Determination of Existing Shift Modifications using the Standard Methods Automated Records Tool (SMART)

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# Introduction

The Standard Methods Automated Records Tool (SMART) is designed to automate many steps involved in the computation of continuous records of streamflow. This paper describes the methods used in SMART to apply shift corrections to a standard stage-discharge rating using a three-point shift-adjustment variation diagram (V-diagram). Specific steps that are described include how: to determine the optimum shift for a discharge measurement, to use the optimum shift to modify the existing V-diagram, to check the validity of the modified V-diagram, and to examine the gage-height record between measurements to determine when to apply the modified V-diagram. The flow chart of decisions and computations made by SMART is shown appendix A.

SMART is based on the Automated Records Tool (ART) originally developed by Indiana Water Science Center and used in several Water Science Centers. SMART, however, takes a more restrictive view of allowable shifting that is thought more hydraulically justifiable in a national application. Some of the shifts applied by ART will be rejected in SMART.

## Limitations

There are several limitations to the methodologies implemented in SMART. Three specific limitations relate to the application of shift corrections using a V-diagram. Shift corrections using V-diagrams can be applied only at sites with a standard stage-discharge rating. The method to create a V-diagram has not been implemented in SMART; only the method to modify an existing V-diagram. This method is designed to shift only the low-water section of the stage-discharge rating. Existing high-end shifts may be retained but will not be created or modified. ***SMART cannot be used as a substitute for the application of hydraulic knowledge by experienced hydrographers. In some cases SMART based shifts will require modifications. In ALL cases SMART based shifts need thorough review and evaluation.***

# Modifying an existing three-point shift-adjustment variation diagram

The steps to apply a shift correction using a V-diagram in SMART are;

1. Compute the optimum shift for the discharge measurement and compare that shift against the ratings,
2. Check the optimum shift against the existing V-diagram and modify the V-diagram subject to the SMART application rules,
3. Validate the modified V-diagram to assure that it has a valid slope and does not cross the stage-discharge rating,
4. Determine whether the modified V-diagram is applied on the rising or receding limb of the hydrograph and the date and time of the application, and
5. Apply the modified V-diagram.

Each of the first four steps will be discussed in more detail in this paper.

1. Computation of an optimum shift and comparison against existing shifted and base ratings

To compute the optimum shift SMART first calculates the percent difference between the measured discharge and both the current base (unshifted) and shift-adjusted ratings as retrieved from the National Water Information System (NWIS) database. The percent difference between the measured and rated discharges is computed using the equation

*percent difference = ((measured discharge – rated discharge) / rated discharge) x100 (eq 1)*

This percent difference is then compared to the percentage associated with the measurement uncertainty rating. Field personnel (hydrographers) rate the uncertainty of each discharge measurement based on site conditions and other criteria (Rantz in WSP 2175 Vol. 1, chapter 5 pp 179-183). The rating choices used by field personnel are;

* Excellent; uncertainty of two percent or less,
* Good; uncertainty ranging from more than 2 percent to five percent,
* Fair; uncertainty ranging from more than 5 percent to eight percent, or
* Poor; uncertainty more than eight percent.

SMART treats a measurement with an uncertainty of poor as if the uncertainty rating is fair.

If the actual percent difference between measured and rated discharge is less than or equal to the uncertainty rating, the measurement is considered to confirm either the base or shift adjusted rating. SMART performs this check initially against the current shift-adjusted rating. If the shift-adjusted rating is confirmed the optimal shift is set to the existing shift at the measurement gage height. This will lead to continuation of the existing shift. If the current shift-adjusted rating is not confirmed by the measurement then a further check is made against the base rating. If the measurement confirms the base rating the optimum shift for that discharge measurement is set to zero. This will lead to no shift being applied.

If the discharge measurement does not confirm the current shift-adjusted or base stage-discharge rating, the optimum shift for the discharge measurement is computed using the current base stage-discharge rating. The rated discharge is found and the gage height associated with the discharge is used to compute the optimum shift. The optimum shift is computed using the equation.

*Optimum shift = rating gage height – measurement gage height (eq 2)*

1. Modification of the shift-adjustment variation diagram

The existing three-point V-diagram is modified by adjusting the shift associated with the upper, base, and lower points but not the gage height associated with those points. The upper, base, and lower point gage heights are identified by the hydrographer based on an analysis of the channel and overbank geometry and rating characteristics and should not be automatically modified by any process that does not respect that analysis.

