DEPARTMENT OF ECOLOGY
State of Washington

Standard Operating Procedure EAP082, Version 1.2

Correction of Continuous Stage Records Subject to Instrument Drift

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Purpose of this document

The Washington State Department of Ecology develops Standard Operating Procedures (SOPs) to document agency practices related to sampling, field and laboratory analysis, and other aspects of the agency's technical operations.

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Correction of Continuous Stage Records Subject to Instrument Drift, Analysis of Instrument Drift, and Calculation of Potential Error in Continuous Stage Records

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SIGNATURES AVAILABLE UPON REQUEST

Please note that the Washington State Department of Ecology's Standard Operating Procedures (SOPs) are adapted from published methods, or developed by in-house technical and administrative experts. Their primary purpose is for internal Ecology use, although sampling and administrative SOPs may have a wider utility. Our SOPs do not supplant official published methods. Distribution of these SOPs does not constitute an endorsement of a particular procedure or method.

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Although Ecology follows the SOP in most instances, there may be instances in which Ecology uses an alternative methodology, procedure, or process.

SOP Revision History

Revision Date	Rev number	Summary of changes	Section	Reviser(s
10/5/2012	1.0	New SOP	all	Kammin
12/30/2015	1.1	Added language indicating newly developed automated error analysis application.	1.1	Shedd
12/30/2015	1.1	Added Sensitivity Drift Analysis and Correction method.	6.2.2.3	Shedd
12/30/2015	1.1	Updated References section.	10.2	Shedd
12/30/2015	1.1	Grammatical and formatting.	all	Shedd
12/31/2015	1.1	Recertified	all	Kammin
12/12/2018	1.2	Revised and updated sections	all	Shedd
3/15/2019	1.2	Formatting and accessibility updates.	all	Froese

1.0 Purpose and Scope

1.1 This Environmental Assessment Program (EAP) Standard Operating Procedure (SOP) describes methods of correcting continuous stage records subject to instrument drift. This document explains methods for identification, analysis, and management of various types of instrument drift occurring in continuous stage records. Methods of calculation for potential error caused by instrument drift are also discussed. An automated error analysis application developed after the initial writing of this document identifies and computes errors introduced to daily flow values caused by instrument drift. However, EAP staff must understand the basis of these calculations in order to correctly evaluate and apply the results of the error analysis application.

2.0 Applicability

2.1 EAP staff will follow this Standard Operating Procedure when correcting stage records to match gage height observations with corresponding points in the stage record.

2.2 Staff will follow the methods presented in this document to identify and analyze instrument drift. Refer to this document when analyzing and correcting potential error introduced to daily flow values caused by logger drift.

3.0 Definitions

3.1 Primary Gage Index (PGI): The most stable and reliable gage at a site, the PGI serves as the base gage for the station to which the recording gage is directly referenced. Consider all other gages at a station as secondary.

3.2 Gage Height: The water surface level, usually measured in hundredths of a foot on a readable stationary gage.

3.3 Calibration: The check of a measuring instrument against an accurate standard to determine any deviation, and then correct for errors. For purposes of the following discussions regarding calibration, the “measuring instrument” refers to the data logger. The “accurate standard” refers to the gage height of the PGI. “Correct for errors” in this context does not necessarily mean direct correction of the instrument in the field, rather the correction or accounting of errors in the stage record resulting from drift.

3.4 Potential Error**:** A calculated percentage expressing the highest probable error in the stage record for a designated period, usually a day or a year.

3.5 Drift: An undesired change in instrument output over time, not a function of real changes in water surface elevation (Freeman et al., 2004).

3.6 Stable Drift: A condition in which the calibration shift stabilizes over time and reflects a consistent difference between true gage height and instrument output. Note that stable drift can contain relatively small errors due to minor variations between gage height and instrument output.

3.7 Sensitivity Drift: A change in slope of the best fit straight line between an initial calibration and later calibrations where the differences between true gage height and instrument output changes linearly (Freeman et al., 2004). Sensitivity drift exhibits a clear pattern in the data, trending either upward (positive drift) or downward (negative drift) as stage increases or decreases, with a strong correlation between corrected stage and data shift.

3.8 Random Drift: A condition in which drift occurs, but lacks a specific type or identifiable cause. The amount of drift or the distance between corresponding points of initial and later calibrations are not consistent. We assume random drift occurs incrementally over time between calibrations.

3.9 Data Shift: A factor used to compensate for instrument drift that represents the difference between PGI observations and the logged stage record. These shift factors adjust the stage record to individual gage height observations. Data shifts are applied automatically to a data set whenever a report is generated from Hydstra™.

3.10 Aliased Data Set: In the context of this SOP, a raw stage dataset where the Hydstra™ parameter reference is changed to that of corrected stage without applying data shifts. This "aliased" data set is then compared to the original raw data set, to which data shifts are applied, to assess the magnitude of potential drift error.

4.0 Personnel Qualifications/Responsibilities

4.1 Users of this document will typically work in the Hydrogeologist job classification. Mostly those with Principle Investigator or Basin Lead responsibilities will apply the procedures presented herein. Sufficient training in the Hydstra™ data management software is required to perform the operations in this SOP.

5.0 Equipment, Reagents, and Supplies

5.1 An Ecology-issued computer with network and web access.

5.2 Access to Hydstra™ Time Series Management software.

6.0 Summary of Procedure

6.1 Correction of Instrument Drift

6.1.1 At the time a flow monitoring station is initially installed, the datalogger and transducer are calibrated so that the reported stage matches the water level read from the PGI. This equipment detects and reports fluctuating differences in gage height as flow increases or decreases at predetermined time intervals (typically 15 minutes). Over time, the value reported by the instrument may drift from the actual water level at the PGI resulting in an inaccurate stage record. If the record goes uncorrected, erroneously reported discharge values will result.

