In Reply Refer To: February 23, 2017
Mail Stop 415

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 ($V_{\text{mean, meas}}$) by dividing the measured discharge by the rated area from the stage-area rating at the standard cross section. Estimate the uncertainty of $V_{\text{mean, meas}}$ using the quality rating of the discharge measurement. This means that the error bars for $V_{\text{mean, meas}}$ 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 $V_{\text{mean, meas}}$ to the computed (also called rated) mean channel velocity ($V_{\text{mean, comp}}$).
4. If the $V_{\text{mean, comp}}$ is within the rated uncertainty of $V_{\text{mean, meas}}$ (scenario 1, fig. 1), shift analysis is complete and no further action is required. If the $V_{\text{mean, comp}}$ is outside the rated accuracy of $V_{\text{mean, meas}}$, 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 $V_{\text{mean, meas}}$ on the rating to determine under which scenario the measurement lies (fig. 1):
   a. If the error bars on $V_{\text{mean, meas}}$ 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 $V_{\text{mean, meas}}$ 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 $V_{\text{mean, meas}}$ 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 $V_{\text{mean}}$ 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:

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

Where $V_{\text{mean mea}}$ is the measured mean channel velocity

$V_{\text{index}}$ is the average synchronized index velocity during the measurement

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

$$
\text{Optimum shift} = \frac{(V_{\text{mean mea}} - \text{rating intercept})}{\text{rating slope1} + (\text{rating slope2} \times \text{stage})} - V_{\text{index}} 
$$

Where:

rating slope1 is the regression coefficient on the $V_{\text{index}}$ 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](https://www.usgs.gov/pubs-misc/2005/2005-07). 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).

Harry Jenter
Deputy Chief, Office of Surface Water

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


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):

\[
\hat{y} - t s \sqrt{\frac{1}{n} + \frac{(x_0 - \bar{x})^2}{SS_x}}, \quad \hat{y} + t s \sqrt{\frac{1}{n} + \frac{(x_0 - \bar{x})^2}{SS_x}}
\]

(1)

Where:

- \( t \) is the two-tailed \( t \) statistic for a specified \( \alpha \) in the prediction interval calculation \((1-\alpha/2) \times 100\%\) (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:

\[
\hat{y} - ts, \quad \hat{y} + ts
\]

(2)

REFERENCE
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:

<table>
<thead>
<tr>
<th>Measurement No.</th>
<th>Date</th>
<th>Flow, Q (cfs)</th>
<th>Stage (ft)</th>
<th>Rated Area (ft$^2$)</th>
<th>Vindex (ft/sec)</th>
<th>Vmean_meas (Q/Rated Area) (ft/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/2/2013</td>
<td>14,000</td>
<td>43.53</td>
<td>13,625</td>
<td>1.07</td>
<td>1.03</td>
</tr>
<tr>
<td>2</td>
<td>11/15/2013</td>
<td>23,500</td>
<td>43.89</td>
<td>13,814</td>
<td>1.87</td>
<td>1.70</td>
</tr>
<tr>
<td>3</td>
<td>12/6/2013</td>
<td>11,700</td>
<td>54.44</td>
<td>19,574</td>
<td>0.69</td>
<td>0.60</td>
</tr>
<tr>
<td>4</td>
<td>12/15/2013</td>
<td>2,040</td>
<td>62.69</td>
<td>18,597</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>5</td>
<td>1/6/2014</td>
<td>1,150</td>
<td>46.07</td>
<td>14,436</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>6</td>
<td>1/29/2014</td>
<td>30,800</td>
<td>43.92</td>
<td>13,829</td>
<td>2.39</td>
<td>2.23</td>
</tr>
<tr>
<td>7</td>
<td>2/10/2014</td>
<td>38,700</td>
<td>47.72</td>
<td>15,853</td>
<td>2.74</td>
<td>2.44</td>
</tr>
<tr>
<td>8</td>
<td>3/2/2014</td>
<td>25,400</td>
<td>44.45</td>
<td>14,108</td>
<td>2.10</td>
<td>1.80</td>
</tr>
<tr>
<td>9</td>
<td>3/13/2014</td>
<td>6,320</td>
<td>42.14</td>
<td>12,907</td>
<td>0.50</td>
<td>0.49</td>
</tr>
<tr>
<td>10</td>
<td>3/16/2014</td>
<td>18,100</td>
<td>45.32</td>
<td>14,569</td>
<td>1.42</td>
<td>1.24</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Station Name:</th>
<th>Bogus Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station Number:</td>
<td>11111111</td>
</tr>
<tr>
<td>Index Velocity Rating No:</td>
<td>1.0</td>
</tr>
<tr>
<td>Select Rating Type From List:</td>
<td>Simple Linear</td>
</tr>
</tbody>
</table>