Two shapes of V-diagrams are modified using the procedures employed in SMART. They are the “half house” and the “truss” shaped V-diagrams (Figure 1). A third shape of V-diagram, the “reversed half house,” is not modified by SMART as SMART is limited to modifications to the lower end of the rating. The following sections describe the methodology for modifying each of these V-diagram shapes with different measurement gage heights.

Figure .– The two shapes of V-diagrams (blue) which are modified by SMART and one (red) which is not.

### Shift Type 1: Half-house shaped shift-adjustment variation diagram

A half-house shaped V-diagram represents a condition in which the shifts associated with the base and lower points are equal. The shift associated with the upper point typically is equal to zero but does not have to be equal to zero.

#### Scenario 1A: Discharge measurement confirms the current shift

When the discharge measurement confirms the current shift, the current shift is continued in effect without modification.

Figure 2.– A half-house shaped V-diagram when the discharge measurement confirms the current shift.

#### Scenario 1B: Discharge measurement confirms the rating

When the discharge measurement confirms the rating and the measurement gage height is less than or equal to the upper point gage height of the existing V-diagram, the modified V-diagram is created by setting the shifts associated with the upper, base, and lower points of the existing V-diagram to zero. This method effectively converts any shaped V-diagram into a straight-line V-diagram but maintains the existing V-diagram’s upper, base, and lower point gage heights allowing the diagram to be modified when subsequent discharge measurements are processed. The dashed line in Figure 3 shows the modified V-diagram when measurement A is used to modify the existing V-diagram.

If the measurement gage height is greater than the existing V-diagram’s upper point gage height and the upper point shift is equal to zero, the base and lower point gage heights and shifts are not modified. If the upper point shift is not equal to zero the modified V-diagram is created by setting the upper point shift to zero.

Figure 3.– Modification of a half-house shaped V-diagram when the discharge measurement confirms the current stage-discharge rating and the measurement gage height is less than or equal to the upper point gage height of the existing V-diagram.

#### Scenario 1C: Measurement gage height is greater than or equal to the upper point gage height of the existing half-house shaped shift-adjustment variation diagram.

SMART does not modify the existing V-diagram when the measurement gage height is greater than the upper point gage height of the existing V-diagram and the upper point shift is equal to zero. For that condition SMART places a message in a summary that states the measurement gage height is greater than the upper point gage height and that the existing V-diagram will be used.

When the measurement gage height is greater than or equal to the existing V-diagram’s upper point gage height and the upper point shift is not equal to zero the modified V-diagram is created by setting the upper point shift to the optimum measurement shift. Figure 4 shows the modified V-diagram when measurement A is used to modify the existing V-diagram.

When the optimum shift for a discharge measurement is equal to zero and the upper point shift of the existing V-diagram is not equal to zero, the upper point shift of the modified V-diagram will be set equal to zero. Modifications by future discharge measurements will never again modify the upper point shift.

Figure 4.– Modification of a half-house shaped V-diagram when the measurement gage height is equal to the upper point gage height of the existing V-diagram and the upper point shift of the existing V-diagram is not equal to zero.

#### Scenario 1D: Measurement gage height is less than the upper point gage height and is greater than the base point gage height of the existing half-house shaped shift-adjustment variation diagram.

When the measurement gage height is greater than the base point gage height but less than the upper point gage height of the existing V-diagram, a line is developed using the existing V-diagram’s upper point gage height and shift and the measurement gage height and the optimum shift. The line is extended to the existing V-diagram’s base point gage height to determine the base point shift for the modified V-diagram. The lower point shift is set equal to the base point shift of the modified V-diagram. Figure 5 shows the modified V-diagram when measurement A is used to modify the existing V-diagram. The shift for the base point is computed using the equation

*newbaseshift = (baseght – (measght – ((upght – measght) / (upshift-measshift)) \* measshift)) /   
((upght – measght) / (upshift-measshift))* (eq 3)

where

newbaseshift = base point shift for the modified V-diagram

baseght = base point gage height of the existing V-diagram

measght = measurement gage height

upght = upper point gage height of the existing V-diagram

upshift = upper point shift of the existing V-diagram

measshift = optimum shift for the discharge measurement being processed

Figure 5– Modification of a half-house shaped V-diagram when the measurement gage height is greater than the base point gage height and less than the upper point gage height of the existing V-diagram.