6.1.2 Depending on the type and severity of the drift, the logger may be reset to the observed PGI value in the field at the time of the gage height observation. However, field recalibrations should remain limited to circumstances when severe drift error, or damage or movement of station infrastructure occurs. If consistently severe random drift persists, take steps to mitigate the situation such as increasing sampling times, installing bubble chambers, and programming regular auto-purging on bubbler systems. Clean and, if necessary, replace submersible transducers. Check the mounting and calibration of radar levels. If severe drift conditions continue, consider repositioning infrastructure or moving the station to a more suitable location.

6.1.3 The underlying assumption in most cases of instrument drift is that it occurs incrementally over time. This assumption holds that the least amount of drift is found at the start of the data set or the initial calibration when the logger and PGI match, then progresses over time until reaching the next calibration point where the amount of drift is presumed greatest.

6.1.4 There are two ways to apply corrections to data sets in which drift has occurred: Time-weighted filter adjustments and data shift adjustments.

6.1.4.1 Time-Weighted Filter Adjustments

6.1.4.1.1 Largely outdated and no longer the preferred procedure, we only apply time-weighted filter adjustments in rare circumstances.

6.1.4.1.2 The time-weighted filter adjustment method uses explicit changes to the data set to correct continuous data incrementally from one observed stage height to the next. See Chapter 4 of the Hydstra™ User's Manual (Springer, 2004) for detailed instructions on applying time-weighted data adjustments.

6.1.5 Data Shift Adjustments

6.1.5.1 The current method for correcting stage height data uses the Hydstra™ data shift function to apply shift factors to correct for instrument drift. This method provides significant advantages over time-weighted filter adjustments, both in ease of use and immediacy of results. Data shift capabilities permit corrections to telemetered stage records immediately upon entry of independent PGI observations into Hydstra™. These corrections are automatically applied to both the archive and telemetry data records.

6.1.5.2 The use of data shifts renders the time-weighted adjustments mostly unnecessary. The current process for correcting continuous data is detailed in the Hydstra User's Manual Addendum A: "Preparing Continuous Data and Data Shifts for Annual Review" (Springer, 2010).

6.2 Analysis of Logger Drift

6.2.1 Prior to submittal of annual discharge records for senior-level review, carefully analyze the stage record as well as the Hydstra™ record of corrections to determine the types of drift occurring throughout the record. The type of drift will affect how the final stage record is edited, how daily error percentages are determined, and influence the overall evaluation of the quality of the discharge record.

6.2.2 There are three basic types of logger drift: random, sensitivity, and stable drift.

6.2.2.1 Random drift, characterized by contiguous differences between the record and PGI observations are not consistent in their magnitude. Random drift does not meet the requirements of stable drift described below. The differences between the stage record and PGI observations do not form a linear relationship consistent with sensitivity drift, also described below.

6.2.2.2 We adjust random drift in the final data record by applying either time-weighted filter adjustments or data shifts.

6.2.2.3 Sensitivity Drift Analysis and Correction

6.2.2.3.1 In preparation for the annual review process, analyze instrument drift using linear regression to determine whether or not sensitivity drift occurs at each station. Do this by regressing the corrected stage values against the data shifts in the Hydstra™ utility HYPLOTXY.