Simple Linear
- Intercept: 0.0044
- Slope: 0.901
- Full Equation: \( \text{Index} = -0.0044 + 0.901 \times \text{Index} \)

Compound Linear
- Line #1 (Vx <= breakpoint 1)
  - Intercept: 
  - Slope: 
  - Full Equation: \( \text{Index} = \) 
- Breakpoint 1 at Vx = 
- Computed Vm at Vx = 

![Plot showing prediction intervals (orange lines) around rating no. 1:](image-url)
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:

<table>
<thead>
<tr>
<th>Measurement No.</th>
<th>Date</th>
<th>Flow, Q (cfs)</th>
<th>Stage (ft)</th>
<th>Rated Area (ft²)</th>
<th>V_mean_meas (Q/Rated Area) (ft/sec)</th>
<th>V_mean_rated (ft/sec)</th>
<th>% Difference</th>
<th>Measurement Rating</th>
<th>Optimum Shift (ft/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>04/28/2014</td>
<td>6.540</td>
<td>43.53</td>
<td>13,625</td>
<td>1.00</td>
<td>0.48</td>
<td>0.90</td>
<td>P</td>
<td>-46%</td>
</tr>
<tr>
<td>12</td>
<td>05/11/2014</td>
<td>15,600</td>
<td>43.69</td>
<td>13,814</td>
<td>1.60</td>
<td>1.13</td>
<td>1.44</td>
<td>F</td>
<td>-21%</td>
</tr>
<tr>
<td>13</td>
<td>05/26/2014</td>
<td>24,800</td>
<td>54.44</td>
<td>19,574</td>
<td>1.72</td>
<td>1.27</td>
<td>1.55</td>
<td>G</td>
<td>-18%</td>
</tr>
<tr>
<td>14</td>
<td>08/05/2014</td>
<td>23,800</td>
<td>52.69</td>
<td>18,597</td>
<td>1.75</td>
<td>1.28</td>
<td>1.57</td>
<td>F</td>
<td>-19%</td>
</tr>
<tr>
<td>15</td>
<td>08/16/2014</td>
<td>31,200</td>
<td>45.07</td>
<td>14,426</td>
<td>2.41</td>
<td>2.16</td>
<td>2.17</td>
<td>F</td>
<td>0%</td>
</tr>
<tr>
<td>16</td>
<td>07/07/2014</td>
<td>11,500</td>
<td>43.92</td>
<td>13,629</td>
<td>1.31</td>
<td>0.83</td>
<td>1.18</td>
<td>F</td>
<td>-29%</td>
</tr>
<tr>
<td>17</td>
<td>09/30/2014</td>
<td>8,410</td>
<td>47.72</td>
<td>15,863</td>
<td>0.62</td>
<td>0.53</td>
<td>0.55</td>
<td>P</td>
<td>-4%</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Validation Measurement Nos.</th>
<th>Scenario No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15, 17</td>
<td>1</td>
</tr>
<tr>
<td>11, 12, 13, 14, 16</td>
<td>5</td>
</tr>
</tbody>
</table>

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:

\[
\text{Optimum shift} = \frac{(V_{\text{mean}} - \text{rating intercept})}{\text{rating slope}} - V_{\text{index}}
\]

Where \(V_{\text{mean}}\) is the measured mean channel velocity

\(V_{\text{index}}\) is the average synchronized index velocity during the measurement

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

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

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 ($V_{\text{index}} < 1.0$ 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 $V_{\text{index}}=0.0$ 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:

<table>
<thead>
<tr>
<th>$V_{\text{index}}$ (ft/sec)</th>
<th>Shift to $V_{\text{index}}$ (ft/sec)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>Tied back into rating at (0,0) to avoid large, open-ended shift at low velocities</td>
</tr>
<tr>
<td>1.00</td>
<td>-0.46</td>
<td>Based on measurement no. 11</td>
</tr>
<tr>
<td>2.41</td>
<td>0.00</td>
<td>Based on measurement no. 15</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>04/29/2014</td>
<td>5,540</td>
<td>41.33</td>
<td>13,625</td>
<td>1.00</td>
<td>0.48</td>
<td>0.90</td>
<td>-46%</td>
<td>P</td>
<td>0.66</td>
<td>-0.46</td>
<td>0%</td>
</tr>
<tr>
<td>12</td>
<td>05/01/2014</td>
<td>10,600</td>
<td>41.88</td>
<td>13,614</td>
<td>1.60</td>
<td>1.13</td>
<td>1.44</td>
<td>-21%</td>
<td>F</td>
<td>-0.34</td>
<td>-0.29</td>
<td>-4%</td>
</tr>
<tr>
<td>13</td>
<td>05/06/2014</td>
<td>24,600</td>
<td>48.44</td>
<td>19,574</td>
<td>1.72</td>
<td>1.27</td>
<td>1.35</td>
<td>-18%</td>
<td>G</td>
<td>-0.31</td>
<td>-0.25</td>
<td>-4%</td>
</tr>
<tr>
<td>14</td>
<td>06/02/2014</td>
<td>23,800</td>
<td>52.89</td>
<td>18,597</td>
<td>1.75</td>
<td>1.24</td>
<td>1.57</td>
<td>-19%</td>
<td>F</td>
<td>-0.32</td>
<td>-0.25</td>
<td>-5%</td>
</tr>
<tr>
<td>15</td>
<td>06/06/2014</td>
<td>31,200</td>
<td>57.07</td>
<td>14,456</td>
<td>2.81</td>
<td>2.16</td>
<td>2.17</td>
<td>0%</td>
<td>F</td>
<td>-0.01</td>
<td>0.00</td>
<td>0%</td>
</tr>
<tr>
<td>16</td>
<td>07/05/2014</td>
<td>11,500</td>
<td>43.90</td>
<td>13,829</td>
<td>1.33</td>
<td>0.83</td>
<td>1.38</td>
<td>-29%</td>
<td>F</td>
<td>-0.38</td>
<td>-0.36</td>
<td>-2%</td>
</tr>
<tr>
<td>17</td>
<td>08/30/2014</td>
<td>6,410</td>
<td>47.75</td>
<td>15,063</td>
<td>0.62</td>
<td>0.53</td>
<td>0.55</td>
<td>-4%</td>
<td>P</td>
<td>0.03</td>
<td>0.00</td>
<td>-5%</td>
</tr>
</tbody>
</table>

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 $V_{\text{index}} < 1.0$ 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:

<table>
<thead>
<tr>
<th>Measurement No.</th>
<th>Date</th>
<th>Flow, Q (cfs)</th>
<th>Stage (ft)</th>
<th>Rated Area (ft²)</th>
<th>$V_{index}$ (ft/sec)</th>
<th>$V_{mean meas}$ (Q/Rated Area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>710</td>
<td>06/22/2015</td>
<td>223</td>
<td>6.3</td>
<td>257</td>
<td>0.31</td>
<td>0.75</td>
</tr>
<tr>
<td>717</td>
<td>07/02/2015</td>
<td>88.9</td>
<td>5.4</td>
<td>261</td>
<td>0.54</td>
<td>0.44</td>
</tr>
<tr>
<td>718</td>
<td>07/21/2015</td>
<td>58.6</td>
<td>5.96</td>
