Herrera Environmental Consultants, Inc.

Memorandum

To	Project File 06-03509-002
From	Dylan Ahearn, Herrera Environmental Consultants
Date	August 8, 2010
Subject	Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **AG62**

This memorandum reviews hydrologic data collected at monitoring location AG62 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location AG62 represents agricultural land use in the Puyallup River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder
3. Water was added to the cylinder
4. Five measurements were taken with the pressure transducer, and the results were averaged
5. The average measured depth was compared with the manually measured depth to determine the percent error

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -1.0 percent to 0.0 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928006).

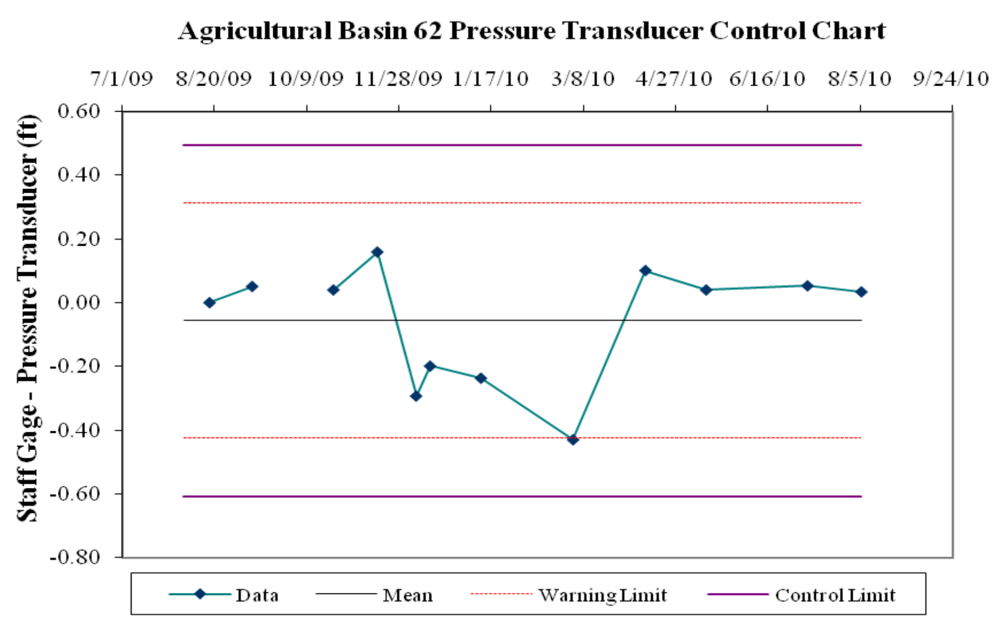
Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.385	1.4	-1.0
Post-monitoring	1.0	1.0	0.0

Sensor Drift and Displacement

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the water level sensors were conducted on 12 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift did not exceed the warning limit of plus or minus 1 standard deviation from the mean. The maximum drift measured between calibrations was 0.53 feet. However, this drift was not related to sensor error but rather a manual displacement of the sensor during the maintenance visit on March 10, 2010 (i.e., sensor was placed above the original location). To correct for both displacement and sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.



Gap in record indicates period of no flow.

Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the AG62 transducer are presented in Table 2 and Figure 2. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Table 2. Hydrologic data correction history for location AG62.

Date of Correction	User	From	To	Comment
10/28/2009 10:52	dyu	8/17/2009 14:21	9/9/2009 15:36	Drift Correction with Calibration Drift value of 0.051 and Fouling Drift value of 0.000 Feet H2O
12/11/2009 9:46	dyu	7/27/2009 9:06	8/3/2009 8:51	Offset Correction with value of -0.918 Feet H2O
12/11/2009 9:48	dyu	8/3/2009 9:06	8/11/2009 4:51	Offset Correction with value of -1.437 Feet H2O
12/11/2009 9:50	dyu	8/11/2009 5:06	8/17/2009 13:06	Advanced Correction (Date/Time, Value, Diff): (2009-08-11 05:06:06, -0.879 -1.472) (2009-08-17 13:06:06, 0.209, -1.538)
12/28/2009 11:10	dyu	9/29/2009 15:36	10/23/2009 15:06	Drift Correction with Calibration Drift value of 0.009 and Fouling Drift value of 0.000 Feet H2O
12/28/2009 11:16	dyu	10/23/2009 15:21	11/16/2009 9:51	Drift Correction with Calibration Drift value of -0.309 and Fouling Drift value of 0.000 Feet H2O
12/28/2009 11:20	dyu	11/16/2009 10:06	11/16/2009 10:51	Delete spike
12/28/2009 11:20	dyu	11/16/2009 9:51	11/16/2009 11:06	Interpolate Gap(Linear) - fill deleted region
12/28/2009 11:25	dyu	12/7/2009 10:06	12/7/2009 10:21	Delete spike caused by jump during site visit
12/28/2009 11:25	dyu	12/7/2009 9:51	12/7/2009 10:36	Interpolate Gap(Linear) - fill deleted spike
3/4/2010 0:08	dyu	12/7/2009 10:36	12/14/2009 23:36	Advanced Correction (Date/Time, Value, Diff): (2009-12-07 10:36:02, 0.71, -0.082) (2009-12-14 23:36:02, 0.79, -0.208)
3/4/2010 0:10	dyu	12/14/2009 23:51	1/11/2010 12:21	Advanced Correction (Date/Time, Value, Diff): (2009-12-14 23:51:02, 0.79, -0.199) (2010-01-11 12:21:02, 1.52, -0.236
3/4/2010 0:11	dyu	1/11/2010 12:36	3/2/2010 10:21	Advanced Correction (Date/Time, Value, Diff): (2010-01-11 12:36:02, 1.52, -0.235) (2010-03-02 10:21:02, 0.75, -0.449)
4/15/2010 10:12	dyu	3/10/2010 14:21	3/10/2010 14:21	Delete drop
4/15/2010 10:13	dyu	3/10/2010 14:06	3/10/2010 14:36	Interpolate Gap(Linear) - fill deleted drop
4/15/2010 10:14	dyu	3/2/2010 10:36	3/2/2010 11:36	Delete aberrant spike
4/15/2010 10:16	dyu	3/2/2010 11:51	4/10/2010 14:51	Advanced Correction (Date/Time, Value, Diff): (2010-03-02 11:51:02, 0.75, -0.094) (2010-04-10 14:51:02, 0.75, 0.064)

Table 2 (continued). Hydrologic data correction history for location AG62.

Date of Correction	User	From	To	Comment
4/15/2010 10:16	dyu	3/2/2010 10:21	3/2/2010 11:51	Interpolate Gap(Linear) - fill deleted spike
6/2/2010 21:58	dyu	4/10/2010 15:06	5/13/2010 11:06	Advanced Correction (Date/Time, Value, Diff): (2010-04-10 15:06:02, 0.75, 0.102) (2010-05-13 11:06:02, 0.69, 0.102)
7/15/2010 10:47	dyu	5/13/2010 11:21	7/7/2010 8:06	Advanced Correction (Date/Time, Value, Diff): (2010-05-13 11:21:02, 0.69, 0.093) (2010-07-07 08:06:02, 0.65, 0.129)
8/10/2010 12:54	dyu	7/7/2010 8:21	8/5/2010 12:21	Offset Correction with value of 0.093 Feet H2O
8/10/2010 12:54	dyu	7/7/2010 7:51	7/7/2010 8:36	Delete region
8/10/2010 12:54	dyu	7/7/2010 7:36	7/7/2010 8:51	Interpolate Gap(Linear)
8/10/2010 12:56	dyu	7/7/2010 9:06	8/5/2010 12:06	Drift Correction with Calibration Drift value of -0.015 and Fouling Drift value of 0.000 Feet H2O

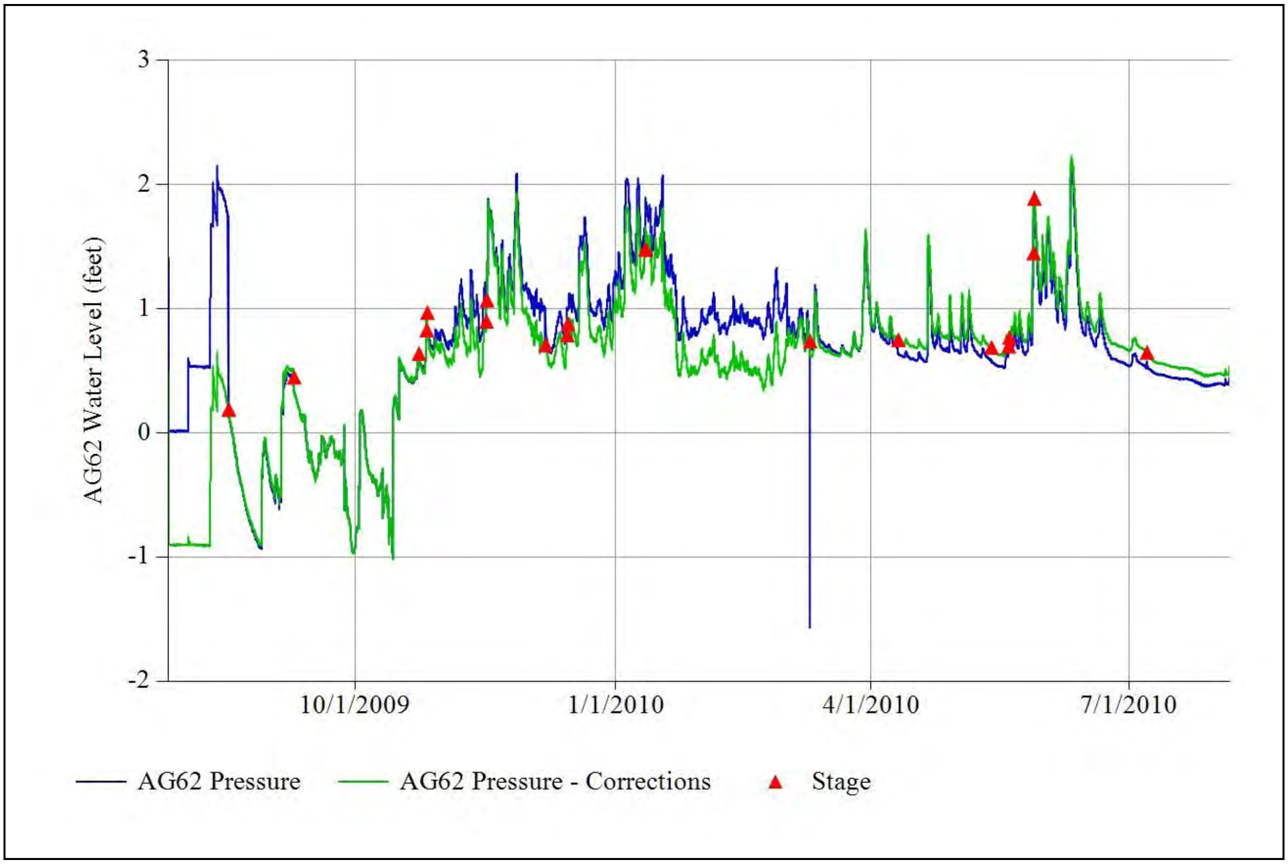
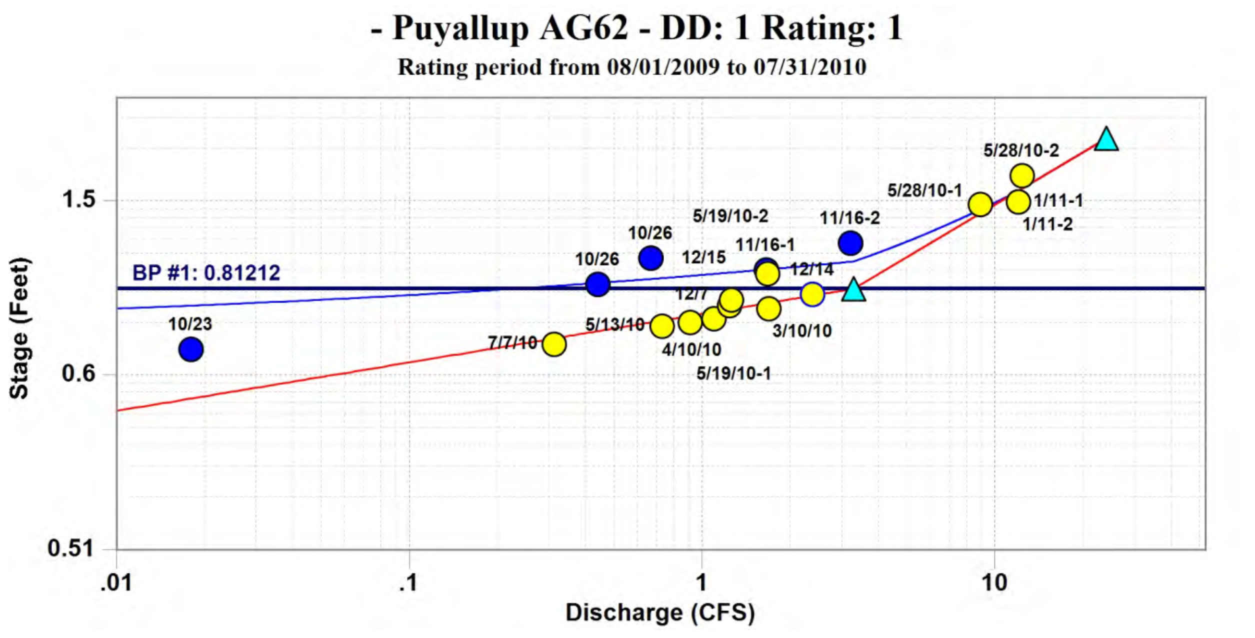


Figure 2. Corrected and raw water level data from location AG62.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location AG62 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Seventeen discharge measurements were collected at location AG62 during the 1-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with use of the rating curves. The rating curve for this location included a shift that occurred due to scour following high flow conditions on November 17, 2009. The shift was applied to data collected before this date (see blue line in Figure 3). The standardized root mean square (SRMS) error for the primary rating curve (red line in Figure 3) is 22.3 percent, while the SRMS for the shifted portion of the rating curve is 41.8 percent. The error introduced into the data from unstable channel morphology was reduced by introducing a shift in the rating curve. This resulted in an overall rating that was of an acceptable quality given the unstable channel conditions.



Note: blue line and blue circles for rating data before 11/17/09, red line and yellow circles for rating data after 11/17/09, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location AG62.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At AG62, the highest manually measured flow was 12.4 cfs, while the highest recorded flow was 18.2 cfs. Consequently, the highest recorded flows were only 1.5 times higher than the highest manually measured flow, well within the guideline of 2.5.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

To assess if the AG62 hydrograph is representative of agricultural basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from an agricultural basin in western Washington. Since there were no existing rain gauges with reliable data records located within the AG62 basin, rainfall and runoff comparisons could not be made. As a result, the AG62 hydrograph was assessed without comparison to rainfall.

The AG62 hydrograph is presented in Figure 4. There was no base flow during the dry season indicating an absence of irrigation return flow. The flow peaks tend to converge in the wet season indicating flow attenuation and elevated winter base flow, but not as much base flow as identified in the forested basins. Although there was no indication of return flow from irrigation, these results indicate that the AG62 hydrograph is typical (representative) of agricultural basins in western Washington.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record are missing due to equipment malfunction or other operational problems. There were minimal data gaps (less than 0.1 percent of the record) during the monitoring period (see Table 2). Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

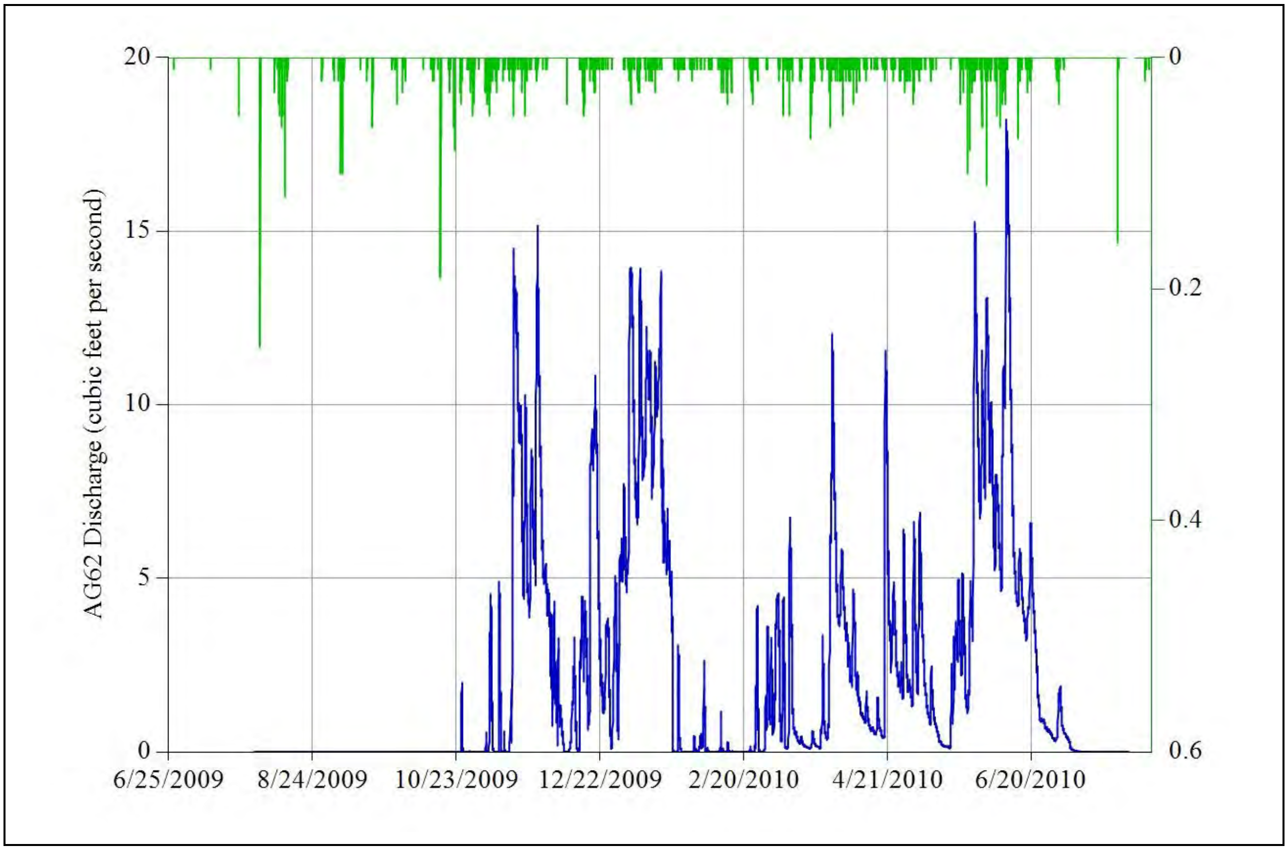


Figure 4. AG62 hydrograph.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location AG62. There was one shift in the rating curve and the rating curve errors were relatively high, but this amount of flow conversion error is generally expected when rating small dynamic stream channels. This error is accounted for in the final pollutant loading values for this station by reporting the data as a range between the 25th and 75th percentile. After assessing the quality of the hydrologic data at location AG62, it was found that the data can be used without qualification.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology, by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

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Memorandum

To Project File 06-03509-002

From Dylan Ahearn, Herrera Environmental Consultants

Date August 8, 2010

Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **AG143**

This memorandum reviews hydrologic data collected at monitoring location AG143 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location AG143 represents agricultural land use in the Puyallup River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.9 percent to 3.2 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928005).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.387	1.4	-0.9
Post-monitoring	1.033	1.0	3.2

Sensor Drift and Displacement

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the water level sensors were conducted on 12 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift did not exceed the warning limit of plus or minus 1 standard deviation from the mean. The maximum drift between calibrations was 0.04 feet. To correct for drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

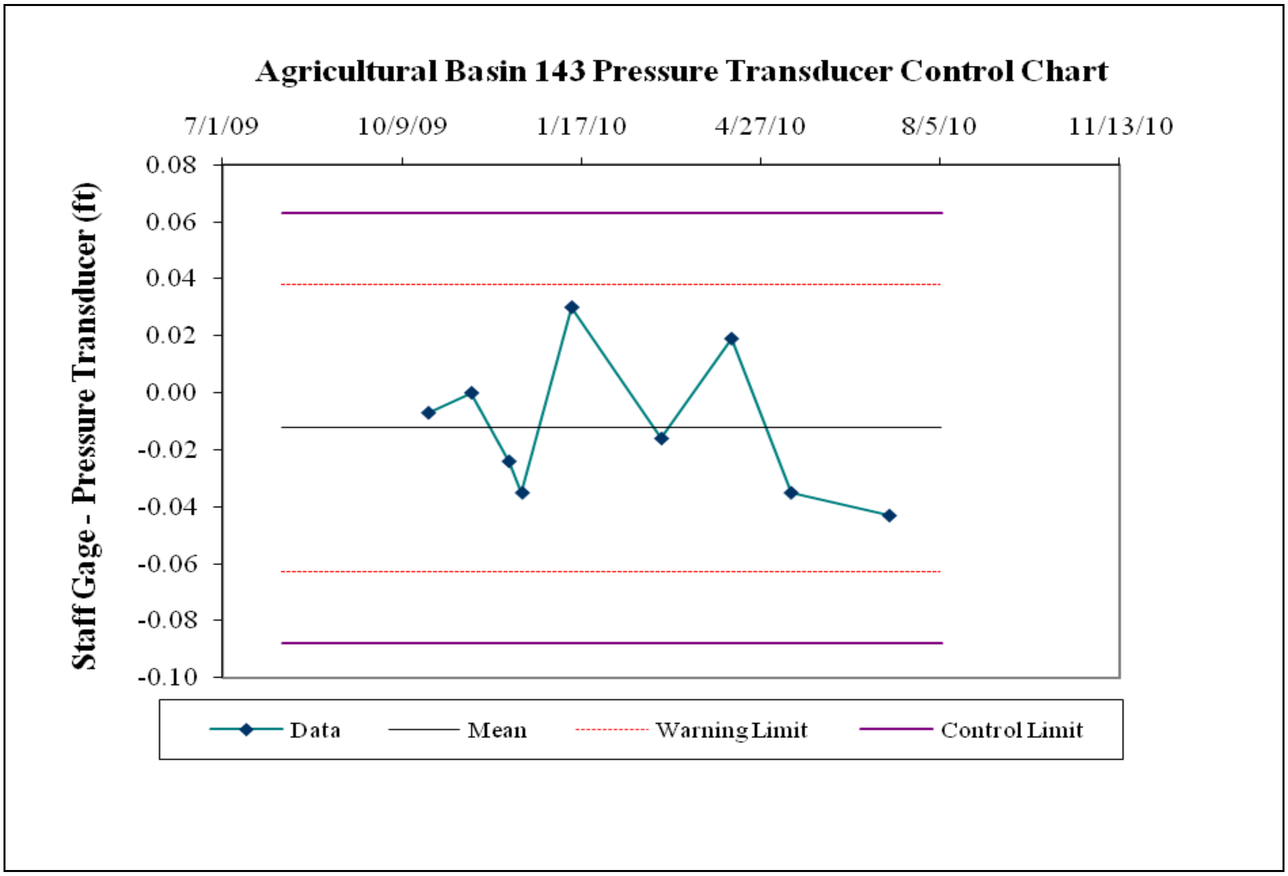


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing Bias

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the AG143 transducer are presented in Table 2 and Figure 2. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Table 2. Hydrologic data correction history for location AG143.