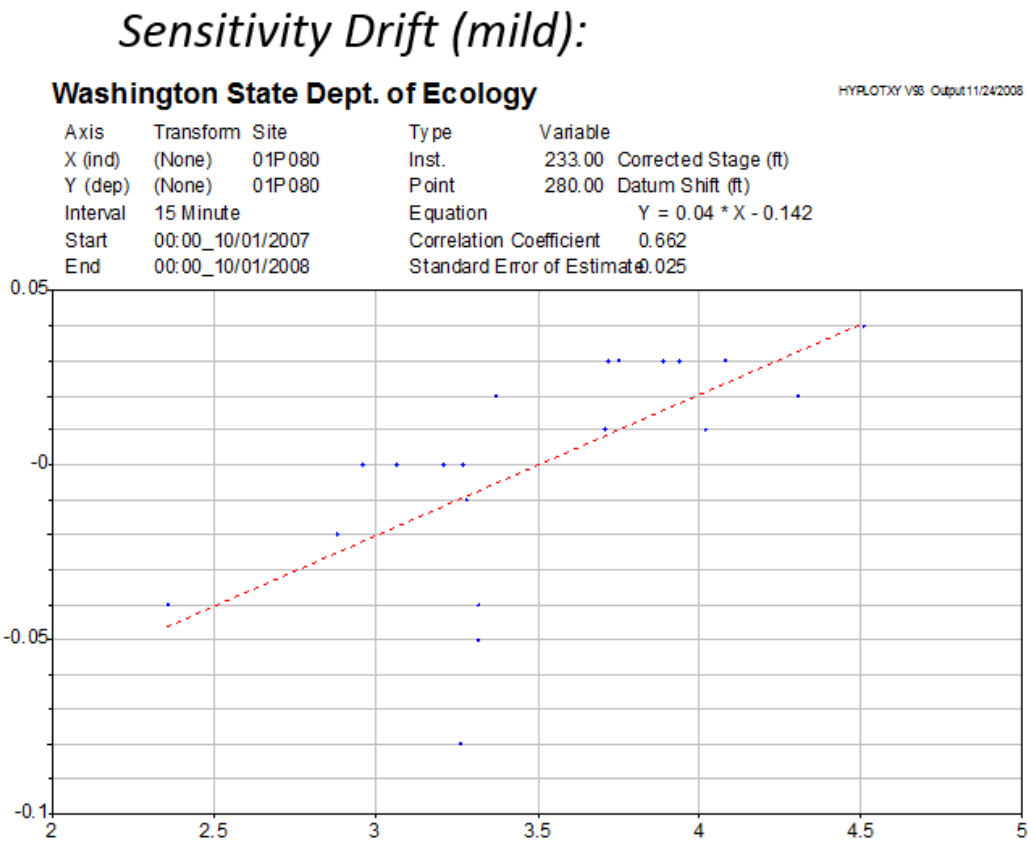

Figure 1. Prior to submitting records for review, analyze pressure transducer drift by regressing corrected stage values against data shifts to determine the magnitude of sensitivity drift at each station.

6.2.2.3.2 Sensitivity drift will exhibit a clear pattern in the data, trending either upward (positive drift) or downward (negative drift) as stage increases, and shows a strong correlation ($r \geq 0.80$) between corrected stage and data shift.

6.2.2.4 If sensitivity drift is found at a station, data shifts alone may not adequately correct it, as they may tend to underestimate the magnitude of drift at high flows. Use the results of the stage vs. data shift regression to derive a "drift curve" that varies the magnitude of drift by stage height. Steps for correcting sensitivity drift in a data set are detailed in the Hydstra™ User's Manual Addendum A: "Preparing Continuous Data and Data Shifts for Annual Review" (Springer, 2010).

6.2.2.5 Stable drift Analysis

6.2.2.5.1 Stable drift occurs when the difference between recorded stages and PGI observations remain steady and nearly equal over the course of two or more site visits.

6.2.2.5.2 Neglecting to address stable drift can result in substantial inaccuracies of published annual potential error determinations as well as inappropriate data quality assignments.

6.2.2.5.3 Consider periods of stable drift when assessing potential error caused by instrument drift. We define stable drift as a set of two or more contiguous differences between logger recordings and gage height observations where the range of differences between highest and lowest exceeds no more than 0.03 feet and the standard deviation of the differences do not exceed 0.015 feet.

6.2.2.5.4 The automated error analysis application, referred to in section 1.0 of this document identifies and computes stable drift errors and applies these errors to the daily record of potential error.

6.2.2.5.5 Stable drift error takes the form: $U = \frac{\sum_{n}^{i=1}\left|\left(\frac{x-y}{x}\right)\right|_i}{n} * 100$

Where U = mean error for the stable drift period expressed in percent
x= discharge corresponding to an observed gage height
y= discharge corresponding to offset logger value
n=number of x and y pairs in the stable drift period.

6.2.2.5.6 Offset logger value in the above equation is expressed in the form

$\emptyset = r - \frac{\sum_{n}^{i=1}(r-g)_i}{n}$

Where ∅=offset logger value (in feet)
r=raw logged stage value (in feet)
g=observed gage height value (in feet)
n=number of r and g pairs in stable drift period.

6.2.2.5.7 Appendix A provides a table and brief summation presenting the identification and calculation methods involved in computing stable drift error.

6.3 Potential Error Calculation and Quality Code Assignments

6.3.1 In finalizing water year data, we report the amount of potential error introduced to the record from instrument drift and assign an appropriate quality designation.

6.3.2 The automated error analysis application determines potential error due to instrument drift and calculates daily differences in predicted discharge between the aliased raw record and the original raw record.

6.3.3 To correctly calculate potential error through the automated error analysis application, do not include in the drift assessment erroneously recorded data due to instrument damage, low battery voltage, anomalous spikes, or any other invalid data. In addition, exclude periods of channel icing from the assessment. For periods of backwater condition, if a valid rating curve exists for the backwater period, include the continuous data for that period in the assessment. Otherwise, exclude these data from the assessment. While these circumstances may still produce a correct record of gage height, in the absence of a valid stage-discharge relationship the error calculations will be incorrect.

6.3.4 Treat stage records influenced by tidal spikes the same as normal stage records. While these spikes represent a temporary breakdown of the stage-discharge relationship, a comparison of tidally-influenced stations in Ecology's streamflow monitoring network showed an impact of less than 2% of total discharge.

6.3.5 In order to preclude erroneous data from reporting, assign a quality code of 200 to any erroneously recorded data in the aliased raw data set, as well as to periods with invalid stage and discharge relationships (i.e., backwater, ice-impacted, etc.). If erroneous data reports, the resulting calculated error does not reflect instrument drift even if data points match and the percent error is zero. Zero percent values computed from erroneous stage data and subsequently calculated in the annual drift error will cause an underestimation of the annual drift error. Erroneous data assigned quality code 200 will show up on the daily discharge table as a blank value and will be excluded from all calculations.

6.3.6 Potential error caused by instrument drift is calculated in the following form:

$$e = \frac{|y-x|}{x} * 100$$

Where e = the absolute value of the percent error between daily discharge reported from the raw record and discharge reported the aliased record. Thus,

x= mean daily reported discharge from the raw record (with data shifts applied) and

y= mean daily reported discharge from the aliased raw record.

6.3.6 Continuous stage data collected during periods of unstable drift are assigned quality codes based on the results of the automated error assessment. Quality codes derived from the error assessment application are determined using a tiered approach whereby the difference (*Diff Q*) and percent difference *(% Diff*) between raw and adjusted daily flow values are used to determine the appropriate quality code (*QC*):

Table 1. Quality codes are assigned to data sets based on a tiered approach depending on the difference and corresponding percent difference in daily flows between raw and adjusted data sets.

