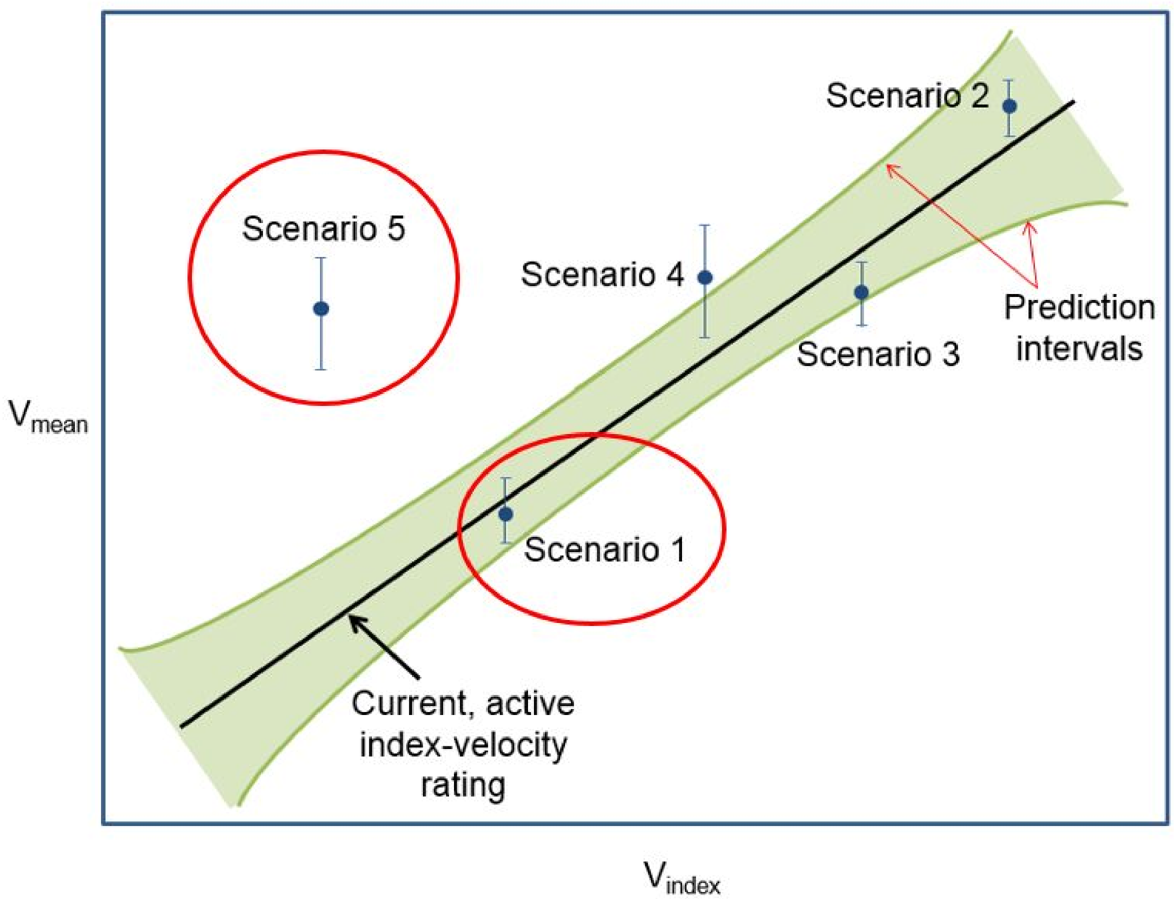
Attachment B. Flowchart Illustrating Steps to Follow to Determine When to Shift



Attachment C. Shifting Example #1: Bogus River

Overview

All flow at this site is unidirectional but is affected by backwater. This example illustrates a 3-pt negative shift curve to rating no. 1 based on vegetation growth in the channel. The shift curve was supported by several validation measurements and field observations. Examples of shift scenarios 1 and 5 (fig. 1, extracted from OSW Memo 2017.03 and shown below) are described.



Index-Velocity Rating

Index-velocity rating no. 1 was developed on 3/20/2014 based on 10 measurements made between 10/2/13 and 3/16/14. The rating was a simple linear regression (SLR) with R^2 = 0.996 and standard error = 0.055.

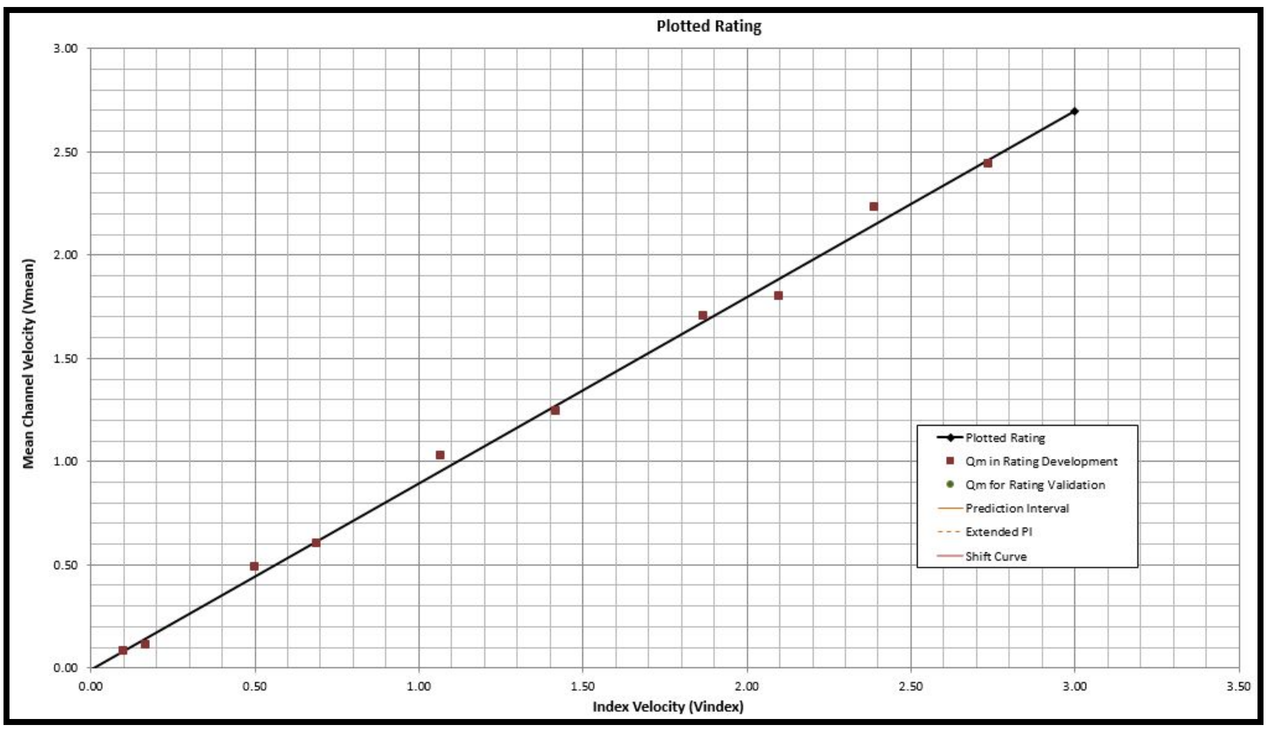
Table of measurements used to develop rating no. 1:

Bogus Creek

Index-Velocity Rating No. 1

Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)
1	10/2/2013	14,000	43.53	13,625	1.07	1.03
2	11/15/2013	23,500	43.89	13,814	1.87	1.70
3	12/8/2013	11,700	54.44	19,574	0.69	0.60
4	12/15/2013	2,040	52.69	18,597	0.17	0.11
5	1/6/2014	1,150	45.07	14,436	0.10	0.08
6	1/29/2014	30,800	43.92	13,829	2.39	2.23
7	2/10/2014	38,700	47.72	15,863	2.74	2.44
8	3/2/2014	25,400	44.45	14,108	2.10	1.80
9	3/13/2014	6,320	42.14	12,907	0.50	0.49
10	3/16/2014	18,100	45.32	14,569	1.42	1.24

Measurements and rating line fit plot:



Uncertainty of the Rating

The uncertainty of rating no. 1 was assessed by calculating 95% prediction intervals. Tables shown below are from Excel templates that calculate prediction intervals and guide decisions on shifting.

Table showing rating coefficients and automatically-calculated statistics for the calculation of prediction intervals:

Station Name: Bogus Creek
Station Number: 11111111

Index Velocity Rating No: 1.0

Select Rating Type From List: **Simple Linear**

Show Simple Linear Statistics | Show Compound Linear Statistics | Show Multi Variable Statistics | Clear Current Index Velocity Table | Hide Simple Linear Statistics

Note: Important! Must select Rating Type and enter regression coefficients below to properly compute Rated Vmean in "ADVM Qm Summary" tab!

Enter regression coefficients below or link directly to the coefficients in your regression statistics output:

Simple Linear	
Intercept	-0.0044
Slope	0.901
Full Equation:	*Vmean = -0.0044 + (0.901 * Vindex)*

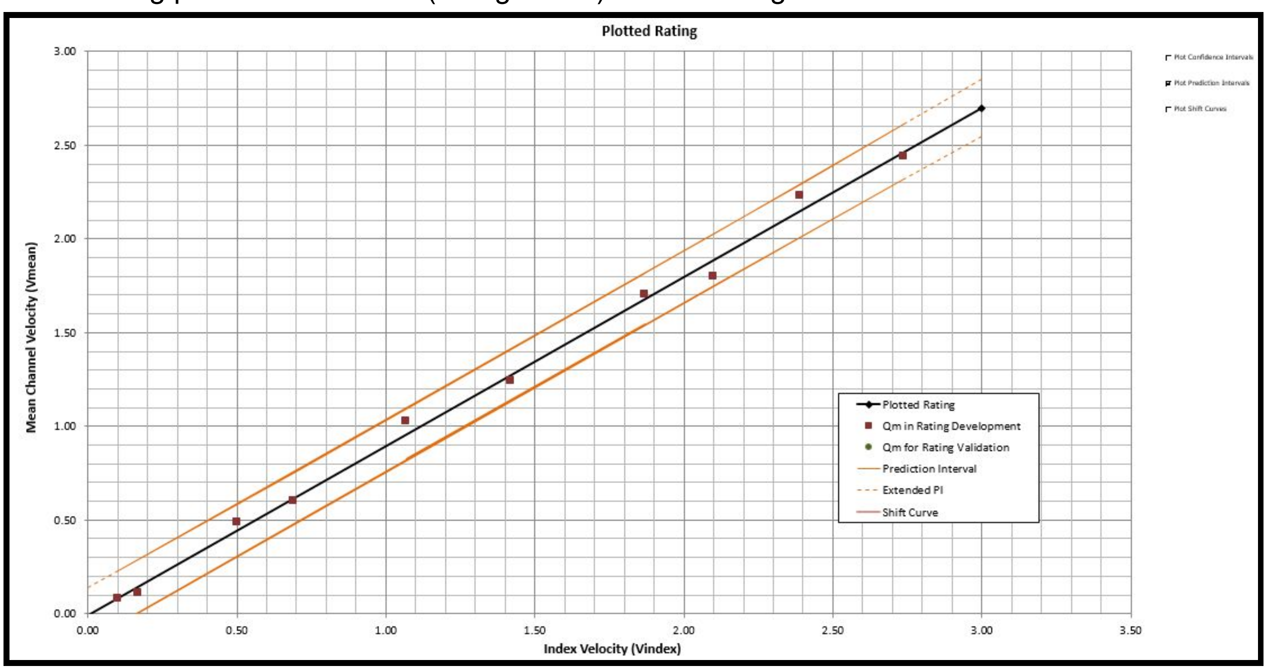
Compound Linear	
Line #1 (Vx <= breakpoint 1)	
Intercept	
Slope	
Full Equation:	*Vmean = + (* Vindex)*
Breakpoint 1 at Vx =	
Computed Vm at Vx =	#VALUE!

Index Velocity (Output for ADAPS)	Mean Velocity (Output for ADAPS)
0.00	-0.004
3.00	2.699

Simple Linear	
Intercept	-0.004
Slope (Vi)	0.901
Standard Error	0.055
No. of Observations (Qms)	10
Degrees Freedom	8
Probabiliy (95%)	0.05
T Statistic	2.306
(All Vi Used) Mean	1.31
SS Regression (Explained)	6.514
SS Residuals (Unexplained)	0.024
SSxx	8.02

Must load measurement in next tab to complete

Plot showing prediction intervals (orange lines) around rating no. 1:



Rating Validation Measurements

Discharge measurement nos. 11-17 were made to validate rating no. 1 after development. All validation measurements were input into Excel templates for guiding shifting decisions.