Date of Correction	User	From	To	Comment
12/17/2009 16:24	dyu	7/27/2009 9:21	9/9/2009 14:55	Offset Correction with value of -1.833 Feet H2O
1/24/2010 11:57	dyu	10/23/2009 13:34	11/16/2009 13:34	Advanced Correction (Date/Time, Value, Diff): (2009-10-23 13:34:05, 0.723, -0.005) (2009-11-16 13:34:05, 0.6, -0.064)
1/24/2010 12:06	dyu	11/16/2009 14:04	12/7/2009 11:49	Advanced Correction (Date/Time, Value, Diff): (2009-11-16 14:04:05, 0.6, -0.023) (2009-12-07 11:49:05, 0.35, -0.025)
1/24/2010 12:07	dyu	11/16/2009 13:49	11/16/2009 13:49	Delete spike
1/24/2010 12:07	dyu	11/16/2009 13:34	11/16/2009 14:04	Interpolate Gap(Linear)
1/24/2010 12:15	dyu	12/7/2009 12:49	12/14/2009 21:04	Advanced Correction (Date/Time, Value, Diff): (2009-12-07 12:34:05, 0.35, -0.022) (2009-12-14 21:04:05, 0.401, -0.035)
1/24/2010 12:15	dyu	12/7/2009 12:19	12/7/2009 12:34	Delete region
1/24/2010 12:15	dyu	12/7/2009 11:49	12/7/2009 12:49	Interpolate Gap(Linear)
1/24/2010 12:18	dyu	12/14/2009 21:19	1/11/2010 11:19	Advanced Correction (Date/Time, Value, Diff): (2009-12-14 21:19:05, 0.403, -0.036) (2010-01-11 11:19:05, 1.05, 0.026)
1/24/2010 12:19	dyu	12/14/2009 20:34	12/14/2009 20:49	Delete region
1/24/2010 12:19	dyu	12/14/2009 20:19	12/14/2009 21:04	Interpolate Gap(Linear)
4/15/2010 10:03	dyu	1/11/2010 11:34	3/2/2010 12:19	Advanced Correction (Date/Time, Value, Diff): (2010-01-11 11:34:05, 1.073, 0.042) (2010-03-02 12:19:05, 0.629, -0.018)
4/15/2010 10:10	dyu	3/2/2010 12:34	4/10/2010 12:34	Advanced Correction (Date/Time, Value, Diff): (2010-03-02 12:34:05, 0.626, -0.020) (2010-04-10 12:34:05, 0.699, 0.000)
6/2/2010 21:56	dyu	4/10/2010 12:49	5/13/2010 16:19	Advanced Correction (Date/Time, Value, Diff): (2010-04-10 12:49:05, 0.699, 0.010) (2010-05-13 16:19:05, 0.5, -0.038)
7/15/2010 10:44	dyu	5/13/2010 16:34	5/13/2010 21:49	Offset Correction with value of -0.029 Feet H2O
7/15/2010 10:45	dyu	5/13/2010 22:04	7/7/2010 11:49	Advanced Correction (Date/Time, Value, Diff): (2010-05-13 22:04:05, 0.491, -0.054) (2010-07-07 11:49:05, 0.71, -0.043)
8/10/2010 11:34	dyu	7/7/2010 12:04	8/5/2010 13:49	Advanced Correction (Date/Time, Value, Diff): (2010-07-07 12:04:05, 0.711, -0.041) (2010-08-05 13:49:05, 0, -0.266)

Flow Conversion Bias

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location AG143 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate held velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Fifteen discharge measurements were collected at location AG143 during the 1-year study.

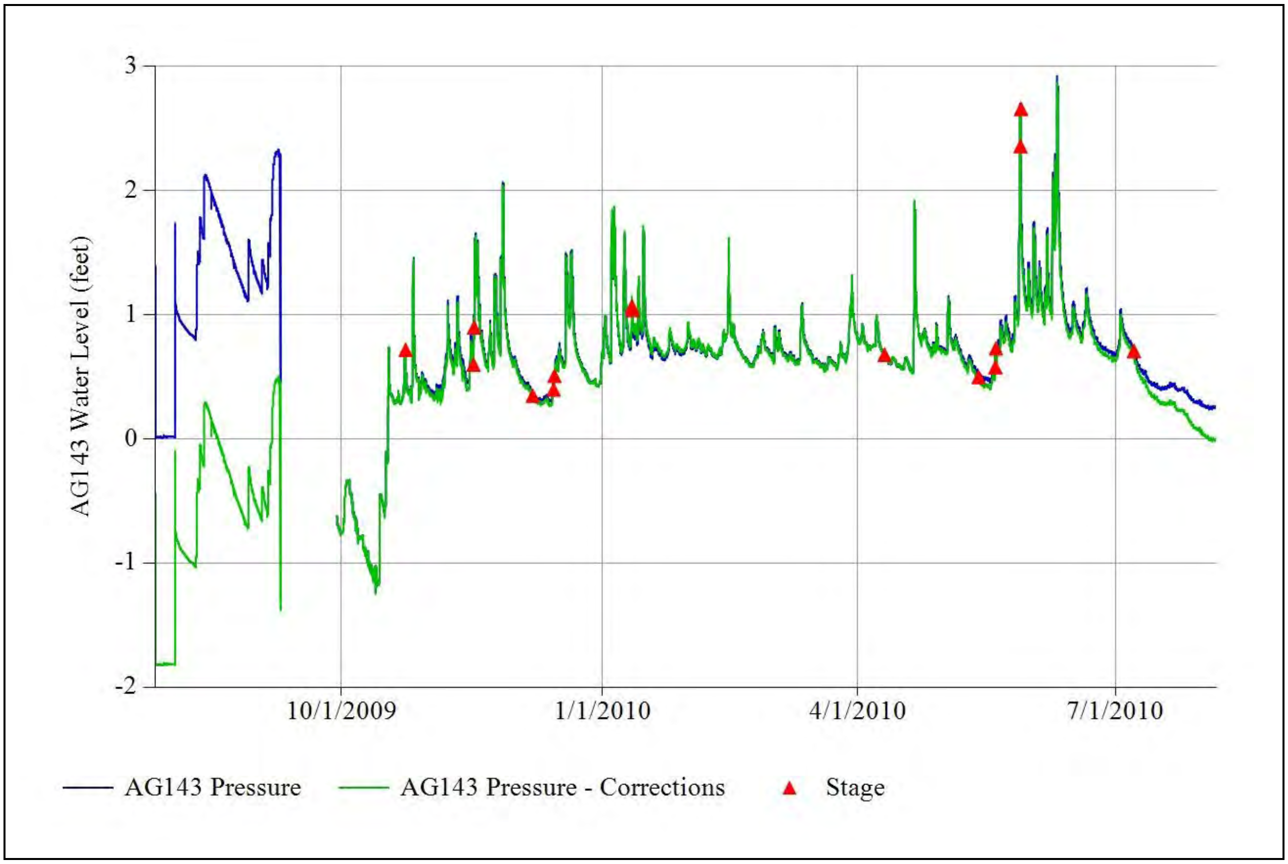
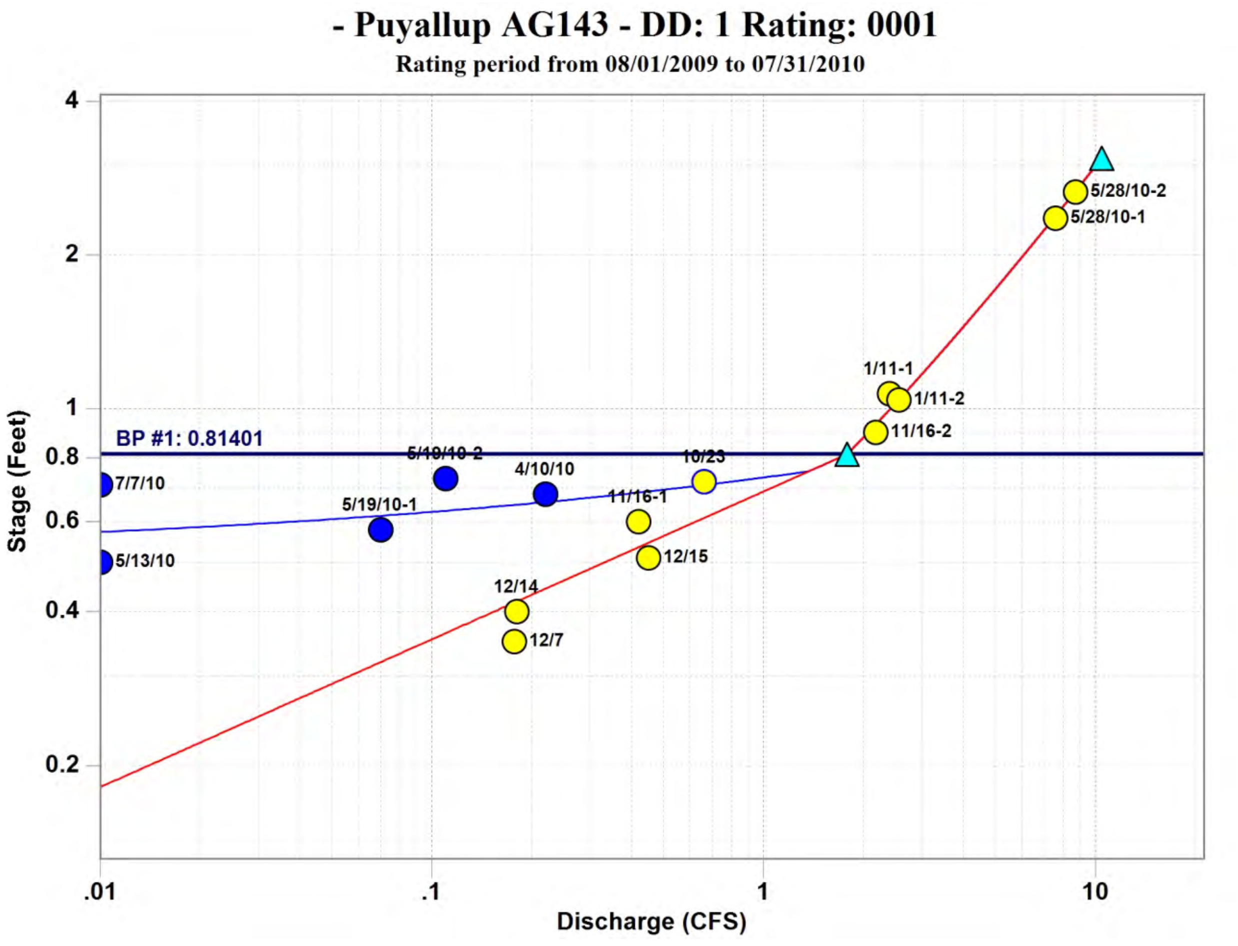


Figure 2. Corrected and raw water level data from location AG143.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. Rating curves for this location included a shift that occurred due to channel aggradation following high flow conditions in January 2010. The shift applies to data below the break point after January 18, 2010. The standardized root mean square (SRMS) error for the primary rating is 33.1 percent while the SRMS for the shifted portion of the rating is 46.7 percent. The error introduced into the data from an unstable channel morphology was reduced by introducing a shift into the rating curve. This resulted in an overall rating that was of an acceptable quality given the unstable channel conditions.



Note: blue line and blue circles for rating data after 1/18/10, red line and yellow circles for rating data before 1/18/10, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location AG143.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At AG143, the highest manually measured flow was 8.7 cfs, while the highest recorded flow was 9.5 cfs. Consequently, the highest recorded flows were only 1.1 times higher than the highest manually measured flow, well within the guideline of 2.5.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

To assess if the AG143 hydrograph was representiave of agricultural basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a agricultural basin in western Washington. Since there were no existing rain gauges with reliable data records located within the AG143 basin, rainfall and runoff comparisons could not be made. As a result, the AG143 hydrograph was assessed without comparison to rainfall.

The AG143 hydrograph is presented in Figure 4. There was no base flow during the dry season indicating an absence of irrigation return flow. The flow peaks tend to converge in the wet season indicating flow attenuation and elevated winter base flow, but not as much base flow as identified in the forested basins. Although there was no indication of return flow from irrigation, these results indicate that the AG143 hydrograph is typical (representative) of agricultural basins in western Washington.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal data gaps during the monitoring period (Table 2). There was one large data gap in

September 2009, but this occurred before there was flow in the channel so it was not counted toward the MQO. Therefore, the MQO for completeness of hydrological data was met.

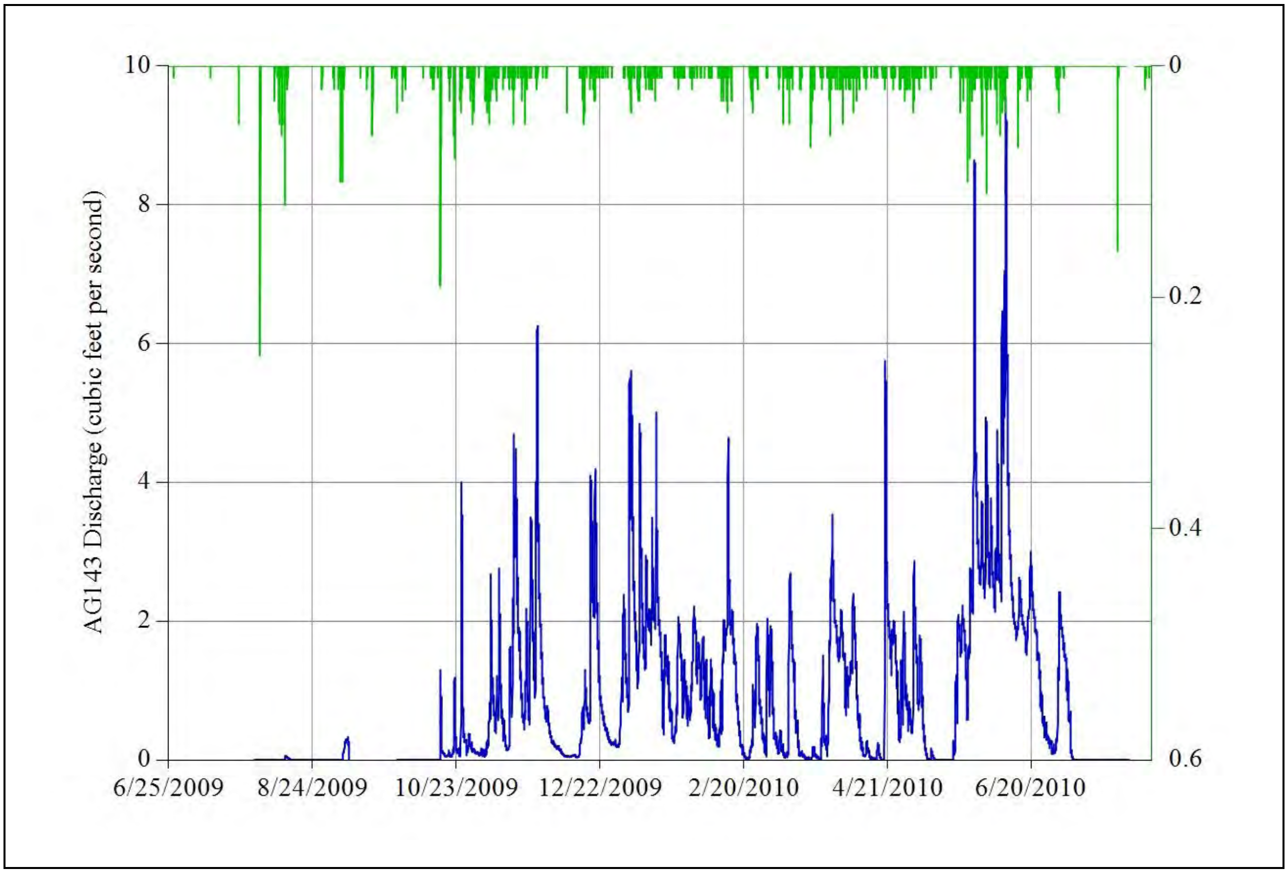


Figure 4. AG143 hydrograph.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location AG143. There was one shift in the rating curve and the rating curve errors were relatively high, but this amount of flow conversion error is generally expected when rating small dynamic stream channels. This error is accounted for in the final pollutant loading values for this station by reporting the data as a range between the 25th and 75th percentile. After assessing the quality of the hydrologic data at location AG143, it was found that the data can be used without qualification.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

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Herrera Environmental Consultants, Inc.

Memorandum

To	Project File 06-03509-002
From	Dylan Ahearn, Herrera Environmental Consultants
Date	August 8, 2010
Subject	Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **AG174**

This memorandum reviews hydrologic data collected at monitoring location AG174 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location AG174 represents agricultural land use in the Snohomish River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -1.4 percent to -2.4 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928007).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.381	1.4	-1.41
Post-monitoring	0.977	1.0	-2.38

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the water level sensors were conducted on 13 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements (control limit) was used as a threshold to assess monitoring equipment function. If the sensor drifted past the control limit the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, the sensor drift did not exceed the warning limit of plus or minus 1 standard deviations from the mean. The maximum drift at this location was 0.30 feet, which is high relative to the other locations. To correct for this sensor drift and all sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

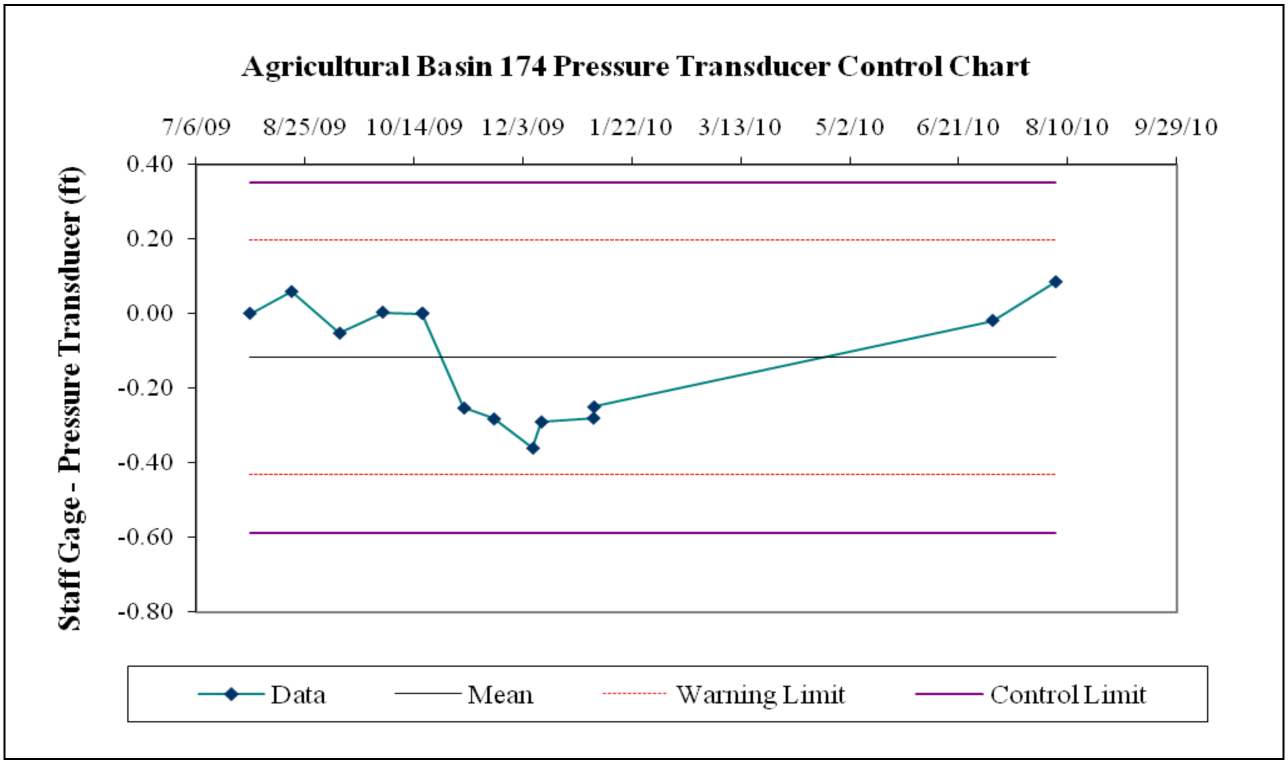


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the AG174 transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a poor quality. Inadequate ventilation in the stilling well caused a partial vacuum to form, which affected the data from the start of the study until December 7, 2009 when the issue was finally resolved by drilling ventilation holes in the top of the stilling well. In addition, a large data gap exists in the data from January 18, 2010 to April 7, 2010. This data gap was the result of sensor failure and subsequent replacement.

To improve the quality of the level data a few measures were taken. First, the level data from location RB202 was used to model the missing AG174 level data. This process involved creating a linear model that related a high quality portion of the RB202 level data with a high quality

Table 2. Hydrologic data correction history for location AG174.