#### Scenario 1E: Measurement gage height is equal to or less than the base point gage height of the existing half-house shaped shift-adjustment variation diagram

When the measurement gage height is equal to or less than base point gage height of the existing V-diagram, the base and lower point shifts of the modified V-diagram are set equal to the optimum shift. Figure 6 shows the modified V-diagram if measurements A, B, or C were used to modify the existing V-diagram. If measurement C is used to modify the existing V-diagram, the lower point gage height is not modified, only the lower point shift.

Figure 6.– Modification of a half-house shaped V-diagram when the measurement gage height is equal to or less than the base point gage height of the existing V-diagram.

### Shift Type 2: Truss shaped shift-adjustment variation diagram

A truss shaped V-diagram is one that the upper and base point shifts are not equal and the base and lower point shifts are not equal. Neither the upper or lower point shifts have to be zero.

#### Scenario 2A: Discharge measurement confirms the current shift

When the discharge measurement confirms the current shift, the current shift is continued in effect without modification.

Figure 7.– A truss shaped V-diagram when the discharge measurement confirms the shift.

#### Scenario 2B: Discharge measurement confirms the rating

If a discharge measurement confirms the rating and the measurement gage height is less than or equal to the upper point gage height of the existing V-diagram, the shifts associated with the upper, base, and lower points are set equal to zero of the modified V-diagram. This method effectively converts the truss shaped V-diagram into a straight-line V-diagram but maintains the existing V-diagram’s gage heights permitting the modified V-diagram to be adjusted when subsequent discharge measurements are processed. Figure 8 shows the modified V-diagram after measurement A is used to modify the existing V-diagram. Once the truss shaped V-diagram has been converted to a straight line V-diagram, subsequent measurements will modify the existing V-diagram as if it were a standard half-house diagram.

Figure 8.– Modification of a truss shaped V-diagram when the discharge measurement confirms the current discharge rating.

#### Scenario 2C: Measurement gage height is greater than or equal to the upper point gage height of the existing truss shaped shift-adjustment variation diagram

When the measurement gage height is equal to or greater than the upper point gage height of the existing V-diagram and the upper point shift is not equal to zero, the upper point shift of the modified V-diagram is set equal to the optimum shift. Figure 9 shows the modified V-diagram when measurements A or B are used to modify the existing V-diagram when the upper point shift is not equal to zero. If the upper point shift for the existing V-diagram were zero no changes to the existing V-diagram would be made for either measurement A or B. If the upper point shift is zero that shift will never be changed by SMART.

Figure 9.– Modification of a truss shaped V-diagram when the measurement gage height is equal to or greater than the upper point gage height of the existing V-diagram.

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#### Scenario 2D: Measurement gage height is less than the upper point gage height and greater than or equal to the base point gage height of the existing truss shaped shift adjustment variation diagram.

When the measurement gage height is greater than the base point gage height but less than the upper point gage height of the existing V-diagram, a line is developed using the upper point gage height and shift and the measurement gage height and the optimum shift. The line is extended to the base point gage height of the existing V-diagram to determine the base point shift for the modified V-diagram. No change is made to the upper or lower point shifts of the modified V-diagram. Figure 10 shows the modified V-diagram when measurement A was used to modify the existing V-diagram. Equation 3 was used to compute the base point shift for the modified V-diagram. If the measurement gage height is equal to the base point gage height the base point shift of the modified V-diagram is set equal to the optimum shift.

Figure 10.– Modification of a truss shaped V-diagram when the measurement gage height is greater than the base point gage height and less than the upper point gage height of the existing V-diagram.

#### Scenario 2E: Measurement gage height is less than the base point gage height but greater than the lower point gage height of the existing truss shaped shift-adjustment variation diagram.

When the measurement gage height is less than the base point gage height but greater than the lower point gage height of the existing V-diagram, a line is developed using the lower point gage height and shift and the measurement gage height and the optimum shift. The line is extended to the base point gage height of the existing V-diagram to determine the base point shift for the modified V-diagram. Equation 4 was used to determine the base point shift of the modified V-diagram. Figure 11 shows the modified V-diagram when measurement A was used to modify the existing V-diagram.

Figure 11.– Modification of a truss shaped V-diagram when the measurement gage height is less than the base point gage height and greater than the lower point gage height of the existing V-diagram.

#### Scenario 2F: Measurement gage height is equal to or less than the lower point gage height of the existing truss shaped shift adjustment variation diagram

When the measurement gage height is equal to or less than the existing V-diagram’s lower point gage height the lower point shift of the modified V-diagram is set equal to the optimum shift. Figure 12 shows the modified V-diagram when measurement A or B were used to modify the existing V-diagram. If the lower point shift of the existing V-diagram in Figure 12 had been equal to zero, the modified V-diagrams for measurements A and B would be the same.