Tie	***% Diff***		***Diff Q***	***QC***
1	0-20%	OR	<0.5	2
2	≥20%	AN	≥0.5	50
3	≥50%	AN	≥5	164
4	≥100%	AN	≥50	179

6.3.7 Data must meet both the % Diff and Diff Q criteria to be coded according to that tier. If data meets one, but not both criteria, it falls into the tier above. For example, if a day has a difference of 100% and a difference in Q < 5 cfs, that meets the criteria for tier 2, and thus coded 50. If the difference was >100% and the difference in Q was greater than 5 cfs but less than 50 cfs, it would get a code 164. In order for the data to be coded 179, it would have to have a percent difference greater than 100% and a difference in discharge greater than 50 cfs.

6.3.8 Quality codes are applied on a daily basis. If a day meets the criteria for a given tier, all stage values for that day are coded according to that tier.

6.3.8.1 For a detailed description of how to apply quality codes to the continuous record, refer to the Hydstra™ User's Manual (Springer, 2004).

7.0 Records Management

7.1 Several databases in the Hydstra™ Time Series Management Software store continuous stage records, instantaneous gage height observations, and applied data shifts.

7.2 It is possible to compile Data Review Worksheets at any time as these are produced from stored records in the Hydstra™ Time Series Management Software.

7.3 Sensitivity drift regression run in the Hydstra™ regression analysis package HYPLOTXY are saved in a graphics format such as jpeg.

7.4 Typically, staff will store analyses of instrument drift including stable drift analysis in Microsoft© Excel® workbooks.

7.5 All electronic files and Hydstra™ related materials are saved to a folder on a network server. The contents of this server are backed up daily to prevent data loss.

8.0 Quality Control and Quality Assurance Section

8.1 Senior staff, through the senior-level review process, evaluate all submitted records and data analyses materials for accuracy and compliance with the methods presented in this document.

9.0 Safety

9.1 Most of the work described in this document takes place in an office setting. Staff will follow building and office safety policies and procedures when working in the office. Refer to the agency Safety Manual (Washington Department of Ecology, 2017) for information regarding building and office safety.

9.2 When collecting streamflow information in the field, staff will follow all EAP safety policies and guidelines. Refer to the EAP Safety Manual (EAP, 2017) for further information.

10.0 References

10.1 Freeman, L., M. Carpenter, D. Rosenberry, J. Rousseau, R. Unger, and J. McLean. 2004. Use of Submersible Pressure Transducers in Water-Resources Investigations: Chapter A of Book 8, Instrumentation Section A: Instruments for Measurement of Water Level. United States Geological Survey, Publication.

10.2 Environmental Assessment Program. 2017. Environmental Assessment Program Safety Manual, March, 2017. Washington State Department of Ecology, Olympia.

10.3 Washington Department of Ecology. 2017. Washington Department of Ecology Safety Program Manual, April, 2017. Washington State Department of Ecology, Olympia.

10.4 Springer, C. 2004. HYDSTRA™ Version 9.0 Users' Manual, 2nd Revision. Unpublished Internal Document. Environmental Assessment Program, Washington State Department of Ecology, Olympia.

10.5 Springer, C. 2010. Preparing Continuous Data and Data Shifts for Annual Review, Revised November 2010. Addendum to HYDSTRA™ Version 9.0 Users' Manual, 2nd Revision. Unpublished Internal Document. Environmental Assessment Program, Washington State Department of Ecology, Olympia.

Appendix A

Table A-1 below shows the analysis of 31 samples submitted by Freshwater Monitoring Unit staff. The samples submitted consisted of date and time stamped logger recordings and corresponding primary gage index (PGI) observations. The samples were subjectively identified by staff as stable drift periods.
Described in section 6.2.2.4.3, the criteria of range (0.03 ft.) and standard deviation (0.015 ft.) are the respective averages of the 31 sample sets. As a result, 22 of the samples met or exceeded the average range and standard deviation of the 31 samples. The 22 samples meeting the criteria yielded a mean error of 2.4 percent.

The true error of any stable drift period may be higher or lower than the 2.4 percent figure. The high and low error values in the sample set were 8.4 and 0.4 percent respectively. The standard deviation of the 2.4 percent average was 1.9 percent. The median error was 2.1 percent.