Date of Correction	User	From	To	Comment
12/16/2009 10:47	dyu	11/5/2009 21:56	11/19/2009 15:41	Advanced Correction (Date/Time, Value, Diff): (2009-11-05 21:56:56, 0.982, -0.260) (2009-11-19 15:41:56, 1.614, 0.000) - correct jump during site visit
12/23/2009 14:22	dyu	11/19/2009 15:56	12/7/2009 13:41	Drift Correction with Calibration Drift value of -0.360 and Fouling Drift value of 0.000 Feet H2O
12/28/2009 14:04	dyu	11/5/2009 22:11	11/19/2009 15:41	Advanced Correction (Date/Time, Value, Diff): (2009-11-05 22:11:56, 1, -0.247) (2009-11-19 15:56:56, 1.673, 0.000)
12/28/2009 14:06	dyu	11/5/2009 22:11	11/19/2009 15:41	Drift Correction with Calibration Drift value of 0.4448 and Fouling Drift value of 0.0000 Feet H2O
12/28/2009 14:10	dyu	11/19/2009 16:11	12/7/2009 13:56	Advanced Correction (Date/Time, Value, Diff): (2009-11-19 15:56:562.12, -0.2450) (2009-12-07 13:56:560.9, -0.3730)
12/28/2009 14:12	dyu	12/7/2009 14:11	12/11/2009 11:26	Advanced Correction (Date/Time, Value, Diff): (2009-12-07 14:11:560.9, -0.3770) (2009-12-11 11:26:560.78, -0.2920)
12/28/2009 15:43	dyu	11/19/2009 15:56	11/19/2009 15:56	Delete spike
12/28/2009 15:43	dyu	11/19/2009 15:41	11/19/2009 16:11	Interpolate Gap(Linear) - fill deleted spike
12/28/2009 18:02	dyu	7/30/2009 12:26	8/18/2009 15:56	Advanced Correction (Date/Time, Value, Diff): (2009-07-30 12:26:56, 0.78, -0.001) (2009-08-18 16:11:560.7 0.069)
12/28/2009 18:03	dyu	8/18/2009 16:11	9/9/2009 19:11	Advanced Correction (Date/Time, Value, Diff); (2009-08-18 16:11:56, 0.7, 0.069) (2009-09-09 19:11:56, 0.72, 0.025)
12/28/2009 18:05	dyu	9/9/2009 19:26	9/29/2009 12:26	Advanced Correction (Date/Time, Value, Diff): (2009-09-09 19:26:56, 0.717, -0.028) (2009-09-29 12:41:56, 0.58, 0.015)
12/28/2009 18:07	dyu	9/29/2009 12:41	10/17/2009 15:26	Advanced Correction (Date/Time, Value, Diff): (2009-09-29 12:41:56, 0.58, 0.015) (2009-10-17 15:11:56, 1.63, -0.234)
12/28/2009 18:08	dyu	10/17/2009 15:26	10/17/2009 19:56	Advanced Correction (Date/Time, Value, Diff): (2009-10-17 15:26:56, 1.63, -0.234) (2009-10-17 20:11:56, 1.63, -0.209)
12/28/2009 18:10	dyu	10/17/2009 20:11	11/5/2009 21:56	Advanced Correction (Date/Time, Value, Diff): (2009-10-17 20:11:56, 1.63, -0.209) (2009-11-05 21:41:56, 1.007, -0.224)

Table 2 (continued). Hydrologic data correction history for location AG174.

Date of Correction	User	From	To	Comment
1/24/2010 10:25	dyu	12/11/2009 11:41	1/4/2010 13:41	Advanced Correction (Date/Time, Value, Diff): (2009-12-11 11:41:56, 0.78, -0.289) (2010-01-04 13:41:56, 1.181, -0.239)
4/20/2010 16:58	dyu	1/4/2010 13:56	2/3/2010 7:26	Offset Correction with value of -0.246 Feet H2O
7/28/2010 14:51	dyu	4/6/2010 12:30	7/6/2010 13:45	Advanced Correction (Date/Time, Value, Diff): (2010-04-06 12:30:00, 0.864, 0.020) (2010-07-06 13:45:00, 0.732, -0.015)
8/10/2010 11:07	dyu	7/6/2010 14:00	8/4/2010 13:45	Advanced Correction of (Date/Time Value Diff) (2010-07-06 14:00:000.735 -0.017) (2010-08-04 13:45:000.75 0.080)
8/30/2010 11:55	dahearn	3/29/2010 13:44	3/29/2010 13:59	Delete drop
8/30/2010 11:56	dahearn	3/29/2010 13:29	3/29/2010 14:14	Interpolate Gap(Linear) - spike/drop fill
8/30/2010 11:57	dahearn	2/2/2010 6:56	4/6/2010 18:15	Advanced Correction (Date/Time, Value, Diff): (2010-02-02 06:56:56, 1.191, 0.000) (2010-04-06 18:15:00, 1.065, -0.095)
8/31/2010 15:21	dahearn	1/18/2010 9:41	4/7/2010 21:45	Fill Region with modeling:[Name = LRUntitled][Type = Linear Regression][Equation: T=-1.05558+1.54189*S1][Target Name = AG174 Pressure][Error = 0.083][Number of Surr. = 1][#1: RB202 Pressure]
8/31/2010 15:24	dahearn	1/18/2010 15:41	4/7/2010 21:45	Offset Correction with value of -0.383 Feet H2O - post model adjust
8/31/2010 15:28	dahearn	1/15/2010 19:41	1/18/2010 15:26	Advanced Correction (Date/Time, Value, Diff): (2010-01-15 19:41:56, 1.887, 0.000) (2010-01-18 15:26:56, 1.171, -0.365)
8/31/2010 15:33	dahearn	12/5/2009 8:11	12/5/2009 15:56	Interpolate Gap(Linear) - noisy signal smooth
8/31/2010 15:34	dahearn	12/4/2009 8:41	12/5/2009 8:11	Interpolate Gap(Linear) - noisy signal smooth
8/31/2010 15:34	dahearn	12/2/2009 19:41	12/4/2009 8:56	Interpolate Gap(Linear) - noisy signal smooth
8/31/2010 15:35	dahearn	12/2/2009 10:11	12/2/2009 18:41	Interpolate Gap(Linear) - noisy signal smooth

portion of the AG174 data. This relationship was then used to fill the gap in the AG174 data based on the existing RB202 level data for the same period of time that the gap occurred. The error associated with the model was 8.3 percent. The model assumes that the relationship between water level data at AG174 and RB202 is constant through time. In order to reduce the error associated with this assumption the RB202 and AG174 hydrographs were compared visually prior to modeling. It was determined from this assessment that the stations hydrographs were similar enough to generate a valid model. The result of this modeling can be seen in Figure 2 and the application of the model is presented in Table 2. Despite the efforts made to fill data gaps with modeling, the resultant AG174 data should be used with caution and flagged as estimates. In addition, any pollutant loading calculations that are based on the AG174 flow data should also be considered estimates.

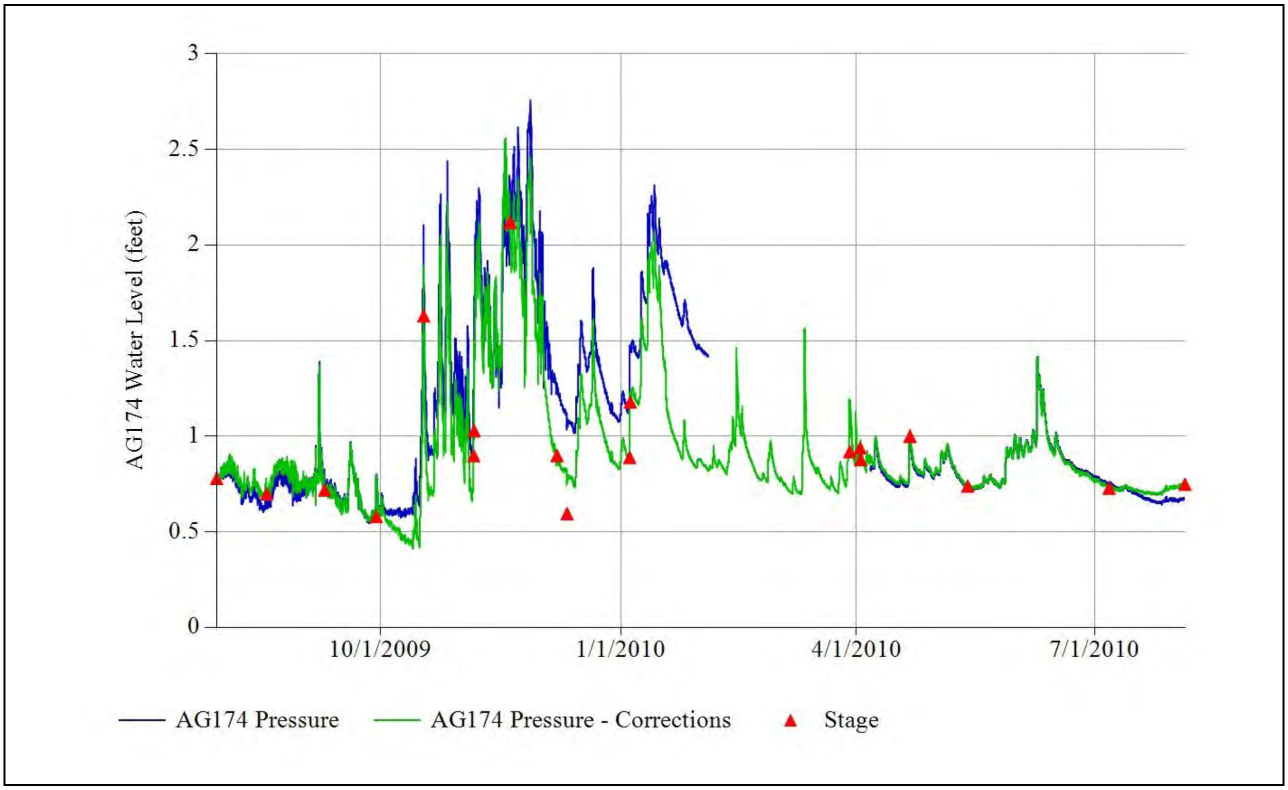
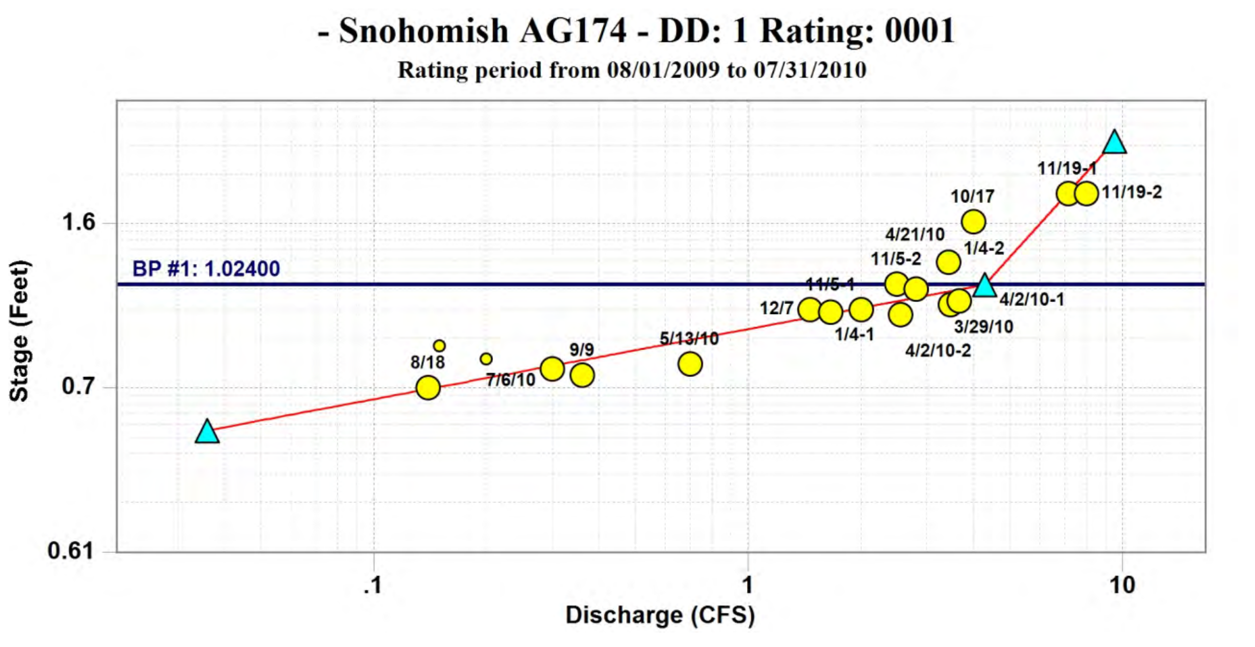


Figure 2. Corrected and raw water level data from location AG174.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location AG174 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Eighteen discharge measurements were collected at location AG174 during the 1-year study.



Note: red line and yellow circles for rating of all data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location AG174.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating curve is 46.7 percent. Because of this relatively high degree of error, the data gap modeling noted above, and the unusual hydrograph shape noted below, all flow data for AG174 level data should be flagged as estimates.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At AG174, the highest manually measured flow was 8.0 cfs, while the highest recorded flow was 7.8 cfs. Consequently, the guideline was met.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

To assess if the AG174 hydrograph was representative of agricultural basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a agricultural basin in western Washington. Since there were no existing rain gauges with reliable data records located within the AG174 basin, rainfall and runoff comparisons could not be made. As a result, the AG174 hydrograph was assessed without comparison to rainfall.

Figure 4 provides the AG174 hydrograph. There was base flow and a substantial response to rainfall during the dry season. The flow peaks converged in the wet season indicating flow attenuation and elevated winter base flow. The form of the flow peaks is unique from the other locations as some peaks are flashy and some very broad. It is difficult to say what type of land use this unusual hydrograph form represents as data quality issues may be interfering with the interpretation.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There was a 79-day data gap from January 18, 2010 to April 7, 2010 (see Figure 2). This gap represents 21.6 percent of the data, but the MQO was met because the gap was filled with modeled data from RB202.

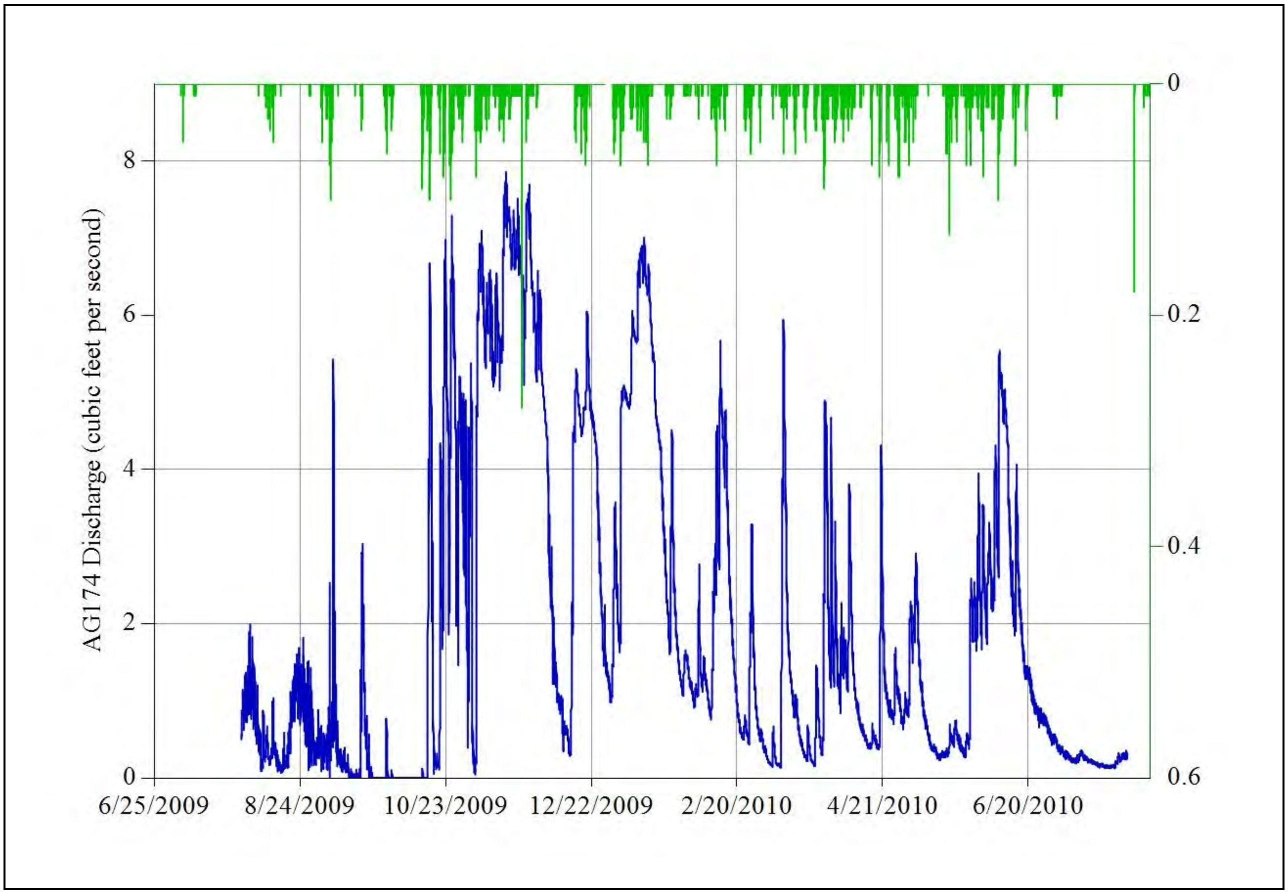


Figure 4. AG174 hydrograph.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

The water level and stream flow data from AG174 had numerous quality assurance issues. The data from January 18, 2010 to April 7, 2010 were missing and replaced with modeled data from RB202. In addition, rating curve had a high degree of error and the hydrograph form was unusual. These factors combine to result is a hydrograph of poor quality. After assessing the quality of the hydrologic data at location AG174, it was found that the hydrologic data should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from AG174 should be closely examined to determine if low quality flow data is controlling pollutant loading patterns.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology, by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. United States Government Printing Office, Denver, Colorado.

Herrera Environmental Consultants, Inc.

Memorandum

To Project File 06-03509-002

From Dylan Ahearn, Herrera Environmental Consultants

Date August 8, 2010

Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **AGG**

This memorandum reviews hydrologic data collected at monitoring location AGG from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location AGG represents agricultural land use in the Snohomish River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from 0.0 percent to 0.36 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928017).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.400	1.4	0.0
Post-monitoring	1.003	1.0	0.36

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the water level sensors were conducted on 14 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in instrument drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to both warning and control limits. As shown in Figure 1, on one occasion the sensor drift exceeded the warning limit of plus or minus 1 standard deviation from the mean. The maximum drift at this location was 0.22 feet, which is relatively high compared to the other locations. To correct for this sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

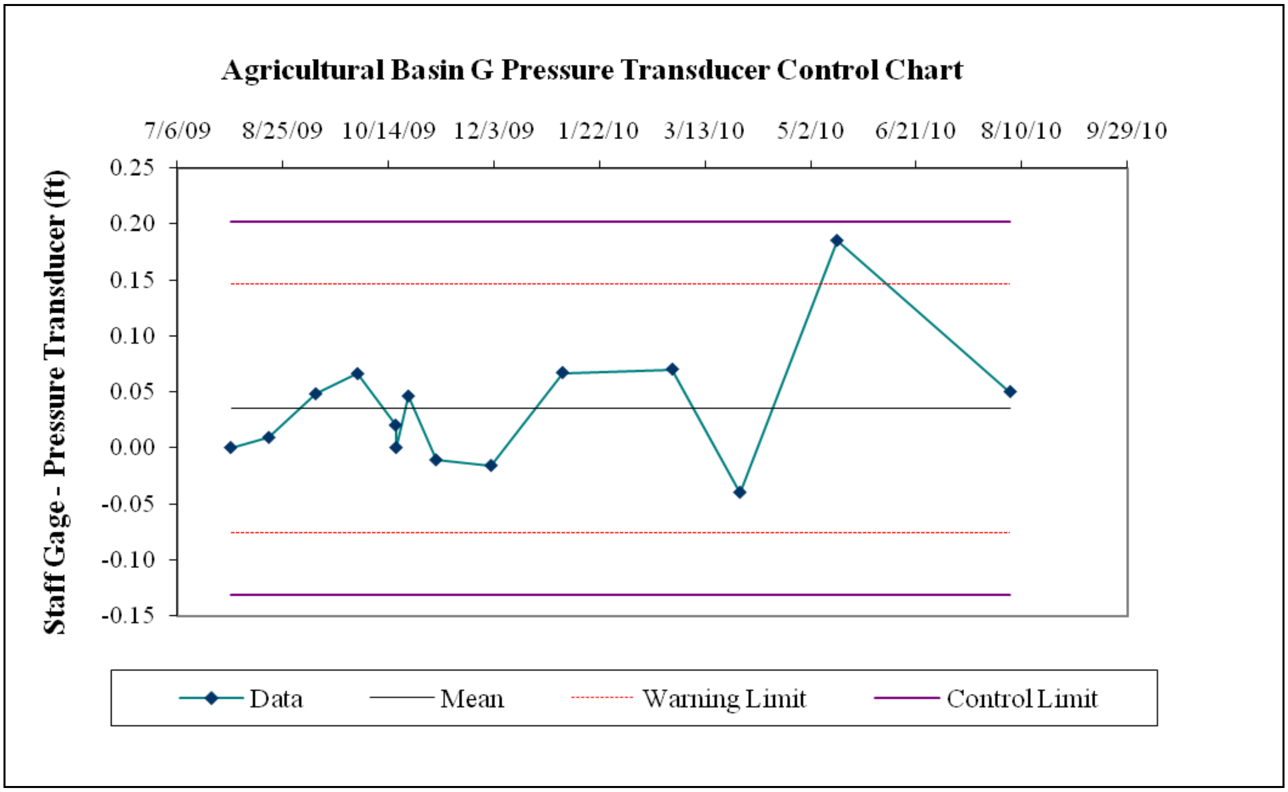


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the AGG transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of an average quality. A large data gap exists in the data from May 14, 2010 to July 8, 2010. This data gap was the result of sensor failure and subsequent replacement. In order to fill this large data gap, the level data from AG174 was used to model the missing AGG level data. This process involved creating an adaptive neuro-fuzzy inference system (ANFIS) model that related a high quality portion of the AG174 level data with a high quality portion of the AGG data. This relationship was then used to fill the gap in the AGG data based on the existing AG174 level data for the same period of time that the gap occurred. The error associated with the model was 25 percent. The model assumes

Table 2. Hydrologic data correction history for location AGG.