Table of validation measurements:

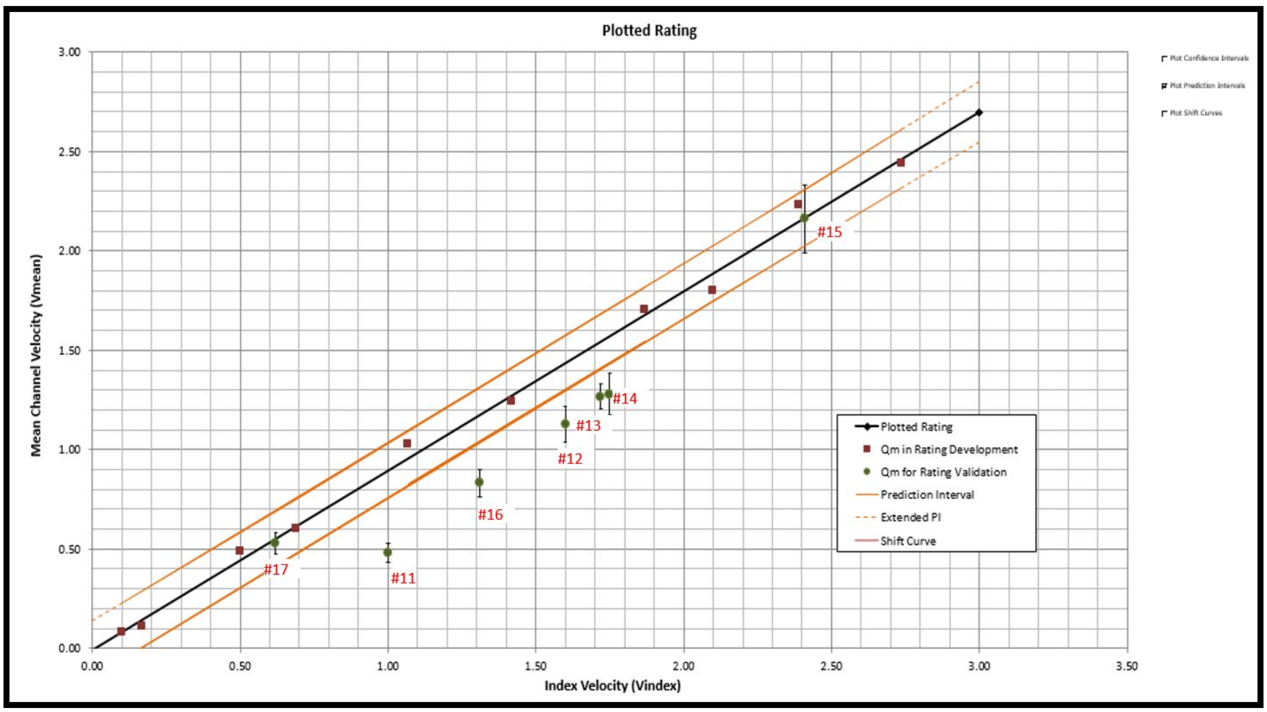
Bogus Creek

Index-Velocity Rating No. 1 - Validation Measurements

Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)	Vmean_rated (ft/sec)	% Difference	Measurement Rating	Optimum Shift (ft/sec)
11	04/28/2014	6,540	43.53	13,625	1.00	0.48	0.90	-46%	P	-0.46
12	05/11/2014	15,600	43.89	13,814	1.60	1.13	1.44	-21%	F	-0.34
13	05/26/2014	24,800	54.44	19,574	1.72	1.27	1.55	-18%	G	-0.31
14	06/05/2014	23,800	52.69	18,597	1.75	1.28	1.57	-19%	F	-0.32
15	06/16/2014	31,200	45.07	14,436	2.41	2.16	2.17	0%	F	-0.01
16	07/07/2014	11,500	43.92	13,829	1.31	0.83	1.18	-29%	F	-0.38
17	09/30/2014	8,410	47.72	15,863	0.62	0.53	0.55	-4%	P	-0.03

The template automatically calculated error bars on each measurement according to the measurement rating (E,G,F,P, or user-defined) and calculated the optimum shift. Additionally, the template plotted the validation measurements on the rating line fit plot. The validation measurements are shown in green; the error bars indicate the uncertainty of the measurement according to its rating (E-2%, G-5%, F-8%, P-10%, or user-defined).

Plot of validation measurements (in green, with their error bars) on the rating:



Measurement no. 11, made on April 28, 2014, was rated “good” but plotted -46% off the rating. The hydrographer noted that substantial vegetative growth was present in the stream in the vicinity of the ADVM and standard cross section. She also noted that temperatures since the last visit on March 16 have been warm and that turbidity in the river has been low, which created prime conditions for vegetation to grow. A beam check on the ADVM showed that the vegetation was not obstructing the beams. She also noted that velocities appeared to be more rapid than normal near the surface at similar flows.

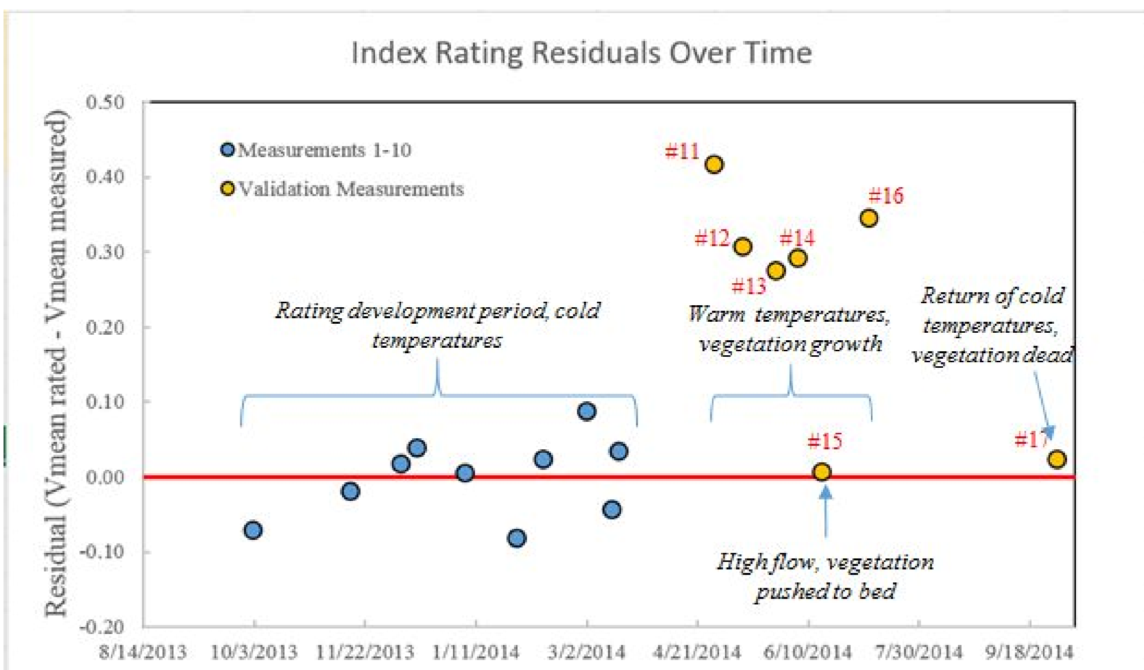
Measurement nos. 12, 13, and 14, made on May 11, May 26, and June 5, respectively, all plotted -21 to -18% off the rating. The hydrographer noted that the vegetation observed during measurement no. 11 was still present in the river. She again performed a beam check and found that the vegetation did not appear to obstruct the ADVM beams.

Measurement no. 15, made on June 16, was made during high flows and plotted within 0.3% of the rating. The hydrographer noted that the vegetation was still present in the channel but appeared to be pushed over by the high flows and was lying fairly flat on the riverbed where observable.

Measurement no. 16, made on June 7, was made during flows lower than the previous visit and plotted -29% off the rating, similar to measurement nos.12-14. The hydrographer noted that the vegetation was still present but again appeared to be raised. She performed a beam check and found that the vegetation still did not appear to obstruct the ADVM beams.

Measurement no. 17, made on September 30, matched the rating within 4.4%. The hydrographer noted that the vegetation appeared to be dead and that the water and air temperatures were colder than during the previous visit.

The departure of each measurement from the rating (the rating residuals) also was plotted over time, by the date of the measurement (plot is annotated with notes from hydrographer):



Justification and Calculation of Shifts

The reported values and error bars for validation measurements fall within the following scenarios:

Validation Measurement Nos.	Scenario No.
15, 17	1
11, 12, 13, 14, 16	5

Following policy in OSW Memo 2017.03, **check measurements were made for measurement nos. 11-14 and 16** (but are not shown in this example). All check measurements confirmed the original measurements. Shifts can be justified for measurement nos. 11-14 and 16 based on their plotting position relative to the uncertainties of the measurements and rating and based on the hydrographer's observations. Shifts are not needed or justified for measurement nos. 15 and 17 because they validate the rating within their rated accuracy.

At the time of each measurement, a temporary shift was entered because the shift could be justified based on visual observations (vegetation growth). The temporary shifts were the "optimum" shifts calculated as:

$$Optimum\ shift\ = \frac{(V\,mean\ -\ rating\ intercept)}{rating\ slope}\ -\ V\,index$$

Where V_{mean} is the measured mean channel velocity
V_{index} is the average synchronized index velocity during the measurement

For example, the optimum shift for measurement no. 11 was calculated as:

$$Optimum\ shift\ = \frac{(0.48 + 0.0038)}{0.90}\ -\ 1.0\ = -0.46\ \text{ft/sec}$$

The applied shifts were reviewed at the end of the record period to determine whether measurements could be grouped or whether a single shift curve could be used to represent the entire period.

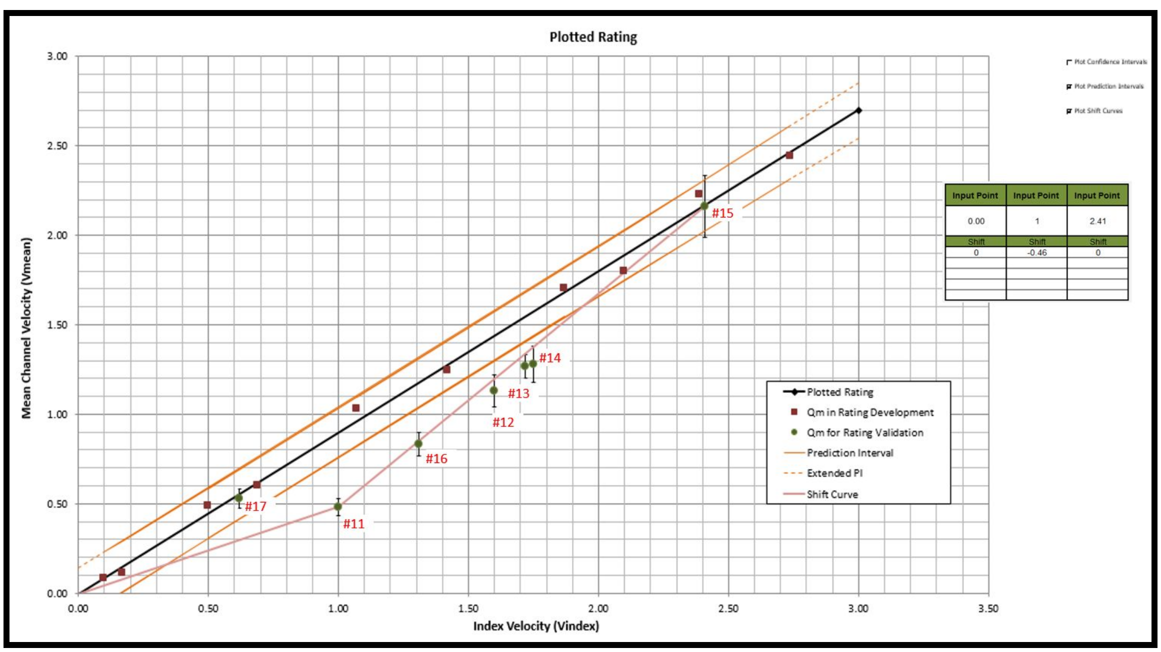
The vegetation on the streambed and banks constricted flow and caused measured velocities to be higher than what they would have been during rating development near the center of the channel, within the ADVM's measurement volume. As a result, the applied shift is negative. Based on hydrographer notes, the vegetation growth that caused a change in the index-velocity rating came into effect sometime between measurement nos. 10 and 11, remained in place through the summer but had a lesser effect at high flows, and ended between measurement nos. 16 and 17.

The hydrographer calculated a single shift curve with an inflection point, based on measurement no. 11, that fell within the error bars of measurement nos. 12-14. The shift curve tied back into the rating at high flows (confirmed by measurement no. 15), when the vegetation was pushed down on the riverbed. The hydrographer was concerned about applying a large, open-ended shift to low velocities (V_{index} < 1.0 ft/sec), which might result in erroneous negative discharges. The vegetation likely would have an influence on the rating at low velocities, but no measurements had yet been made during periods of vegetation growth and low velocities to confirm the shifts. The hydrographer decided to bring the shift curve back to the rating at V_{index}=0.0 ft/sec and planned to closely watch conditions in future periods of vegetation growth to better define shifts at low velocities. The applied 3-pt shift curve was as follows:

V_{index} (ft/sec)	Shift to V_{index} (ft/sec)	Comments
0.00	0.00	Tied back into rating at (0,0) to avoid large, open-ended shift at low velocities
1.00	-0.46	Based on measurement no. 11
2.41	0.00	Based on measurement no. 15

Measurement no. 16 confirmed the shift curve, falling between the 2nd and 3rd input points with an optimum calculated shift of -0.38 ft/sec. The shift applied during the time of measurement no. 16, based on the shift curve, was -0.36 ft/sec.