Date	Log St.	Log St. Q	Obs St.	Obs St. Q	Diff Ft.	Avg.Diff Ft.	Log-Avg. Diff Ft.	Log-Avg. Diff Ft. Q	% Diff	Diff Ft. STDEV	Range	Notes
Sample 1	**35L050 (from rating 10)**											
2/19/2008	5.73	27.5	4.96	10.6	0.77	0.78	4.95	10.4	**1.89**	**0.014**	**0.02**	
2/28/2008	5.69	26.4	4.9	9.11	0.79	0.78	4.91	9.36	**2.74**			
								Average	**2.32**			
Sample 2	**01A140 (from rating 5)**											
10/11/2007	7.61	2821	7.01	1688	0.6	0.61	7	1673	**0.89**	**0.014**	**0.02**	
10/25/2007	8.13	4433	7.51	2593	0.62	0.61	7.52	2615	**0.85**			
								Average	**0.87**			
Sample 3	**01A140 (from rating 5)**											
11/8/2007	7.34	2250	6.56	1060	0.78	0.8	6.54	1035	**2.36**	**0.028**	**0.04**	
11/15/2007	7.49	2551	6.67	1200	0.82	0.8	6.69	1226	**2.17**			
Sample 4	**01A140 (from rating 2)**											
12/13/2007	8.21	4776	6.42	966	1.79	1.80	6.41	956	**1.04**	**0.013**	**0.03**	
12/18/2007	8.16	4559	6.36	909	1.8	1.80	6.36	909	**0.00**			
1/3/2008	8.06	4151	6.26	823	1.8	1.80	6.26	823	**0.00**			
1/24/2008	7.84	3418	6.02	649	1.82	1.80	6.04	661	**1.85**			
								Average	**0.72**			
Sample 5	**01A140 (from rating 2)**											
2/6/2008	5.93	595	5.81	531	0.12	0.10	5.83	540	**1.69**	**0.019**	**0.05**	
2/14/2008	6.39	937	6.29	848	0.1	0.10	6.29	848	**0.00**			
2/28/2008	6.2	775	6.1	700	0.1	0.10	6.10	700	**0.00**			
3/13/2008	6.64	1198	6.56	1109	0.08	0.10	6.54	1087	**1.98**			
3/19/2008	6.32	874	6.2	775	0.12	0.10	6.22	791	**2.06**			
4/3/2008	5.99	630	5.92	589	0.07	0.10	5.89	572	**2.89**			
4/10/2008	6.03	655	5.91	583	0.12	0.10	5.93	595	**2.06**			
4/24/2008	6.07	680	5.97	618	0.1	0.10	5.97	618	**0.00**			
Sample 6	**01A140 (from rating 2)**											
4/29/2008	6.93	1571	6.92	1556	0.01	0.03	6.90	1528	**1.80**	**0.017**	**0.03**	
4/30/2008	6.79	1381	6.75	1330	0.04	0.03	6.76	1342	**0.90**			
5/13/2008	6.72	1293	6.68	1245	0.04	0.03	6.69	1257	**0.96**			
Sample 7	**01C070 (from rating 4)**											
10/7/2007	2.19	21.6	2.16	20	0.03	0.03	2.16	20	**0.00**	**0.013**	**0.04**	
10/25/2007	2.8	62.5	2.76	59.2	0.04	0.03	2.77	60	**1.35**			
11/1/2007	2.38	33.9	2.36	32.8	0.02	0.03	2.35	32.3	**1.52**			
11/8/2007	2.43	36.6	2.42	36.1	0.01	0.03	2.40	35	**3.05**			
11/8/2007	2.43	36.6	2.4	35	0.03	0.03	2.40	35	**0.00**			
11/16/2007	3.28	113	3.25	109	0.03	0.03	3.25	109	**0.00**			
11/16/2007	3.3	116	3.25	109	0.05	0.03	3.27	112	**2.75**			
								Average	**1.24**			

Sample 8	**01C070 (from rating 4)**											
12/4/2007	3.41	131	3.31	117	0.1	0.07	3.34	121	**3.42**	**0.019**	**0.05**	
12/6/2007	2.97	78	2.89	70.4	0.08	0.07	2.90	71.3	**1.28**			
12/13/2007	2.5	40.8	2.44	37.2	0.06	0.07	2.43	36.6	**1.61**			
12/17/2007	2.81	63.3	2.76	59.2	0.05	0.07	2.74	57.6	**2.70**			
1/3/2008	2.82	64.2	2.75	58.4	0.07	0.07	2.75	58.4	**0.00**			
Sample 9	**01C070 (from rating 5)**											
3/19/2008	2.66	64.7	2.55	57	0.11	0.12	2.54	56.3	**1.23**	**0.010**	**0.02**	
4/3/2008	2.53	55.7	2.41	47.5	0.12	0.12	2.41	47.5	**0.00**			
4/10/2008	2.61	61.1	2.48	52.4	0.13	0.12	2.49	53.1	**1.34**			
								Average	**0.85**			
Sample 10	**01C070 (from rating 2)**											
10/10/2006	0.84	5.05	0.83	4.87	0.01	0.01	0.83	4.87	**0.00**	**0.005**	**0.01**	
10/19/2006	0.88	5.8	0.87	5.61	0.01	0.01	0.87	5.61	**0.00**			
10/23/2006	0.86	5.42	0.86	5.42	0	0.01	0.85	5.23	**3.51**			
10/25/2006	0.87	5.61	0.87	5.61	0	0.01	0.86	5.42	**3.39**			
10/31/2006	0.91	6.42	0.9	6.21	0.01	0.01	0.90	6.21	**0.00**			
								Average	**1.38**			
Sample 11	**01C070 (from rating 3)**											
11/20/2006	2.4	79.6	2.26	60	0.14	0.14	2.26	60	**0.00**	**0.015**	**0.03**	
12/4/2006	2.2	52.4	2.08	39.3	0.12	0.14	2.06	37	**5.85**			
12/12/2006	2.93	178	2.78	146	0.15	0.14	2.79	148	**1.37**			
								Average	**2.41**			
Sample 12	**01C070 (from rating 3)**											
12/19/2006	2.63	117	2.36	73.7	0.27	0.26	2.38	76.6	**3.93**	**0.021**	**0.03**	
1/2/2007	2.88	167	2.64	119	0.24	0.26	2.63	117	**1.68**			
Sample 13	**01C070 (from rating 3)**											
1/18/2007	2.1	41.4	2.17	48.9	-0.07	-0.06	2.16	47.8	2.25	0.012	0.02	
1/23/2007	2.59	110	2.64	119	-0.05	-0.06	2.65	121	**1.68**			
2/1/2007	2.03	33.9	2.1	41.4	-0.07	-0.06	2.09	40.4	**2.42**			
								Average	**2.12**			
Sample 14	**01A140 (from rating 3)**											
10/10/2006	4.11	302	4.09	292	0.02	0.02	4.09	292	**0.00**	**0.015**	**0.03**	
10/19/2006	4.26	377	4.26	377	0	0.02	4.24	367	**2.65**			
10/25/2006	4.2	348	4.17	332	0.03	0.02	4.18	337	**1.51**			
								Average	**1.39**			
Sample 15	**01A140 (from rating 2)**											
12/12/2006	7.29	2157	7.5	2572	-0.21	-0.22	7.51	2593	**0.82**	**0.020**	**0.06**	