Date of Correction	User	From	To	Comment
10/28/2009 10:30	dyu	7/31/2009 8:57	8/18/2009 10:12	Drift Correction with Calibration Drift value of 0.009 and Fouling Drift value of 0.000 Feet H2O
10/28/2009 10:31	dyu	8/18/2009 10:27	9/9/2009 15:12	Drift Correction with Calibration Drift value of 0.048 and Fouling Drift value of 0.000 Feet H2O
11/4/2009 12:46	dyu	10/17/2009 16:27	10/23/2009 10:42	Drift Correction with Calibration Drift value of 0.046 and Fouling Drift value of 0.000 Feet H2O
12/28/2009 15:46	dyu	9/9/2009 15:27	9/29/2009 10:27	Advanced Correction (Date/Time, Value, Diff): (2009-09-09 15:27:28, 0.56, 0.043) (2009-09-29 10:27:28, 0.57, 0.062)
12/28/2009 15:51	dyu	9/29/2009 10:42	10/17/2009 9:57	Advanced Correction (Date/Time, Value, Diff): (2009-09-29 10:42:28, 0.57, 0.062) (2009-10-17 09:42:28, 1.797, 0.210)
12/28/2009 15:53	dyu	10/17/2009 9:57	10/17/2009 16:12	Advanced Correction (Date/Time, Value, Diff): (2009-10-17 09:57:28, 1.756, 0.217) (2009-10-17 16:12:28, 1.48, 0.077)
12/28/2009 16:00	dyu	10/17/2009 16:27	10/23/2009 11:57	Advanced Correction (Date/Time, Value, Diff): (2009-10-17 16:27:28, 1.467, 0.075) (2009-10-23 11:42:28, 0.9, 0.023)
12/28/2009 16:03	dyu	10/23/2009 11:57	11/5/2009 13:27	Advanced Correction (Date/Time, Value, Diff): (2009-10-23 11:57:28, 0.9, 0.019) (2009-11-05 13:42:28, 1.09, 0.001)
1/24/2010 10:29	dyu	11/5/2009 13:42	11/5/2009 13:42	Delete region
1/24/2010 10:29	dyu	11/5/2009 13:27	11/5/2009 13:57	Interpolate Gap(Linear)
1/24/2010 10:32	dyu	11/5/2009 13:57	12/1/2009 15:27	Drift Correction with Calibration Drift value of 0.0541 and Fouling Drift value of 0.0000 Feet H2O
1/24/2010 10:32	dyu	12/1/2009 15:42	12/1/2009 16:12	Delete region
1/24/2010 10:32	dyu	12/1/2009 15:27	12/1/2009 16:27	Interpolate Gap(Linear)
1/24/2010 10:35	dyu	12/1/2009 16:27	1/4/2010 12:12	Drift Correction with Calibration Drift value of 0.1120 and Fouling Drift value of 0.0000 Feet H2O
3/3/2010 23:06	dyu	1/4/2010 12:12	2/25/2010 11:42	Advanced Correction (Date/Time, Value, Diff): (2010-01-04 12:12:28, 1.914, 0.076) (2010-02-25 11:42:28, 1.23, 0.046)

Table 2 (continued). Hydrologic data correction history for location AGG.

Date of Correction	User	From	To	Comment
4/20/2010 17:01	dyu	2/25/2010 12:12	3/29/2010 9:12	Advanced Correction (Date/Time, Value, Diff): (2010-02-25 11:57:28, 1.23, 0.076) (2010-03-29 09:12:28, 1.57, 0.074)
4/20/2010 17:01	dyu	2/25/2010 11:57	2/25/2010 11:57	Delete drop
4/20/2010 17:02	dyu	2/25/2010 11:42	2/25/2010 12:12	Interpolate Gap(Linear)
6/2/2010 21:29	dyu	3/29/2010 9:27	3/29/2010 9:27	Delete drop
6/2/2010 21:29	dyu	3/29/2010 9:12	3/29/2010 9:42	Interpolate Gap(Linear)
6/2/2010 21:31	dyu	3/29/2010 10:42	5/14/2010 9:42	Advanced Correction (Date/Time, Value, Diff): (2010-03-29 10:42:28, 1.57, 0.014) (2010-05-14 09:42:28, 1.36, 0.185)
6/2/2010 21:32	dyu	3/29/2010 10:27	3/29/2010 10:27	Delete region
6/2/2010 21:32	dyu	3/29/2010 10:12	3/29/2010 10:42	Interpolate Gap(Linear)
8/10/2010 11:09	dyu	7/8/2010 13:30	8/4/2010 11:15	Offset Correction with value of 0.049 Feet H2O
8/27/2010 16:43	dahearn	5/13/2010 18:27	7/10/2010 1:30	Delete Region - Data gap from transducer malfunction filled with modeled data from AG174
8/30/2010 10:23	dahearn	5/12/2010 15:12	7/11/2010 23:00	Fill Region with modeling:[Name = ANFIS][Type = ANFIS][Target Name = AGG Pressure][Error = 0.358][Number of Surr. = 1][#1: AG174 Pressure]
8/30/2010 10:36	dahearn	5/12/2010 15:12	7/11/2010 23:00	Advanced Correction (Date/Time, Value, Diff): (2010-05-12 15:12:28, 1.384, 0.828) (2010-07-11 23:00:38, 1.096, 0.559)

that the relationship between water level data at AGG and AG174 is constant through time. In order to reduce the error associated with this assumption, the AG174 and AGG hydrographs were compared visually prior to modeling. It was determined from this assessment that the stations hydrographs were similar enough to generate a valid model. The result of this modeling can be seen in Figure 2 and the application of the model is presented in Table 2. Although the error for the modeled section of data is relatively high, the modeled data period occurred after the wet season had ended and, consequently, the majority of the flow record was not affected by the modeling. Because the remainder of the data record was of a high quality, it is recommended that the hydrologic data for this location may be used without qualification.

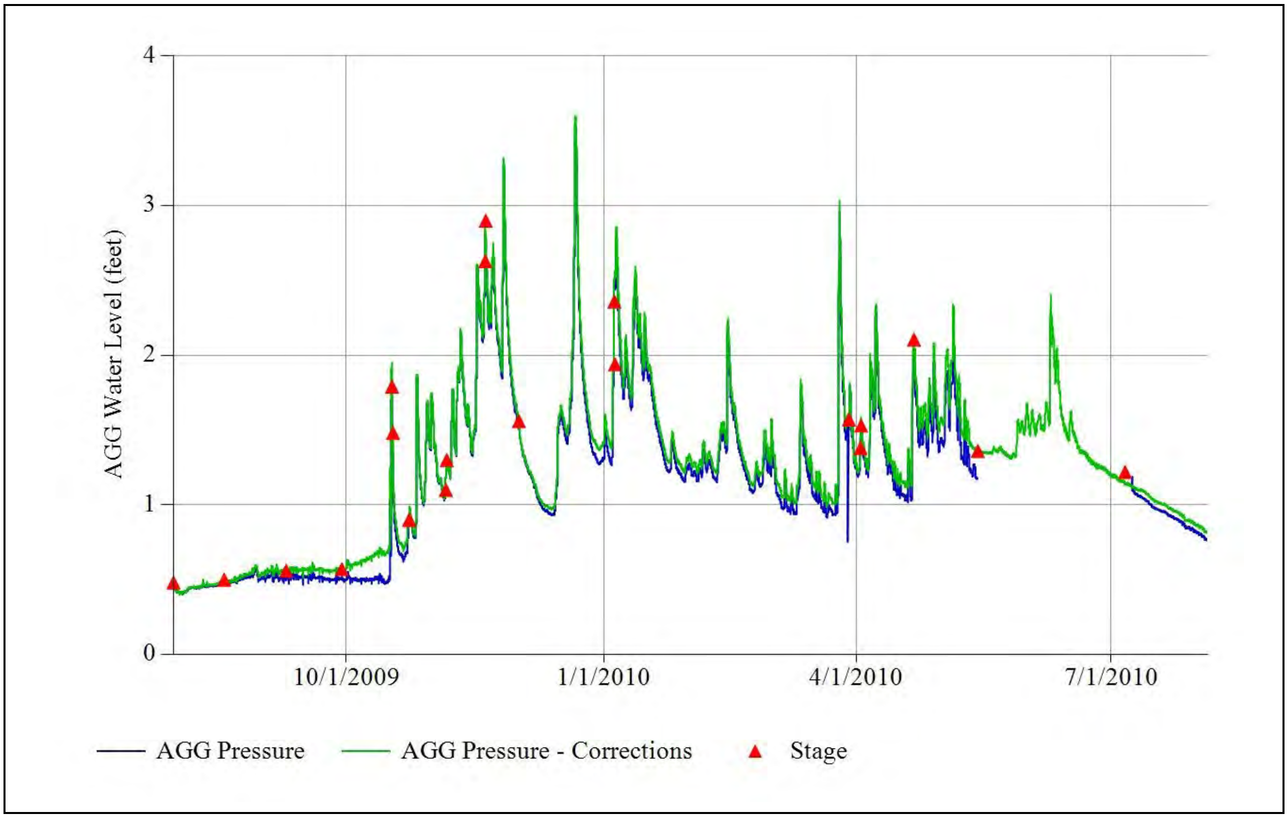
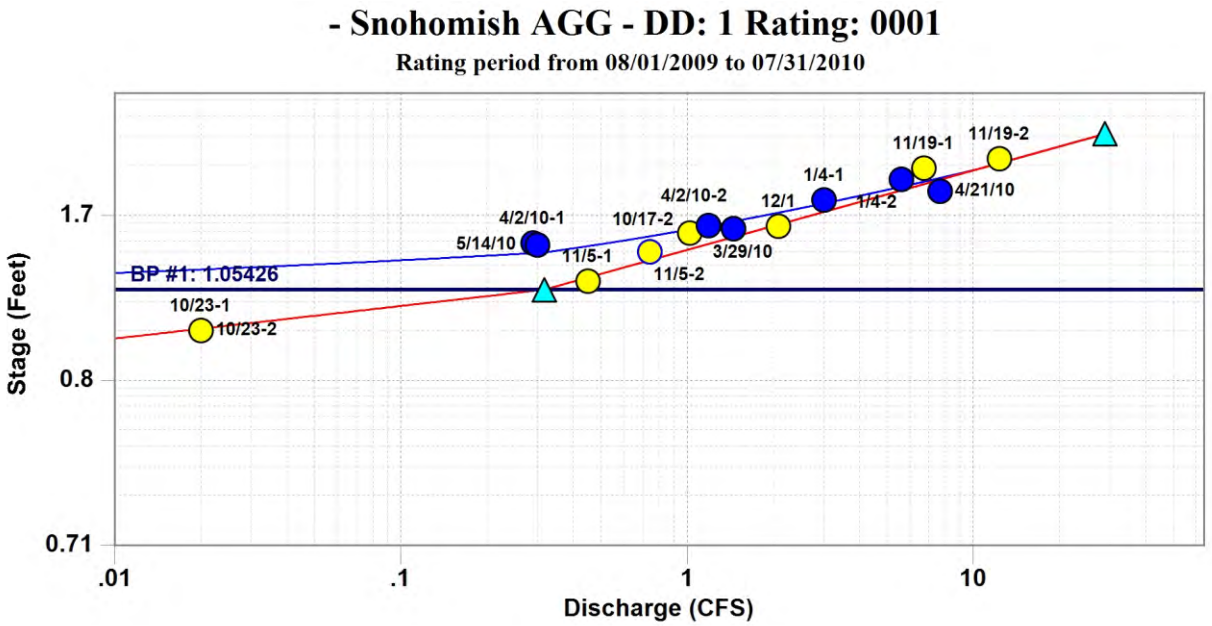


Figure 2. Corrected and raw water level data from location AGG.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location AGG to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Sixteen discharge measurements were collected at location AGG during the 1-year study.



Note: red line and yellow circles for rating data before 12/22/09, blue line and blue circles for rating data after 12/22/09, and triangles for artificial breakpoints or endpoints.

Figure 3. **Water level (stage) discharge relationship (rating curve) for monitoring location AGG.**

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The rating curve for this location included a shift that occurred due to aggradation following a large storm event on December 22, 2009. The shift applies to data collected after this date (see blue line in Figure 3). The standardized root mean square (SRMS) error for the primary rating curve (red line in Figure 3) is 22 percent while the SRMS for the shifted portion of the rating curve is 33.4 percent. The error introduced into the data from an unstable channel morphology was reduced by introducing a shift into the rating curve. This resulted in an overall rating that was of an acceptable quality given the unstable channel conditions.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At AGG, the highest manually measured flow was 12.3 cfs, while the highest recorded flow was 24.6 cfs. Consequently, the guideline was met.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

To assess if the AGG hydrograph was representative of agricultural basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from an agricultural basin in western Washington. Since there were no existing rain gauges with reliable data records located within the AGG basin, rainfall and runoff comparisons could not be made. As a result, the AGG hydrograph was assessed without comparison to rainfall.

The AGG hydrograph is presented in Figure 4. There was no base flow or response to rainfall during the dry season indicating an absence of irrigation return flow. The flow peaks converged in the wet season indicating flow attenuation and elevated winter base flow., However, base flow was not as high as in the forested basins in this study. Although there was no indication of return flow from irrigation, this hydrograph appears to be typical for a small agricultural basin.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There was a 55-day data gap from May 14, 2010 to July 8, 2010 (Figure 2). This gap represents 15 percent of the data, but the MQO was met because the gap was successfully filled with modeled data from AG174.

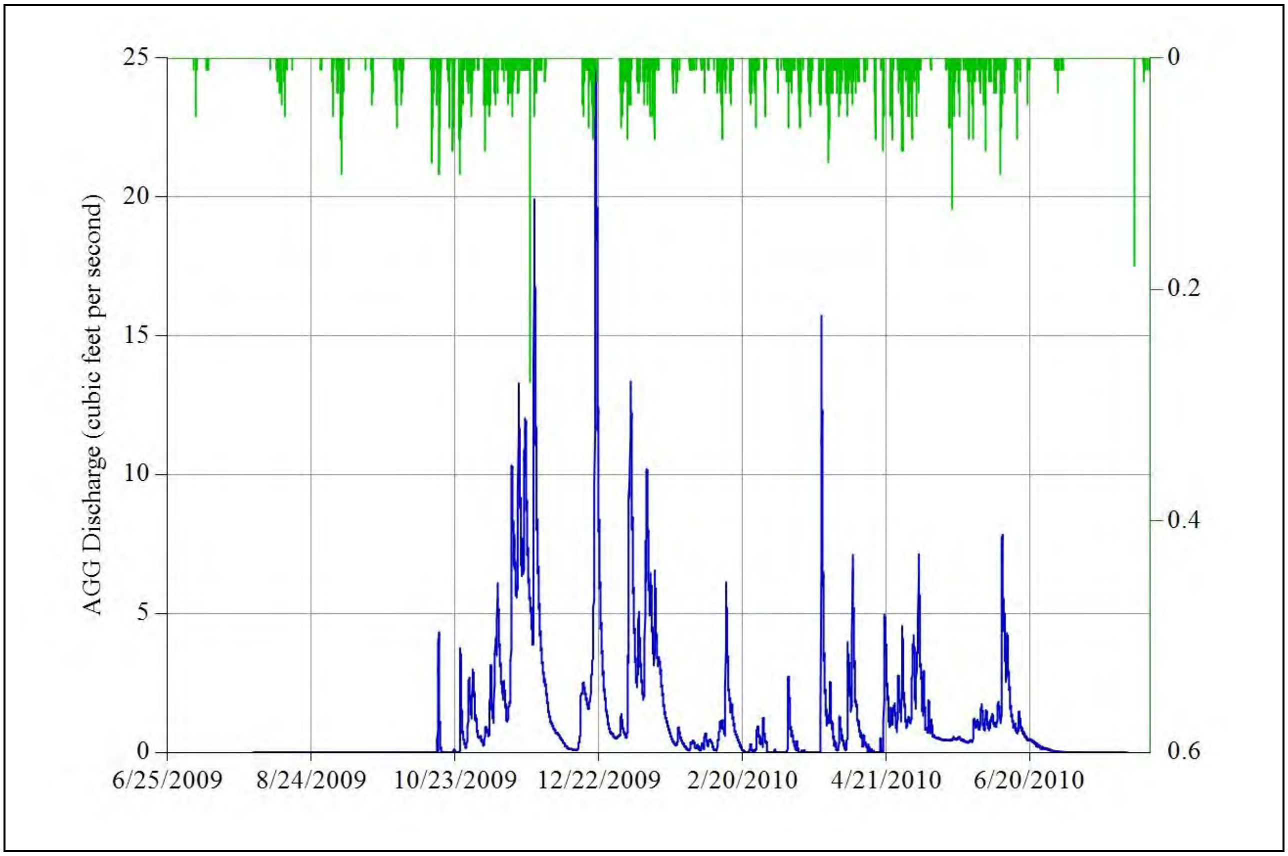


Figure 4. AGG hydrograph.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location AGG. Data from May 14, 2010 to July 8, 2010 were missing and replaced with modeled data from AG174. A moderate amount of error was observed in the modeled data (25 percent) and the rating curves. These factors combine to result is a hydrograph of average quality. After assessing the quality of the hydrologic data and characteristics of the hydrograph at location AGG, it was found that the hydrologic data should used without qualification. Although there were some quality assurance issues, the overall form of the hydrograph was judged to be reasonably accurate. The error associated with the hydrograph from this station is accounted for in the final pollutant loading values by reporting the data as a range between the 25th and 75th percentile.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology, by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. United States Government Printing Office, Denver, Colorado.

Herrera Environmental Consultants, Inc.

Memorandum

To	Project File 06-03509-002
From	Dylan Ahearn, Herrera Environmental Consultants
Date	August 8, 2010
Subject	Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **CB335**

This memorandum reviews hydrologic data collected at monitoring location CB335 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location CB335 represents commercial land use in the Snohomish River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.4 percent to 0.0 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928015).

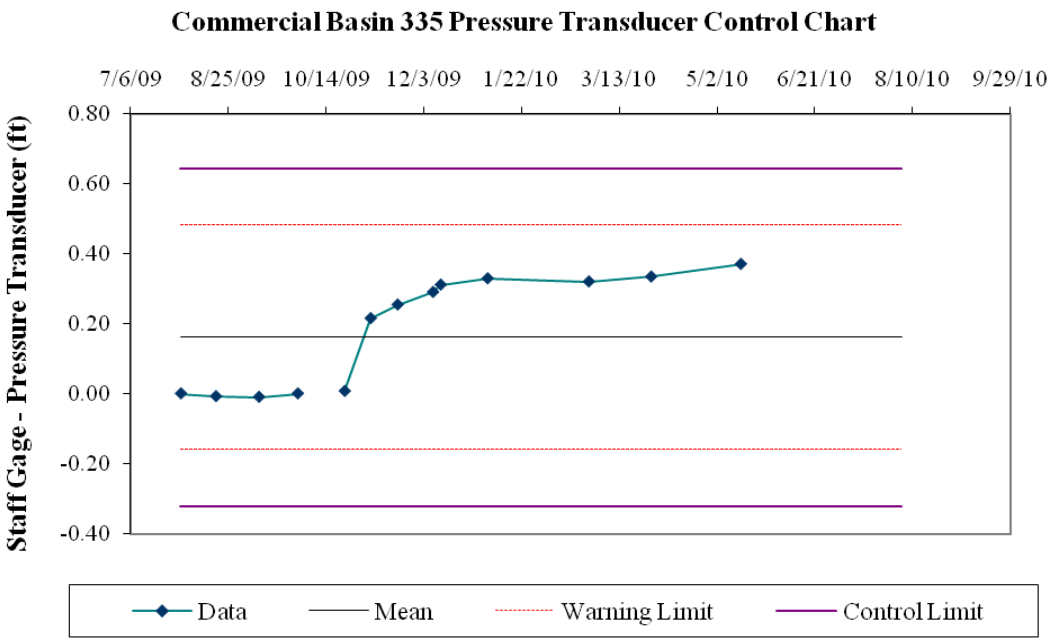
Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.400	1.4	0.0
Post-monitoring	0.996	1.0	-0.4

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the level sensors were conducted on 15 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift did not exceed the warning limit of plus or minus 1 standard deviation from the mean. The maximum drift measured between calibrations was 0.22 feet. To correct for sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.



Gap in record indicates period of no flow.

Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the CB335 transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a high quality. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. It should be noted that there was an offset shift on December 7, 2010 because the offset value within the sensor was inadvertently changed, and the subsequent data were corrected for the change in offset value. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Table 2. Hydrologic data correction history for location CB335.

Date of Correction	User	From	To	Comment
12/28/2009 14:59	dyu	7/31/2009 11:57	8/18/2009 11:39	Drift Correction with Calibration Drift value of -0.011 and Fouling Drift value of 0.000 Feet
12/28/2009 15:08	dyu	8/18/2009 11:54	9/9/2009 12:24	Advanced Correction (Date/Time, Value, Diff): (2009-08-18 11:54:09, 0.58, -0.008) (2009-09-09 12:24:09, 0.6, -0.027)
12/28/2009 15:13	dyu	10/23/2009 10:39	11/5/2009 17:39	Advanced Correction (Date/Time, Value, Diff): (2009-10-23 10:39:09, 0.99, 0.043) (2009-11-05 17:24:09, 0.9, 0.016)
12/28/2009 15:15	dyu	11/5/2009 17:24	11/19/2009 12:09	Advanced Correction (Date/Time, Value, Diff): (2009-11-05 17:39:09, 0.9, 0.014) (2009-11-19 12:09:09, 1.35, 0.244)
12/28/2009 18:18	dyu	11/19/2009 12:24	12/7/2009 15:24	Advanced Correction (Date/Time, Value, Diff): (2009-11-19 12:24:09, 1.35, 0.024) (2009-12-07 15:39:09, 0.62, 0.016)
12/28/2009 18:18	dyu	11/19/2009 12:09	11/19/2009 12:09	Delete drop
12/28/2009 18:18	dyu	11/19/2009 11:54	11/19/2009 12:24	Interpolate Gap(Linear) - fill deleted drop
1/21/2010 14:32	dyu	12/7/2009 15:39	12/7/2009 15:39	Delete drop
1/21/2010 14:33	dyu	12/7/2009 15:24	12/7/2009 16:09	Interpolate Gap(Linear)
1/21/2010 14:39	dyu	12/7/2009 16:39	12/11/2009 13:39	Advanced Correction (Date/Time, Value, Diff): (2009-12-07 16:39:09, 0.62, 0.220) (2009-12-11 13:54:09, 0.61, 0.184)
1/21/2010 14:40	dyu	12/11/2009 13:54	12/11/2009 14:09	Delete region
1/21/2010 14:46	dyu	12/11/2009 14:39	1/4/2010 14:39	Advanced Correction (Date/Time ,Value, Diff): (2009-12-11 14:24:09, 0.61, 0.278) (2010-01-04 14:39:09, 0.9, 0.294)
1/24/2010 21:58	dyu	12/11/2009 14:24	12/11/2009 14:24	Delete region
1/24/2010 21:58	dyu	12/11/2009 13:39	12/11/2009 14:39	Interpolate Gap(Linear)
1/24/2010 21:59	dyu	11/16/2009 11:24	11/16/2009 11:24	Delete drop
1/24/2010 21:59	dyu	11/16/2009 11:09	11/16/2009 11:39	Interpolate Gap(Linear) - fill deleted drop region
3/3/2010 22:43	dyu	1/4/2010 14:54	2/25/2010 10:39	Advanced Correction of (Date/Time Value Diff) (2010-01-04 14:54:090.9 0.275) (2010-02-25 10:39:090.61 0.311)

Table 2 (continued). Hydrologic data correction history for location CB335.

