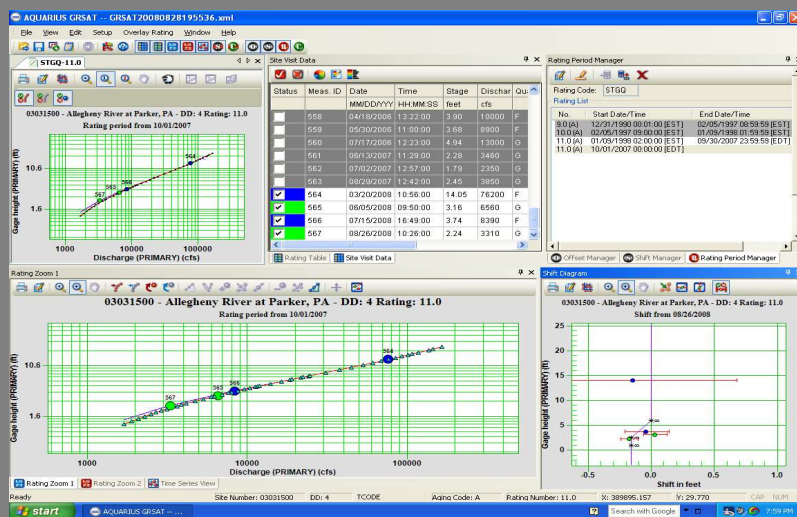


Stage-Discharge Relations

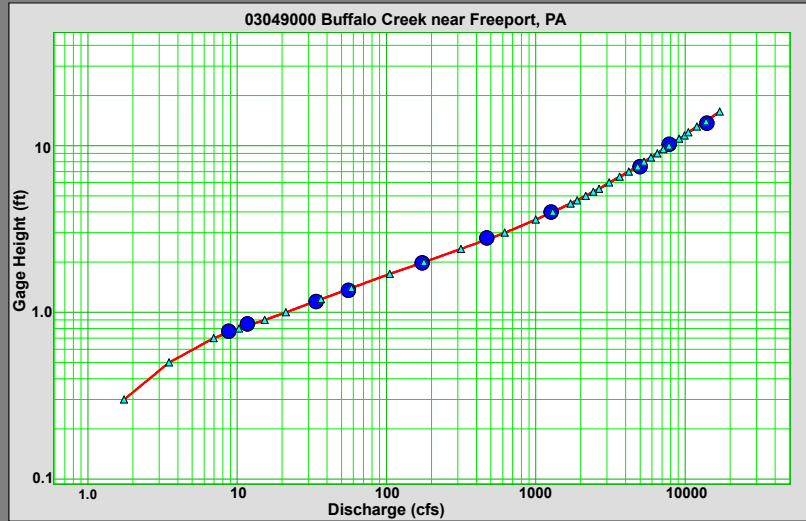


Narrated by Joe Nielsen



This module will discuss the fundamentals of developing stage-discharge relations. Developing stage-discharge relations is one of the primary components in the surface water records computation process.

Stage-discharge relations are often referred to as “Ratings”.



The USGS uses stage-discharge relations to convert stage data collected at gaging stations to water discharge. These relations are also known as ratings. Ratings are developed based on discharge measurements made at a wide range of gage heights or stages.

The intent of this module is to acquaint you with basic concepts related to developing and applying stage-discharge relations.

You will learn:

- That a stage-discharge relation is commonly called a “rating”,
- What controls the shape of ratings,
- Methods used to develop ratings that can be extended and interpolated with confidence,
- How we plot and analyze ratings,
- What is done when ratings change.



In this module, you will be familiarized with ratings including what controls the shape of a rating and the basic concepts about how they are developed. How ratings are plotted and analyzed will be demonstrated. Also, you will learn how changes to the rating are handled.

Stage data are needed to develop a rating.



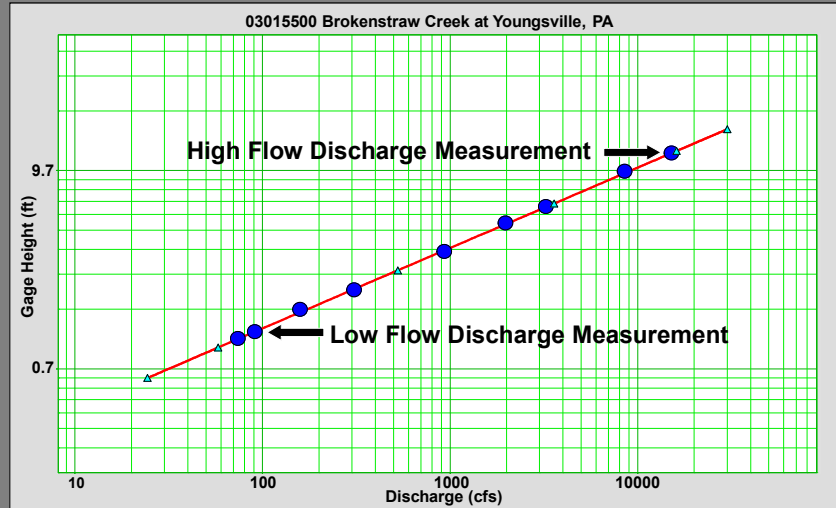
Examples of “staff” gages



The fundamental piece of data collected at most streamflow gaging stations is stream stage, or gage height, which is the height of the water surface above some datum. These data are usually recorded on a data recorder and often transmitted to USGS offices via real-time telemetry to provide a continuous record of stage and the related discharge.

Note that a continuous record of stage is not required in the development of a rating. A non-recording gage, such as a vertical staff, is sufficient.

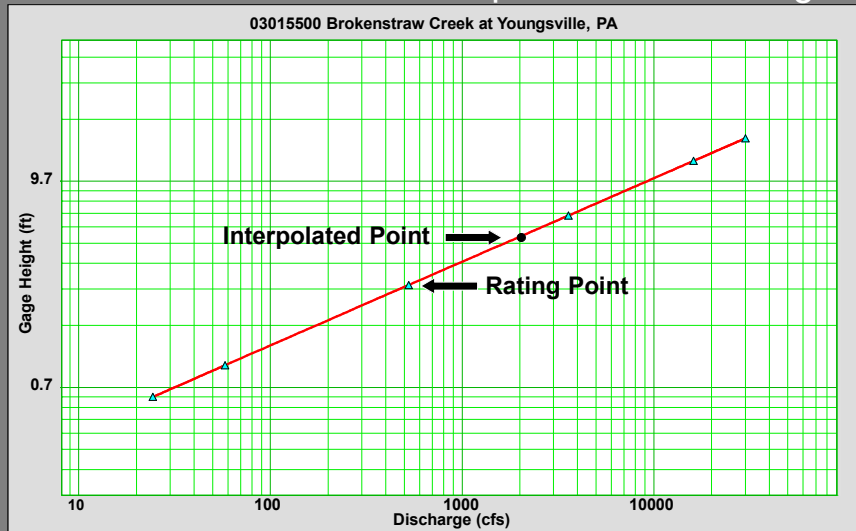
Discharge measurements must be made throughout the entire range of stage to accurately define a rating.