12/19/2006	6.84	1447	7.1	1829	-0.26	-0.22	7.06	1765	3.50			
1/2/2007	7.89	3561	8.1	4311	-0.21	-0.22	8.11	4351	0.93			
1/9/2007	7.02	1703	7.24	2067	-0.22	-0.22	7.24	2067	0.00			
1/18/2007	6.33	882	6.54	1087	-0.21	-0.22	6.55	1098	1.01			
1/23/2007	7.08	1797	7.29	2157	-0.21	-0.22	7.30	2175	0.83			
2/1/2007	6.26	823	6.47	1015	-0.21	-0.22	6.48	1025	0.99			
2/13/2007	6.37	918	6.58	1131	-0.21	-0.22	6.59	1142	0.97			
2/20/2007	7.2	1997	7.46	2488	-0.26	-0.22	7.42	2407	3.26			
3/1/2007	6.25	815	6.45	995	-0.2	-0.22	6.47	1015	2.01			
3/6/2007	6.42	966	6.64	1198	-0.22	-0.22	6.64	1198	0.00			
Sample 16	**28C110 (from rating 1)**											
12/12/2006	4.27	2.75	4.35	4.49	-0.08	-0.07	4.34	4.31	4.01	0.014	0.02	
12/19/2006	4.28	2.98	4.34	4.31	-0.06	-0.07	4.35	4.49	4.18			
								Average	4.09			
Sample 17	**28C110 (from rating 1)**											
8/21/2008	4.31	3.68	4.43	6.17	-0.12	-0.15	4.46	6.91	11.99	0.021	0.06	
8/26/2008	4.2	1.5	4.35	4.49	-0.15	-0.15	4.35	4.49	0.00			
9/9/2008	4.13	0.715	4.31	3.68	-0.18	-0.15	4.28	2.98	19.02			
9/23/2008	4.16	1.04	4.33	4.12	-0.17	-0.15	4.31	3.68	10.68			
9/24/2008	4.15	0.925	4.31	3.68	-0.16	-0.15	4.30	3.43	6.79			
10/6/2008	4.24	2.15	4.39	5.27	-0.15	-0.15	4.39	5.27	0.00			
10/23/2008	4.17	1.14	4.3	3.43	-0.13	-0.15	4.32	3.94	14.87			
Sample 18	**28C110 (from rating 1)**											
5/18/2009	4.52	8.58	4.46	6.91	0.06	0.06	4.46	6.91	0.00	0.008	0.02	
5/18/2009	4.5	7.99	4.45	6.66	0.05	0.06	4.44	6.42	3.60			
6/1/2009	4.45	6.66	4.39	5.27	0.06	0.06	4.39	5.27	0.00			
6/1/2009	4.45	6.66	4.38	5.06	0.07	0.06	4.39	5.27	4.15			
								Average	1.94			
Sample 19	**32A120 (from rating 12)**											
6/12/2008	4.7	711	4.48	617	0.22	0.24	4.46	609	1.30	0.011	0.03	
6/16/2008	4.16	495	3.94	421	0.22	0.24	3.92	414	1.66			
6/19/2008	3.76	365	3.53	299	0.23	0.24	3.52	296	1.00			
6/26/2008	3.06	181	2.83	131	0.23	0.24	2.82	129	1.53			
7/3/2008	2.55	75.9	2.3	42.4	0.25	0.24	2.31	43.6	2.83			
7/10/2008	2.21	33.3	1.97	14.5	0.24	0.24	1.97	14.5	0.00			
7/17/2008	2.16	28.8	1.91	11.5	0.25	0.24	1.92	11.9	3.48			
7/23/2008	2.33	45.9	2.08	21.8	0.25	0.24	2.09	22.6	3.67			
7/31/2008	2.23	35.2	1.99	15.7	0.24	0.24	1.99	15.7	0.00			
8/7/2008	2.23	35.2	1.98	15.1	0.25	0.24	1.99	15.7	3.97			
8/14/2008	2.19	31.5	1.94	12.9	0.25	0.24	1.95	13.4	3.88			