The shift curve (pink) was plotted with the validation measurements on the rating line fit plot:



After the application of the shift curve, all validation measurements plotted within 5% of the rating:

Bogus Creek
Index-Velocity Rating No. 1 - Validation Measurements

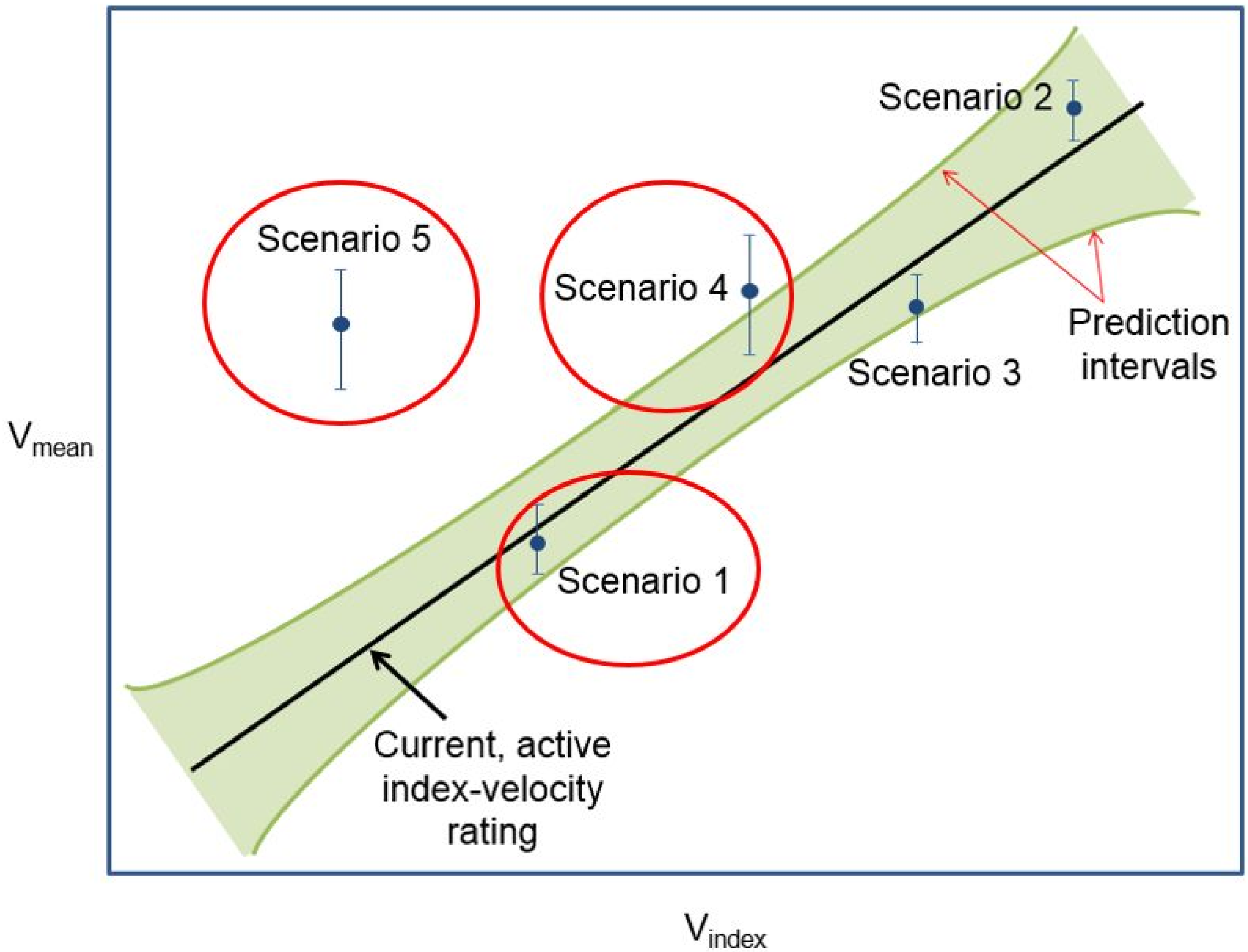
Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)	Vmean_rated (ft/sec)	% Difference	Measurement Rating	Optimum Shift (ft/sec)	Applied Shift (ft/sec) - Based on Shift	% Difference After Shift
11	04/28/2014	6,540	43.53	13,625	1.00	0.48	0.90	-46%	P	-0.46	-0.46	0%
12	05/11/2014	15,600	43.89	13,814	1.60	1.13	1.44	-21%	F	-0.34	-0.29	-4%
13	05/26/2014	24,800	54.44	19,574	1.72	1.27	1.55	-18%	G	-0.31	-0.25	-4%
14	06/05/2014	23,800	52.69	18,597	1.75	1.28	1.57	-19%	F	-0.32	-0.25	-5%
15	06/16/2014	31,200	45.07	14,436	2.41	2.16	2.17	0%	F	-0.01	0.00	0%
16	07/07/2014	11,500	43.92	13,829	1.31	0.83	1.18	-29%	F	-0.38	-0.36	-2%
17	09/30/2014	8,410	47.72	15,863	0.62	0.53	0.55	-4%	P	-0.03	0.00	-5%

Air and water temperature records were used to determine when to start the shift curve between measurement nos. 10 and 11. Average temperatures remained cool until about April 2, then steadily increased. The shift curve was started on April 2 and was prorated over time until measurement no. 11. The shift curve was then held constant through the summer. Conditions were watched closely for opportunities to make measurements at V_{index} < 1.0 ft/sec and better define the low end of the shift curve. Air and water temperature records were again used to determine when to end the shift curve between measurement nos. 16 and 17. Average temperatures substantially dropped starting about September 15. The shift curve was held constant through September 15, then was prorated over time to 0 on measurement no. 17.

Attachment C. Shifting Example #2: Granite Creek

Overview

All flow at this site is unidirectional but is affected by backwater. This example illustrates a 3-pt positive shift curve to rating no. 1 based on upstream landslides that changed the velocity distribution at the gage. The shift curve was supported by several validation measurements and field observations. Examples of shift scenarios 1, 4, and 5 (fig. 1, extracted from OSW Memo 2017.03 and shown below) are described.



Index-Velocity Rating

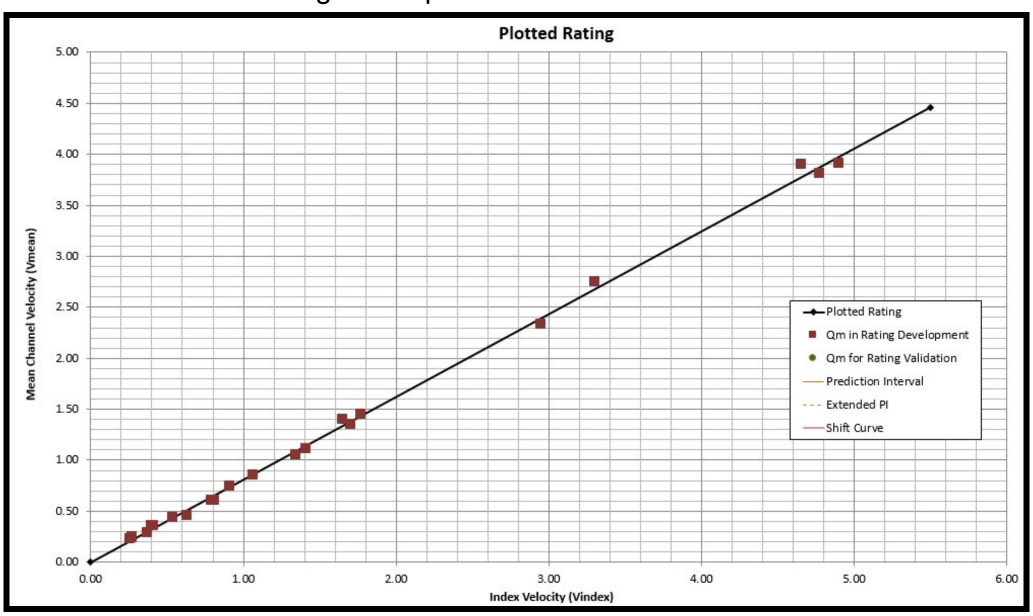
Index-velocity rating no. 1 was developed on 6/20/2016 based on 22 measurements made between 6/22/15 and 6/10/16, nos. 716-738 omitting no. 732 because of a noted error in the discharge measurement. The rating was a simple linear regression (SLR) with R^2 = 0.998 and standard error = 0.05.

Table of measurements used to develop rating no. 1:

Granite Creek
Index-Velocity Rating No. 1

Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)
716	06/22/2015	223	6.3	297	0.91	0.75
717	07/02/2015	87.9	5.4	201	0.54	0.44
718	07/21/2015	58.6	5.96	260	0.26	0.23
719	08/11/2015	83.2	6.18	284	0.37	0.29
720	08/19/2015	73.2	6.26	293	0.27	0.25
721	08/19/2015	70.8	6.24	290	0.27	0.24
722	09/29/2015	268	7.56	440	0.81	0.61
723	09/29/2015	265	7.55	439	0.79	0.60
724	10/03/2015	909	7.13	390	2.95	2.33
725	10/04/2015	3083	10.45	809	4.77	3.81
726	10/04/2015	3124	10.38	799	4.90	3.91
727	10/04/2015	3135	10.4	802	4.65	3.91
728	10/05/2015	1434	8.24	521	3.30	2.75
729	10/07/2015	495	6.81	354	1.65	1.40
730	10/19/2015	127	6.78	350	0.41	0.36
731	12/22/2015	543	6.99	374	1.77	1.45
733	03/09/2016	490	6.90	363	1.70	1.35
734	04/07/2016	387	6.92	366	1.34	1.06
735	04/07/2016	398	6.85	357	1.41	1.11
736	05/05/2016	287	6.66	337	1.06	0.85
737	05/06/2016	154	6.64	335	0.63	0.46
738	06/10/2016	123	6.67	338	0.40	0.36

Measurements and rating line fit plot:



<u>Uncertainty of the Rating</u>

The uncertainty of rating no. 1 was assessed by calculating 95% prediction intervals. Tables shown below are from Excel templates that calculate prediction intervals and guide decisions on shifting.

Table showing rating coefficients and automatically-calculated statistics for the calculation of prediction intervals:

Station Name:	Granite Creek
Station Number:	00998877
Index Velocity Rating No:	1.0
Select Rating Type From List:	Simple Linear

Show Simple Linear Statistics | Show Compound Linear Statistics | Show Multi Variable Statistics | Clear Current Index Velocity Table | Hide Simple Linear Statistics

Note: Important! Must select Rating Type and enter regression coefficients below to properly compute Rated Vmean in "ADVM Qm Summary" tab!

Enter regression coefficients below or link directly to the coefficients in your regression statistics output:

Simple Linear	
Intercept	0.0005
Slope	0.811
Full Equation:	*Vmean = 0.0005 + (0.811 * Vindex)*

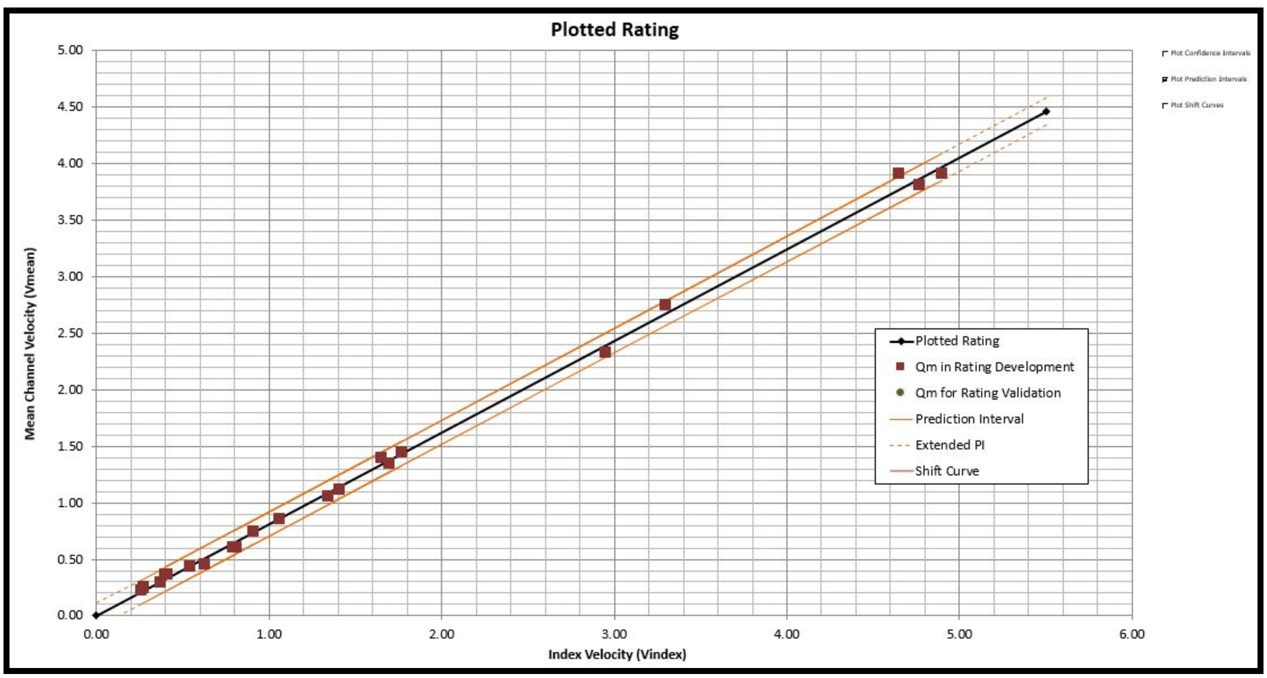
Compound Linear	
Line #1 (Vx <= breakpoint 1)	
Intercept	
Slope	
Full Equation:	*Vmean = + (* Vindex)*
Breakpoint 1 at Vx =	
Computed Vm at Vx =	#VALUE!

Index Velocity (Output for ADAPS)	Mean Velocity (Output for ADAPS)
0.00	0.001
5.50	4.461

Simple Linear	
Intercept	0.0005
Slope (Vi)	0.811
Standard Error	0.05
No. of Observations (Qms)	22
Degrees Freedom	20
Probabiliy (95%)	0.05
T Statistic	2.086
(All Vi Used) Mean	1.60
SS Regression (Explained)	32.197
SS Residuals (Unexplained)	0.053
SSxx	48.92

Must load measurement in next tab to complete

Plot showing prediction intervals (orange lines) around rating no. 1:



Rating Validation Measurements

Discharge measurement nos. 739-750 were made to validate rating no. 1 after development. All validation measurements were input into Excel templates for guiding shifting decisions.