USGS

Discharge measurements are made at low, moderate and high flows and the measured discharge and gage height are then plotted to define the rating shape. Typically, measurements are made at a preset interval, such as every six weeks, as well as during periods of high and low flows. Discharge measurements made by indirect methods are sometimes used to define the upper end of a rating.

A computer interpolates the stage discharge values between the defined points on the rating.



A rating curve developed by hand graphically must be processed so that a computer can calculate water discharge for every stage. This is done by first adding rating points that adequately define the rating curve. The computer then interpolates between these “input points” to determine discharge at all stages.

A rating table is prepared from the rating curve.

U.S. DEPARTMENT OF THE INTERIOR - U.S. GEOLOGICAL SURVEY - WATER RESOURCES

STATION NUMBER 03049000 Buffalo Creek near Freeport, PA SOURCE AGENCY USGS STATE 42 COUNTY 019

Rating for Discharge (DCP) (cfs)

RATING ID: 41.0 TYPE: stage-discharge EXPANSION: logarithmic

OFFSET: 0.00

EXPANDED RATING TABLE

Gage height, feet	Discharge (cfs)										DIFF IN Q PER .1 UNITS
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	
0.30	1.8*	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.4	2.5	0.80
0.40	2.6	2.7	2.8	2.9	2.9	3.0	3.1	3.2	3.3	3.4	0.90
0.50	3.5*	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.7	4.9	1.6
0.60	5.1	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.7	1.9
0.70	7.0*	7.2	7.6	7.9	8.2	8.5	8.9	9.2	9.6	9.9	3.3
0.80	10.3*	10.7	11.2	11.7	12.1	12.6	13.1	13.7	14.2	14.7	5.0
0.90	15.3*	15.8	16.4	16.9	17.5	18.1	18.7	19.3	19.9	20.6	5.9
1.00	21.2*	21.8	22.5	23.2	23.8	24.5	25.2	25.9	26.7	27.4	7.0
1.10	28.2	28.9	29.7	30.5	31.3	32.2	33.0	33.8	34.7	35.6	8.3
1.20	36.5*	37.4	38.4	39.3	40.3	41.3	42.3	43.4	44.4	45.5	10.0
1.30	46.5	47.6	48.8	49.9	51.0	52.2	53.4	54.6	55.8	57.0	11.8
1.40	58.3*	59.6	60.9	62.2	63.5	64.8	66.2	67.6	69.0	70.4	13.6
1.50	71.9	73.3	74.8	76.3	77.8	79.4	80.9	82.5	84.1	85.7	15.5
1.60	87.4	89.0	90.7	92.4	94.2	95.9	97.7	99.5	101	103	17.6
1.70	105*	107	109	111	113	115	118	120	122	124	21.0
1.80	126	129	131	133	136	138	141	143	146	148	25.0
1.90	151	153	156	159	161	164	167	169	172	175	27.0



The computer develops a rating table that provides the discharge for any gage height or stage defined by the rating curve. The rating table allows us to determine the exact discharge for any stage rather than approximate the discharge from a plot of the rating curve.

Here is how to read a “rating table”.

STATION NUMBER 03049000 Buffalo Creek near Freeport, PA
 Rating for Discharge (DCP) (cfs)
 RATING ID: 41.0 TYPE: stage-discharge EXPANSION: logarithmic
 OFFSET: 0.00

EXPANDED RATING TABLE

Gage height, feet	.00	.01	.02	.03	.04		.09	DIFF IN Q PER .1 UNITS
0.30	1.8*	1.8	1.9	2.0	2.1		2.5	0.80
0.40	2.6	2.7	2.8	2.9	3.0		3.4	0.90
0.50	3.5*	3.6	3.7	3.8	3.9		4.9	1.6
0.60	5.1	5.2	5.4	5.6	5.8		7	1.9
0.70	7.0*	7.2	7.4	7.6	7.8		9.9	3.3
0.80	10.3*	10.7	11.2	11.7	12.1		14.7	5.0
0.90	15.3*	15.8	16.4	16.9	17.5		20.6	5.9

USGS

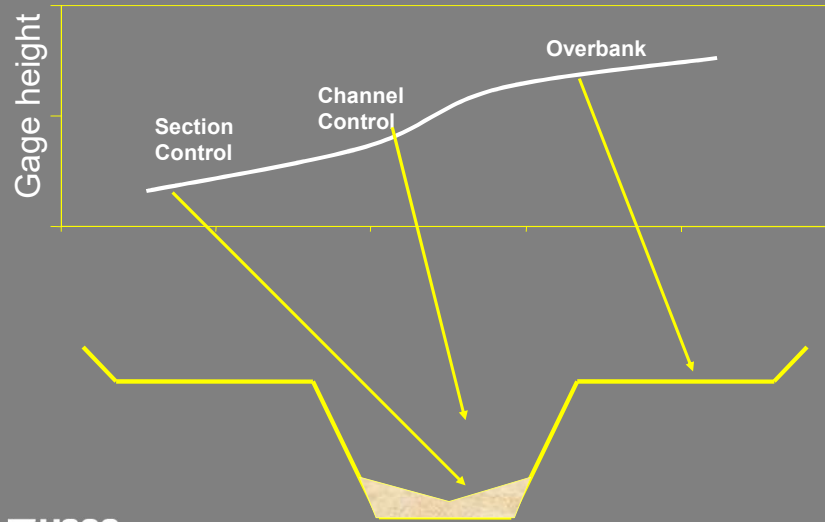
To determine the discharge at a gage height of 0.62 ft on this rating table, find the gage height reading to the nearest tenth of a foot at or below the gage height of interest on the left side of the rating table, in this case 0.60 ft. Next, locate the column for the hundredths reading of .02 at the top of the rating table. Now move horizontally across the table from the 0.60 gage height reading until you reach the column for .02. The discharge at a gage height of 0.62 ft is 5.4 cubic feet per second. Rating descriptor points are the points used to define the rating and are identified by an asterisk on the rating table. The interpolated points are computer generated discharge values based on the rating descriptor or input points.

Rating Controls



This section of the module will cover rating controls.

The shape of ratings is controlled by the channel and features in the channel.



The relation of stage to discharge is usually controlled by a section or reach of channel downstream from the gage that eliminates the effect of all other downstream conditions on the water-surface elevation at the orifice or intake for the gage. This section or reach is known as the station control because it “controls” the stage for a given discharge at the gage. This diagram summarizes the types of controls often found at gaging stations. We will discuss each type of control in this section of this class.