<td>260</td>
<td>0.26</td>
<td>0.23</td>
</tr>
<tr>
<td>719</td>
<td>08/11/2015</td>
<td>83.2</td>
<td>6.18</td>
<td>264</td>
<td>0.37</td>
<td>0.29</td>
</tr>
<tr>
<td>720</td>
<td>09/10/2015</td>
<td>73.2</td>
<td>6.25</td>
<td>293</td>
<td>0.27</td>
<td>0.25</td>
</tr>
<tr>
<td>721</td>
<td>09/19/2015</td>
<td>79.0</td>
<td>6.21</td>
<td>290</td>
<td>0.27</td>
<td>0.24</td>
</tr>
<tr>
<td>722</td>
<td>09/28/2015</td>
<td>268</td>
<td>7.56</td>
<td>448</td>
<td>0.01</td>
<td>0.61</td>
</tr>
<tr>
<td>723</td>
<td>09/29/2015</td>
<td>265</td>
<td>7.55</td>
<td>439</td>
<td>0.79</td>
<td>0.69</td>
</tr>
<tr>
<td>724</td>
<td>10/03/2015</td>
<td>509</td>
<td>7.13</td>
<td>390</td>
<td>2.85</td>
<td>2.33</td>
</tr>
<tr>
<td>725</td>
<td>10/04/2015</td>
<td>3083</td>
<td>10.45</td>
<td>809</td>
<td>4.77</td>
<td>3.81</td>
</tr>
<tr>
<td>726</td>
<td>10/04/2015</td>
<td>3124</td>
<td>10.36</td>
<td>799</td>
<td>4.90</td>
<td>3.91</td>
</tr>
<tr>
<td>727</td>
<td>10/04/2015</td>
<td>3135</td>
<td>10.4</td>
<td>802</td>
<td>4.65</td>
<td>3.91</td>
</tr>
<tr>
<td>728</td>
<td>10/06/2015</td>
<td>1434</td>
<td>8.24</td>
<td>521</td>
<td>3.30</td>
<td>2.75</td>
</tr>
<tr>
<td>729</td>
<td>10/17/2015</td>
<td>486</td>
<td>8.81</td>
<td>354</td>
<td>1.65</td>
<td>1.40</td>
</tr>
<tr>
<td>730</td>
<td>10/19/2015</td>
<td>127</td>
<td>6.79</td>
<td>366</td>
<td>0.41</td>
<td>0.36</td>
</tr>
<tr>
<td>731</td>
<td>12/22/2015</td>
<td>543</td>
<td>6.99</td>
<td>374</td>
<td>1.77</td>
<td>1.45</td>
</tr>
<tr>
<td>733</td>
<td>03/09/2016</td>
<td>490</td>
<td>6.90</td>
<td>363</td>
<td>1.70</td>
<td>1.35</td>
</tr>
<tr>
<td>734</td>
<td>04/07/2016</td>
<td>387</td>
<td>6.92</td>
<td>366</td>
<td>1.34</td>
<td>1.56</td>
</tr>
<tr>
<td>735</td>
<td>04/07/2016</td>
<td>398</td>
<td>6.85</td>
<td>367</td>
<td>1.41</td>
<td>1.11</td>
</tr>
<tr>
<td>736</td>
<td>05/06/2016</td>
<td>297</td>
<td>6.66</td>
<td>337</td>
<td>1.06</td>
<td>0.85</td>
</tr>
<tr>
<td>737</td>
<td>05/06/2016</td>
<td>154</td>
<td>6.64</td>
<td>336</td>
<td>0.63</td>
<td>0.46</td>
</tr>
<tr>
<td>738</td>
<td>06/10/2016</td>
<td>123</td>
<td>6.67</td>
<td>338</td>
<td>0.40</td>
<td>0.36</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Station Name:</th>
<th>Granite Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station Number:</td>
<td>00998877</td>
</tr>
<tr>
<td>Index Velocity Rating No:</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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