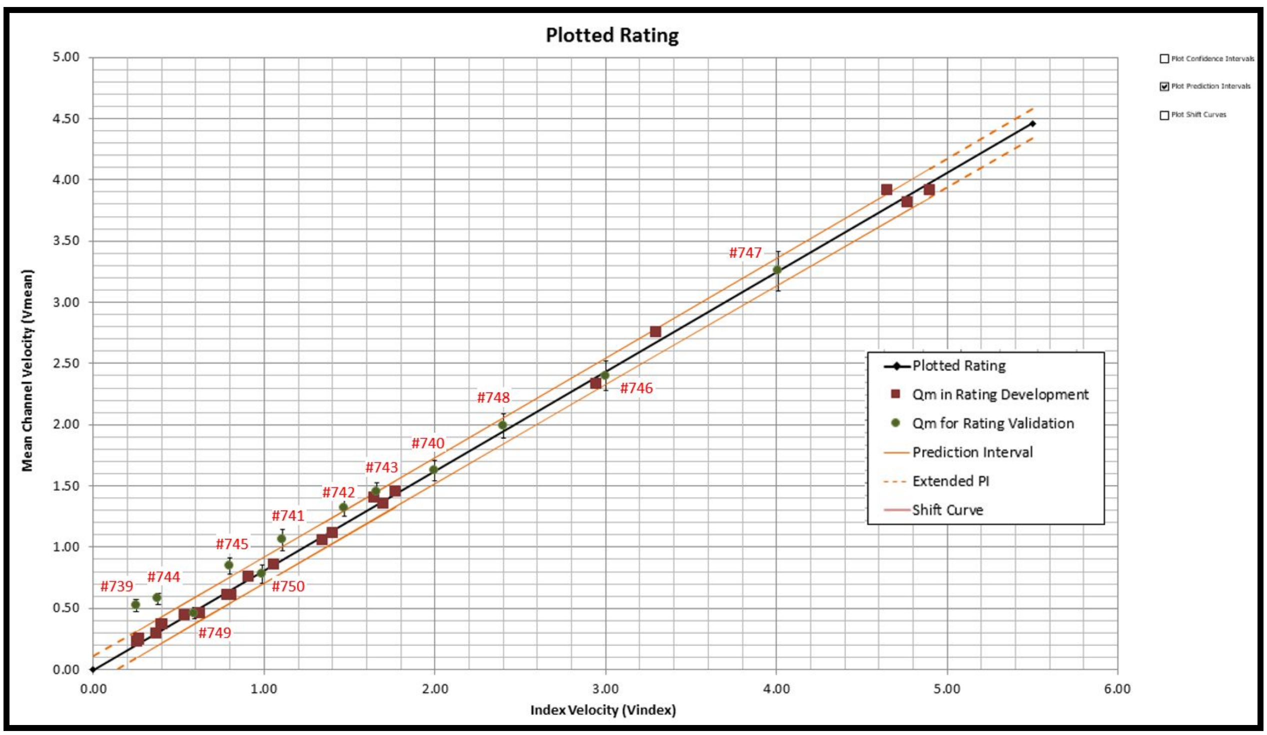
Table of validation measurements:

Granite Creek
Index-Velocity Rating No. 1 - Validation Measurements

Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)	Vmean_rated (ft/sec)	% Difference	Measurement Rating	Optimum Shift (ft/sec)
739	07/15/2016	203	7.12	389	0.25	0.52	0.20	157%	P	0.39
740	08/19/2016	652	7.23	402	2.00	1.62	1.62	0%	G	0.00
741	09/23/2016	451	7.44	426	1.11	1.06	0.90	18%	F	0.20
742	10/28/2016	465	6.80	353	1.47	1.32	1.19	11%	G	0.16
743	12/02/2016	562	7.11	388	1.66	1.45	1.35	8%	G	0.13
744	01/06/2017	202	6.77	349	0.38	0.58	0.31	87%	F	0.33
745	02/10/2017	319	7.01	376	0.80	0.85	0.65	31%	F	0.25
746	03/17/2017	1,025	7.45	427	3.00	2.40	2.43	-1%	G	-0.04
747	04/21/2017	1,800	8.50	553	4.01	3.25	3.25	0%	G	0.00
748	05/26/2017	790	7.19	397	2.40	1.99	1.95	2%	G	0.05
749	06/30/2017	90	5.35	195	0.59	0.46	0.48	-4%	P	-0.02
750	08/04/2017	222	6.19	285	0.99	0.78	0.80	-3%	P	-0.03

The template automatically calculated error bars on each measurement according to the measurement rating (E,G,F,P, or user-defined) and calculated the optimum shift. Additionally, the template plotted the validation measurements on the rating line fit plot. The validation measurements are shown in green; the error bars indicate the uncertainty of the measurement according to its rating (E-2%, G-5%, F-8%, P-10%, or user-defined).

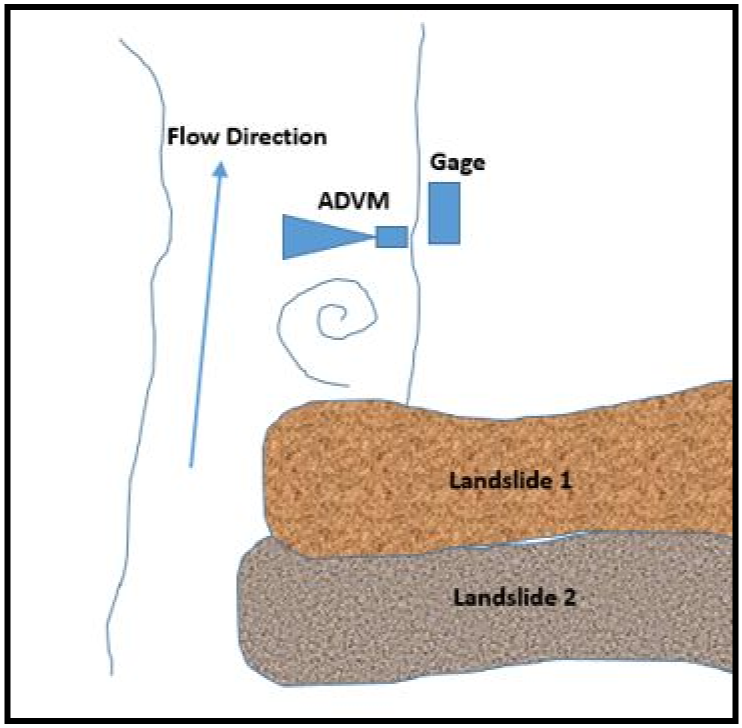
Plot of validation measurements (in green, with their error bars) on the rating:



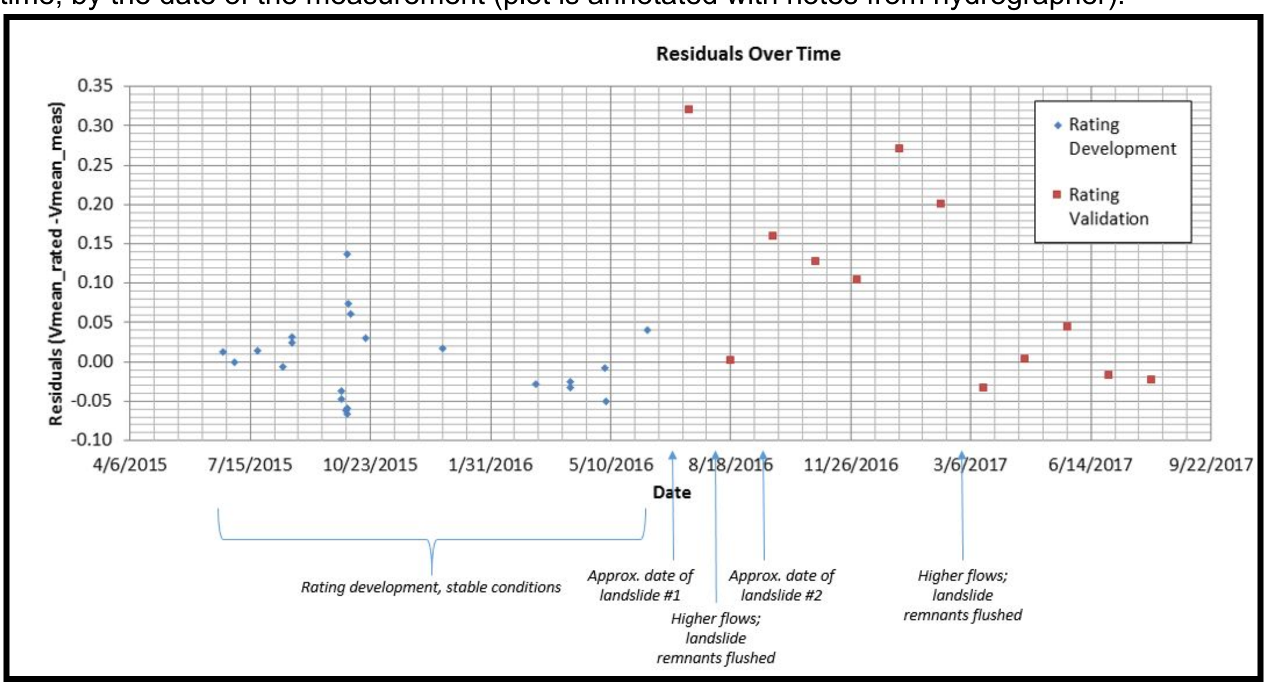
The following table summarizes notes and observations during site visits and measurements during the period of rating validation:

Date	Site Visit or Meas?	Notes
07/15/2016	Meas #739	Today noticed a landslide had occurred on the right bank (bank where ADVM is mounted) about 50’ upstream of gage. May have occurred during rain event on 7/12/16. Lots of sand and gravel in channel at landslide site but none seems to have migrated to the gage site. Right side of channel partially blocked upstream of gage. Flow distribution at gage appears to have changed; highest velocities now hugging left bank; eddy zone now near ADVM. Measured Q much higher than rated Q.
08/19/2016	Meas #740	Higher flows 8/18 – 8/19. Meas plotted on rating. A lot of material from upstream landslide appears to have been flushed down the channel past the gage.
09/22/2016	Site Visit	Another landslide noted on right bank about 80’ upstream of gage. Didn’t have measurement equipment with me. Will return tomorrow. Flows have stayed fairly high since last measurement.
09/23/2016	Meas #741	Due to upstream landslide, flow distribution at gage appears to have changed; highest velocities again hugging left bank. Measured Q much higher than rated Q.
10/28/2016	Meas #742	Ditto on notes from 9/23. I wonder if the pattern will persist and a new rating will be needed?
12/02/2016	Meas #743	Ditto on notes from 9/23.
01/06/2017	Meas #744	Ditto on notes from 9/23.
02/10/2017	Meas #745	Ditto on notes from 9/23.
03/16/2017	Site Visit	High flows at site. ADCP malfunctioned, and we did not have a backup so did not make a measurement. Will return tomorrow. In-channel sediment from upstream landslide appears to be flushed well downstream.
03/17/2017	Meas #746	Made a measurement. Plotted on the original rating.
04/21/2017	Meas #747	Plotted on the original rating.
05/26/2017	Meas #748	Plotted on the original rating.
06/30/2017	Meas #749	Plotted on the original rating.
08/04/2017	Meas #750	Plotted on the original rating.

Site sketch noting approximate locations of gage and landslides:



The departure of each measurement from the rating (the rating residuals) also was plotted over time, by the date of the measurement (plot is annotated with notes from hydrographer):



Justification and Calculation of Shifts

The reported values and error bars for validation measurements fall within the following scenarios:

Validation Measurement Nos.	Scenario No.
740, 746, 747, 748, 749, 750	1
741, 742, 743	4
739, 744, 745	5

Following policy in OSW Memo 2017.03, **check measurements were made for measurement nos. 739, 744, and 745** (but are not shown in this example). All check measurements confirmed the original measurements. Shifts can be justified for measurement nos. 739, 744, and 745 based on their plotting position relative to the uncertainties of the measurements and rating and based on the hydrographer's observations of site conditions. Shifts also can be justified for measurement nos. 741, 742, and 743 because they support a trend in departure from the rating that is further backed up by observations of site conditions. Shifts are not needed or justified for measurements nos. 740 and 746-750 because they validate the rating within their rated accuracy.

At the time of each measurement, a temporary shift was entered because the shift could be justified based on visual observations (upstream landslide altering downstream velocity patterns). The temporary shifts were the "optimum" shifts calculated as:

$$Optimum\ shift\ = \frac{(V\ mean\ -\ rating\ intercept)}{rating\ slope}\ -\ V\ index$$

Where V_{mean} is the measured mean channel velocity

V_{index} is the average synchronized index velocity during the measurement

For example, the optimum shift for measurement no. 741 was calculated as:

$$Optimum\ shift\ = \frac{(1.06 - 0.0005)}{0.811}\ -\ 1.11\ = 0.20 \text{ ft/sec}$$

The applied shifts were reviewed at the end of the record period to determine whether measurements could be grouped or whether a single shift curve could be used to represent the entire period.