Ratings, or portions of ratings, can be controlled by a single cross section of the channel.



Such controls are called "Section" controls.

A section control may be natural or manmade; it may be a ledge of rock across the channel, a boulder-covered riffle, an overflow dam, or any other physical feature capable of maintaining a fairly stable relation between stage and discharge.

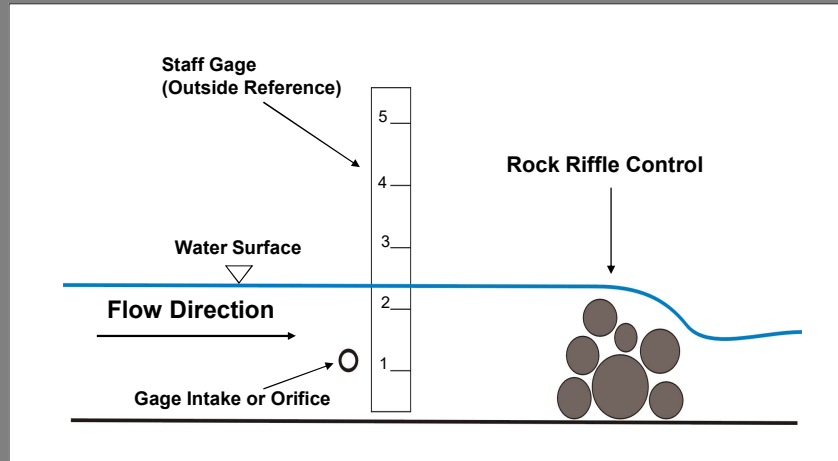
Section controls can also be artificial structures such as concrete dams.



USGS

Section controls can also be artificial structures such as concrete dams or weirs.

Section controls can be identified by a break in the water surface downstream from the gage.



Section controls can be identified by looking downstream from the gage. The first break in the water surface from the gage pool generally defines the section control. Although section controls can be effective throughout the full range in stage at a site, their effect is usually limited to low to moderate stages.

At higher stages, the physical features of the channel downstream from the gage often control the stage-discharge relation.



Such controls are referred to as “Channel” controls.



At higher stages the physical features of the reach of channel downstream from the gage often control the stage discharge relation. Under such conditions the level of the water at the gage is not affected by a single channel cross section. Rather characteristics of the channel reach downstream of the gage form the control. Many factors such as size, roughness, slope, and shape of the channel affect the stage at the gage for any given discharge.

There is no break in water surface slope in this view of the channel below a gage, therefore, the channel is the control.



This is an example of a stream under channel control. There is no break in water surface slope in this view of the channel below a gage. Although there are exceptions, this generally means the channel is the control.

When a stream flows overbank, the characteristics of both the channel and the flood-plain affect the rating.



← Flow Overbank



At high flows a stream can overflow the natural channel into the flood plain. Under such conditions, characteristics of both the channel and the flood plain affect the stage-discharge relation. When a stream overflows the banks and the flood plain is very wide on at least one side, there is a significant increase in discharge for a minimal increase in stage at the gage.

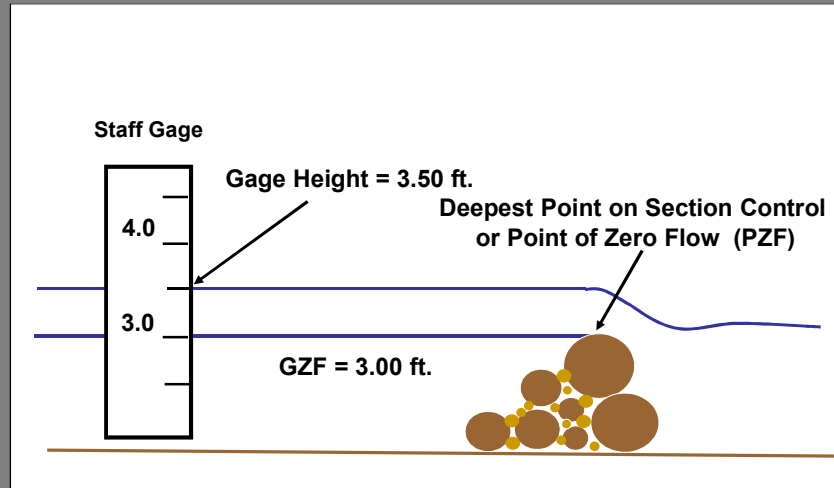
You must collect detailed information on channel characteristics to adequately define ratings.

- For example, you must define:
 - At what stage flow no longer occurs.
 - The range in stage affected by the “section” control.
 - How channel shape varies with stage.
 - At what stage overbank flow occurs.



Information about the channel shape is key to developing sound ratings. Some of the information that must be assessed are shown here. Such information comes from discharge measurements, miscellaneous field notes and surveying notes.

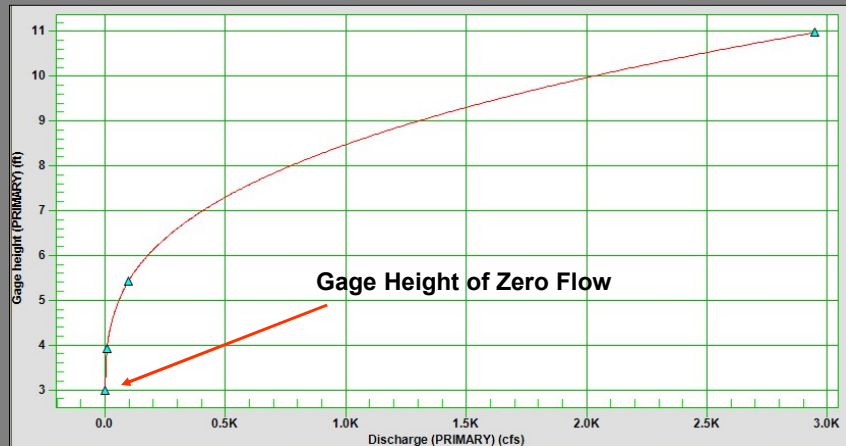
The gage height of zero flow (GZF) is the stage that is a particularly important piece of information that is relatively easy to collect.