Date of Correction	User	From	To	Comment
4/20/2010 16:42	dyu	2/25/2010 11:09	3/29/2010 8:09	Advanced Correction (Date/Time, Value, Diff): (2010-02-25 10:54:09, 0.61, 0.311) (2010-03-29 08:09:09, 0.9, 0.329)
4/20/2010 16:42	dyu	2/25/2010 10:54	2/25/2010 10:54	Delete drop
4/20/2010 16:43	dyu	2/25/2010 10:39	2/25/2010 11:09	Interpolate Gap(Linear) - fill deleted drop
6/2/2010 21:18	dyu	3/29/2010 8:24	5/14/2010 7:54	Advanced Correction (Date/Time, Value, Diff): (2010-03-29 08:24:09, 0.9, 0.336) (2010-05-14 07:54:09, 0.58, 0.322)
7/28/2010 14:36	dyu	5/14/2010 8:09	7/6/2010 6:39	Advanced Correction (Date/Time, Value, Diff): (2010-05-14 08:09:09, 0.58, 0.324) (2010-07-06 06:39:09, 0.64, 0.333)
8/10/2010 12:16	dyu	7/6/2010 6:54	8/4/2010 8:39	Advanced Correction (Date/Time, Value, Diff) (2010-07-06 06:54:09, 0.658, 0.336) (2010-08-04 08:39:09, 0.64, 0.338)
8/27/2010 13:14	dahearn	10/13/2009 1:54	10/13/2009 18:09	Delete region - anamolous points
8/27/2010 13:14	dahearn	10/13/2009 1:39	10/13/2009 18:24	Interpolate Gap(Linear) - short gap
8/27/2010 13:17	dahearn	10/13/2009 22:24	10/23/2009 12:54	Advanced Correction (Date/Time, Value, Diff): (2009-10-13 22:24:09, 1.098515, 0.121920) (2009-10-23 12:54:09, 0.975963, -0.010789)
8/27/2010 13:22	dahearn	1/4/2010 6:09	1/8/2010 6:09	Advanced Correction (Date/Time, Value, Diff): (2010-01-04 06:09:09, 1.101179, 0.076565) (2010-01-08 06:09:09, 0.610525, 0.000000)

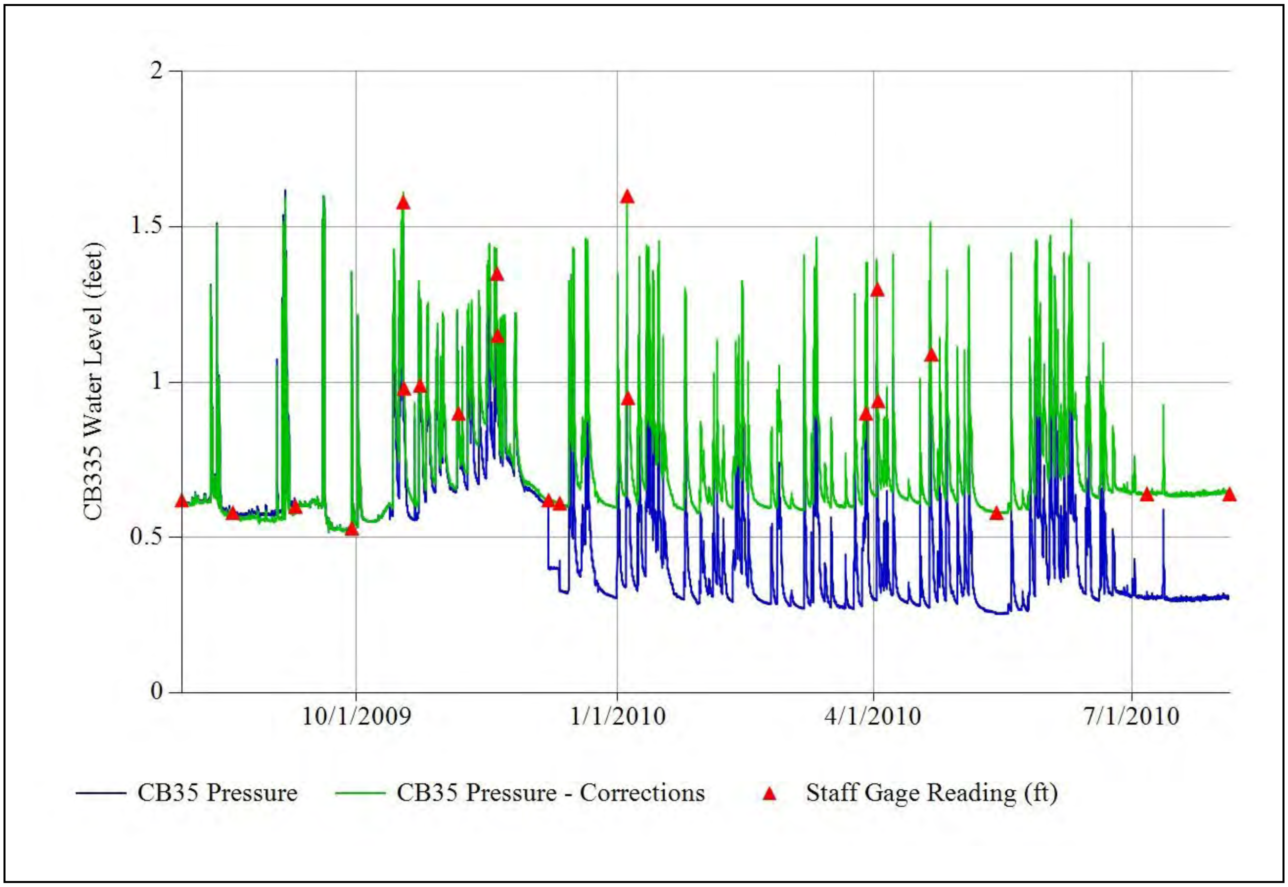


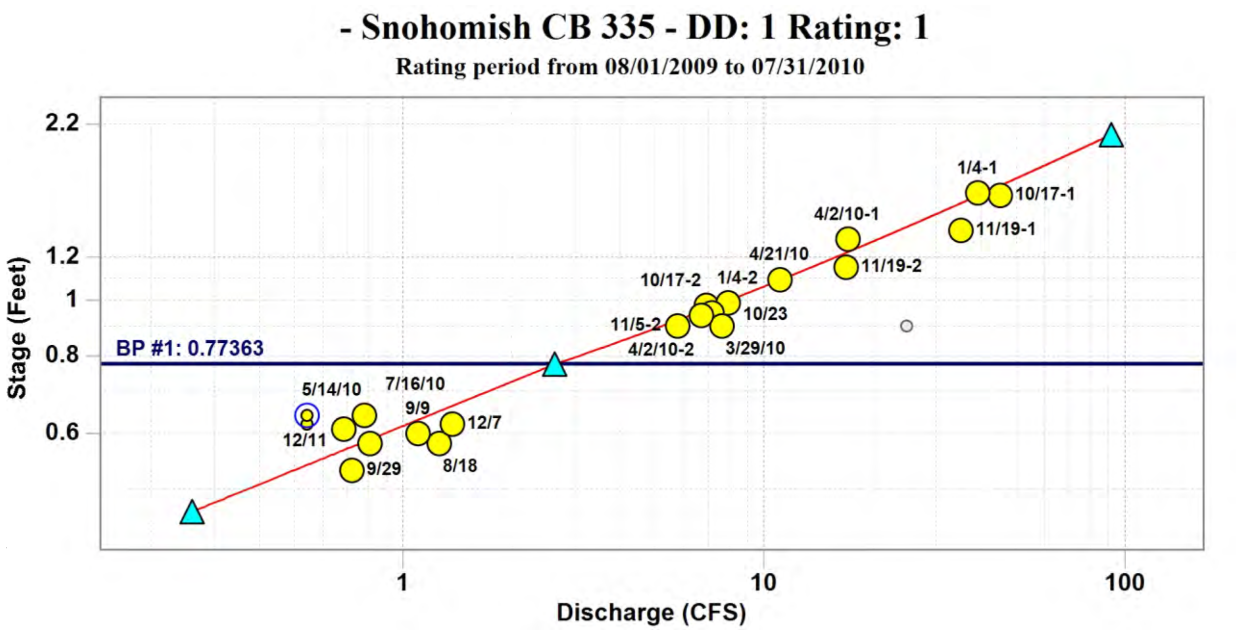
Figure 2. Corrected and raw water level data from location CB335.

Flow Conversion

Because discharge is calculated using water level and water level converted to flow, bias can be introduced by both water level data and the flow conversion process. A rating curve was developed for location CB335 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Twenty-one discharge measurements were collected at location CB335 during the 1-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is 27.8 percent. Although the project QAPP (Herrera 2009) did not provide an MQO for the rating curve bias, the rating curve shown in Figure 3 is considered acceptable given the errors inherent in water level and discharge measurements in a dynamic fluvial environment.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At CB335, the highest manually measured flow was 45.2 cfs, while the highest recorded flow was 44.3 cfs. Consequently, this guideline was met.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location CB335.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

To assess if the CB335 hydrograph is representative of commercial basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a commercial basin in western Washington. Since there were no existing rain gauges with reliable data records located within the CB335 basin, rainfall and runoff comparisons could not be made. As a result, the CB335 hydrograph was assessed without comparison to rainfall.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

The CB335 hydrograph is presented in Figure 4. There is substantial base flow and a flashy response to rainfall events during the dry season. The flow peaks converged very slightly in the wet season indicating some flow attenuation and minimally elevated winter base flow. The response to rainfall was also very flashy in the winter. Taken together, these results indicate that the CB335 hydrograph is typical (representative) of commercial (i.e., highly impervious) basins in western Washington.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal data gaps (less than 0.1 percent of the record) during the monitoring period (see Table 2). Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location CB335. There were no data gaps or shifts in the rating curve, and the rating curve error was relatively low. The flow estimation error is accounted for in the final pollutant loading values for this station by reporting the data as a range between the 25th and 75th percentile. After assessing the quality of the hydrologic data at location CB335, it was found that the data can be used without qualification.

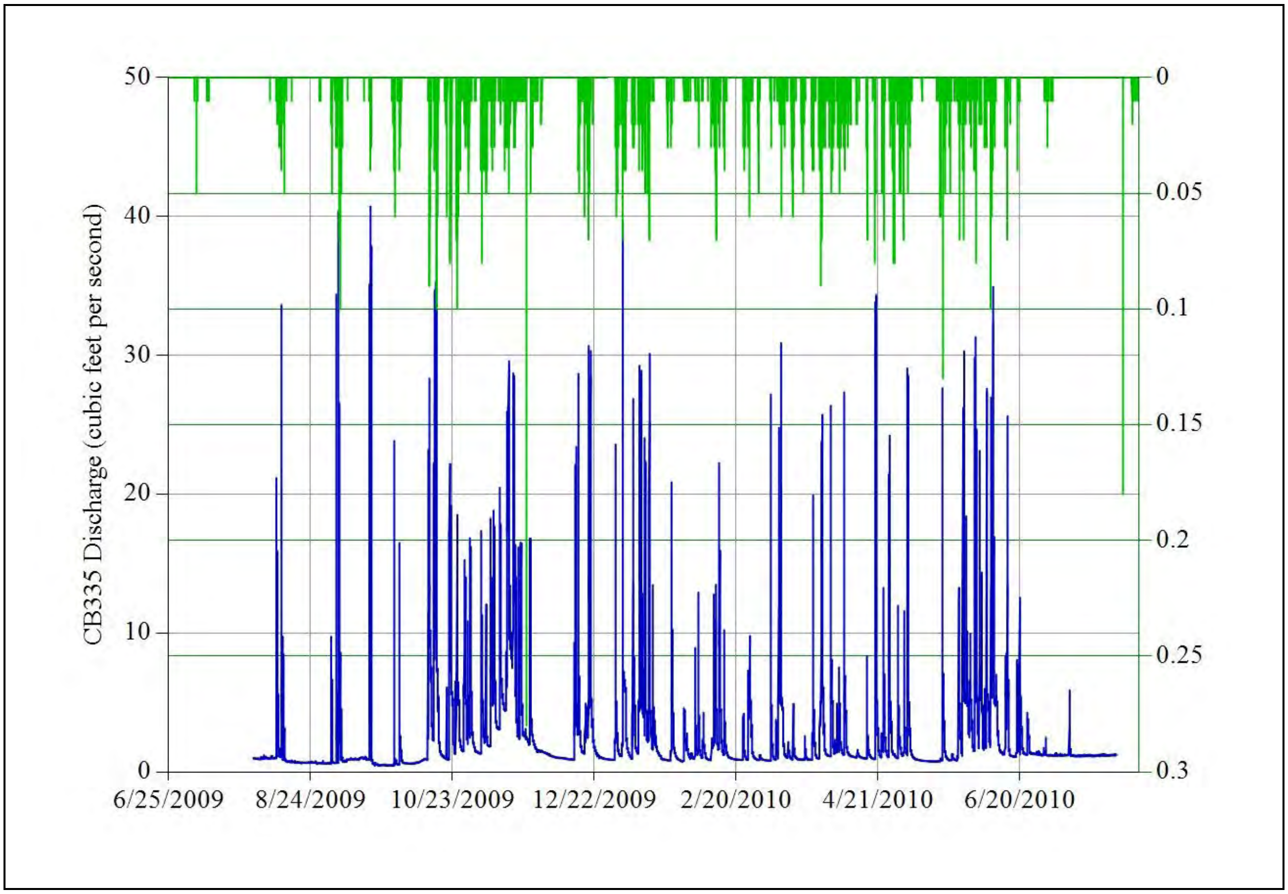


Figure 4. CB335 hydrograph.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology, by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

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Herrera Environmental Consultants, Inc.

Memorandum

To	Project File 06-03509-002
From	Dylan Ahearn, Herrera Environmental Consultants
Date	August 8, 2010
Subject	Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **CBA**

This memorandum reviews hydrologic data collected at monitoring location CBA from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location CBA represents commercial land use in the Puyallup River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.4 percent to -0.8 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928011).

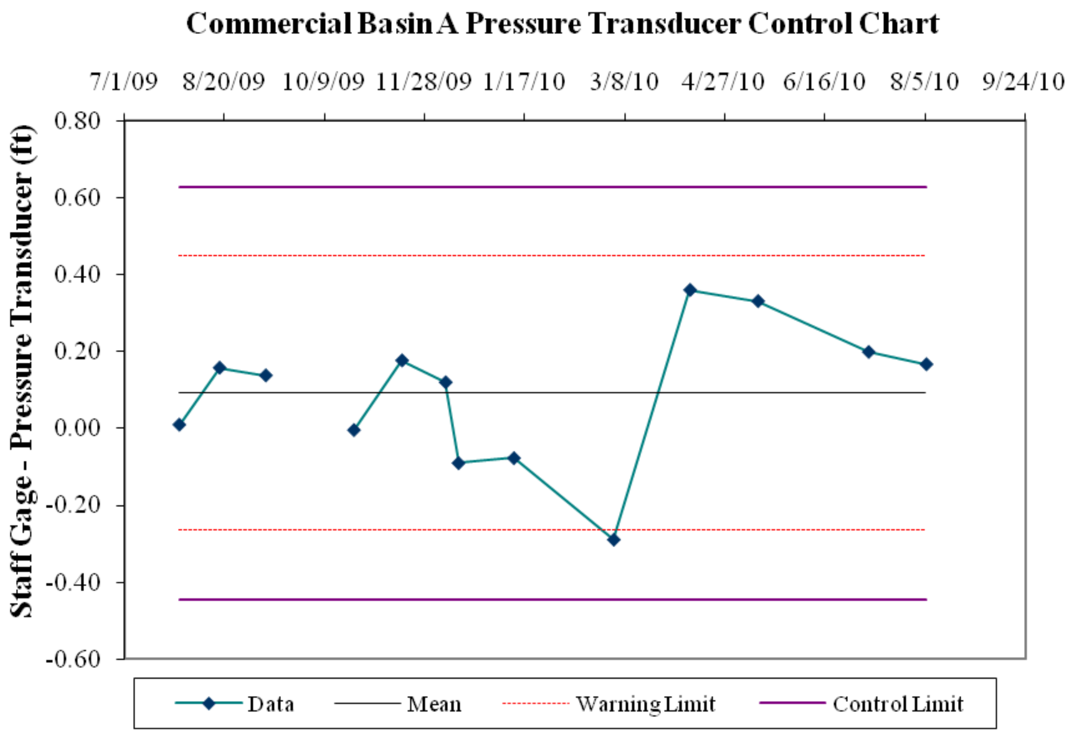
Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.395	1.4	-0.4
Post-monitoring	0.993	1.0	-0.8

Sensor Drift and Displacement

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the water level sensors were conducted on 13 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift slightly exceeded the warning limit of plus or minus 1 standard deviation from the mean on one occasion. The senor was checked at this point and sensor drift subsequently decreased. The maximum drift between calibrations was 0.67 feet, but this was due to the sensor being removed and replaced at a slightly different depth on March 10, 2010. To correct for this displacement and sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.



Gap in record indicates period of no flow.

Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing Bias

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the CBA transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of an average quality. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Table 2. Hydrologic data correction history for location CBA.

Date of Correction	User	From	To	Comment
10/28/2009 10:39	dyu	7/28/2009 12:12	8/17/2009 15:12	Drift Correction with Calibration Drift value of 0.158
10/28/2009 10:40	dyu	7/28/2009 11:12	7/28/2009 11:57	Drift Correction with Calibration Drift value of 0.010
10/28/2009 10:41	dyu	8/17/2009 15:12	9/9/2009 16:42	Drift Correction with Calibration Drift value of 0.138
10/28/2009 10:43	dyu	9/9/2009 16:57	10/23/2009 16:12	Drift Correction with Calibration Drift value of -0.004
11/21/2009 9:17	dyu	10/23/2009 16:27	11/16/2009 17:12	Drift Correction with Calibration Drift value of 0.177
12/10/2009 11:03	dyu	11/16/2009 17:27	12/8/2009 11:57	Drift Correction with Calibration Drift value of 0.120
12/16/2009 11:18	dyu	8/17/2009 15:27	9/9/2009 16:57	Advanced Correction (Date/Time, Value, Diff) (2009-08-17 15:27:17, 2.467, 0.172) (2009-09-09 16:42:17, 2.153, -0.280)
12/16/2009 11:20	dyu	9/9/2009 16:57	9/29/2009 16:12	Advanced Correction (Date/Time, Value, Diff) (2009-09-09 16:57:17, 2.43, 0.136) (2009-09-29 15:57:17, 1.87, 0.030)
12/16/2009 11:23	dyu	11/16/2009 17:27	12/8/2009 11:57	Advanced Correction (Date/Time, Value, Diff) (2009-11-16 17:27:17, 3.845, 0.157) (2009-12-08 11:57:17, 2.815, 0.000)
12/28/2009 10:00	dyu	12/8/2009 12:12	12/14/2009 20:57	Advanced Correction (Date/Time, Value, Diff) (2009-12-08 12:12:17, 2.81, 0.104) (2009-12-14 20:57:17, 3.06, 0.000)
12/28/2009 10:05	dyu	12/11/2009 4:12	12/11/2009 4:12	Delete region - delete drop
12/28/2009 10:05	dyu	12/11/2009 3:57	12/11/2009 4:27	Interpolate Gap(Linear) - fill deleted drop
12/28/2009 10:09	dyu	12/11/2009 4:12	12/14/2009 20:57	Advanced Correction (Date/Time, Value, Diff) (2009-12-11 04:12:17, 3.027, 0.205) (2009-12-14 20:57:17, 2.97, 0.000)
1/24/2010 11:11	dyu	12/14/2009 21:27	1/11/2010 13:27	Advanced Correction (Date/Time, Value, Diff) (2009-12-14 21:27:17, 2.971, -0.112) (2010-01-11 13:27:17, 4.35, -0.084)
1/24/2010 11:12	dyu	12/14/2009 21:12	12/14/2009 21:12	Delete spike
1/24/2010 11:13	dyu	12/14/2009 20:57	12/14/2009 21:27	Interpolate Gap(Linear)
4/15/2010 9:22	dyu	1/11/2010 13:57	3/2/2010 9:57	Advanced Correction (Date/Time, Value, Diff) (2010-01-11 13:42:17, 4.351, -0.090) (2010-03-02 09:57:17, 2.831, -0.290)

Table 2 (continued). Hydrologic data correction history for location CBA.