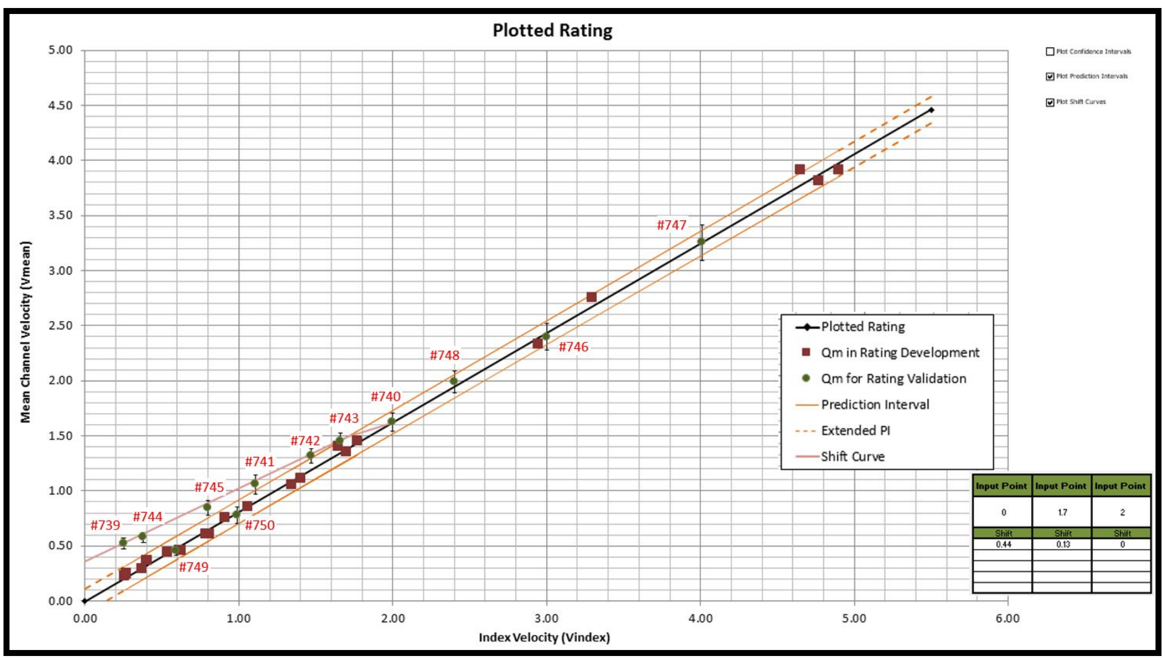
The landslide effectively constricted the channel and caused an eddy in the measurement volume of the ADVM, causing measured velocities to be lower than what they would have been during rating development. As a result, the applied shift is positive. Based on hydrographer notes, the change came into effect sometime between measurement nos. 738 and 739.

The optimum shifts are populated automatically in the Excel template for guiding shifting decisions. Measurement nos. 739, 741, 742, 743, 744, and 745 seems to fit along a similar shift curve, so it appeared that landslides 1 and 2 had a similar effect on the velocity distribution. The shift curve temporarily tied back into the rating once velocities increased due to higher flows and a flushing of sediment from landslide 1 around the time of measurement no. 740. Flows remained high between 8/19/16 and 9/22/16. The effect of landslide 2 was also later flushed by high flows, and conditions returned to normal, sometime between measurement nos. 745 and 746.

Shift input points were entered to develop a best fit line through measurement nos. 739, 741, 742, 743, 744, and 745. A 3-pt shift curve that tied back into the rating at high flows seemed to be appropriate for the period when landslides 1 and 2 occurred:

V_{index} (ft/sec)	Shift to V_{index} (ft/sec)	Comments
0.00	0.44	Based on measurement nos. 739, 741, 742, 744, 745
1.70	0.13	Based on measurement no. 743
2.00	0.00	Based on measurement no. 740

The shift curve (pink) was plotted with the validation measurements on the rating line fit plot:



The applied shift curve is open at the low end, so conditions should be closely watched for opportunities to make additional discharge measurements at Vindex < 0.25 ft/sec and to verify or refine the shift curve. After the application of the shift curve, all validation measurements plotted within 5% of the rating:

Granite Creek

Index-Velocity Rating No. 1 - Validation Measurements

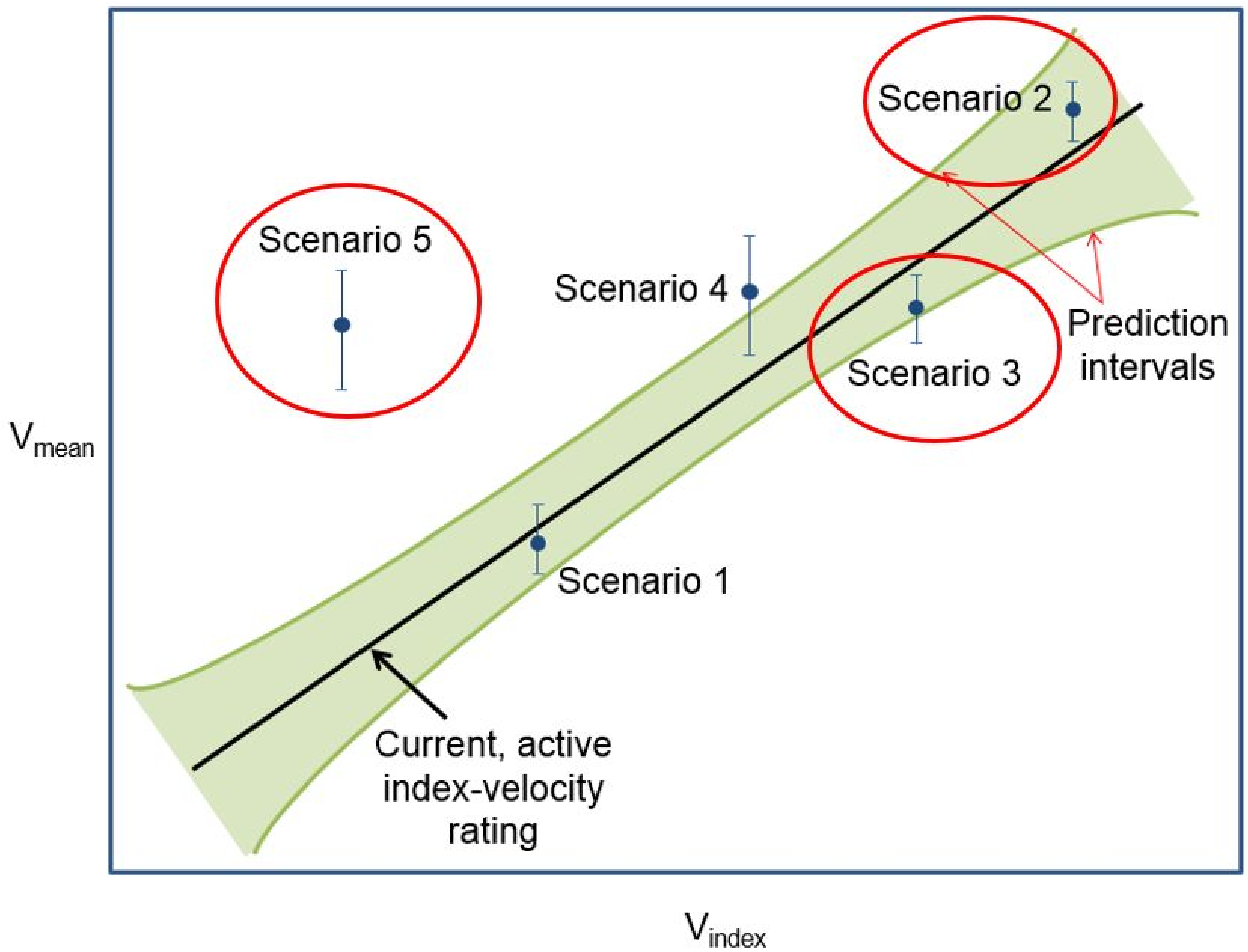
Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)	Vmean_rated (ft/sec)	% Difference	Measurement Rating	Optimum Shift (ft/sec)	Applied Shift (ft/sec) - Based on Shift Curve	% Difference After Shift
739	07/15/2016	203	7.12	389	0.25	0.52	0.20	157%	P	0.39	0.39	0%
740	08/19/2016	652	7.23	402	2.00	1.62	1.62	0%	G	0.00	0.00	0%
741	09/23/2016	451	7.44	426	1.11	1.06	0.90	18%	F	0.20	0.24	-3%
742	10/28/2016	465	6.80	353	1.47	1.32	1.19	11%	G	0.16	0.17	-1%
743	12/02/2016	562	7.11	388	1.66	1.45	1.35	8%	G	0.13	0.14	-1%
744	01/06/2017	202	6.77	349	0.38	0.58	0.31	87%	F	0.33	0.37	-5%
745	02/10/2017	319	7.01	376	0.80	0.85	0.65	31%	F	0.25	0.29	-4%
746	03/17/2017	1,025	7.45	427	3.00	2.40	2.43	-1%	G	-0.04	0.00	-1%
747	04/21/2017	1,800	8.50	553	4.01	3.25	3.25	0%	G	0.00	0.00	0%
748	05/26/2017	790	7.19	397	2.40	1.99	1.95	2%	G	0.05	0.00	2%
749	06/30/2017	90	5.35	195	0.59	0.46	0.48	-4%	P	-0.02	0.00	-4%
750	08/04/2017	222	6.19	285	0.99	0.78	0.80	-3%	P	-0.03	0.00	-3%

Flow and velocity records were used to determine when to start the shift curve between measurements nos. 738 and 739. A change in velocity occurred abruptly, between about 12:00 - 15:00, after high flows on 7/12/16. The shift curve was started on 7/12/16 at 12:00 and was prorated over time until 14:00. The shift curve was then held constant through the beginning of high flows on 3/16/17. The shift curve was then pro-rated to zero at the peak of the hydrograph on 3/16/17, assuming that all sediment had been flushed out. The rating was then applied with no shifts from the peak through measurement nos. 746-750.

Attachment C. Shifting Example #3: D&R Canal

Overview

Flow at this site is bidirectional, caused by diversion gate operation changes. This example illustrates parallel, positive, single point shifts to rating no. 8 based on validation measurements made during a limited range of flows and supported by field and raw data observations. Examples of shift scenarios 2, 3, and 5 (fig. 1, extracted from OSW Memo 2017.03 and shown below) are described.



Index-Velocity Rating

Index-velocity rating no. 8 was developed on 5/1/2016 based on 18 measurements made between 7/31/13 and 4/29/16, nos. 329-349 omitting nos. 335, 338, and 346 because of noted problems with the ADVM during these measurements. The rating was a two-part compound linear regression with a breakpoint around V_{index}=0.08 ft/sec. Due to operation of the diversion gates, velocities tend to occur within three general regimes: negative velocities around -0.50 to -0.70 ft/sec, velocities +/- 0.10 ft/sec and positive velocities around 0.30 to 0.50 ft/sec. Rating no. 8 was developed to preliminarily represent these conditions after a change was made to the ADVM's measurement volume. The rating will be further developed after more measurements are made, particularly to better define the lower segment of the rating. The measurements made when V_{index} was +/- 0.10 ft/sec were used to develop both segments of the rating. The upper rating segment had an R^2 = 0.94 and standard error = 0.034, and the lower rating segment had an R^2 = 0.98 and standard error = 0.054.

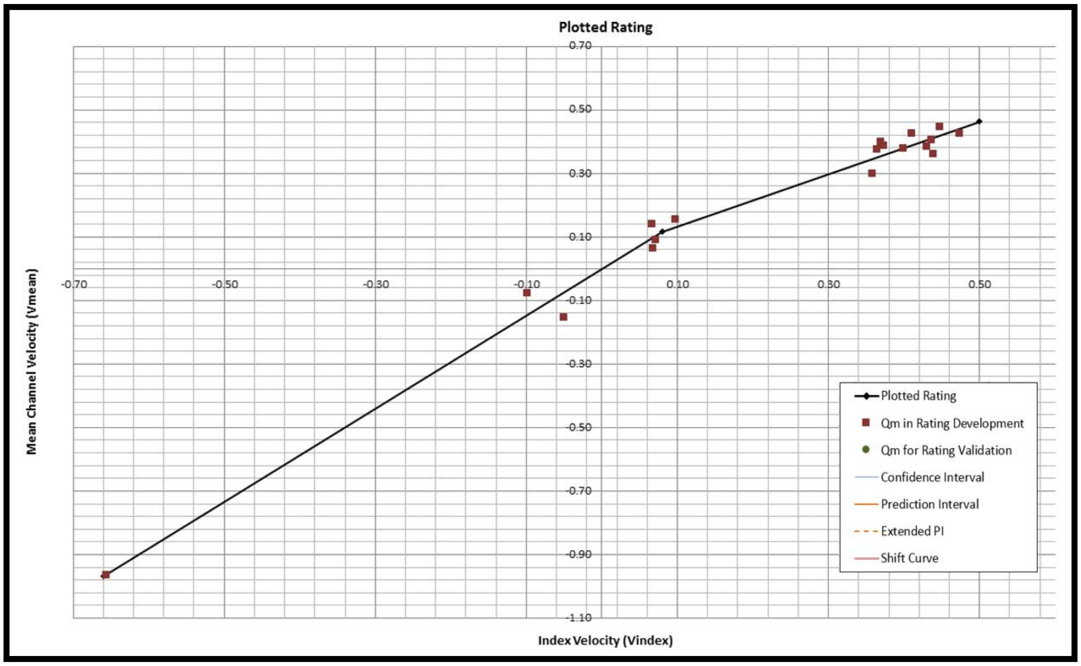
Table of measurements used to develop rating no. 8:

D&R Canal

Index-Velocity Rating No. 8

Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)	Upper/Lower Rating Segment?
329	07/31/2013	108	54.57	360	0.36	0.30	Upper
330	11/14/2013	146	54.64	366	0.37	0.40	Upper
331	11/27/2013	35.7	55.00	395	0.07	0.09	Both
332	11/27/2013	25.2	54.99	394	0.07	0.06	Both
333	11/27/2013	55.8	54.99	394	0.07	0.14	Both
334	11/27/2013	61.2	54.98	393	0.10	0.16	Both
336	03/30/2014	-68.3	55.63	448	-0.05	-0.15	Lower
337	05/01/2014	-587	57.43	608	-0.66	-0.97	Lower
339	08/19/2014	130	53.90	306	0.47	0.42	Upper
340	09/23/2014	153	54.37	344	0.45	0.44	Upper
341	11/25/2014	145	54.78	377	0.43	0.38	Upper
342	04/27/2015	150	55.01	396	0.40	0.38	Upper
343	06/05/2015	150	54.49	353	0.41	0.42	Upper
344	07/22/2015	130	54.09	321	0.44	0.40	Upper
345	08/24/2015	119	53.91	307	0.37	0.39	Upper
347	12/04/2015	154	55.18	410	0.36	0.38	Upper
348	02/25/2016	-35.7	55.72	456	-0.10	-0.08	Lower
349	04/29/2016	139	54.89	386	0.44	0.36	Upper

Measurements and rating line fit plot:



Uncertainty of the Rating

The uncertainty of rating no. 1 was assessed by calculating 95% prediction intervals. Tables shown below are from Excel templates that calculate prediction intervals and guide decisions on shifting.