Note: We refer to the actual location of the Point of Zero Flow, as shown above, as the PZF. We refer to the gage height at which flow is zero as the GZF

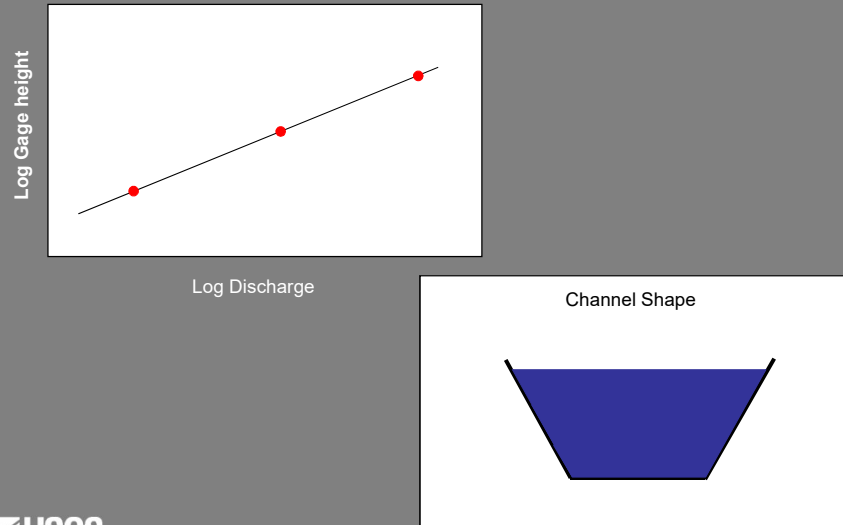
The gage height of zero flow, or GZF, defines the low end of the rating and is useful in developing ratings. In this example, the stream gage height is 3.50 ft. If the stream receded to a gage height of 3.00 ft there would no longer be flow. It is especially important to regularly determine the gage height of zero flow when streams are unstable so that rating changes can be assessed. Often times, the term point of zero flow, or PZF is used interchangeably with GZF. The PZF is actually the physical location of the lowest point on the control. The GZF is typically determined in the field by recording the depth of the current water surface over the PZF and subtracting it from the current stage.

The Gage Height of Zero Flow (GZF) is a point on the rating.



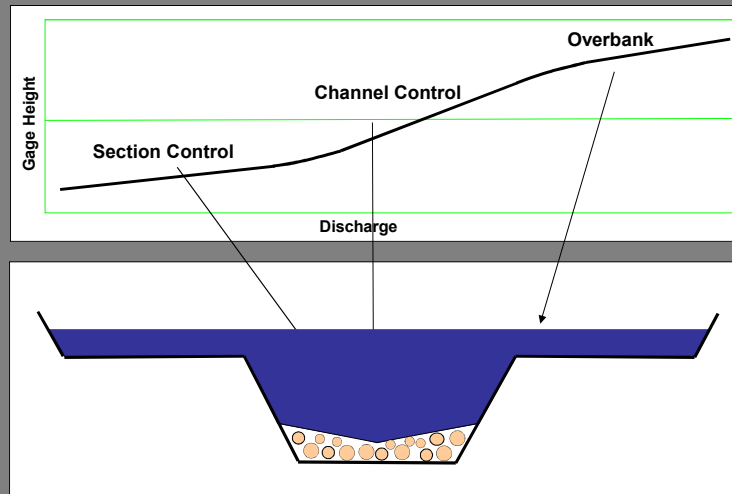
The Gage Height of Zero Flow or GZF measured in the field can be plotted on rectangular scaled paper as a point on the rating. The GZF plotted as a point on the rating allows us to extend the low end of the rating with some confidence. A change in the gage height of zero flow will often indicate a change in the stage-discharge relation at a site.

Some ratings can be represented simply as a straight line on a logarithmic scale.



Ratings affected by a single control through the full range in stage can be represented by a single straight line on logarithmic scaled paper. Such simple ratings often occur when the channel controls the rating at all stages. In this example, you can see the stage and corresponding discharge on the rating curve increase in a straight line as the water level increases in the simplified channel.

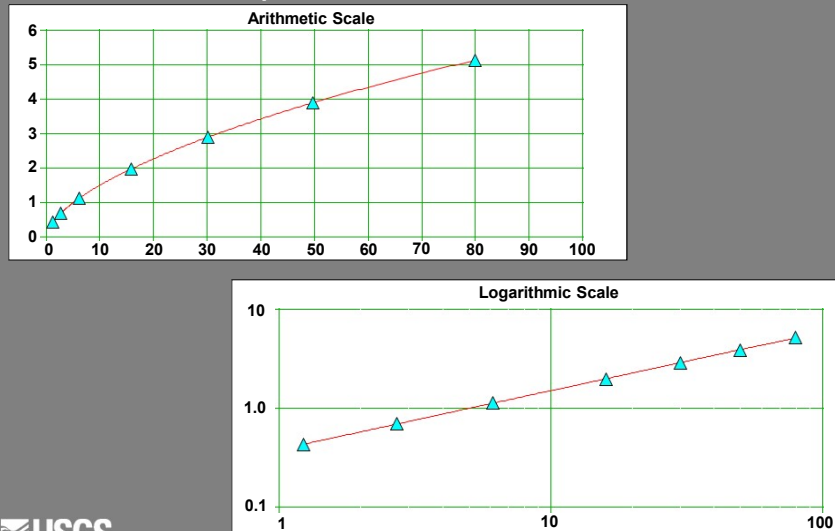
Rating shapes are often complex.



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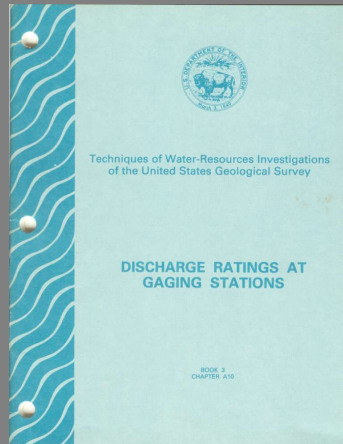
Compound ratings result when the control changes with stage. In this example, the shape of the lower end of the rating is based on a section control. As the stage rises section control is drowned out, or becomes submerged, and the rating shape is the result of the channel control characteristics. The configuration of the floodplain and the channel characteristics shape the upper end of the rating. The slope of a rating will change depending on the type of control. When a river flows overbank into the flood plain the rating will generally bend to the right because a small increase in gage height will result in a much larger increase in discharge based on the increase in cross-sectional area.

Ratings are plotted on logarithmic scales or arithmetic scales. The scale used will dramatically affect their shape.



We try to develop ratings that contain a series of straight line segments that gradually transition from one segment to the next. This is facilitated by plotting ratings on graphs with logarithmic scales. It is easier to accurately interpolate between rating points when the relation is a straight line. Also, straight line segments at the top of the rating can be more accurately extended above the highest measured discharge. The use of arithmetic scales is usually limited to the lower end of ratings because zero values cannot be plotted on log scales.

The TWRI on Discharge Ratings at Gaging Stations is a useful reference for rating and shift development.