Date of Correction	User	From	To	Comment
4/15/2010 9:25	dyu	3/2/2010 10:12	4/9/2010 11:27	Advanced Correction (Date/Time, Value, Diff) (2010-03-02 10:12:17, 2.831, -0.290) (2010-04-09 11:27:17, 2.82, 0.356)
4/15/2010 11:01	dyu	3/10/2010 15:27	3/10/2010 15:27	Delete drop
4/15/2010 11:02	dyu	3/10/2010 15:12	3/10/2010 15:42	Interpolate Gap(Linear) - fill deleted drop
6/2/2010 21:49	dyu	4/9/2010 11:42	5/13/2010 9:57	Advanced Correction (Date/Time, Value, Diff) (2010-04-09 11:42:17, 2.82, 0.357) (2010-05-13 09:57:17, 2.8, 0.334)
7/15/2010 10:16	dyu	5/13/2010 10:12	7/7/2010 15:27	Advanced Correction (Date/Time, Value, Diff) (2010-05-13 10:12:17, 2.8, 0.332) (2010-07-07 15:27:17, 2.58, 0.183)
8/10/2010 12:46	dyu	7/7/2010 15:42	8/5/2010 11:27	Offset Correction with value of 0.184 Feet H2O
8/10/2010 12:48	dyu	7/7/2010 15:57	8/5/2010 11:27	Drift Correction with Calibration Drift value of -0.018
8/30/2010 15:51	dahearn	5/27/2010 8:57	5/28/2010 17:42	Advanced Correction (Date/Time, Value, Diff) (2010-05-27 08:57:17, 2.641, 0.000) (2010-05-28 17:42:17, 5.545, 1.563)

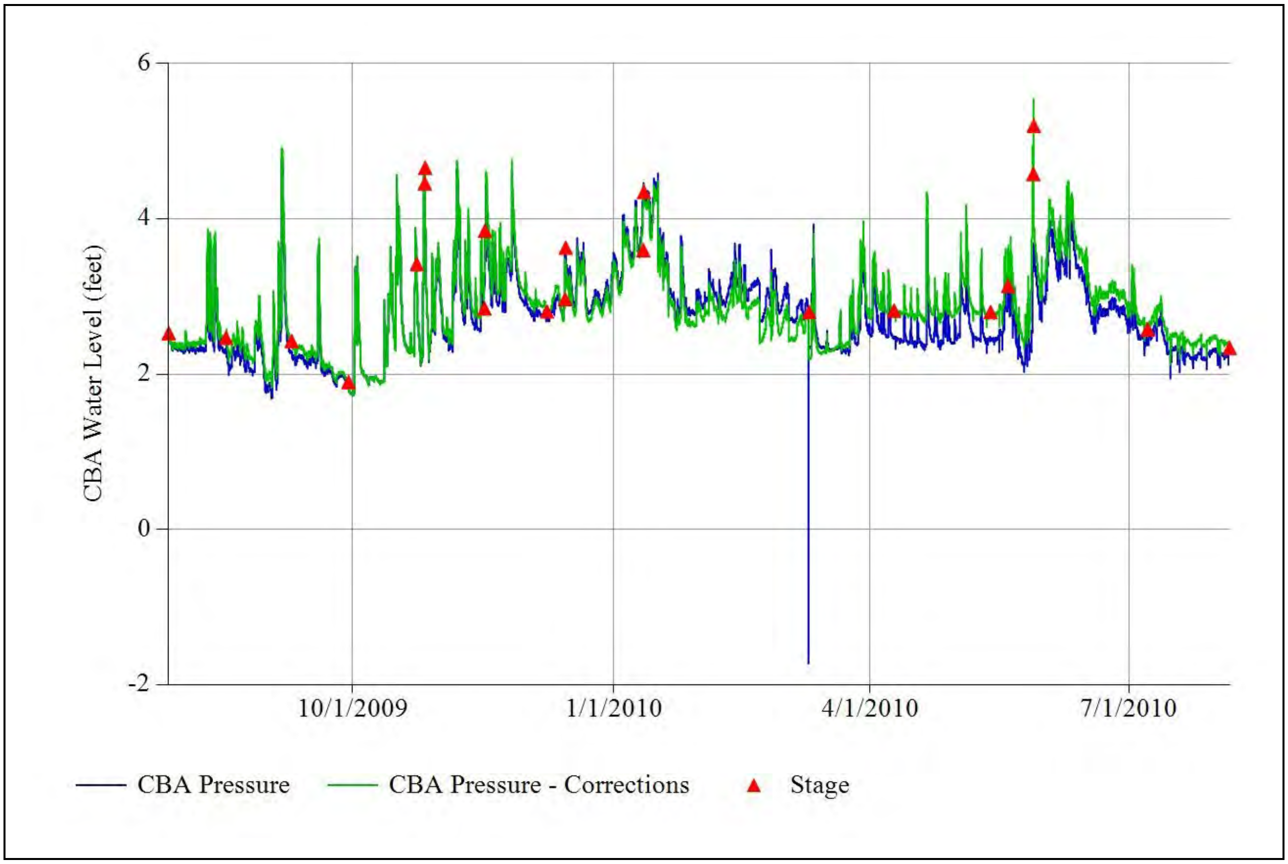


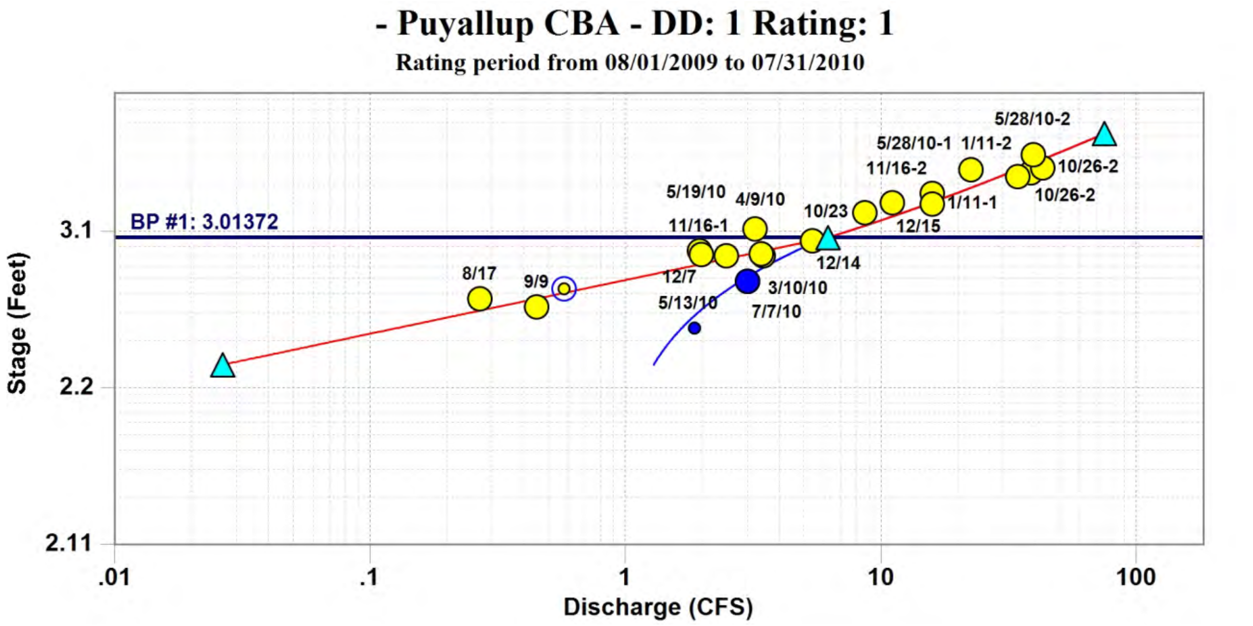
Figure 2. Corrected and raw water level data from location CBA.

Flow Conversion Bias

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location CBA to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Twenty discharge measurements were collected at location CBA during the 1-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The rating curve for this location included a shift that occurred due to scour following high flow conditions on June 9, 2010. The shift applies to data collected after this date (see blue line in Figure 3). The standardized root mean square (SRMS) error for the primary rating curve (red line in Figure 3) is 28.7 percent while the SRMS for the shifted portion of the rating is 12.0 percent. The error introduced into the data from an unstable channel morphology was reduced by introducing a shift into the rating curve. This resulted in an overall rating that was of an acceptable quality given the conditions in the field.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At CBA, the highest manually measured flow was 43 cfs, while the highest recorded flow was 56 cfs. Consequently, the highest recorded flows were only 1.3 times higher than the highest manually measured flow, well within the guideline of 2.5.



Note: red line and yellow circles for rating data before 6/9/10, blue line and blue circles for rating data after 6/9/10, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location CBA.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

To assess if the CBA hydrograph was representative of commercial basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a commercial basin in western Washington. Since there were no existing rain gauges with reliable data records located within the CBA basin, rainfall and runoff comparisons could not be made. As a result, the CBA hydrograph was assessed without comparison to rainfall.

The CBA hydrograph is presented in Figure 4. There is no base flow during the dry season and there was a flashy response to rainfall events. The flow peaks tend to converge in the wet season indicating flow attenuation and elevated winter base flow, but response to rain events was still flashy during the winter. Taken together, these results indicate that the CBA hydrograph is typical (representative) of commercial (i.e., highly impervious) basins in western Washington.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal (less than 0.1 percent of the record) data gaps during the monitoring period (see Table 2). Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location CBA. There was one shift in the rating curve and the rating curve errors were relatively low. The flow estimation error is accounted for in the final pollutant loading values for this station by reporting the data as a range between the 25th and 75th percentile. After assessing the quality of the hydrologic data at location CBA, it was found that the data can be used without qualification.

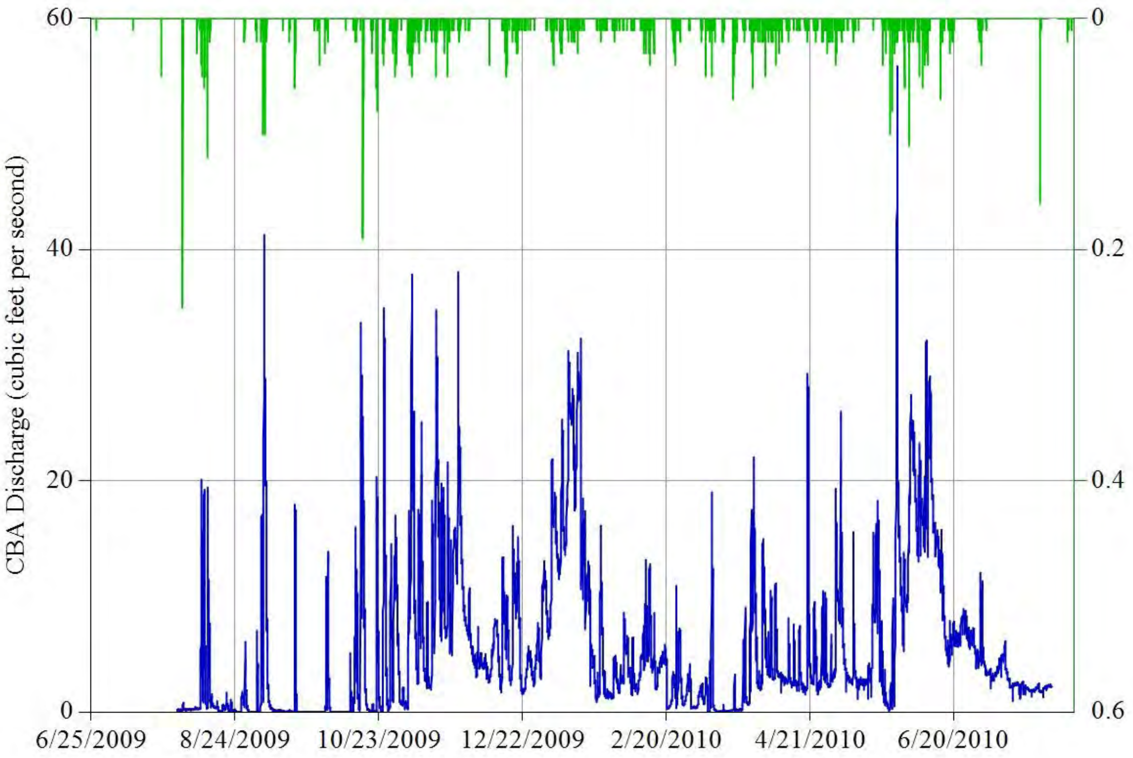


Figure 4. CBA hydrograph.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

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Herrera Environmental Consultants, Inc.

Memorandum

To Project File 06-03509-002

From Dylan Ahearn, Herrera Environmental Consultants

Date August 8, 2010

Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **CBB**

This memorandum reviews hydrologic data collected at monitoring location CBB from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location CBB represents commercial land use in the Puyallup River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves.

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.6 percent to -0.9 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928013).

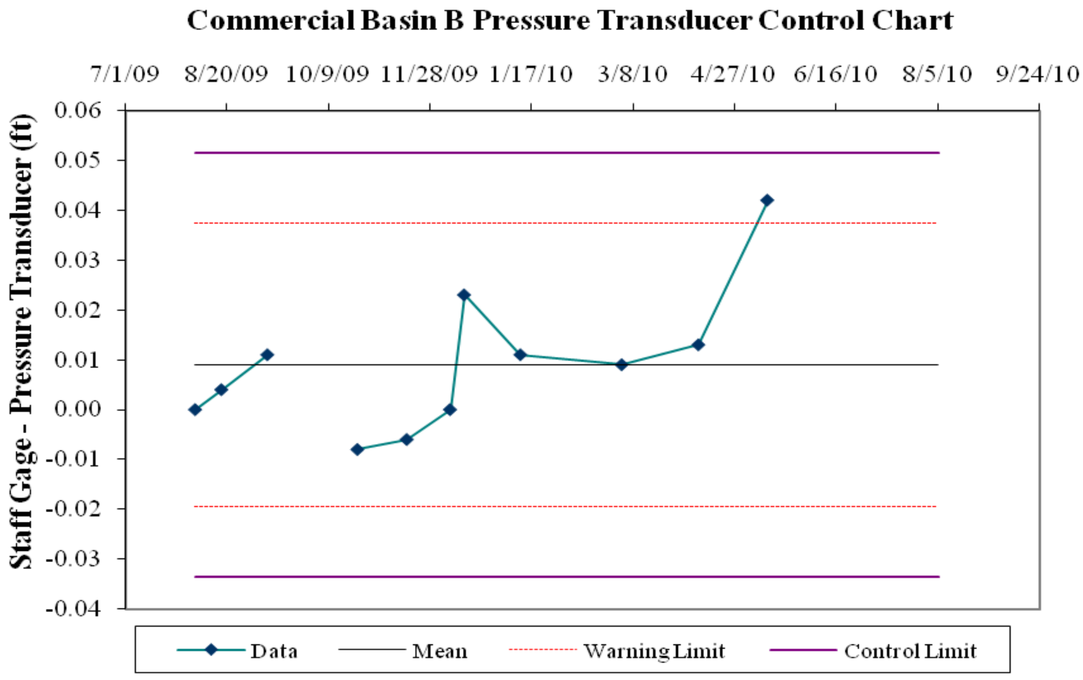
Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.394	1.4	-0.6
Post-monitoring	0.991	1.0	-0.9

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the level sensors were conducted on 11 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and control limits. As shown in Figure 1, sensor drift exceeded the warning limit of plus or minus

1 standard deviation from the mean on one occasion (July 7, 2010). However, the creek was dry at the next calibration visit (August 5, 2010) so the calibration between the staff gauge and the sensor could not be verified. Although this may suggest that the data from July 7, 2010 to the end of the study may be inaccurate, the maximum drift at this location did not exceed 0.03 feet and the stream became dry on the following day (July 8, 2010), indicating that the data were minimally affected. To correct for sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.



Note: Gap in record indicates period of no flow.

Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the CBB transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of an average quality. Because the flow record was nearly complete (with the exception of a data gap early in the study when the stream was dry) and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Table X-2. Hydrologic data correction history for location CBB.

Date of Correction	User	From	To	Comment
11/21/2009 9:21	dyu	9/9/2009 0:12	10/23/2009 9:09	Drift Correction with Calibration Drift value of -0.008 and Fouling Drift value of 0.000 Feet H2O
11/21/2009 9:21	dyu	10/23/2009 9:24	11/16/2009 15:54	Drift Correction with Calibration Drift value of -0.006 and Fouling Drift value of 0.000 Feet H2O
12/11/2009 9:33	dyu	7/27/2009 9:12	8/11/2009 3:42	Offset Correction with value of -0.530 Feet H2O
12/11/2009 9:38	dyu	8/11/2009 6:42	9/9/2009 10:38	Offset Correction with value of -1.129 Feet H2O
12/11/2009 9:38	dyu	8/11/2009 3:57	8/11/2009 6:27	Advanced Correction (Date/Time, Value, Diff) (2009-08-11 03:57:08, -0.519, -0.697) (2009-08-11 06:27:08, -0.501, -1.122)
1/24/2010 11:24	dyu	12/14/2009 22:09	12/15/2009 2:39	Drift Correction with Calibration Drift value of 0.013 and Fouling Drift value of 0.000 Feet H2O
3/3/2010 23:45	dyu	12/15/2009 2:54	1/11/2010 16:09	Advanced Correction (Date/Time, Value, Diff) (2009-12-15 02:54:03, 1.037 0.015) (2010-01-11 16:09:03, 1.98, 0.036)
3/3/2010 23:48	dyu	1/11/2010 16:24	3/2/2010 14:24	Advanced Correction (Date/Time, Value, Diff) (2010-01-11 16:24:03, 1.98, 0.038) (2010-03-02 14:24:03, 0.66, 0.008)
4/15/2010 9:32	dyu	3/2/2010 14:39	4/9/2010 7:09	Advanced Correction (Date/Time, Value, Diff) (2010-03-02 14:39:03, 0.661, 0.010) (2010-04-09 07:09:03, 0.75, 0.014)
6/2/2010 21:51	dyu	4/9/2010 7:24	5/13/2010 6:39	Advanced Correction (Date/Time, Value, Diff) (2010-04-09 07:24:03, 0.75, 0.012) (2010-05-13 06:39:03, 0.49, 0.041)
7/15/2010 10:19	dyu	5/13/2010 6:54	7/7/2010 6:09	Advanced Correction (Date/Time, Value, Diff) (2010-05-13 06:54:03, 0.49, 0.043) (2010-07-07 06:09:03, 0, 0.511)

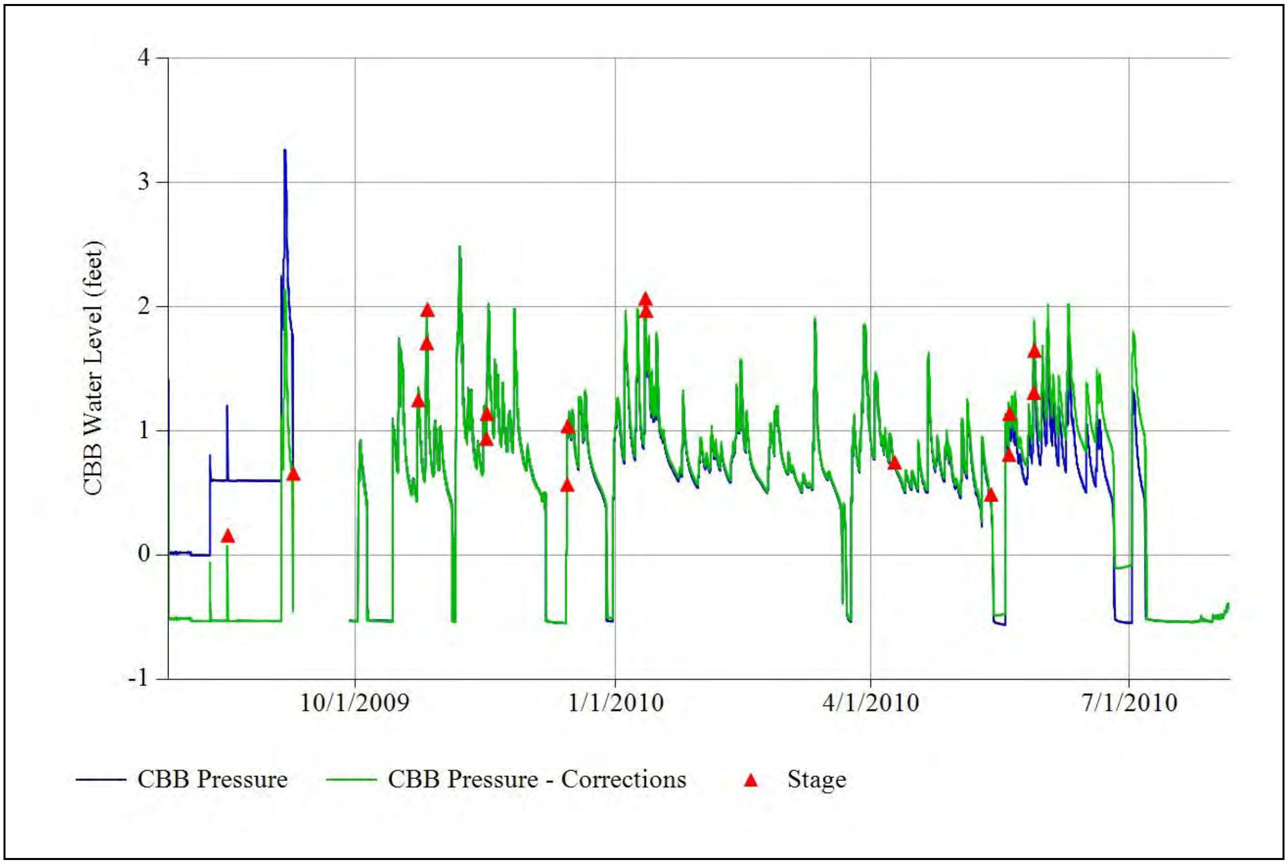


Figure 2. **Corrected and raw water level data from location CBB.**

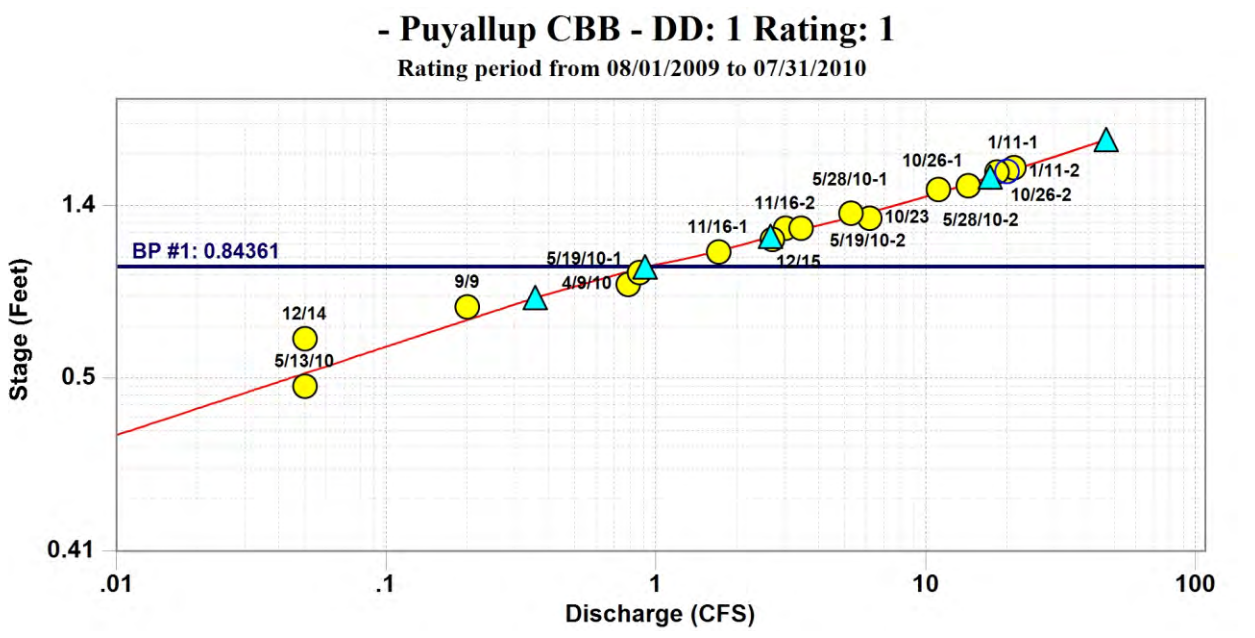
Flow Conversion

Because discharge is calculated using water levels and rating curves, bias can be introduced by both water level data and the flow conversion process. A rating curve was developed for location CBB to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Sixteen discharge measurements were collected at location CBB during the 1-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is 24.6 percent. Although the project QAPP (Herrera 2009) did not provide an MQO for the rating curve bias, the rating curve shown in Figure 3 is considered excellent given the error inherent in manual discharge measurement and water level sensing in a dynamic fluvial environment.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At CBB, the highest manually measured flow was