Table showing rating coefficients and automatically-calculated statistics for the calculation of prediction intervals:

Index Velocity Rating No: 8.0

Select Rating Type From List: Compound Linear

Show Simple Linear Statistics | Show Compound Linear Statistics | Show Multi Variable Statistics | Clear Current Index Velocity Table | Hide Compound Linear Statistics

Note: Important! Must select Rating Type and enter regression coefficients below to properly compute Rated Vmean in "ADVM Qm Summary" tab!

Enter regression coefficients below or link directly to the coefficients in your regression statistics output:

Simple Linear	
Intercept	
Slope	
Full Equation:	*Vmean = + (* Vindex)*

Compound Linear	
Line #1 (Vx <= breakpoint 1)	
Intercept	-0.001
Slope	1.467
Full Equation:	*Vmean = -0.0008 + (1.467 * Vindex)*
Breakpoint 1 at Vx =	0.080
Computed Vm at Vx =	0.117
Line #2 (breakpoint 1 < Vx <= breakpoint 2)	
Intercept	0.054
Slope	0.819
Full Equation:	*Vmean = 0.0537 + (0.819 * Vindex)*
Breakpoint 2 at Vx =	
Computed Vm at Vx =	#VALUE!
Line #3 (Vx > breakpoint 2)	
Intercept	
Slope	
Full Equation:	*Vmean = + (* Vindex)*

Multiple Variable Linear

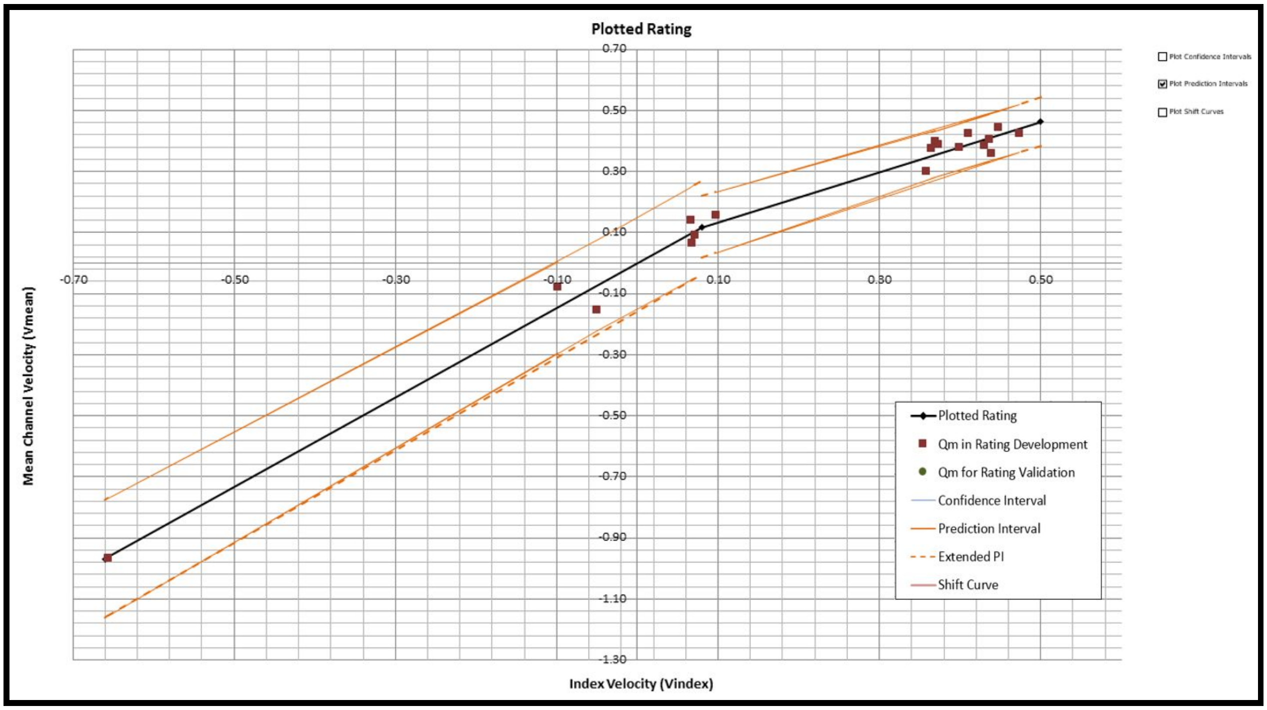
Index Velocity (Output for ADAPS)	Mean Velocity (Output for ADAPS)
-0.66	-0.969
0.08	0.117
0.50	0.463

Compound Linear (Lower)	
Intercept	-0.001
Slope (Vi)	1.467
Standard Error	0.054
No. of Observations (Qms)	7
Degrees Freedom	5
Probabiliy (95%)	0.05
T Statistic	2.571
Max Vi for Regression	0.08
(All Vi Used Regression) Mean	-0.10
SS Regression	0.924
SS Residuals	0.014
SSxx	0.40

Must load measurement in next tab to complete

Compound Linear (Middle)	
Intercept	0.054
Slope (Vi)	0.819
Standard Error	0.034
No. of Observations (Qms)	15
Degrees Freedom	13
Probabiliy (95%)	0.05
T Statistic	2.160
Min Vi for Regression	0.08
Max Vi for Regression	No Third Segment
(All Vi Used Regression) Mean	0.38
SS Regression	0.230
SS Residuals	0.015
SSxx	0.10

Plot showing prediction intervals (orange lines) around rating no. 8:



Rating Validation Measurements

Discharge measurement nos. 350-352 were made to validate rating no. 8 after development. All validation measurements were input into Excel templates for guiding shifting decisions.

Table of validation measurements:

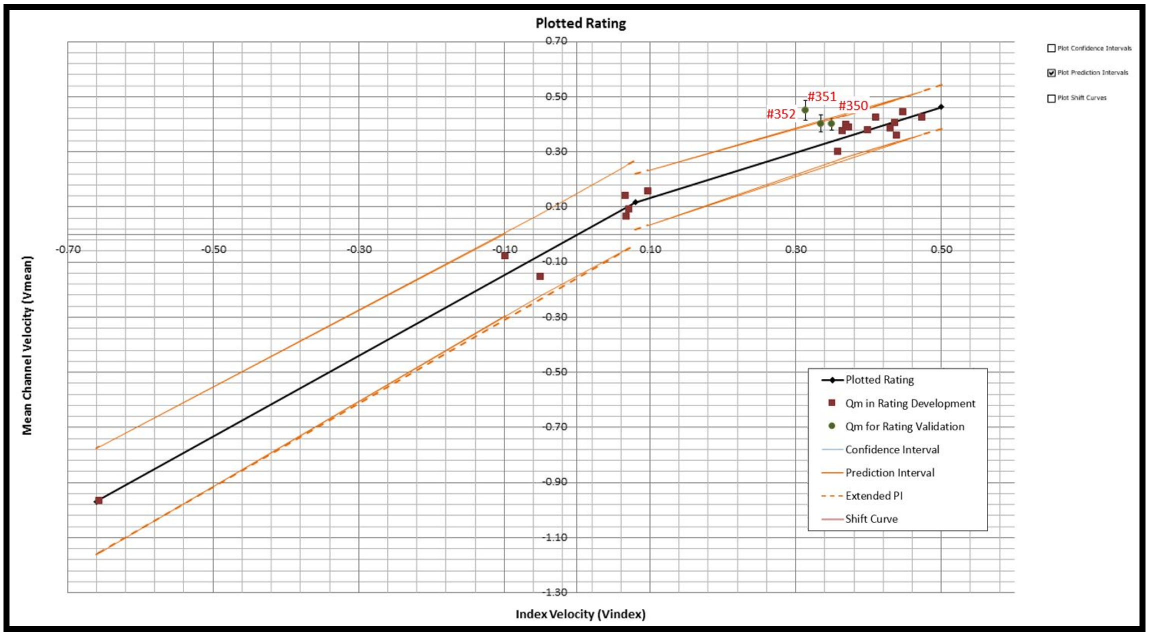
D&R Canal

Index-Velocity Rating No. 8 - Validation Measurements

Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)	Vmean_rated (ft/sec)	% Difference	Measurement Rating	Optimum Shift (ft/sec)
350	05/29/2016	148	54.69	370	0.35	0.40	0.34	18%	G	0.07
351	06/09/2016	141	54.45	350	0.33	0.40	0.33	23%	F	0.09
352	06/24/2016	130	53.67	288	0.31	0.45	0.31	45%	F	0.17

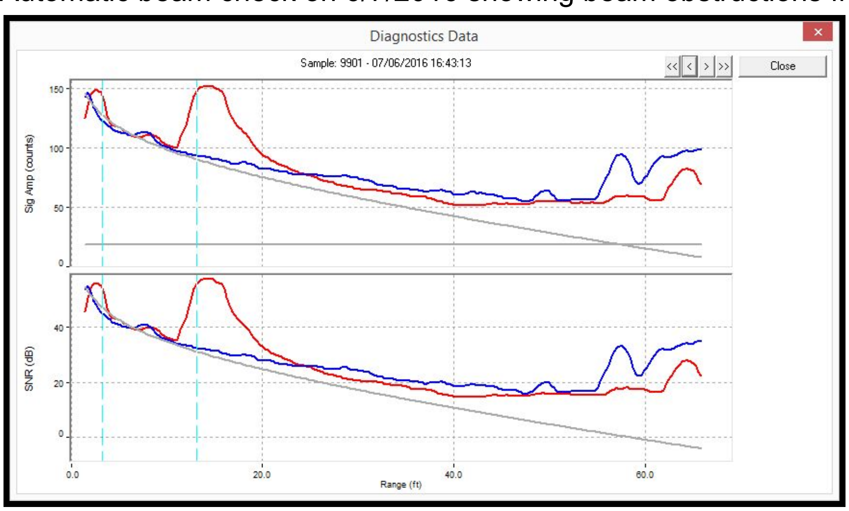
The template automatically calculated error bars on each measurement according to the measurement rating (E,G,F,P, or user-defined) and calculated the optimum shift. Additionally, the template plotted the validation measurements on the rating line fit plot. The validation measurements are shown in green; the error bars indicate the uncertainty of the measurement according to its rating (E-2%, G-5%, F-8%, P-10%, or user-defined).

Plot of validation measurements (in green, with their error bars) on the rating:

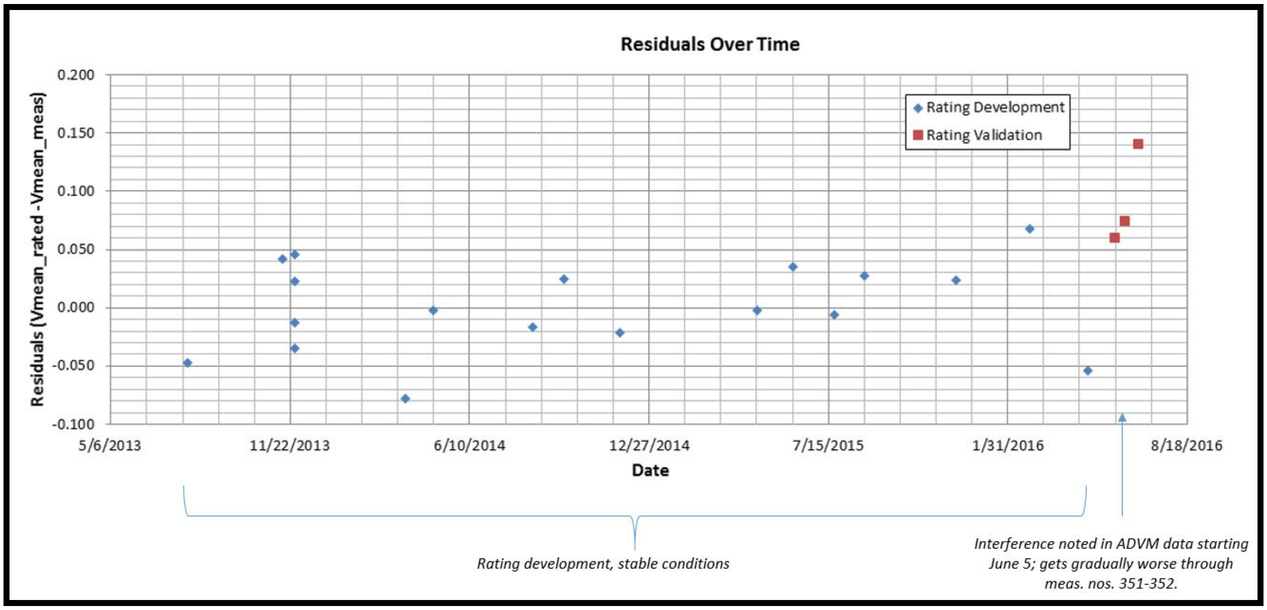


The raw ADVM data (particularly beam amplitudes, velocities, temperature, and automatic beam checks) for measurement nos. 350-352 were reviewed for possible problems. The data showed interference or obstructions in one or both beams that started between measurement nos. 350 and 351 and gradually became worse over time (see figure below). Site inspections noted substantial vegetation growth in the channel during the time of the validation measurements, to a degree not present during rating development. A brief investigation brought to light a recent change in land use in a large part of the basin, which likely caused an increase in nutrient delivery to the canal and promoted vegetation growth. An attempt was made to clear vegetation from the channel, but the hydrographer could not access all of the vegetation within the ADVM’s measurement volume.