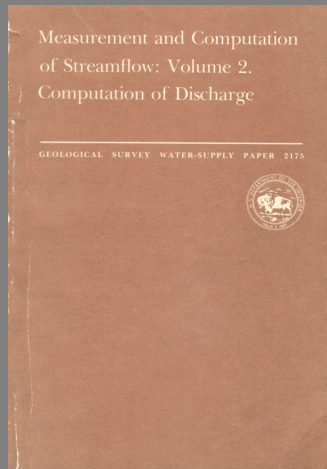


- TWRI Book 3 Chapter A10 Discharge Relations at Gaging Stations
- All TWRI's can be found on the internet at <http://pubs.usgs.gov/twri>
- Click here to go to the reference.



The Techniques of Water-Resources of the USGS are commonly referred to as TWRI's. Discharge Ratings at Gaging Stations is found in TWRI Book 3 Chapter A10, which is an excellent reference for rating and shift development.

Another useful reference is Water-Supply Paper 2175, titled Measurement and Computation of Streamflow: Volume 2. Computation of Discharge.



- WSP 2175 provides detailed information about simple stage-discharge relations.
- Water-Supply Papers are available online at <http://pubs.usgs.gov/wsp/>.
- Click [here](#) to go to the reference.

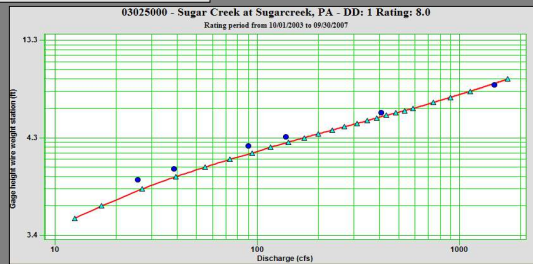
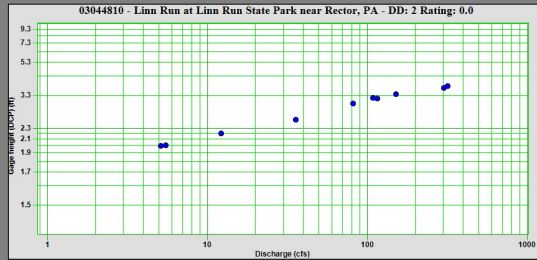
Water-Supply Paper 2175 is also a good resource for additional information about rating development.

Rating Development



In this section of the module we will discuss how we develop ratings.

Ratings are developed for new sites or when an old rating is no longer valid.



We develop ratings for new sites or for exiting sites when the current stage-discharge relation is no longer representative of the channel conditions.

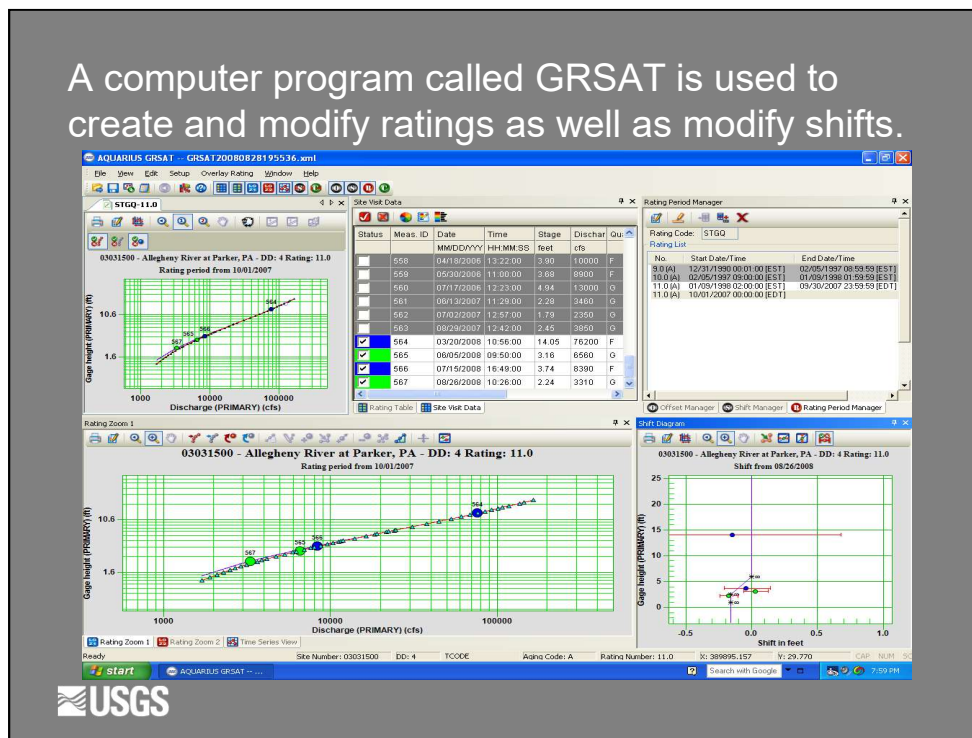
There are many considerations when developing a rating.

- How the control will effect the shape of the rating.
- Determine the discharge measurements that will be used to develop the rating.
- Plot the rating using the Logarithmic Scale.
- If available, plot the previous rating with the new rating.



When we develop ratings, the discharge measurements and associated control condition notes help us create ratings that are accurate representations of the stage-discharge relation at the site. Plotting the rating to the logarithmic scale allows us to create straight line segments with smooth transitions along the rating.

A computer program called GRSAT is used to create and modify ratings as well as modify shifts.



GRSAT can be used to create and modify ratings very quickly while implementing sound rating development principles. GRSAT stands for Graphical Rating and Shift Analysis Tool. When using GRSAT, we no longer have the tedious job of plotting measurements and rating points on graph paper by hand, or manually drawing trial rating curves.

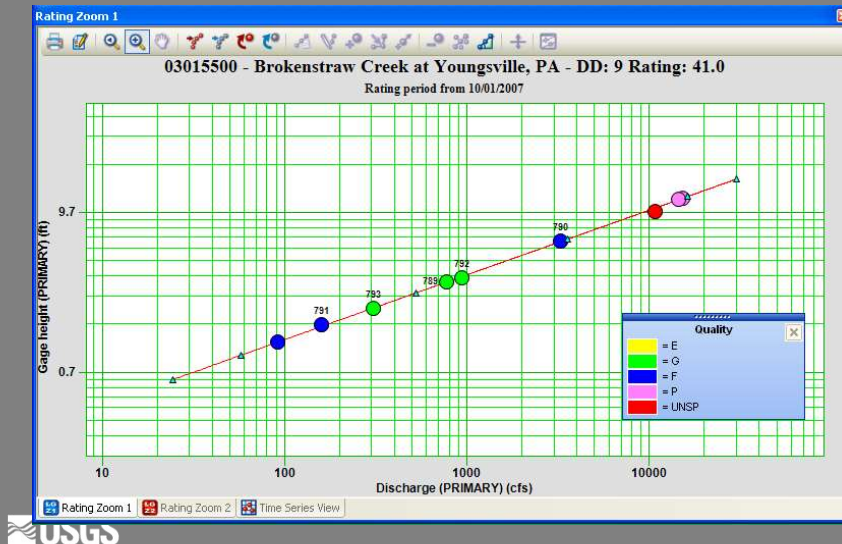
De-select measurements with a debris or ice effected control when developing a rating.