21.1 cfs, while the highest recorded flow was 35.0 cfs. Consequently, the highest recorded flows were only 1.7 times higher than the highest manually measured flow, well within the guideline of 2.5.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location CBB.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see for equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

To assess if the CBB hydrograph was representative of commercial basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a commercial basin in western Washington. Since there were no existing rain gauges with reliable data records located within the CBB basin, rainfall and runoff comparisons could not be made. As a result, the CBB hydrograph was assessed without comparison to rainfall.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

The CBB hydrograph is presented in Figure 4. There was no base flow during the dry season and there was a flashy response to rainfall events. The flow peaks converged slightly in the wet season indicating flow attenuation and elevated winter base flow, but response to rain events was still flashy during the winter. Taken together, these results indicate that the CBB hydrograph is typical (representative) of commercial (i.e., highly impervious) basins in western Washington.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There was a 20-day data gap from September 9, 2009 to September 29, 2009 (Figure 2). This gap occurred during a period of little rain so little, if any, flow was missed. In addition, the gap only constitutes 5.4 percent of the data record. Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

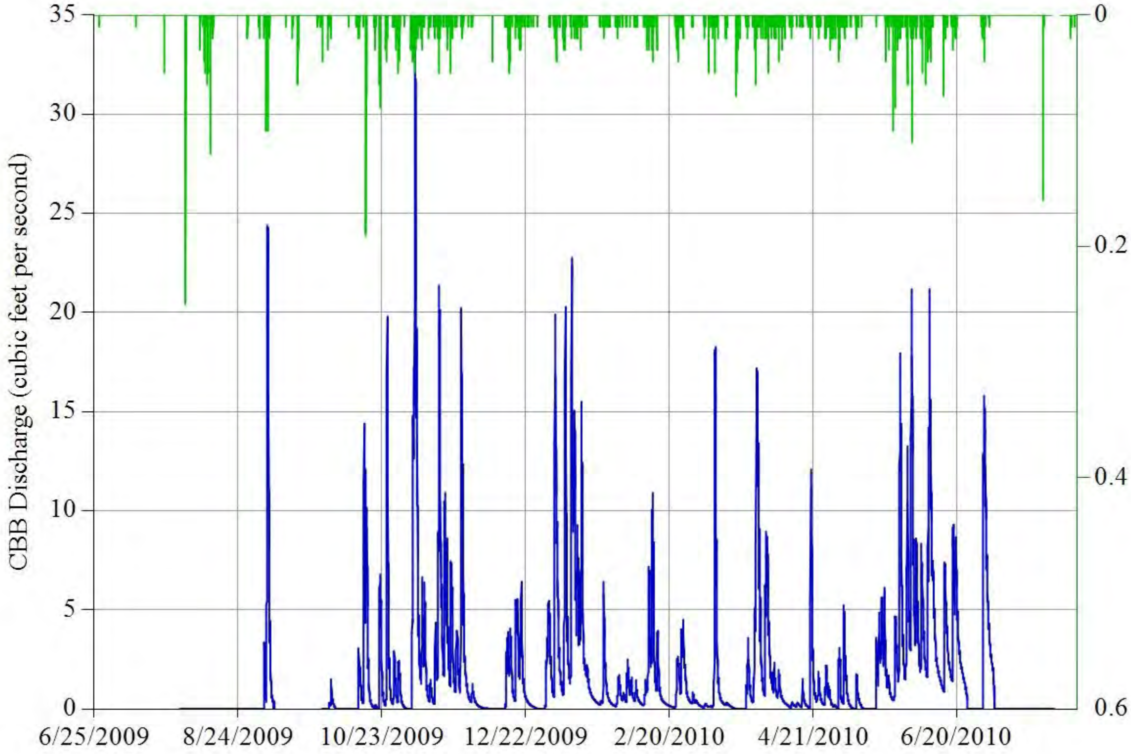


Figure 4. CBB hydrograph.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location CBB. There were no significant gaps in the data record and the rating curve error was relatively low. After assessing the quality of the hydrologic data at location CBB it was found that the data can be used without qualification. The error associated with the hydrograph from this station is accounted for in the final pollutant loading values by reporting the data as a range between the 25th and 75th percentile.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

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Herrera Environmental Consultants, Inc.

Memorandum

To Project File 06-03509-002

From Dylan Ahearn, Herrera Environmental Consultants

Date August 8, 2010

Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **CBX**

This memorandum reviews hydrologic data collected at monitoring location CBX from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location CBX represents commercial land use in the Snohomish River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves.

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error from -0.16 percent to -0.17 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928012).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.397	1.4	-0.17
Post-monitoring	0.999	1.0	-0.16

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the water level sensors were conducted on 14 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift did not exceed the warning limit of plus or minus 1 standard deviation from the mean. The maximum drift measured between calibrations was 0.25 feet. To correct for this sensor drift and all drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

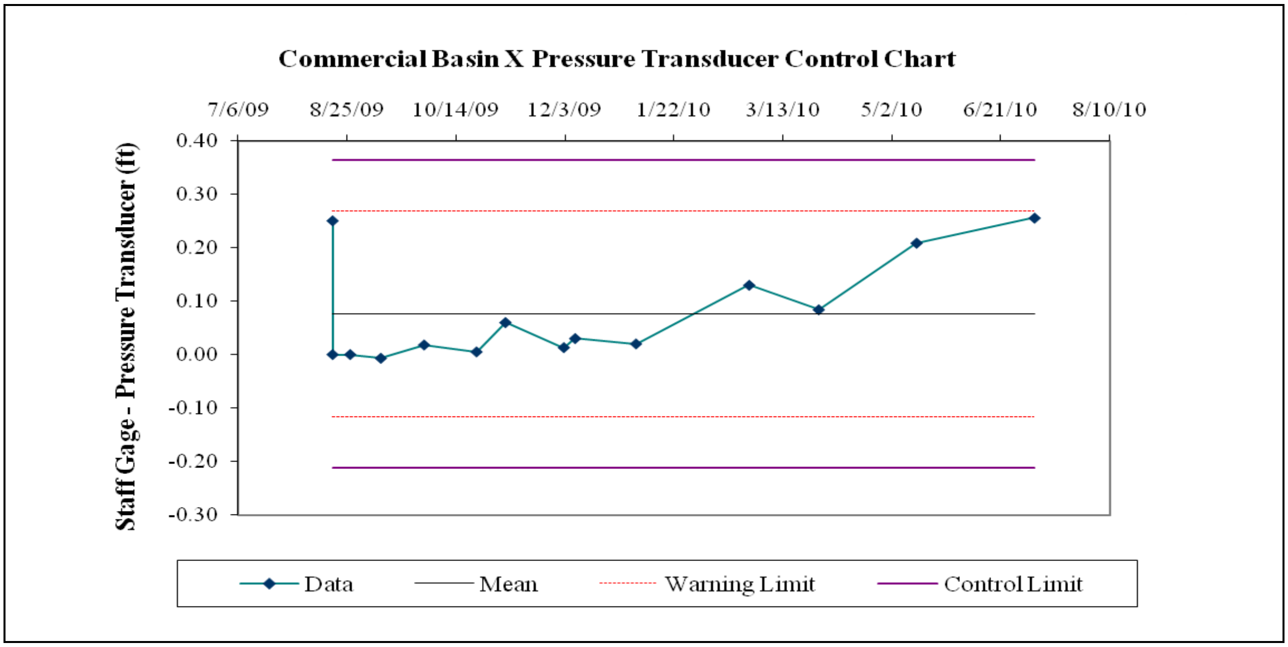


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the CBX transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a high quality. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location CBX to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a

Table 2. Hydrologic data correction history for location CBX.

Date of Correction	User	From	To	Comment
8/30/2009 11:58	dyu	7/31/2009 10:34	8/18/2009 11:01	Drift Correction with Calibration Drift value of 0.251 and Fouling Drift value of 0.000 Feet
8/30/2009 12:00	dyu	8/18/2009 11:16	8/26/2009 8:31	Drift Correction with Calibration Drift value of -0.148 and Fouling Drift value of 0.000 Feet
10/28/2009 10:11	dyu	8/26/2009 12:11	9/9/2009 13:56	Drift Correction with Calibration Drift value of -0.007 and Fouling Drift value of 0.000 Feet
10/28/2009 10:13	dyu	9/9/2009 14:11	9/29/2009 9:26	Drift Correction with Calibration Drift value of 0.018 and Fouling Drift value of 0.000 Feet
10/28/2009 10:13	dyu	9/29/2009 9:41	10/23/2009 10:41	Drift Correction with Calibration Drift value of 0.005 and Fouling Drift value of 0.000 Feet
11/16/2009 9:45	dyu	10/23/2009 10:56	11/5/2009 16:56	Drift Correction with Calibration Drift value of 0.060 and Fouling Drift value of 0.000 Feet
12/10/2009 10:46	dyu	11/5/2009 16:56	12/2/2009 12:11	Drift Correction with Calibration Drift value of 0.013 and Fouling Drift value of 0.000 Feet
12/10/2009 10:47	dyu	12/2/2009 12:11	12/7/2009 17:11	Drift Correction with Calibration Drift value of 0.03 and Fouling Drift value of 0.000 Feet
1/21/2010 13:27	dyu	8/18/2009 10:31	8/18/2009 11:01	Delete region
1/21/2010 13:27	dyu	8/18/2009 10:04	8/18/2009 11:16	Interpolate Gap(Linear)
3/3/2010 22:48	dyu	12/7/2009 17:41	1/4/2010 14:56	Advanced Correction (Date/Time, Value, Diff) (2009-12-07 17:41:15, 0.715, 0.045) (2010-01-04 14:56:15, 1.125, 0.000)
3/3/2010 22:49	dyu	12/7/2009 17:26	12/7/2009 17:26	Delete region
3/3/2010 22:49	dyu	12/7/2009 17:11	12/7/2009 17:41	Interpolate Gap(Linear)
3/3/2010 22:54	dyu	1/4/2010 14:56	2/25/2010 11:56	Advanced Correction (Date/Time, Value, Diff) (2010-01-04 14:56:15, 1.15, 0.025) (2010-02-25 11:56:15, 0.71, 0.133)
4/20/2010 16:45	dyu	2/25/2010 12:11	3/29/2010 9:41	Advanced Correction (Date/Time, Value, Diff) (2010-02-25 12:11:15, 0.71, 0.129) (2010-03-29 09:41:15, 1.15, 0.079)

Table 2 (continued). Hydrologic data correction history for location CBX.

Date of Correction	User	From	To	Comment
6/28/2010 10:30	dyu	3/29/2010 10:11	5/13/2010 7:26	Advanced Correction (Date/Time, Value, Diff) (2010-03-29 09:56:15, 1.15, 0.080) (2010-05-13 07:26:15, 0.5, 0.212)
6/28/2010 10:30	dyu	3/29/2010 9:56	3/29/2010 9:56	Delete region
6/28/2010 10:30	dyu	3/29/2010 9:41	3/29/2010 10:11	Interpolate Gap(Linear)
7/29/2010 10:46	dyu	5/13/2010 7:56	7/6/2010 8:11	Advanced Correction (Date/Time Value Diff) (2010-05-13 07:41:15, 0.51, 0.220) (2010-07-06 08:11:15, 0.4, 0.256)
7/29/2010 10:46	dyu	5/13/2010 7:41	5/13/2010 7:41	Delete region
7/29/2010 10:46	dyu	5/13/2010 7:26	5/13/2010 7:56	Interpolate Gap(Linear)
8/10/2010 10:57	dyu	7/6/2010 8:26	8/4/2010 9:11	Offset Correction with value of 0.242 Feet
8/30/2009 11:58	dyu	7/31/2009 10:34	8/18/2009 11:01	Drift Correction with Calibration Drift value of 0.251 and Fouling Drift value of 0.000 Feet
8/30/2009 12:00	dyu	8/18/2009 11:16	8/26/2009 8:31	Drift Correction with Calibration Drift value of -0.148 and Fouling Drift value of 0.000 Feet

rating curve (Figure 3). Eighteen discharge measurements were collected at location CBX during the 1-year study.

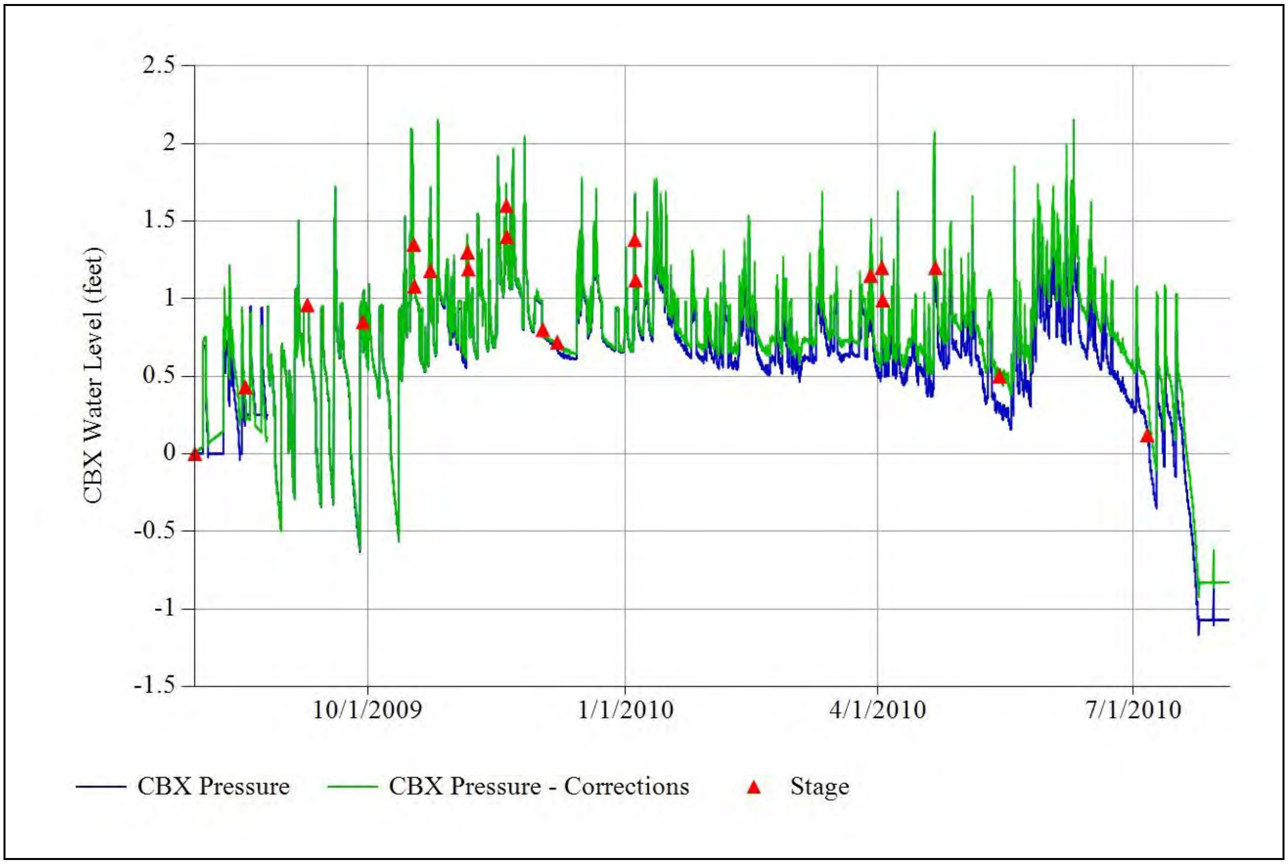


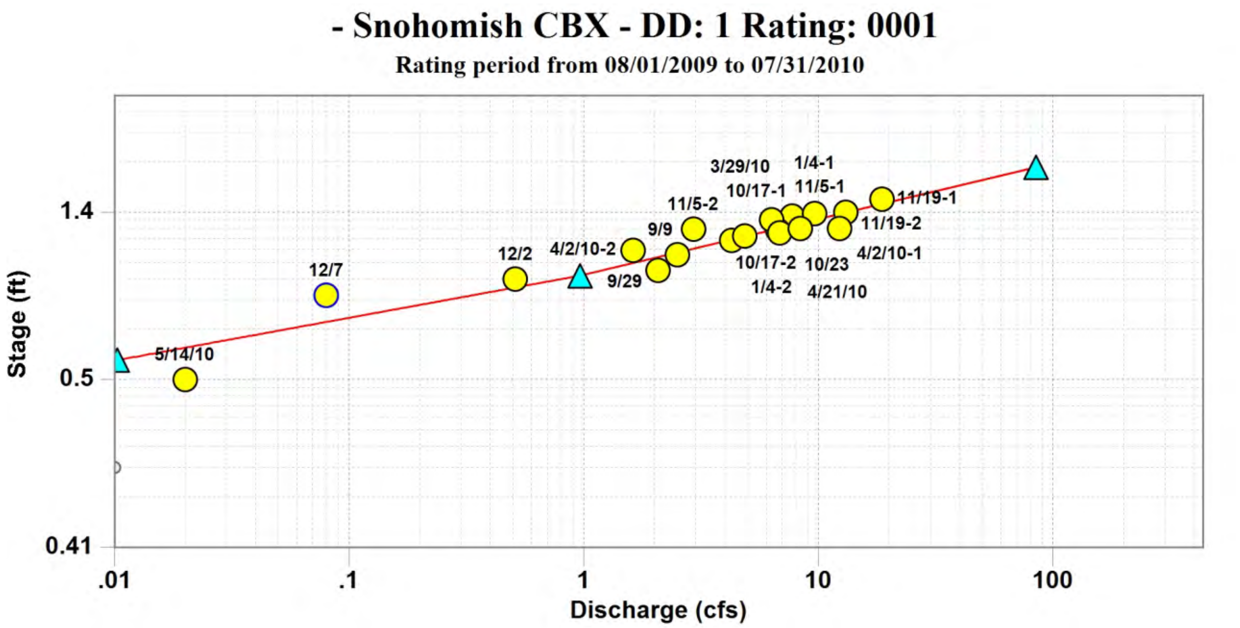
Figure 2. Corrected and raw water level data from location CBX.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is 40.6 percent. Although this is a relatively high degree of error, most of the error is on the low end of the rating curve (i.e., only affecting low flows) and the data is otherwise of a high quality. Therefore, it is recommended that the hydrologic data be used without qualification.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At CBX, the highest manually measured flow was 8.4 cfs, while the highest recorded flow was 8.7 cfs. Consequently, this guideline was met.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location CBX.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

To assess if the CBX hydrograph was representiave of commercial basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a commercial basin in western Washington. Since there were no existing rain gauges with reliable data records located within the CBX basin, rainfall and runoff comparisons could not be made. As a result, the CBX hydrograph was assessed without comparison to rainfall.

The CBX hydrograph is presented in Figure 4. There was minimal base flow and a flashy response to rainfall events during the dry season. The flow peaks converged very slightly in the wet season indicating some flow attenuation and minimally elevated winter base flow. The response to rainfall was also flashy in the winter. Taken together, these results indicate that the CBX hydrograph is typical (representative) of commercial (i.e., highly impervious) basins in western Washington.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

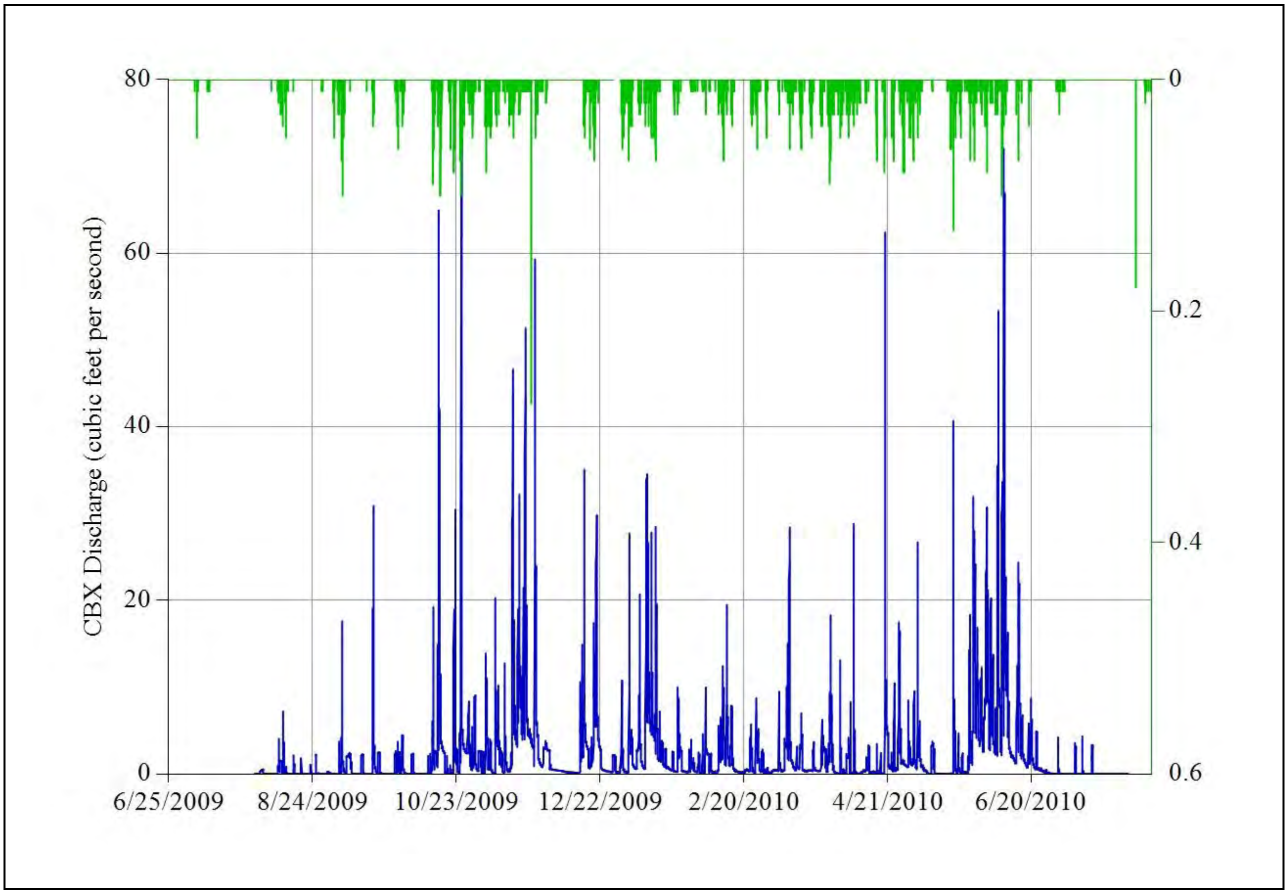


Figure 4. CBX hydrograph.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal (less than 0.1 percent of the record) data gaps during the monitoring period during which there was flow (Table 2). Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location CBX. There were no data gaps or shifts in the rating curve. Although there was a relatively high degree of rating curve error, most of the error was on the low end of the rating curve (i.e., only affecting low flows) and the data are otherwise of a high quality. After assessing the quality of the hydrologic data at location CBX, it was found that the data can be used without qualification. The error associated with the hydrograph from this station is accounted for in the final pollutant loading values by reporting the data as a range between the 25th and 75th percentile.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

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Herrera Environmental Consultants, Inc.