Automatic beam check on 6/7/2016 showing beam obstructions from vegetation:



The departure of each measurement from the rating (the rating residuals) also was plotted over time, by the date of the measurement (plot is annotated with notes from hydrographer):



<u>Justification and Calculation of Shifts</u>

The reported values and error bars for validation measurements fall within the following scenarios:

Validation Measurement No.	Scenario No.
350	2
351	3
352	5

A shift is not justified for measurement no. 350 because its error bars lie completely within the rating's prediction intervals. Following policy in OSW Memo 2017.03, **a check measurement was made for measurement no. 352** (but is not shown in this example). The check measurement confirmed the original measurement. A shift can be justified for measurement no. 352 based on its plotting position relative to the uncertainties of the measurements and rating and based on the hydrographer's observations of site conditions. A shift also can be justified for measurement no. 351 because it supports a trend in departure from the rating that is further backed up by problems noted in the raw ADVM data and observations of site conditions.

At the time of measurement nos. 351 and 352, a temporary shift was entered because the shift could be justified based on visual observations (vegetation growth and beam obstructions). The temporary shifts were the "optimum" shifts calculated as:

$$Optimum\ shift\ = \frac{(V\,mean\ -\ rating\ intercept)}{rating\ slope}\ -\ V\,index$$

Where V_{mean} is the measured mean channel velocity
V_{index} is the average synchronized index velocity during the measurement

For example, the optimum shift for measurement no. 352 (upper rating segment) was calculated as:

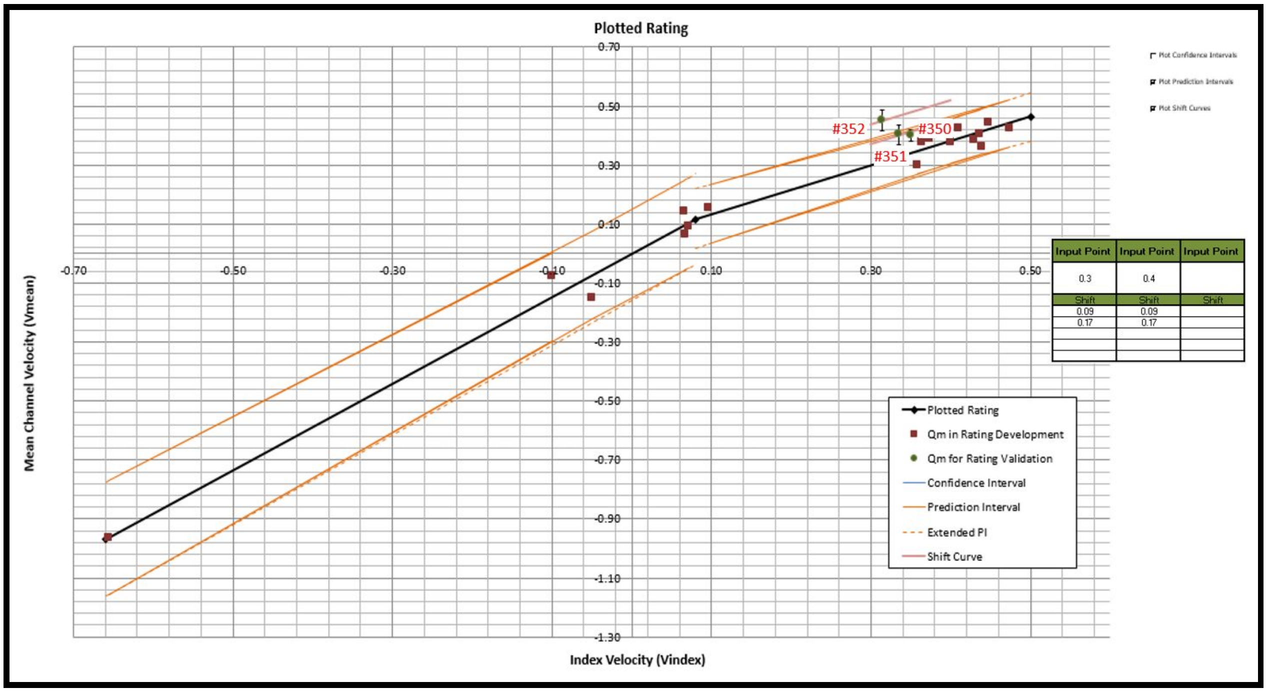
$$Optimum\ shift\ = \frac{(0.45 - 0.054)}{0.819}\ -\ 0.31$$ = 0.17 ft/sec

The vegetation is anchored in the canal bed (not moving at the speed of the water), so the beam obstructions result in velocity measurements that are biased low compared to what they would have been during rating development. As a result, the applied shift is positive. Based on hydrographer notes, the change came into effect sometime between measurement nos. 350 and 351.

Based on the review of the ADVM's automatic beam check data, the vegetation effect on the ADVM beams appears to start on or around June 5, 2016, then gradually gets slightly worse through June 10, and remains fairly constant through June 15. The effect gradually gets even worse through June 20, then remains fairly constant through June 24 and the end of the reviewed period, July 5. A single shift curve for all measurements is not appropriate because of the observed variable effect on beam amplitudes. In this case, parallel, single-point shift curves fit to each validation measurement are acceptable for a temporary period and within a limited range of conditions:

Shift Curve No.	V_{index} (ft/sec)	Shift to V_{index} (ft/sec)	Comments
1	0.30 to 0.40	0.09	Based on measurement no. 351
2	0.30 to 0.40	0.17	Based on measurement no. 352

The shift curves (pink) were plotted with the validation measurements on the rating line fit plot:



After the application of shifts, measurement nos. 351 and 352 plotted within 1% of the rating:

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Measurement No.	Date	Flow, Q (cfs)	Stage (ft)	Rated Area (ft^2)	Vindex (ft/sec)	Vmean_meas (Q/Rated Area) (ft/sec)	Vmean_rated (ft/sec)	% Difference	Measurement Rating	Optimum Shift (ft/sec)	Applied Shift (ft/sec)	% Difference After Shift
350	05/29/2016	148	54.69	370	0.35	0.40	0.34	18%	G	0.07	0.00	18%
351	06/09/2016	141	54.45	350	0.33	0.40	0.33	23%	F	0.09	0.09	0.3%
352	06/24/2016	130	53.67	288	0.31	0.45	0.31	45%	F	0.17	0.17	0.3%

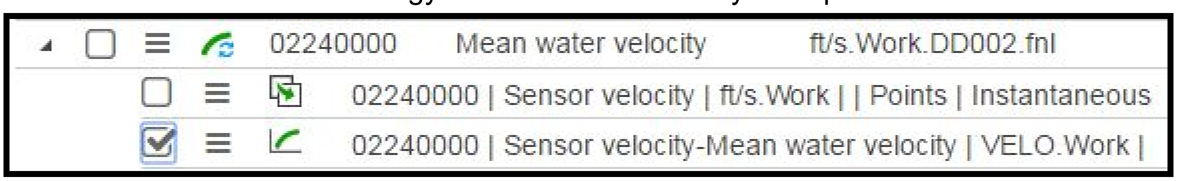
The raw ADVM data and automatic beam checks were used to determine when to start the shift and transition among shift curves during the period of validation measurements. Shift curve no. 1 (shift = 0.09 ft/sec) was prorated from zero just before the interference was noted on June 5 then put into full effect at the time of measurement no. 351 on June 9. Shift curve no. 1 was then held constant until June 15. Shift curve no. 1 was prorated to shift curve no. 2 (shift = 0.17 ft/sec) from June 15 to June 20, when conditions were even worse. Shift curve no. 2 was then held constant through measurement no. 352 on June 24 and the end of the reviewed period, July 5. It should be noted that these shift curves are applicable within a narrow range in velocities represented by the validation measurements. Measurements should be made frequently to define the continued effect of the vegetation and should be made immediately if velocities occur outside the conditions of the shift curve. The site may need to be moved if the vegetation persists and continues to obstruct the ADVM beams.

Attachment D. Tip Sheet for Entering Velocity Shifts in the USGS Aquarius Database

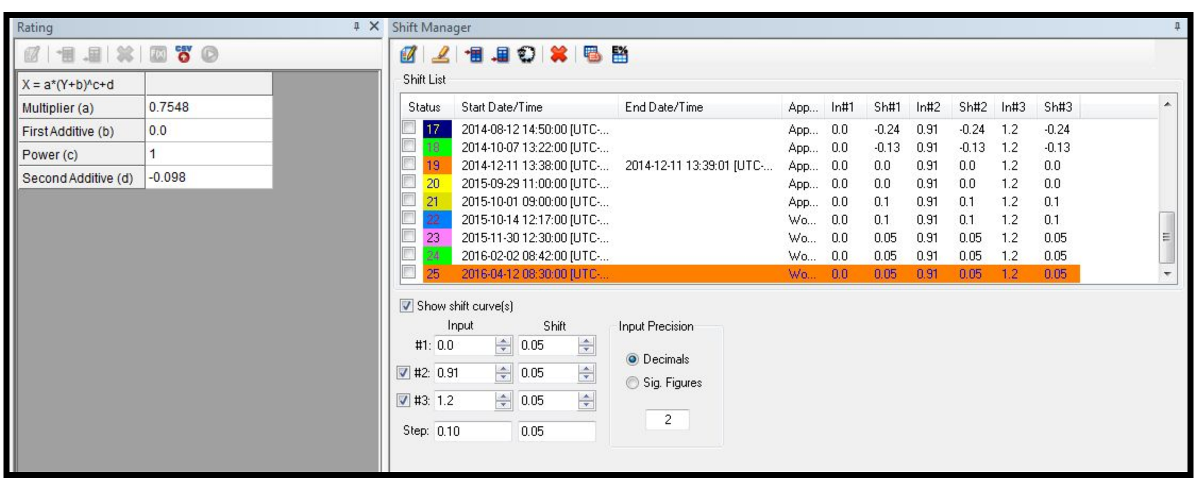
DRAFT *(dev. by Liz Hittle)*
V. 1/18/17

Entering Shifts for Simple Linear Regression (SLR) Ratings

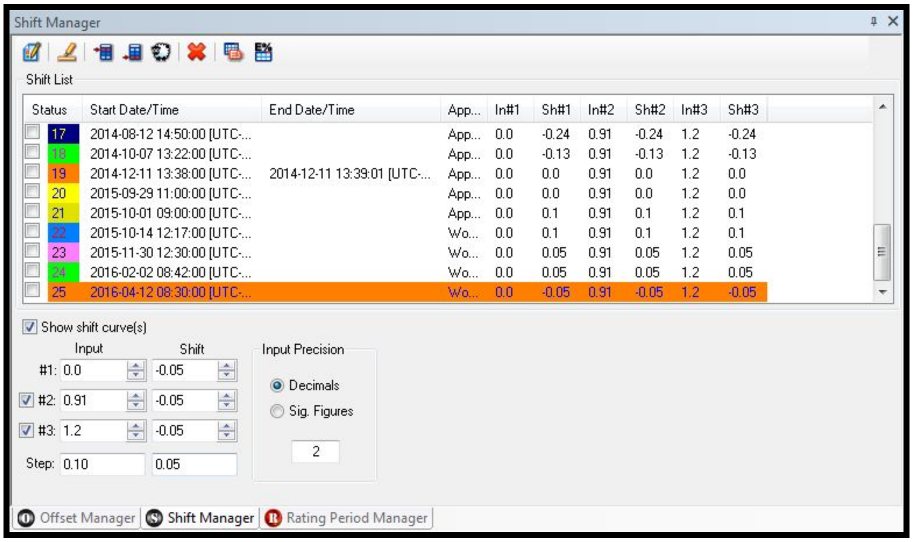
- Rating is implemented within the Rating Development Toolbox (RDT)
  - Follow same procedure as shifting for stage-discharge ratings
    - The difference between shifting stage-discharge and index-velocity ratings in Aquarius is that there is no imbedded tool (no measurements shown on rating) to guide the shift determination. The shift curves must be defined outside Aquarius, preferably using the [Excel-based tool](#) described in OSW Memo 2017.03.
  - Procedure:
    - Open the sensor velocity - mean water velocity rating located under mean water velocity (note that "mean channel velocity" in index velocity terminology is "mean water velocity" in Aquarius.