8/21/2008	2.45	61.5	2.2	32.4	0.25	0.24	2.21	33.3	2.78			
8/28/2008	2.14	26.9	1.89	10.6	0.25	0.24	1.90	11	3.77			
9/4/2008	2.34	47.1	2.1	23.4	0.24	0.24	2.10	23.4	0.00			
9/10/2008	2.31	43.6	2.07	21.1	0.24	0.24	2.07	21.1	0.00			
9/18/2008	2.31	43.6	2.06	20.4	0.25	0.24	2.07	21.1	3.43			
9/25/2008	2.55	75.9	2.3	42.4	0.25	0.24	2.31	43.6	2.83			
								Average	2.13			
Sample 20	**32A120 (from rating 12)**											
10/3/2008	2.43	58.9	2.18	30.7	0.25	0.25	2.18	30.7	0.00	0.004	0.01	
10/10/2008	2.42	57.7	2.17	29.8	0.25	0.25	2.17	29.8	0.00			
10/17/2008	2.35	48.3	2.1	23.4	0.25	0.25	2.10	23.4	0.00			
10/21/2008	2.32	44.7	2.07	21.1	0.25	0.25	2.07	21.1	0.00			
11/2/2008	2.41	56.3	2.16	28.8	0.25	0.25	2.16	28.8	0.00			
11/7/2008	2.49	67	2.24	36.2	0.25	0.25	2.24	36.2	0.00			
11/14/2008	3.15	201	2.9	148	0.25	0.25	2.90	148	0.00			
11/21/2008	2.59	82.4	2.34	47.1	0.25	0.25	2.34	47.1	0.00			
11/28/2008	2.61	85.8	2.36	49.6	0.25	0.25	2.36	49.6	0.00			
12/7/2008	2.78	119	2.54	74.3	0.24	0.25	2.53	72.8	2.02			
12/10/2008	3.03	174	2.79	122	0.24	0.25	2.78	119	2.46			
								Average	0.41			
Sample 21	**32A120 (from rating 12)**											
2/28/2009	3.44	274	3.4	264	0.04	0.05	3.39	261	1.14	0.013	0.03	
3/2/2009	3.55	304	3.51	293	0.04	0.05	3.50	290	1.02			
3/3/2009	3.83	386	3.78	371	0.05	0.05	3.78	371	0.00			
3/13/2009	3.16	204	3.09	187	0.07	0.05	3.11	192	2.67			
3/20/2009	3.67	339	3.61	321	0.06	0.05	3.62	324	0.93			
3/27/2009	3.96	427	3.92	414	0.04	0.05	3.91	411	0.72			
								Average	1.08			
Sample 22	**32A120 (from rating 13)**											
6/12/2009	3.03	129	2.96	116	0.07	0.07	2.96	116	0.00	0.005	0.01	
6/19/2009	2.81	87	2.74	75.7	0.07	0.07	2.74	75.7	0.00			
6/25/2009	2.47	41	2.4	34.3	0.07	0.07	2.40	34.3	0.00			
7/2/2009	2.14	15	2.06	10.7	0.08	0.07	2.07	11.2	4.67			
7/13/2009	2.33	28.4	2.26	22.8	0.07	0.07	2.26	22.8	0.00			
7/22/2009	2.11	13.4	2.04	9.7	0.07	0.07	2.04	9.7	0.00			
7/31/2009	2.08	11.7	2	8.01	0.08	0.07	2.01	8.41	4.99			
8/14/2009	2.22	20	2.14	15	0.08	0.07	2.15	15.5	3.33			
								Average	1.62			
Sample 23	**32A120 (from rating 13)**											
8/28/2009	2.16	16.1	2.08	11.7	0.08	0.07	2.09	12.2	4.27	0.012	0.02	
9/11/2009	2.23	20.7	2.17	16.7	0.06	0.07	2.16	16.1	3.59			

9/25/2009	2.22	20	2.14	15	0.08	0.07	2.15	15.5	3.33			
								Average	3.73			
Sample 24	**03B075 (from rating 1)**											
3/23/2006	3.79	74.9	3.8	76.2	-0.01	-0.01	3.80	76.2	0.00	0.012	0.03	
4/19/2006	4.17	127	4.17	127	0	-0.01	4.18	128	0.79			
6/7/2006	3.83	80.1	3.86	84.1	-0.03	-0.01	3.84	81.4	3.21			
8/9/2006	3.22	22.4	3.22	22.4	0	-0.01	3.23	23	2.68			
9/20/2006	3.18	20.1	3.19	20.6	-0.01	-0.01	3.19	20.6	0.00			
								Average	1.34			
Sample 25	**03B075 (from rating 2)**											
2/21/2007	5.32	370	5.34	375	-0.02	-0.02	5.34	375	0.00	0.006	0.01	
4/11/2007	4.12	119	4.14	122	-0.02	-0.02	4.14	122	0.00			
4/30/2007	4.21	133	4.24	138	-0.03	-0.02	4.23	136	1.45			
								Average	0.48			
Sample 26	**35L050 (from rating 13)**											
1/13/2009	5.29	18.2	5.23	16	0.06	0.08	5.21	15	6.25	0.014	0.04	
1/29/2009	4.91	2.57	4.84	1.34	0.07	0.08	4.83	1.21	9.70			
2/6/2009	4.94	3.26	4.84	1.34	0.1	0.08	4.86	1.62	20.90			
2/19/2009	4.85		4.76		0.09							Q values below rating (less than value shown)
2/24/2009	4.93	3.01	4.86	1.62	0.07	0.08	4.85	1.47	9.26			
3/9/2009	5.12	10.4	5.04	6.49	0.08	0.08	5.04	6.49	0.00			
3/23/2009	5.23	16	5.16	12.4	0.07	0.08	5.15	11.9	4.03			
								Average	8.36			
Sample 27	**35L050 (from rating 11)**											
4/24/2009	5.11	12	5.02	9.52	0.09	0.09	5.02	9.52	0.00	0.010	0.03	
5/10/2009	5.03	9.78	4.95	7.9	0.08	0.09	4.94	7.68	2.78			
5/13/2009	5.01	9.27	4.91	7.06	0.1	0.09	4.92	7.26	2.83			
6/5/2009	4.8	5.09	4.71	3.65	0.09	0.09	4.71	3.65	0.00			
6/17/2009	4.71	3.65	4.64	2.73	0.07	0.09	4.62	2.5	8.42			
6/23/2009	4.74	4.1	4.65	2.85	0.09	0.09	4.65	2.85	0.00			
								Average	2.34			
Sample 28	**35L050 (from ratings 11, 12 and 13)**											
7/20/2009	4.58	2.09	4.5	1.35	0.08	0.08	4.50	1.35	0.00	0.005	0.01	Rating 11
8/10/2009	4.87	3.06	4.78	1.35	0.09	0.08	4.79	1.49	10.37			Rating 12
8/22/2009	4.92	3.6	4.84	1.9	0.08	0.08	4.84	1.9	0.00			Phased Period*
8/30/2009	4.95	4.39	4.87	2.42	0.08	0.08	4.87	2.42	0.00			Phased Period*
9/14/2009	4.93	3.85	4.85	2.06	0.08	0.08	4.85	2.06	0.00			Phased Period*
9/22/2009	4.93	3.01	4.84	1.34	0.09	0.08	4.85	1.47	9.70			Rating 13