Figure 12.– Modification of a truss shaped V-diagram when the measurement gage height is equal to or less than the lower point gage height of the existing V-diagram.

#### Scenario 2G: Optimal shift is on the opposite side of the rating from the truss-shaped shift

When the optimum shift is on the opposite side of the rating from the existing V-diagram the existing shift is not changed. These types of hydraulic transitions require detailed analysis by a hydrographer and are not appropriate for automatic shift application by SMART.

Figure 13.– A truss shaped V-diagram when the optimum shift is on the opposite side of the rating from the existing truss-shaped shift.

### Shift Type 3: Reversed half house shift-adjustment variation diagram

As stated above, these shifts are not adjusted by SMART. In all cases of an existing reversed half house diagram the existing shift will be continued regardless of the indicated shift and a message sent to the user.

### Shift Type 4: One and Two point shift-adjustment variation diagram

Two point V-diagrams are modified using the same procedures as the upper portion of the half-house V-diagram. If the existing V-diagram is a one point V-diagrams the shift for that modified V-diagram is always set equal to the optimum shift.

1. Validate the slope and position of the modified shift-adjustment variation diagram

Once the modified V-diagram has been created using SMART a check is made to verify that the modified V-diagram is valid. If the upper or lower limbs of the V-diagram are not a straight line the slopes of the lines are tested. The modified V-diagram is rejected when the slope is greater than 1.5 or less than -0.67 but greater than -1 (Bartlett, William, written communication). Also, if the slope of the line is less than -1.00 the modified shift diagram is rejected. (Bartlett, William, written communication). The slope of the upper limb is computed using the equation

 (eq 5)

where

slope = slope of the upper limb of the shift-adjustment variation diagram,

gup = upper gage height of the modified V-diagram,

gbp = base gage height of the modified V-diagram,

sup = upper gage height shift of the modified V-diagram, and

sbp = base gage height shift of the modified V-diagram.

The slope of the lower limb is computed using the equation

 (eq 6)

where

slope = slope of the lower limb of the shift-adjustment variation diagram,

sbp = base gage height shift of the modified V-diagram,

slp = lower gage height shift of the modified V-diagram,

gbp = base gage height of the modified V-diagram, and

glp = lower gage height of the modified V-diagram.

Using the modified V-diagram used in Figure 12 the slope of the upper limb would be

(0 – 0.35) / (5.25 – 3.50) = (-.35/1.75) = -0.2

and for the lower limb the slope would be

(.35 - .2) / (3.50 - .75) = (.15/2.75) = 0.055

A separate check is made to assure that the modified V-diagram does not cross the standard stage-discharge rating. This check compares upper and base point shifts of the modified V-diagram to identify whether one of the shifts is positive and the other is negative. A similar check is also made to identify whether the same condition exist for the lower and base point shifts. If the V-diagrams cross the rating the modified V-diagram is rejected and the existing V-diagram remains in effect.

1. Determine when a modified shift-adjustment variation diagram is applied

The transition from the existing V-diagram to the modified V-diagram occurs either during a peak event or is prorated between the previous and current discharge measurements if no peak event has occurred between the two measurements. A peak event is defined as any rise over 0.33 feet. This threshold is being used by all USGS staff where ART and SMART has been installed and has worked effectively in almost all cases.

When a modified V-diagram is applied to a peak event, how that V-diagram is applied depends on whether the shift is a “scour shift” or “fill shift”. Scour shifts are applied on the rising limb of the hydrograph as the stage increases and fill shifts are applied on the receding limb as the stage decreases. A shift is determined to be a fill or scour shift by looking at the differences between the base point shifts associated with the existing V-diagram and the modified V-diagram. A fill shift occurs when the modified V-diagram’s base point shift is greater than the existing V-diagram’s base point shift. A scour shift is when the modified V-diagram’s base point shift is less than the existing V-diagram’s base point shift. If the two base point shifts are equal the modified V-diagram is prorated between the previous and current discharge measurements.

For a scour shift, SMART will hold the existing V-diagram constant until the start of the rise in stage and prorate to the modified V-diagram over the rising limb with the modified V-diagram in full effect at the peak. SMART prepares the period to be approved and locked by adding the modified V-diagram at the date and time of the current discharge measurement.