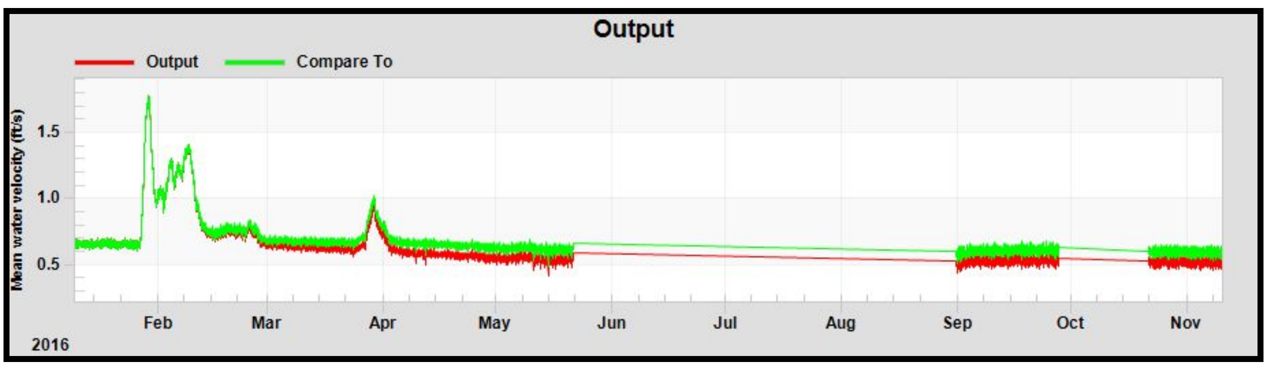
    - In the Shift Manager, enter shifts calculated in outside program in the shift curve table:
      - Positive shift curve:



- Negative shift curve:



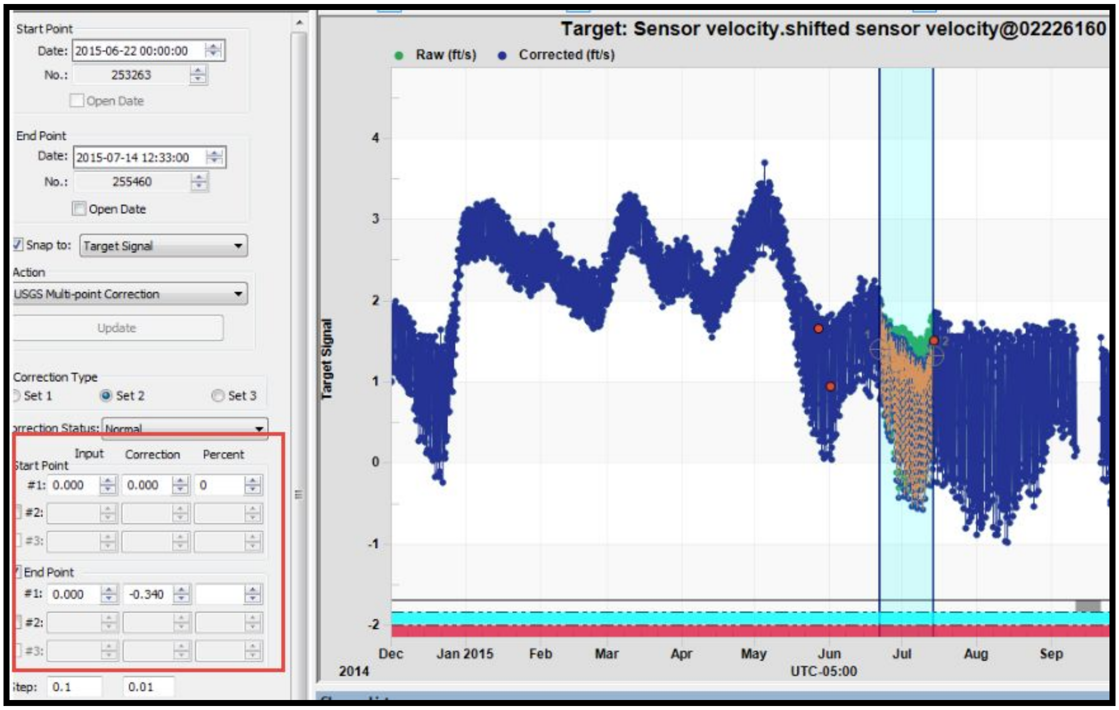
  - There will not be measurements shown in the field visit table, but the rating equation will be available to view.
  - The output view shows the effect of the shift on mean water velocity
    - Green is what is computed in the database “at the time”.
    - Red is data computed by what is in RDT, including any changes that have been made in that session but not saved.



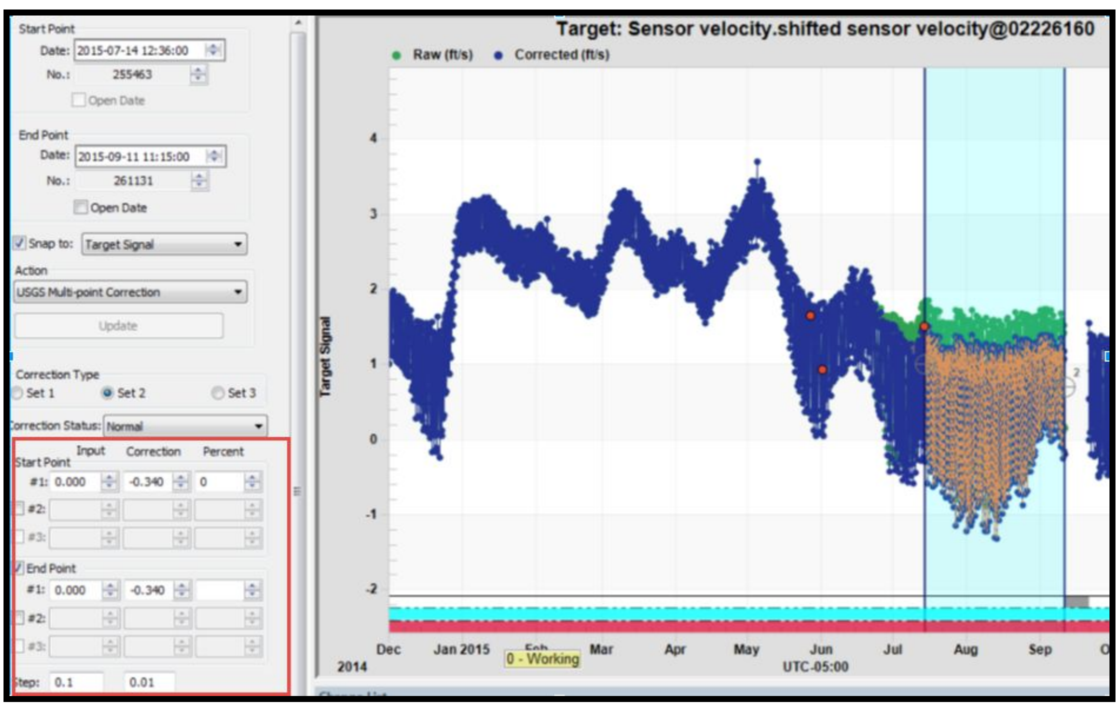
Entering Shifts for Multiple Linear Regression (MLR) Ratings

- Whether an MLR rating is implemented as an equation in the mean water velocity time series, or as a coefficient rating with RDT, **shifts must be applied as a correction to sensor velocity**
- Procedure:
  - The corrections will be applied to sensor velocity. *See NOTE at bottom if sensor velocity is displayed on NWISWeb.

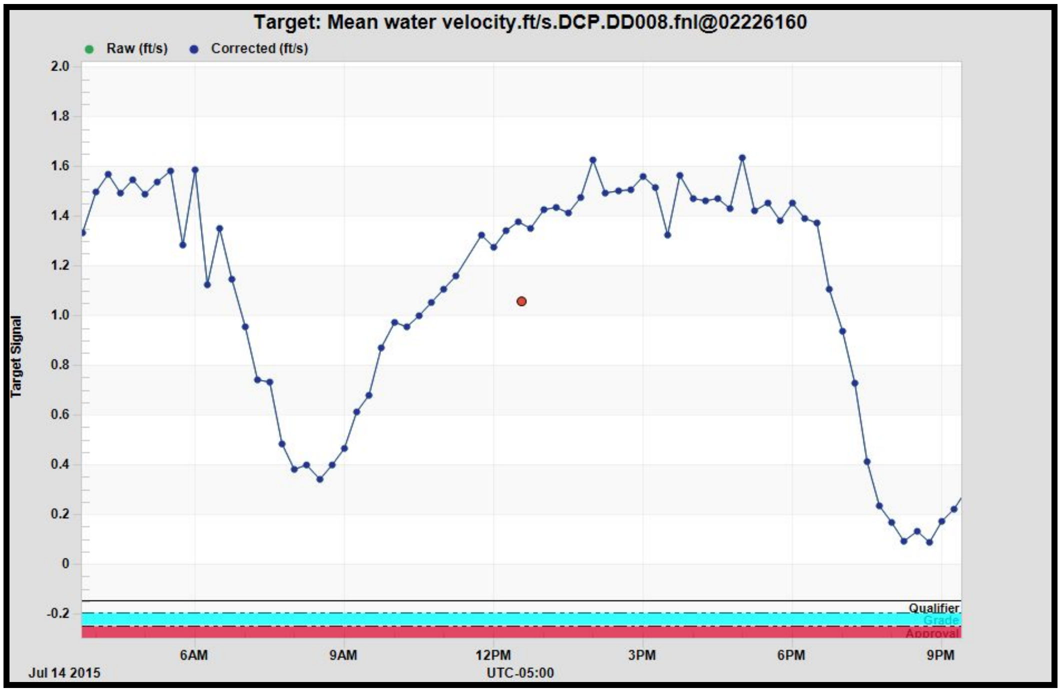
- Open sensor velocity in Data Correction Toolbox
- Again, the shift magnitudes must be defined outside Aquarius, preferably using the Excel-based tool described in OSW Memo 2017.03. Input the corrections as USGS multi-point corrections.
- Example:
  - Prorated shift from 0 to -0.34



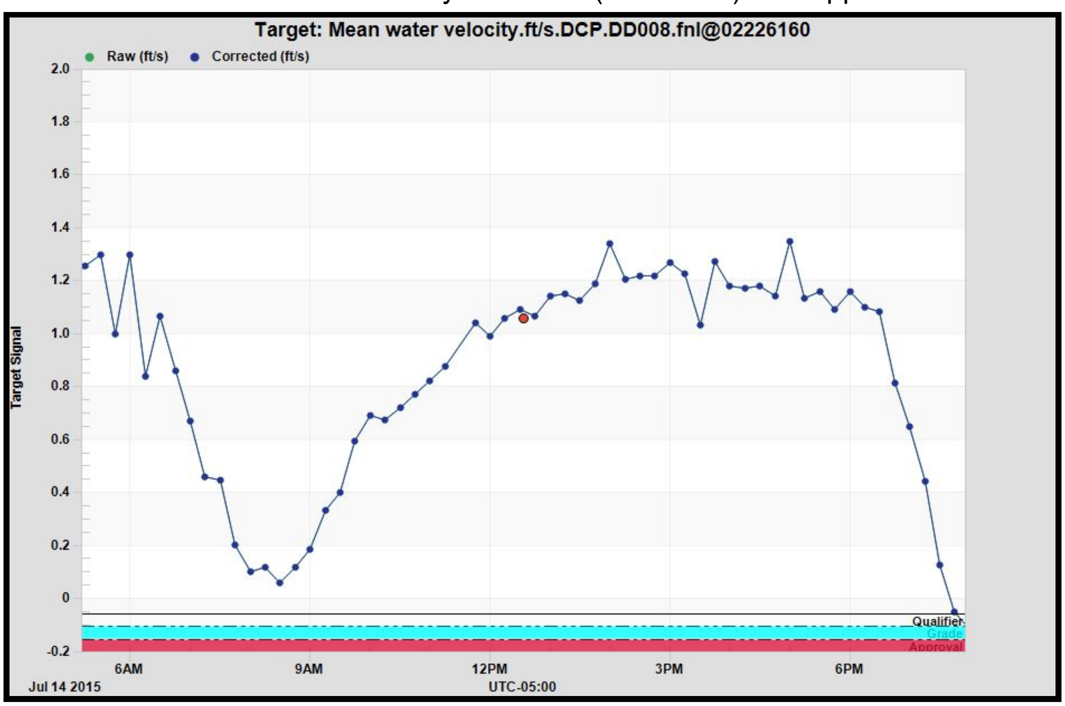
  - Parallel shift of -0.34



- Mean water velocity before shift (correction) was applied

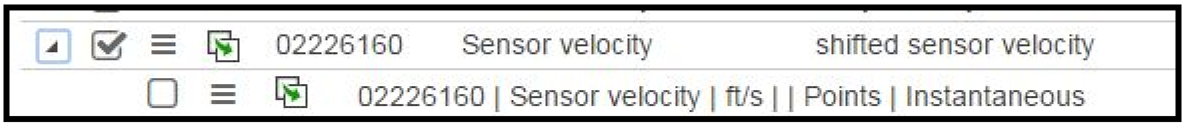


- Mean water velocity after shift (correction) was applied



***NOTE:** USGS prohibits changing a correct input parameter (for example, stage) just to get the correct output parameter (for example, discharge, in the case of a stage-discharge relationship) as stated in OSW Memo 2005.07. For MLR ratings, the application of a data correction to represent a shift would result in a change to the index-velocity data in Aquarius. As a result, raw index-velocity data at streamgages with shifts applied to MLR ratings must not be displayed to the public on NWISWeb unless a separate “pass-through” velocity parameter is created in AQUARIUS to hold the shifted (corrected) index-velocity data, which is then used to calculate discharge. In this case, only the raw “uncorrected” index-velocity data, but not the “pass through” velocity data, can be displayed on NWISWeb.

Example:



“Shifted sensor velocity” sensor velocity was created as a pass through from “ft/s” sensor velocity. “Shifted sensor velocity” sensor velocity is used in the vel-Q computations, “ft/s” sensor velocity is what would be displayed on NWISWeb.