**Important! Must select Rating Type and enter regression coefficients below to properly compute Index Velocity in "AVM Qm Summary" tab!**

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

**Simple Linear**
- Intercept: 0.0005
- Slope: 8.81

**Fitted Equation:** \( \text{Index Velocity} = 0.0005 + (8.81 \times \text{Index Velocity}) \)

**Compound Linear**
- Intercept: 0.0005
- Slope: 8.81

**Fitted Equation:** \( \text{Index Velocity} = a + (b \times \text{Index Velocity}) \)

**Breakpoint 1 at Vx =**
- Computed Vm at Vx = #VALUE!

**Simple Linear**
- Intercept: 0.0005
- Slope (a): 8.81
- Standard Error: 0.00
- Degrees Freedom: 52
- Probability (65%): 0.05
- T Statistic: 2.98
- (All Vx Used) Mean: 1.68
- SS Regression (Explained): 52.197
- SS Residuals (Uncaptured): 0.053
- SSxx: 48.32

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:

<table>
<thead>
<tr>
<th>No.</th>
<th>Date</th>
<th>Flow, Q (cfs)</th>
<th>Stage (ft)</th>
<th>Vmean_meas (Q/Rated Area)</th>
<th>Vmean_rated (ft/sec)</th>
<th>% Difference</th>
<th>Measurement Rating</th>
<th>Optimum Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>739</td>
<td>07/15/2010</td>
<td>203</td>
<td>7.12</td>
<td>369</td>
<td>0.25</td>
<td>0.52</td>
<td>0.20</td>
<td>157%</td>
</tr>
<tr>
<td>740</td>
<td>07/19/2016</td>
<td>652</td>
<td>7.23</td>
<td>402</td>
<td>2.00</td>
<td>1.62</td>
<td>1.62</td>
<td>0%</td>
</tr>
<tr>
<td>741</td>
<td>09/23/2016</td>
<td>451</td>
<td>7.44</td>
<td>426</td>
<td>1.11</td>
<td>1.06</td>
<td>0.90</td>
<td>18%</td>
</tr>
<tr>
<td>742</td>
<td>10/28/2016</td>
<td>485</td>
<td>6.80</td>
<td>353</td>
<td>1.47</td>
<td>1.32</td>
<td>1.19</td>
<td>11%</td>
</tr>
<tr>
<td>743</td>
<td>12/02/2016</td>
<td>562</td>
<td>7.11</td>
<td>388</td>
<td>1.66</td>
<td>1.45</td>
<td>1.35</td>
<td>8%</td>
</tr>
<tr>
<td>744</td>
<td>01/06/2017</td>
<td>202</td>
<td>6.77</td>
<td>349</td>
<td>0.58</td>
<td>0.58</td>
<td>0.31</td>
<td>87%</td>
</tr>
<tr>
<td>745</td>
<td>02/10/2017</td>
<td>319</td>
<td>7.01</td>
<td>376</td>
<td>0.80</td>
<td>0.85</td>
<td>0.65</td>
<td>31%</td>
</tr>
<tr>
<td>746</td>
<td>03/17/2017</td>
<td>1,025</td>
<td>7.45</td>
<td>427</td>
<td>3.00</td>
<td>2.40</td>
<td>2.43</td>
<td>-1%</td>
</tr>
<tr>
<td>747</td>
<td>04/21/2017</td>
<td>1,800</td>
<td>8.50</td>
<td>553</td>
<td>4.01</td>
<td>3.25</td>
<td>3.25</td>
<td>0%</td>
</tr>
<tr>
<td>748</td>
<td>05/26/2017</td>
<td>790</td>
<td>7.19</td>
<td>397</td>
<td>2.40</td>
<td>1.96</td>
<td>1.95</td>
<td>2%</td>
</tr>
<tr>
<td>749</td>
<td>06/30/2017</td>
<td>80</td>
<td>5.35</td>
<td>195</td>
<td>0.59</td>
<td>0.46</td>
<td>0.48</td>
<td>-4%</td>
</tr>
<tr>
<td>750</td>
<td>08/04/2017</td>
<td>222</td>
<td>6.19</td>
<td>285</td>
<td>0.99</td>
<td>0.78</td>
<td>0.80</td>
<td>-3%</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Date</th>
<th>Site Visit or Meas?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>07/15/2016</td>
<td>Meas #739</td>
<td>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.</td>
</tr>
<tr>
<td>08/19/2016</td>
<td>Meas #740</td>
<td>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.</td>
</tr>
<tr>
<td>09/22/2016</td>
<td>Site Visit</td>
<td>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.</td>
</tr>
<tr>
<td>09/23/2016</td>
<td>Meas #741</td>
<td>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.</td>
</tr>
<tr>
<td>10/28/2016</td>
<td>Meas #742</td>
<td>Ditto on notes from 9/23. I wonder if the pattern will persist and a new rating will be needed?</td>
</tr>
<tr>
<td>12/02/2016</td>
<td>Meas #743</td>
<td>Ditto on notes from 9/23.</td>
</tr>
<tr>
<td>01/06/2017</td>
<td>Meas #744</td>
<td>Ditto on notes from 9/23.</td>
</tr>
<tr>
<td>02/10/2017</td>
<td>Meas #745</td>
<td>Ditto on notes from 9/23.</td>
</tr>
<tr>
<td>03/16/2017</td>
<td>Site Visit</td>
<td>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.</td>
</tr>
<tr>
<td>03/17/2017</td>
<td>Meas #746</td>
<td>Made a measurement. Plotted on the original rating.</td>
</tr>
<tr>
<td>04/21/2017</td>
<td>Meas #747</td>
<td>Plotted on the original rating.</td>
</tr>
<tr>
<td>05/26/2017</td>
<td>Meas #748</td>
<td>Plotted on the original rating.</td>
</tr>
<tr>
<td>06/30/2017</td>
<td>Meas #749</td>
<td>Plotted on the original rating.</td>
</tr>
<tr>
<td>08/04/2017</td>
<td>Meas #750</td>
<td>Plotted on the original rating.</td>
</tr>
</tbody>
</table>
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:

<table>
<thead>
<tr>
<th>Validation Measurement Nos.</th>
<th>Scenario No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>740, 746, 747, 748, 749, 750</td>
<td>1</td>
</tr>
<tr>
<td>741, 742, 743</td>
<td>4</td>
</tr>
<tr>
<td>739, 744, 745</td>
<td>5</td>
</tr>
</tbody>
</table>

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:

\[
\text{Optimum shift} = \frac{(V_{\text{mean}} - \text{rating intercept})}{\text{rating slope}} - V_{\text{index}}
\]

Where \(V_{\text{mean}}\) is the measured mean channel velocity

\(V_{\text{index}}\) is the average synchronized index velocity during the measurement

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

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

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:

<table>
<thead>
<tr>
<th>( V_{\text{index}} ) (ft/sec)</th>
<th>( \text{Shift to } V_{\text{index}} ) (ft/sec)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.44</td>
<td>Based on measurement nos. 739, 741, 742, 744, 745</td>
</tr>
<tr>
<td>1.70</td>
<td>0.13</td>
<td>Based on measurement no. 743</td>
</tr>
<tr>
<td>2.00</td>
<td>0.00</td>
<td>Based on measurement no. 740</td>
</tr>
</tbody>
</table>

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 \( V_{\text{index}} < 0.25 \) 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:

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.