For a fill shift, the current V-diagram is held constant until the peak and the modified shift-adjustment variation diagram is prorated into full effect using the upper or base point gage heights of the existing V-diagram. The fill shift is determined to be in full effect using one of two conditions. If the gage height of the peak stage is greater than the modified V-diagram’s upper point gage height, the fill shift is in full effect when the gage height falls below the modified V-diagram’s upper point gage height. If the peak is less than the upper point gage height, the base point gage height of the modified V-diagram is used as the point where the fill shift is in full effect. The period is prepared for approval and locking by adding the modified V-diagram at the date and time of the current discharge measurement.

The peak between the previous and current discharge measurement is the greatest value of gage height between the previous and current discharge measurement being processed. To find the peak the corrected unit value gage heights between the previous and current discharge measurements are retrieved. SMART evaluates the data from the date and time of the previous discharge measurement to that of the current discharge measurement to identify the maximum gage height. The maximum gage height between the two measurements is considered to be the peak gage height. To identify a peak event SMART steps back in time through the data from the peak gage height while keeping track of the minimum gage height recorded in the data—the current minimum gage height. SMART subtracts the current minimum gage height from the gage height being examined. If the result of this calculation is 0.33 feet or greater, SMART identifies the date and time of the current minimum gage height to be the beginning of the peak event.

This method has worked well for a vast majority of the discharge measurements processed using ART and SMART however; several limitations to its application have been identified. Figure 14 shows the results of this methodology when applied to a double peak, one of the methodology’s limitations. SMART identified the peak gage height and the preceding gage heights were examined until a reversal of 0.33 feet is found, as noted by the peak gage height, the beginning of rise in gage height, and reversal point (Figure 14). If the shift were a scour shift it would be acceptable, and in some cases preferable, for the current V-diagram to be held constant to the beginning of the initial rise, not at the reversal between the first and second peaks.

If the example V-diagrams used throughout this document were applied to this event then the point where SMART would bring a fill shift into full effect is noted by the shift full effect entry in Figure 14.

Figure 14.– Figure showing a gage-height hydrograph and the points used to apply a modified V-diagram.

# Program Limitations

Listed below are steps in SMART that need improvement in future releases.

* For each of the shapes of V-diagrams used by SMART a description is needed of the hydraulic conditions that would make such a V-diagram necessary. Descriptions of the hydrologic events that would create the modifications described are also needed. This information could be used to identify diagram shapes that are not hydraulically correct.
* When the gage heights associated with a V-diagram are not modified, the assumption that the points of a diagram will remain the same after a scour shift needs to be verified.
* After a measurement confirms a rating, a three point straight line V-diagram is created by SMART. Future modifications make a half-house shaped diagram. The assumption to only modified straight-line V-diagrams to half-house shaped diagrams needs to be reevaluated.
* Additional tests could be identified and included in SMART to assure that the modified V-diagram is valid.
* Improved methods are needed to determining when a peak event starts and stops.
* A process is needed to examine the stage-discharge rating to determine over what range of stage do control transitions occur and use this information when modifying a V-diagram.
* Processes to modify the shifting mechanisms to account for other non-event based shifting, such as aquatic growth shifts.
* Better integration between SMART and SWAMI to facilitate the flow of information and decisions from the field to better guide SMART application.

# Summary

This report describes the procedures used by Standard Methods Automated Record Tool (SMART) to modify existing V-diagrams using a discharge measurement and the optimum shift for that measurement and to apply the modified V-diagram in computation of continuous records of streamflow. Described in the report are the steps used to compute the optimum shift for a discharge measurement and to determine whether the measurement confirms the rating or current V-diagram. Also described are the methodologies used by to modify the existing V-diagram when that diagram is in the shape of a half-house, reversed half house, or truss shaped shift-adjustment variation diagram. Described for each shaped V-diagram are the methodologies used to modify the existing V-diagram when the measurement gage height is

* greater than the upper gage height of the existing V-diagram,
* equal to the upper gage height of the existing V-diagram,
* between the base and upper gage heights of the existing V-diagram,
* equal to the base gage height of the existing V-diagram,
* between the base and lower gage height of the existing V-diagram,
* equal to the lower gage height of the existing V-diagram, or
* less than the lower gage height of the existing V-diagram.

Also described in the report are the procedures used by SMART to evaluate whether the modified V-diagram has an appropriate slope and when to apply the modified V-diagram when the shift is either a scour or fill shift.

# APPENDIX A—Flow chart showing the logic used by Indiana’s Automated Records Tool to compute a shift and modify the existing V-diagrams.