9/30/2009	4.93	3.85	4.84	1.9	0.09	0.08	4.85	2.06	**8.42**			Phased Period*
								Average	**4.07**			
Sample 29	**17C075 (from ratings 3 and 4)**											
12/21/2007	1.61	15.1	1.65	16	-0.04	-0.04	1.65	16.6	**3.75**	**0.009**	**0.02**	Rating 3
12/30/2007	1.45	9.95	1.48	10.8	-0.03	-0.04	1.49	11.1	**2.78**			Rating 3
1/4/2008	2.5	69.9	2.55	72.7	-0.05	-0.04	2.54	72.2	**0.69**			Rating 3
1/11/2008	1.9	28.5	1.95	31.4	-0.05	-0.04	1.94	30.8	**1.91**			Rating 4
1/17/2008	1.7	18.4	1.75	21	-0.05	-0.04	1.74	20.4	**2.86**			Rating 4
								Average	**2.40**			
Sample 30	**17C075 (from rating 4)**											
6/6/2008	1.61	14.3	1.62	14.7	-0.01	-0.02	1.63	15.1	**2.72**	**0.008**	**0.02**	
6/15/2008	1.51	10.4	1.53	11.2	-0.02	-0.02	1.53	11.2	**0.00**			
6/23/2008	1.4	4.24	1.42	5.07	-0.02	-0.02	1.42	5.07	**0.00**			
6/27/2008	1.36	2.94	1.38	3.54	-0.02	-0.02	1.38	3.54	**0.00**			
7/2/2008	1.33	1.99	1.36	2.94	-0.03	-0.02	1.35	2.59	**11.90**			
7/14/2008	1.3	1.33	1.31	1.53	-0.01	-0.02	1.32	1.74	**13.73**			
7/18/2008	1.28	1	1.31	1.53	-0.03	-0.02	1.30	1.33	**13.07**			
7/26/2008	1.27	0.87	1.3	1.33	-0.03	-0.02	1.29	1.16	**12.78**			
8/3/2008	1.28	1	1.3	1.33	-0.02	-0.02	1.30	1.33	**0.00**			
8/11/2008	1.28	1	1.3	1.33	-0.02	-0.02	1.30	1.33	**0.00**			
8/23/2008	1.26	1.64	1.29	2.17	-0.03	-0.02	1.28	2	**7.83**			Phased Period*
9/1/2008	1.25		1.28		-0.03							Phased Period*/ Q values below rating (less than value shown)
9/7/2008	1.22		1.25		-0.03							Phased Period*/ Q values below rating (less than value shown)
								Average	**5.64**			
Sample 31	**17C075 (from rating 4)**											
2/2/2008	1.38	3.54	1.42	5.07	-0.04	-0.05	1.43	5.53	**9.07**	**0.005**	**0.01**	
2/7/2008	1.48	8.53	1.52	10.8	-0.04	-0.05	1.53	11.2	**3.70**			
2/15/2008	1.57	12.7	1.62	14.7	-0.05	-0.05	1.62	14.7	**0.00**			
2/21/2008	1.49	9.28	1.54	11.6	-0.05	-0.05	1.54	11.6	**0.00**			
2/27/2008	1.45	6.59	1.5	10.1	-0.05	-0.05	1.50	10.1	**0.00**			
								Average	**2.56**			

Table A-1. Stable Drift Analysis

*Discharge values for observations during phased periods are averages of separate discharges at same stage between two phased ratings.

Stable Drift Analysis:

Average Standard Deviation = 0.013
Percent Average Diff obs st. Q = 2.4
Stdev of Percent Average Diff obs st. Q = 1.9
Average Range = 0.03

Log St. = logged stage at time of PGI observation.
Obs. St. = observed stage at PGI.
Obs. St. Q = discharge as read from active rating table corresponding to observed gage height value at PGI.
Diff. Ft. = difference between the logged stage value and the PGI observation.
Avg. Diff Ft. = average of the set of differences in feet.
Log-Avg. Diff Ft. = stage of difference between logged stage value and average difference in feet
Log-Avg. Diff Ft. Q = discharge as read from appropriate rating table corresponding to Log-Avg. Diff Ft. value
% Diff = difference in discharge expressed in percent between Obs. St. Q and Log-Avg. Diff Ft. Q
Average % Diff = average of the set of % differences in discharges between Obs. St. Q and Log-Avg. Diff Ft. Q
Diff Ft. STDEV = standard deviation of differences between logged stage value and PGI observation. Threshold value for stable drift consideration is 0.015 ft.
Range = difference between greatest Diff Ft. value and least Threshold value for stable drift consideration is 0.03 ft.

Samples with average % diff met the established criteria for standard deviation and range of diff Ft.