Status	Meas. ID	Date	Time	Stage	Dischar	Quality	Condition	R Error	S Error	T.Differ
		MM/DD/YYYY	HH:MM:SS	feet	cfs			%	%	%
✓	583	09/11/2006	14:15:00	5.71	11300	G	CLER	-5.6	-1.5	-5.6
✗	584	06/13/2007	14:39:00	3.12	2580	G	ALGA	-8.1	ALGAE	0.3
✓	585	06/25/2007	15:48:00	2.91	2370	F	CLER	1.2	6.1	1.2
✗	586	08/29/2007	08:14:00	3.30	3090	G	ALGA	-6.5	0.2	-6.5
✓	587	12/11/2007	10:15:00	6.19	13700	G	CLER	-2.5	0.3	-2.5
✓	588	03/20/2008	17:37:00	10.85	42700	F	CLER	4.8	4.8	4.8
✓	589	05/27/2008	13:53:00	4.29	5780	G	CLER	-10.3	-1.6	-1.6
✓	590	07/07/2008	10:47:00	4.39	6290	G	CLER	-7.1	1.9	1.9
✓	591	08/26/2008	13:56:00	3.16	2770	G	CLER	-5.7	0.3	0.3
✓	592	08/26/2008	14:37:00	3.16	2780	G	CLER	-5.4	0.7	0.7
✗	593	09/23/2008	16:58:00	3.22	2840	G	LGDB	-8.2	LIGHT DEBRIS	



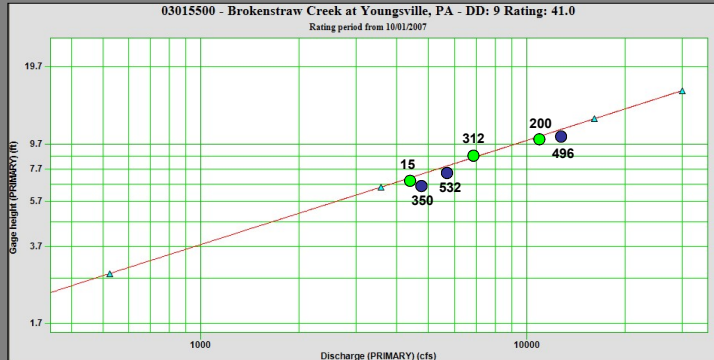
The control condition should be considered when determining what measurements to use to develop a new rating. Under most circumstances, you will not use measurements with a control affected by debris, ice, or algal growth for rating development. In the computer program GRSAT, measurements can easily be selected or de-selected by control condition for viewing on the rating curve.

The quality that the discharge measurement was given should also be considered in rating development.



Measurement uncertainty can be qualified as excellent (less than 2%), good (2-5%), fair (5-8%), or poor (over 8%) based on the field conditions under which the measurement was made. If no uncertainty is specified in the database then the measurement uncertainty will be indicated as unspecified. In GRSAT, a predefined color classification scheme can be used to identify the uncertainty of a measurement on the rating. When developing a rating, you can give measurements with less uncertainty more weight over measurements of higher uncertainty.

Recent and historical high flow measurements should be considered when developing a new rating.

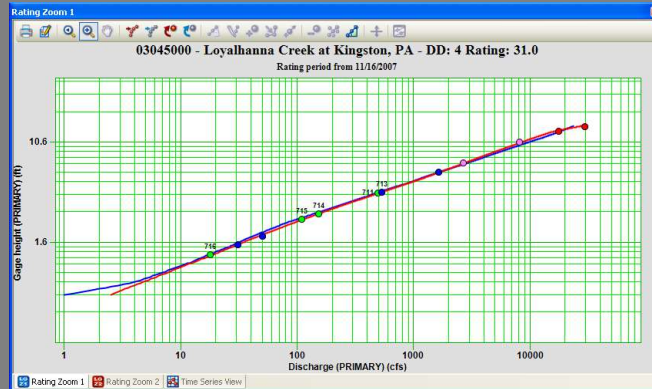


- Blue measurements are recent.
- Green measurements are historical.



Since high flow measurements are typically not made as often as lower flow measurements and as the upper end of the rating is generally more stable, it is good to compare recent and historical high flow measurements when creating a new rating. Often no modification is needed to the upper end of a rating when the lower end is changed. In this example, there has been a definitive change in the upper end of the rating.

When new ratings are developed they should be compared to previous ratings.



- The red line is the new rating.
- The blue line is the previous rating.

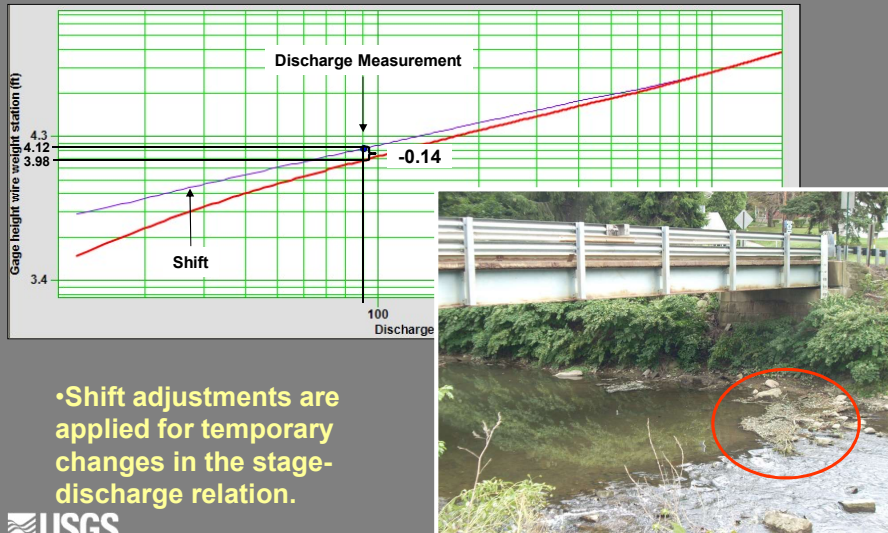


When a new rating is being developed which replaces an existing rating, we plot the new and old rating together to verify that the new rating shape is reasonable. In this example, the old rating is plotted in blue along side the new rating in red. The ratings have similar shapes with some modification to the new rating at the lower and upper ends.



In this section of the module, the use of shifts to adjust for temporary changes in the stage-discharge relation will be covered.