<table>
<thead>
<tr>
<th>Measurement No.</th>
<th>Date</th>
<th>Flow, Q (cfs)</th>
<th>Stage (ft)</th>
<th>Staged Area (ft²)</th>
<th>Velocity (ft/sec)</th>
<th>Rating (ft/sec)</th>
<th>% Difference</th>
<th>Measurement Rating</th>
<th>Optimum Shift (ft/sec)</th>
<th>Percentage of Shift Curve</th>
<th>Applied Shift (ft/sec)</th>
<th>% Difference After Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>730</td>
<td>07/16/2016</td>
<td>203</td>
<td>7.12</td>
<td>389</td>
<td>0.23</td>
<td>0.33</td>
<td>0.20</td>
<td>15%</td>
<td>G</td>
<td>0.00</td>
<td>0.00</td>
<td>0%</td>
</tr>
<tr>
<td>740</td>
<td>08/10/2016</td>
<td>652</td>
<td>7.23</td>
<td>402</td>
<td>2.00</td>
<td>1.61</td>
<td>1.62</td>
<td>0%</td>
<td>G</td>
<td>0.00</td>
<td>0.00</td>
<td>0%</td>
</tr>
<tr>
<td>741</td>
<td>08/25/2016</td>
<td>451</td>
<td>7.44</td>
<td>426</td>
<td>1.11</td>
<td>1.06</td>
<td>0.90</td>
<td>10%</td>
<td>G</td>
<td>0.16</td>
<td>0.17</td>
<td>1%</td>
</tr>
<tr>
<td>742</td>
<td>10/28/2016</td>
<td>465</td>
<td>6.60</td>
<td>553</td>
<td>1.47</td>
<td>1.12</td>
<td>1.19</td>
<td>12%</td>
<td>G</td>
<td>0.13</td>
<td>0.14</td>
<td>1%</td>
</tr>
<tr>
<td>743</td>
<td>05/02/2016</td>
<td>562</td>
<td>7.11</td>
<td>368</td>
<td>1.68</td>
<td>1.15</td>
<td>1.35</td>
<td>2%</td>
<td>G</td>
<td>0.03</td>
<td>0.04</td>
<td>1%</td>
</tr>
<tr>
<td>744</td>
<td>01/06/2017</td>
<td>202</td>
<td>6.77</td>
<td>349</td>
<td>0.38</td>
<td>0.39</td>
<td>0.31</td>
<td>8%</td>
<td>F</td>
<td>0.33</td>
<td>0.37</td>
<td>5%</td>
</tr>
<tr>
<td>745</td>
<td>02/10/2017</td>
<td>310</td>
<td>7.01</td>
<td>376</td>
<td>0.83</td>
<td>0.83</td>
<td>0.63</td>
<td>21%</td>
<td>F</td>
<td>0.25</td>
<td>0.29</td>
<td>4%</td>
</tr>
<tr>
<td>746</td>
<td>03/17/2017</td>
<td>1,025</td>
<td>7.46</td>
<td>427</td>
<td>3.00</td>
<td>2.98</td>
<td>2.93</td>
<td>1%</td>
<td>G</td>
<td>-0.04</td>
<td>0.00</td>
<td>1%</td>
</tr>
<tr>
<td>747</td>
<td>03/21/2017</td>
<td>1,800</td>
<td>8.50</td>
<td>553</td>
<td>0.01</td>
<td>2.35</td>
<td>2.35</td>
<td>0%</td>
<td>G</td>
<td>0.00</td>
<td>0.00</td>
<td>0%</td>
</tr>
<tr>
<td>748</td>
<td>05/26/2017</td>
<td>790</td>
<td>7.16</td>
<td>397</td>
<td>2.60</td>
<td>1.99</td>
<td>1.99</td>
<td>2%</td>
<td>G</td>
<td>0.05</td>
<td>0.00</td>
<td>1%</td>
</tr>
<tr>
<td>749</td>
<td>06/30/2017</td>
<td>60</td>
<td>5.35</td>
<td>165</td>
<td>0.50</td>
<td>0.58</td>
<td>0.48</td>
<td>16%</td>
<td>P</td>
<td>-0.02</td>
<td>0.00</td>
<td>4%</td>
</tr>
<tr>
<td>750</td>
<td>07/02/2017</td>
<td>222</td>
<td>6.10</td>
<td>286</td>
<td>0.99</td>
<td>0.79</td>
<td>0.80</td>
<td>-3%</td>
<td>P</td>
<td>-0.01</td>
<td>0.00</td>
<td>-3%</td>
</tr>
</tbody>
</table>
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 $V_{\text{index}} = 0.08$ 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 $V_{\text{index}}$ 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:

<table>
<thead>
<tr>
<th>Measurement No.</th>
<th>Date</th>
<th>Flow, Q (cfs)</th>
<th>Stage (ft)</th>
<th>Rated Area (ft²)</th>
<th>$V_{\text{index}}$ (ft/sec)</th>
<th>$V_{\text{mean meas}}$ (Q/Rated Area)</th>
<th>Upper/Lower Rating Segment?</th>
</tr>
</thead>
<tbody>
<tr>
<td>329</td>
<td>07/31/2013</td>
<td>168</td>
<td>54.57</td>
<td>360</td>
<td>0.36</td>
<td>0.30</td>
<td>Upper</td>
</tr>
<tr>
<td>330</td>
<td>11/14/2013</td>
<td>146</td>
<td>54.84</td>
<td>366</td>
<td>0.37</td>
<td>0.40</td>
<td>Upper</td>
</tr>
<tr>
<td>331</td>
<td>11/27/2013</td>
<td>35.7</td>
<td>55.00</td>
<td>395</td>
<td>0.07</td>
<td>0.09</td>
<td>Both</td>
</tr>
<tr>
<td>332</td>
<td>11/27/2013</td>
<td>25.2</td>
<td>54.99</td>
<td>394</td>
<td>0.07</td>
<td>0.06</td>
<td>Both</td>
</tr>
<tr>
<td>333</td>
<td>11/27/2013</td>
<td>55.8</td>
<td>54.99</td>
<td>394</td>
<td>0.07</td>
<td>0.14</td>
<td>Both</td>
</tr>
<tr>
<td>334</td>
<td>11/27/2013</td>
<td>65.2</td>
<td>54.95</td>
<td>393</td>
<td>0.10</td>
<td>0.15</td>
<td>Both</td>
</tr>
<tr>
<td>336</td>
<td>03/20/2014</td>
<td>-66.3</td>
<td>55.63</td>
<td>446</td>
<td>-0.05</td>
<td>-0.15</td>
<td>Lower</td>
</tr>
<tr>
<td>337</td>
<td>05/01/2014</td>
<td>-557</td>
<td>57.43</td>
<td>608</td>
<td>-0.65</td>
<td>-0.97</td>
<td>Lower</td>
</tr>
<tr>
<td>338</td>
<td>08/19/2014</td>
<td>130</td>
<td>53.90</td>
<td>306</td>
<td>0.47</td>
<td>0.42</td>
<td>Upper</td>
</tr>
<tr>
<td>340</td>
<td>09/23/2014</td>
<td>153</td>
<td>54.37</td>
<td>344</td>
<td>0.45</td>
<td>0.44</td>
<td>Upper</td>
</tr>
<tr>
<td>341</td>
<td>11/25/2014</td>
<td>145</td>
<td>54.73</td>
<td>377</td>
<td>0.43</td>
<td>0.38</td>
<td>Upper</td>
</tr>
<tr>
<td>342</td>
<td>04/27/2015</td>
<td>150</td>
<td>55.91</td>
<td>396</td>
<td>0.40</td>
<td>0.38</td>
<td>Upper</td>
</tr>
<tr>
<td>343</td>
<td>06/05/2015</td>
<td>150</td>
<td>54.49</td>
<td>353</td>
<td>0.41</td>
<td>0.42</td>
<td>Upper</td>
</tr>
<tr>
<td>344</td>
<td>07/22/2015</td>
<td>150</td>
<td>54.59</td>
<td>321</td>
<td>0.44</td>
<td>0.40</td>
<td>Upper</td>
</tr>
<tr>
<td>345</td>
<td>08/24/2015</td>
<td>119</td>
<td>53.91</td>
<td>307</td>
<td>0.37</td>
<td>0.39</td>
<td>Upper</td>
</tr>
<tr>
<td>347</td>
<td>12/04/2015</td>
<td>154</td>
<td>55.13</td>
<td>410</td>
<td>0.36</td>
<td>0.38</td>
<td>Upper</td>
</tr>
<tr>
<td>348</td>
<td>02/25/2016</td>
<td>-35.7</td>
<td>56.72</td>
<td>456</td>
<td>-0.10</td>
<td>-0.08</td>
<td>Lower</td>
</tr>
<tr>
<td>340</td>
<td>04/20/2016</td>
<td>130</td>
<td>64.89</td>
<td>386</td>
<td>0.44</td>
<td>0.36</td>
<td>Upper</td>
</tr>
</tbody>
</table>
 uncertainties 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:

<table>
<thead>
<tr>
<th>Index Velocity Rating No:</th>
<th>8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show Simple Linear Statistics</td>
<td>Show Compound Linear Statistics</td>
</tr>
<tr>
<td>[ \text{Compound Linear} ]</td>
<td></td>
</tr>
<tr>
<td><strong>Line 1</strong> (V&lt;sub&gt;1&lt;/sub&gt; = breakpoint 1)</td>
<td>[ \text{Simple Linear} ]</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.01</td>
</tr>
<tr>
<td>Slope</td>
<td>0.55</td>
</tr>
<tr>
<td>[ \text{Composed Linear} ]</td>
<td></td>
</tr>
<tr>
<td>Line 2 (V&lt;sub&gt;2&lt;/sub&gt; = breakpoint 2)</td>
<td>[ \text{Simple Linear} ]</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.03</td>
</tr>
<tr>
<td>Slope</td>
<td>0.44</td>
</tr>
<tr>
<td>Multiple Variable Linear</td>
<td>[ \text{Simple Linear} ]</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.04</td>
</tr>
<tr>
<td>Slope</td>
<td>0.50</td>
</tr>
<tr>
<td>[ \text{Compound Linear} ]</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>0.00</td>
</tr>
<tr>
<td>Slope</td>
<td>0.17</td>
</tr>
<tr>
<td>Phase</td>
<td>0.44</td>
</tr>
<tr>
<td>[ \text{Compound Linear} ]</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>0.01</td>
</tr>
<tr>
<td>Slope</td>
<td>0.55</td>
</tr>
<tr>
<td>[ \text{Compound Linear} ]</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>0.03</td>
</tr>
<tr>
<td>Slope</td>
<td>0.44</td>
</tr>
<tr>
<td>Multi variable Linear</td>
<td>[ \text{Simple Linear} ]</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.04</td>
</tr>
<tr>
<td>Slope</td>
<td>0.50</td>
</tr>
</tbody>
</table>
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:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>350</td>
<td>05/25/2016</td>
<td>140</td>
<td>54.03</td>
<td>0.35</td>
<td>0.40</td>
<td>0.34</td>
<td>10%</td>
<td>G</td>
<td>0.07</td>
</tr>
<tr>
<td>351</td>
<td>06/09/2016</td>
<td>141</td>
<td>54.45</td>
<td>0.33</td>
<td>0.40</td>
<td>0.38</td>
<td>25%</td>
<td>F</td>
<td>0.09</td>
</tr>
<tr>
<td>352</td>
<td>06/24/2016</td>
<td>130</td>
<td>53.67</td>
<td>0.31</td>
<td>0.45</td>
<td>0.31</td>
<td>45%</td>
<td>F</td>
<td>0.17</td>
</tr>
</tbody>
</table>

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).
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):

![Residuals Over Time](image)

**Justification and Calculation of Shifts**

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

<table>
<thead>
<tr>
<th>Validation Measurement No.</th>
<th>Scenario No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>350</td>
<td>2</td>
</tr>
<tr>
<td>351</td>
<td>3</td>
</tr>
<tr>
<td>352</td>
<td>5</td>
</tr>
</tbody>
</table>

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:
\[
\text{Optimum shift} = \frac{(V_{\text{mean}} - \text{rating intercept})}{\text{rating slope}} - V_{\text{index}}
\]

Where \(V_{\text{mean}}\) is the measured mean channel velocity
\(V_{\text{index}}\) is the average synchronized index velocity during the measurement

For example, the optimum shift for measurement no. 352 (upper rating segment) was calculated as:
\[
\text{Optimum shift} = \frac{(0.45 - 0.054)}{0.819} - 0.31 = 0.17 \text{ ft/sec}
\]

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:

<table>
<thead>
<tr>
<th>Shift Curve No.</th>
<th>(V_{\text{index}}) (ft/sec)</th>
<th>Shift to (V_{\text{index}}) (ft/sec)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.30 to 0.40</td>
<td>0.09</td>
<td>Based on measurement no. 351</td>
</tr>
<tr>
<td>2</td>
<td>0.30 to 0.40</td>
<td>0.17</td>
<td>Based on measurement no. 352</td>
</tr>
</tbody>
</table>

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:

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.
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

![](image1.png)

- Parallel shift of -0.34

![image2.png](image2.png)
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:**

```
|  |  |  |  |  | 02226160 | Sensor velocity | shifted sensor velocity |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  | 02226160 | Sensor velocity | ft/s | Points | Instantaneous |
```

“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.