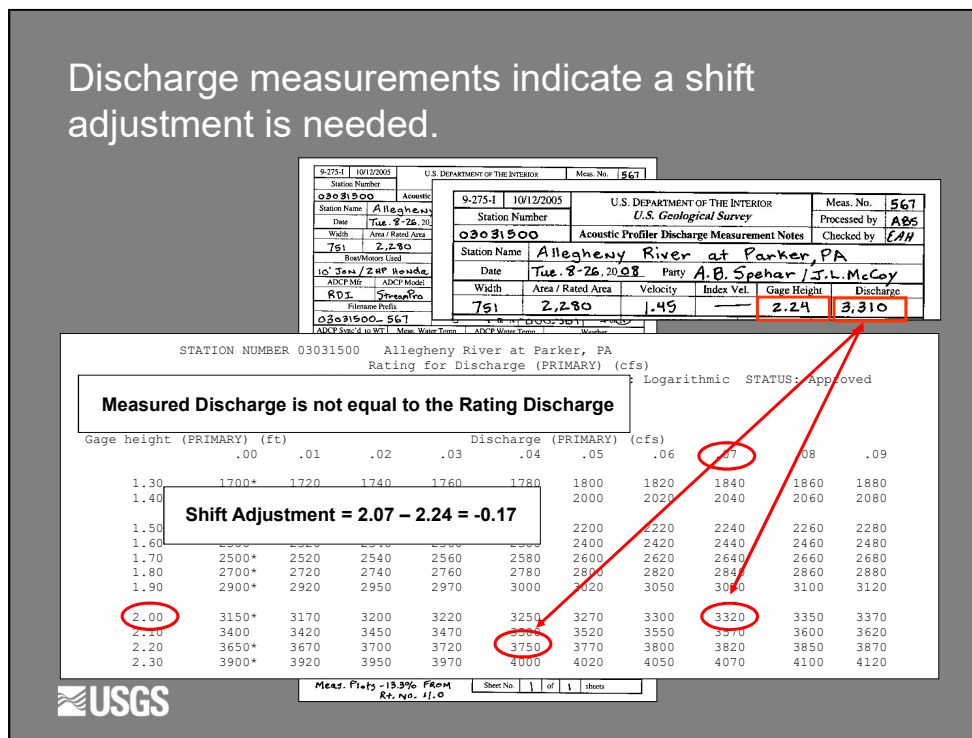
Since gage control conditions change, the stage-discharge relations must be adjusted.



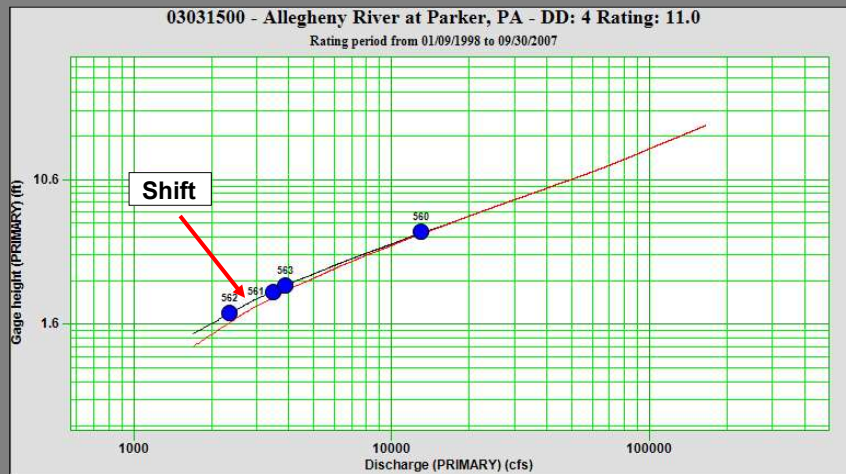
A shift is a modification to an existing rating that is entered as an adjustment, or offset, to the current rating rather than as an entirely new stage-discharge relation. A shift is used as a temporary correction for changes in the rating that are not likely to be permanent, or as an interim estimate of a permanent change until more measurements can be made and a new rating developed. Shifts can also be prorated on or off over time, which allows for the application of gradual changes such as the slow accumulation of debris or growth of aquatic vegetation.

In this example, debris has collected on one side of a rock riffle control. The rating was developed with the control clear of debris so the debris is creating a new stage-discharge relation. The measurement was made at a gage height of 4.12 feet and the measured discharge was 90 cubic feet per second. The gage height on the unshifted, or base, rating at 90 cubic feet per second is 3.98 ft. The shift adjustment is the amount that must be subtracted from the recorded gage height to determine the correct discharge from the rating. In this case the shift amount is 4.12 ft minus 3.98 ft, which is -0.14 ft. You can see the applied shift correction is not constant to the top of the rating but rather merges back into the rating at a higher gage height. The assumption is made that as the flow increases the debris will be drowned out and no longer affect the stage-discharge relation.

Discharge measurements indicate a shift adjustment is needed.



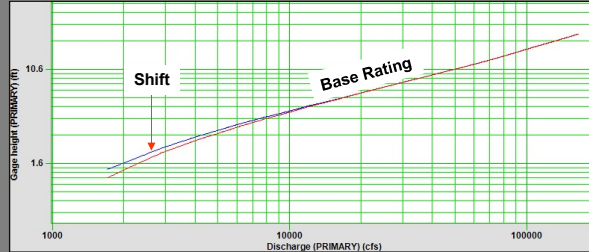
Discharge measurements help define a shift adjustment.



Several discharge measurements plotted on this rating indicate a shift adjustment is needed. The discharge measurement made at a higher gage height does not indicate as much of a shift correction as the measurements made at lower gage height.

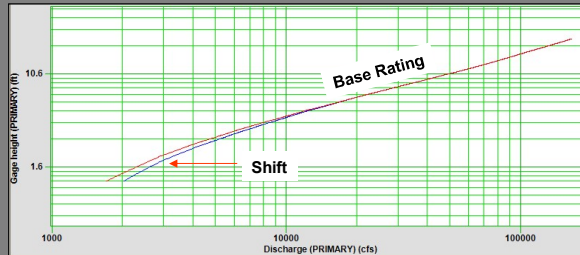
Narration is missing for this slide

Shifts are typically referred to as positive or negative shifts.



- Negative shift,
- Measurement gage height is **more than** rating gage height,
- Correction is subtracted from the gage height.

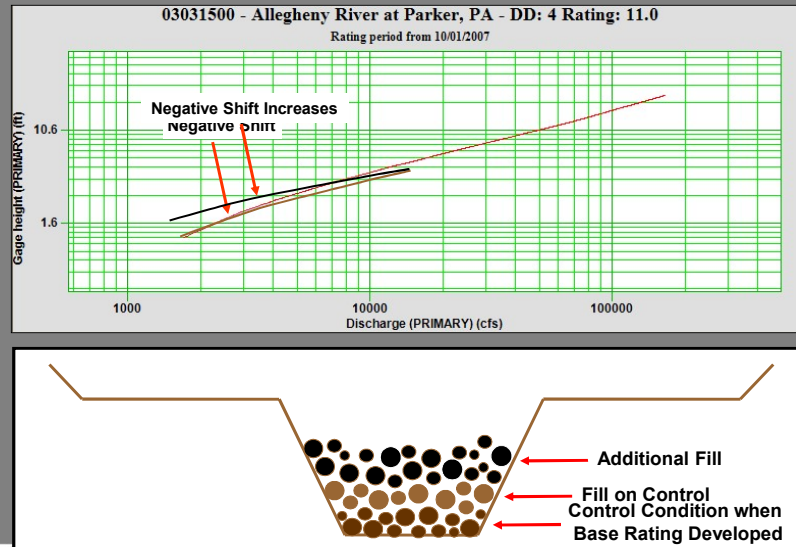
- Positive shift,
- Measurement gage height is **less than** rating gage height,
- Correction is added to the recorded gage height.



Shifts are commonly referred to as positive shifts or negative shifts. If the measurement gage height is more than the rating gage height for a given discharge then the shift correction is minus and called a negative shift. In the records computation process, a negative shift adjustment is subtracted from the gage height record and then the corresponding discharge is determined. A positive shift occurs when the measurement gage height is less than the rating gage height for the same discharge. The shift correction is added to the recorded gage height for a positive shift.

A negative shift is sometimes referred to as a shift to the left because when plotted the shifted rating is to the left of the base rating. Similarly a positive shift can be referred to as a shift to the right.

One reason negative shifts occur is due to fill on the control.

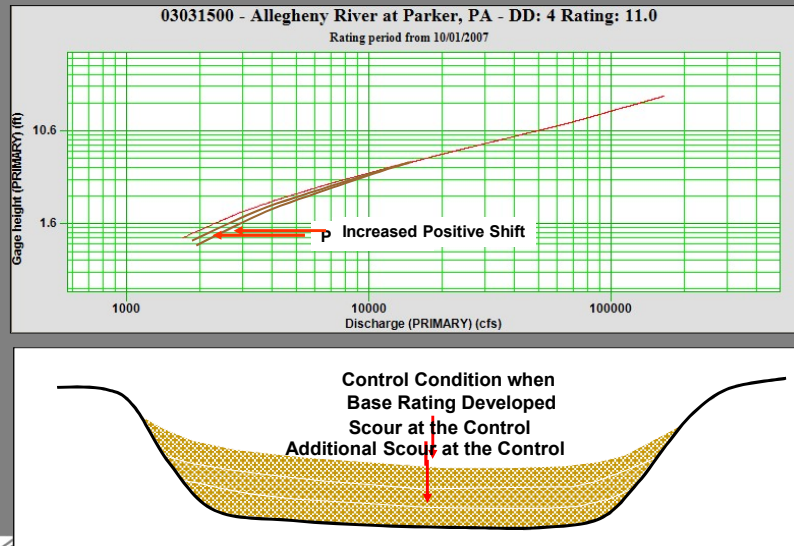


Negative shifts to the rating can occur for various reasons such as the fill of channel material on the control, debris piled on the control or seasonal algal or vegetative growth.

In this illustration, you can see as material is deposited on the control a negative shift will be needed to adjust the stage-discharge relation. As more fill is deposited on the control the amount of the shift needed to adjust the stage-discharge relation increases.

Imagine the discharge at a gaging station is constant over time and someone starts to build a rock dam on top of the section control. The gage height in the gage pool would increase even though the discharge would be the same. A shift correction would be needed, and would be applied by subtracting the shift from the gage height readings to determine the gage height to use in the rating to get the correct discharge.

Scour at the control is a reason for a positive shift.



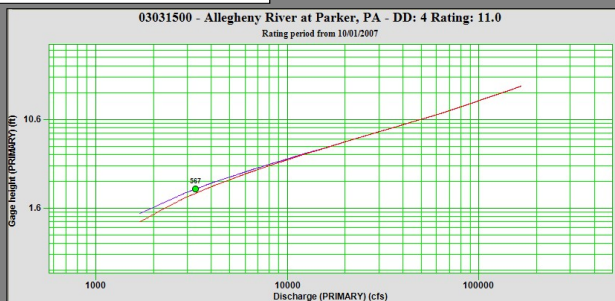
A positive shift or a shift to the right of the rating can be the result of scour at the control.

(click) In this example, a positive shift is applied to the rating as material is scoured or removed from the control section. (click) As more material is removed from the control section the positive shift continues to increase. A shift adjustment must be added to the gage height record to determine the correct discharge.

Control remarks on the measurement sheet can verify the reason for a shift.

Wading cable: ☒ Good upstr., downstr., side bridge ~ 700' ☒ min. span (downstr. of gage)	
Measurement rated: ☒ excellent (20%) ☒ good (50%) ☒ fair (20%) ☒ poor (10%) based on following conditions	
Flow	unsteady
Cross section:	fairly even / channel heavy on right bank
Control:	Rack Riffle (~1500 D.S.) - LIGHT DEBRIS - Grass in
Gage operating:	☒ Yr ☒ N Record removed: ☒ Yr ☒ N Filename: to CARD (starts 5/19)
Battery voltage:	13.53 Volts (Intake) ☒ min. span ☒ max. span ☒ min. span ☒ max. span NO
Bubble-gage psi:	Tank ☒ Line ☒ Bubble rate ☒ / min
Extreme-GH indicators:	Max ☒ Min ☒ CSG Checked ☒ Yr ☒ N
HWM on stick	Ref elev. ☒ HWM elevation ☒
GH of zero flow = GH	depth at control ☒ ft. ☒ Rated at
Meas. Flows -13.3% FROM Rt. No. 11.0	
Sheet No.	1 of 1 sheets

- Negative shift resulting from vegetative growth



Good control conditions remarks on the measurement and inspection forms during site visits provide essential information when doing rating analyses. The type of control, such as section, channel or overbank, should always be noted. Information about the location of a section control can be useful in determining if fill or scour of the control has occurred. Also, as much information as possible should be provided about the condition of the control during a measurement or inspection. The control condition notes help you decide if changes to the rating are permanent or temporary.

The Class Assessment Follows.

- The assessment that follows contains 10 questions.
- Once you have successfully completed tests for all modules you will be given instructions on how to print out a certificate that documents successful completion of the Surface Water Procedures Training Class



Stage-discharge relationships are commonly referred to as "rating".

- 1. Title
- 2. Content

Lesson Assessment

Quiz - 10 questions

Last modified: Sunday, July 23, 2017 at 8:56:15 PM

Properties

On passing, 'Finish' button: [Goes to next slide](#)

On failing, 'Finish' button: [Goes to slide](#)

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 **Edit Properties**

Lesson Assessment

End of class module

- Please close this window and take the next module, if needed.