Memorandum

To Project File 06-03509-002

From Dylan Ahearn, Herrera Environmental Consultants

Date August 8, 2010

Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **FB130**

This memorandum reviews hydrologic data collected at monitoring location FB130 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location FB130 represents forested land use in the Puyallup River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.39 percent to 0.46 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928009).

	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre- Monitoring	1.393	1.4	-0.39
Post- Monitoring	1.005	1.0	0.46

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the water level sensors were conducted on 14 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift exceeded the warning limit of plus or minus 1 standard deviation from the mean on one occasion, but the signal did not exhibit high variability overall, indicating minimal drift. The maximum drift between calibrations was 0.35 feet. To correct for drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

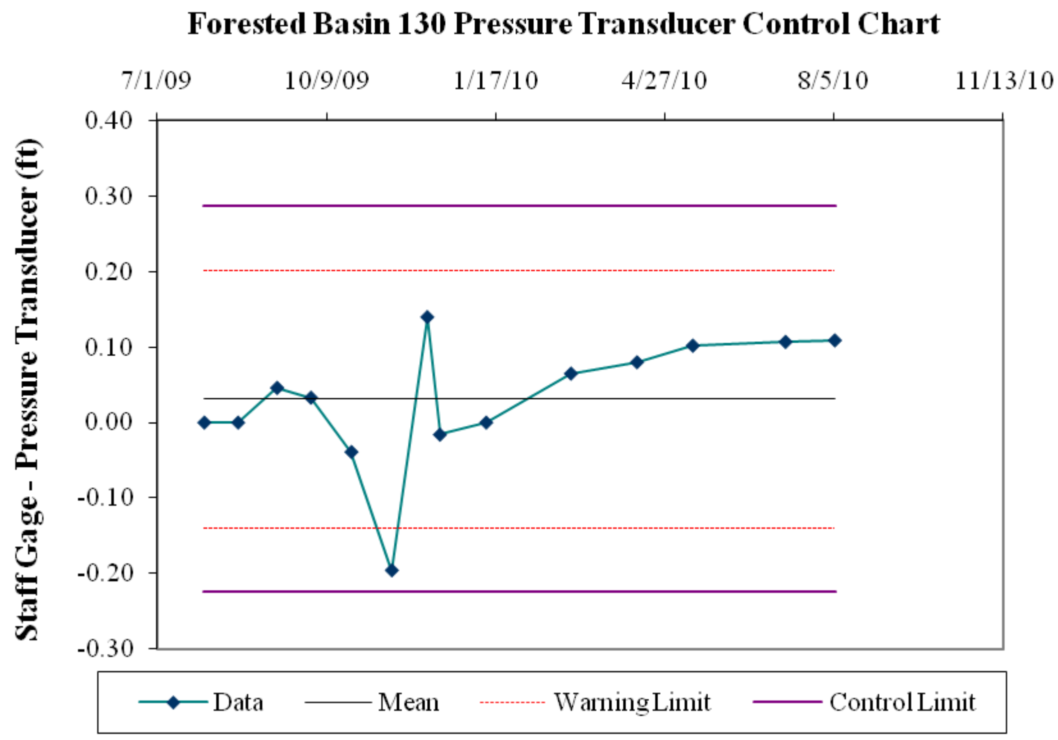


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the FB130 transducer are presented in Table 2 and Figure 2. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Table 2. Hydrologic data correction history for location FB130.

Date of Correction	User	From	To	Comment
10/28/2009 10:54	dyu	9/9/2009 14:58	9/29/2009 14:28	Drift Correction with Calibration Drift value of 0.033 and Fouling Drift value of 0.000 Feet H2O
12/10/2009 11:22	dyu	10/23/2009 14:28	11/16/2009 11:58	Drift Correction with Calibration Drift value of -0.196 and Fouling Drift value of 0.000 Feet H2O
12/15/2009 9:03	dyu	11/16/2009 12:28	11/19/2009 23:43	Advanced Correction (Date/Time, Value, Diff) (2009-11-16 12:13:57, 1.346, -0.200) (2009-11-19 23:43:57, 1.452, -0.310)
12/15/2009 9:03	dyu	11/19/2009 23:58	11/20/2009 0:13	Advanced Correction (Date/Time, Value, Diff) (2009-11-19 23:58:57, 1.451, -0.160) (2009-11-20 00:13:57, 1.444, -0.130)
12/16/2009 11:44	dyu	9/9/2009 14:58	9/29/2009 14:43	Advanced Correction (Date/Time, Value, Diff) (2009-09-09 14:58:57, 1.064, 0.049) (2009-09-29 14:28:57, 1.051, 0.002)
12/16/2009 11:45	dyu	11/16/2009 12:13	11/16/2009 12:13	Delete region - spike during site visit
12/16/2009 11:45	dyu	11/16/2009 11:58	11/16/2009 12:28	Interpolate Gap(Linear) - fill deleted spike
12/28/2009 11:55	dyu	11/16/2009 12:13	11/16/2009 12:13	Delete spike caused by site visit
12/28/2009 11:55	dyu	11/16/2009 11:58	11/16/2009 12:28	Interpolate Gap(Linear) - fill deleted spike
12/28/2009 17:10	dyu	7/28/2009 13:28	8/17/2009 13:13	Advanced Correction (Date/Time, Value, Diff) (2009-07-28 13:28:57, 1, 0.000) (2009-08-17 12:58:57, 1.05, 0.054)
12/28/2009 17:13	dyu	8/17/2009 13:28	9/9/2009 14:43	Advanced Correction (Date/Time, Value, Diff) (2009-08-17 13:13:57, 1.05, 0.057) (2009-09-09 14:43:57, 1.06, 0.043)
12/28/2009 17:13	dyu	8/17/2009 13:13	8/17/2009 13:13	Delete drop
12/28/2009 17:14	dyu	8/17/2009 12:58	8/17/2009 13:28	Interpolate Gap(Linear) - fill deleted drop
12/28/2009 17:19	dyu	9/29/2009 14:58	10/23/2009 14:13	Advanced Correction (Date/Time, Value, Diff) (2009-09-29 14:43:57, 1.039, 0.022) (2009-10-23 14:13:57, 1.499, 0.036)
1/24/2010 13:54	dyu	11/16/2009 12:43	12/7/2009 11:13	Advanced Correction of (Date/Time Value Diff) (2009-11-16 12:28:57, 1.355, -0.191) (2009-12-07 11:13:57, 1.272, -0.014)
1/24/2010 13:54	dyu	11/16/2009 12:28	11/16/2009 12:28	Delete region
1/24/2010 13:54	dyu	11/16/2009 11:58	11/16/2009 12:43	Interpolate Gap(Linear)

Table 2 (continued). Hydrologic data correction history for location FB130.

Date of Correction	User	From	To	Comment
1/24/2010 13:57	dyu	12/7/2009 11:13	12/14/2009 22:28	Drift Correction with Calibration Drift value of 0.031 and Fouling Drift value of 0.000 Feet H2O
3/4/2010 0:39	dyu	2/19/2010 14:43	3/2/2010 10:58	Advanced Correction (Date/Time, Value, Diff) (2010-02-19 14:43:57, 1.334, 0.045) (2010-03-02 10:58:57, 1.28, 0.049)
4/15/2010 10:18	dyu	3/10/2010 12:13	3/10/2010 12:13	Delete drop
4/15/2010 10:19	dyu	3/10/2010 11:58	3/10/2010 12:28	Interpolate Gap(Linear) - fill deleted drop
4/15/2010 10:23	dyu	3/2/2010 11:13	4/10/2010 13:28	Advanced Correction (Date/Time, Value, Diff) (2010-03-02 11:13:57, 1.279, 0.058) (2010-04-10 13:28:57, 1.3, 0.078)
7/15/2010 11:08	dyu	4/10/2010 13:43	5/13/2010 14:13	Advanced Correction (Date/Time, Value, Diff) (2010-04-10 13:43:57, 1.301, 0.053) (2010-05-13 14:28:57, 1.189, 0.062)
7/15/2010 11:09	dyu	5/13/2010 14:28	7/7/2010 9:28	Advanced Correction (Date/Time, Value, Diff) (2010-05-13 14:28:57, 1.19, 0.063) (2010-07-07 09:28:57, 1.23, 0.128)
8/10/2010 12:58	dyu	7/7/2010 9:43	8/5/2010 13:13	Offset Correction with value of 0.102 Feet H2O
8/10/2010 12:59	dyu	7/7/2010 10:43	8/5/2010 13:13	Drift Correction with Calibration Drift value of 0.007 and Fouling Drift value of 0.000 Feet H2O
8/10/2010 13:01	dyu	8/5/2010 13:28	8/9/2010 10:13	Offset Correction with value of 2.618 Feet H2O

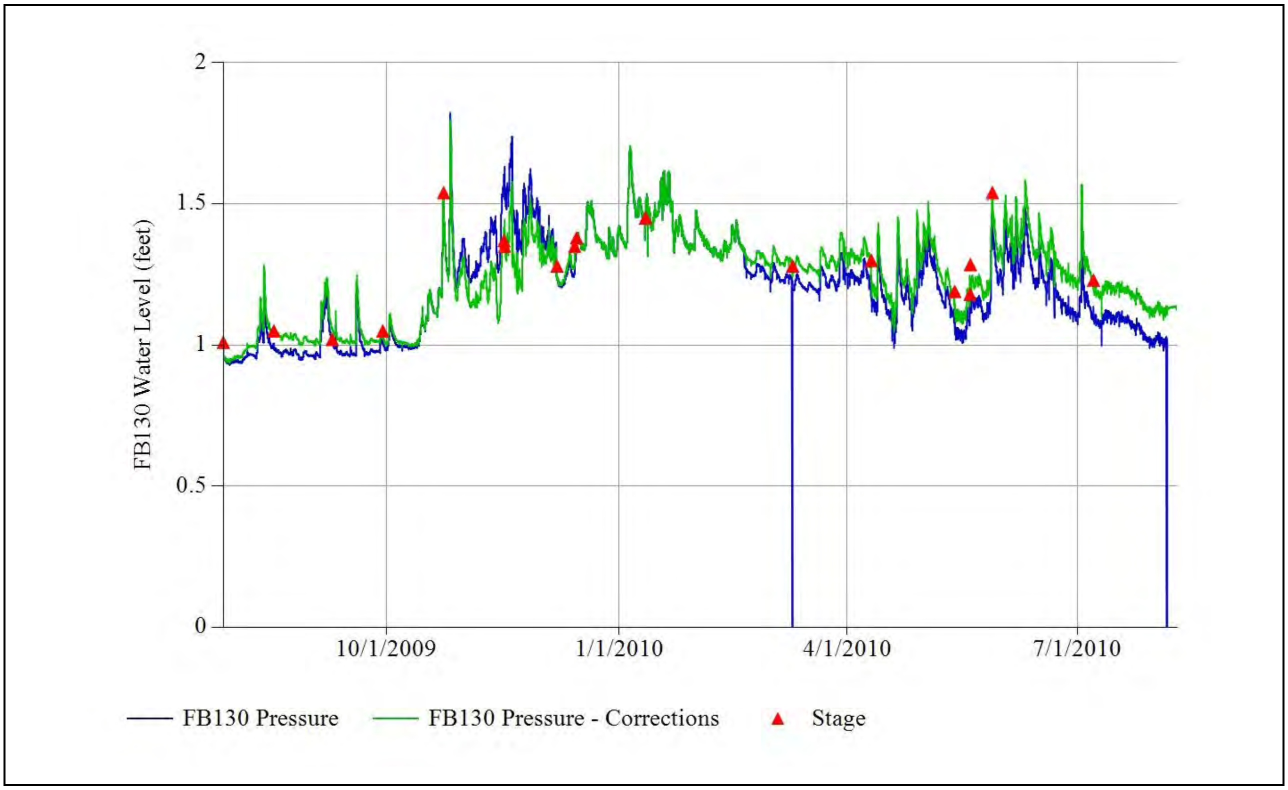


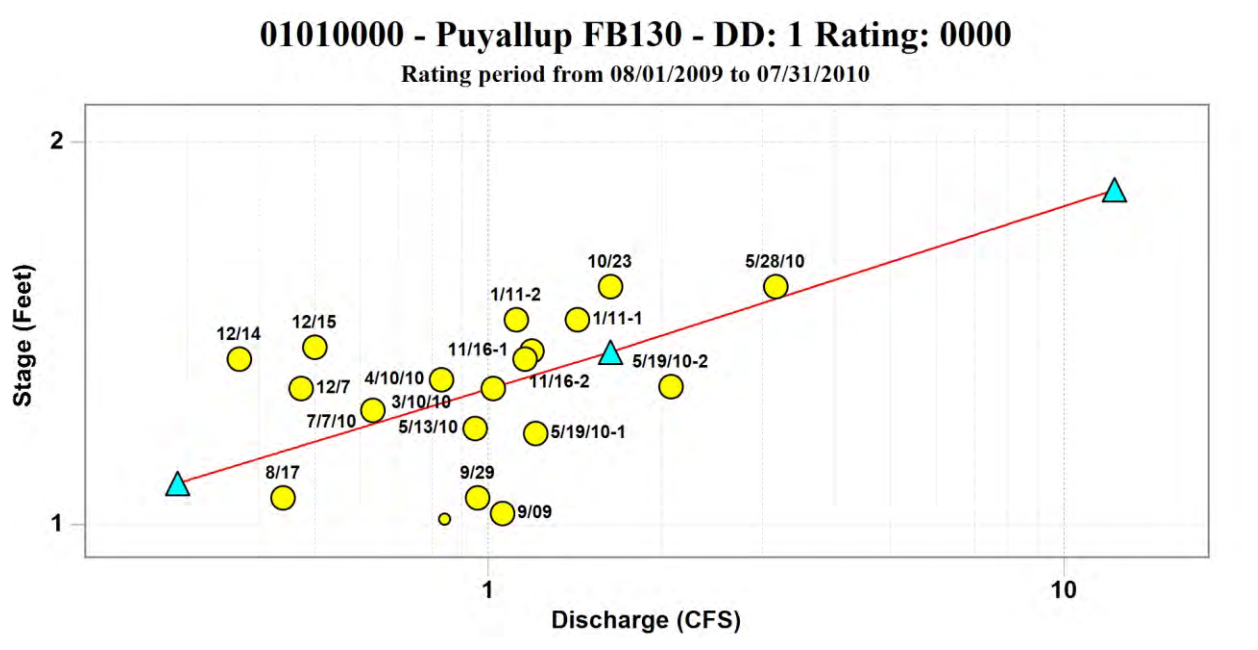
Figure 2. Corrected and raw water level data from location FB130.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location FB130 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Nineteen discharge measurements were collected at location FB130 during the 1-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is 58.3 percent. Of all the flow monitoring locations in this study, FB130 had the least consistent rating curve. This error is carried through into estimates of discharge and consequently all discharge data for this location are qualified as estimates.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At FB130, the highest manually measured flow was 3.2 cfs, while the highest recorded flow was 10.7 cfs. Consequently, the highest recorded flows were 3.3 times higher than the highest manually measured flow. The large amount of error associated with flow values is another reason that discharge data from this location should be considered estimates.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location FB130.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

To assess if the FB130 hydrograph was representative of forested basins in western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a forested basin in western Washington. Since there were no existing rain gauges with reliable data records located within the FB130 basin, rainfall and runoff comparisons could not be made. As a result, the FB130 hydrograph was assessed without comparison to rainfall.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

The FB130 hydrograph is presented in Figure 4. Base flow was intermittent during the dry season. In addition, the flow peaks tend to converge in the wet season indicating flow attenuation and elevated winter base flow. Taken together, these results indicate that the FB130 hydrograph is typical (representative) of forested basins in western Washington. It should be noted that the hydrograph is somewhat noisy and there are occasional flow spikes with minimal attenuation. The noise was due to turbulence at the outlet of the culvert where flow measurements were taken and the spiky flows may be a function of the small nature of the watershed.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal data gaps during the monitoring period (Tables 2), and the majority of gaps were sufficiently short in duration that they could be filled by interpolation. Data gaps represent 0.04 days of the 365 days of monitoring, or 0.001 percent of the data. Therefore, the MQO for completeness was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

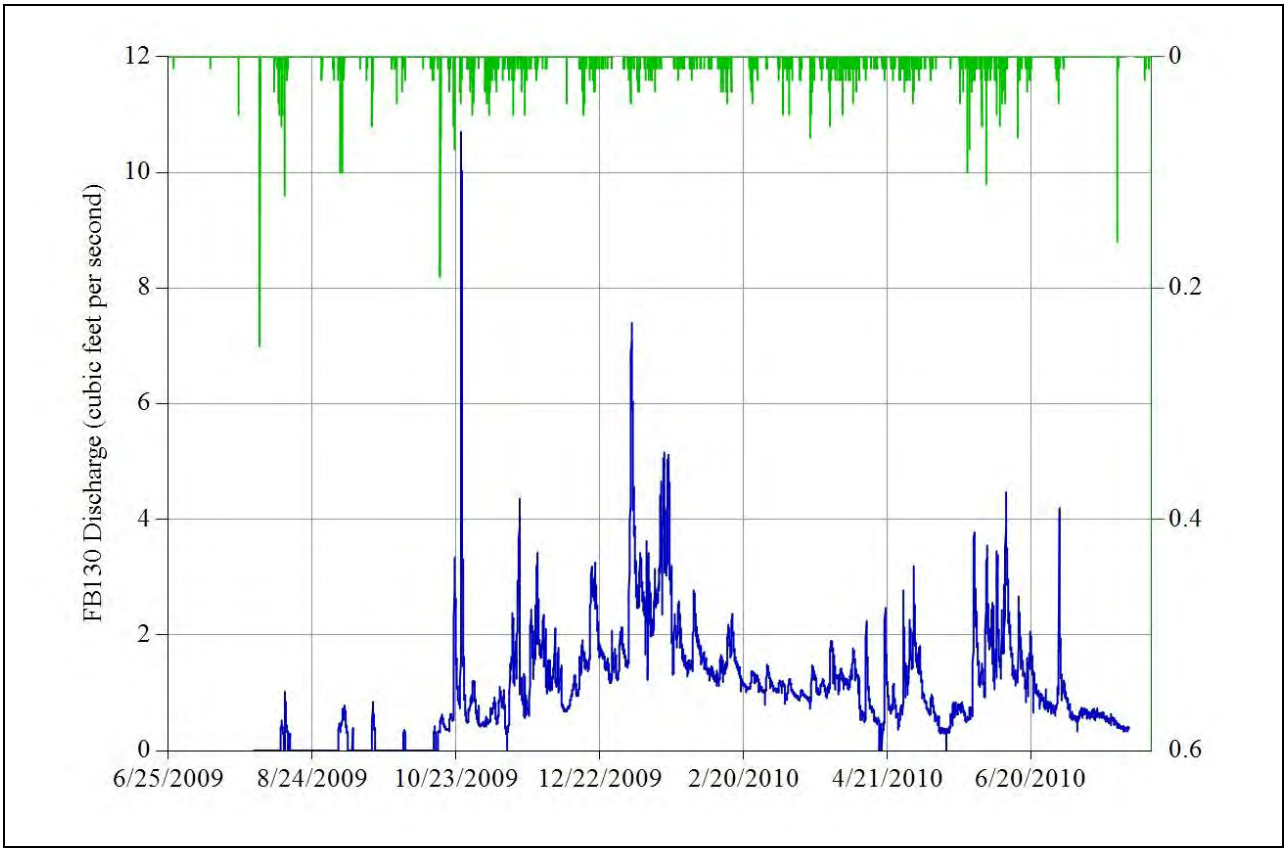


Figure 4. FB130 hydrograph.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location FB130. However, the level data were noisy, the rating curve error was high, and much of the high flow records exceeded the maximum discharge measurement. For these reasons all flow data for this location should be flagged as estimates. In addition, all loading calculations based on the hydrologic data from FB130 should be closely examined to determine if low quality flow data is controlling pollutant loading patterns.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge MEASUREMENTS at GAGING STATIONS. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

Herrera Environmental Consultants, Inc.

Memorandum

To Project File 06-03509-002
From Dylan Ahearn, Herrera Environmental Consultants
Date August 8, 2010
Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **FB200**

This memorandum reviews hydrologic data collected at monitoring location FB200 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location FB200 represents forested land use in the Snohomish River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.04 percent to -0.46 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928002).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.392	1.4	-0.46
Post-monitoring	0.995	1.0	-0.04

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the water level sensors were conducted on 11 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift did not exceed the warning limit of plus or minus 1 standard deviation. The maximum drift between calibrations was 0.18 feet, which is relatively high compared to the other locations. To correct for this sensor drift and all sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

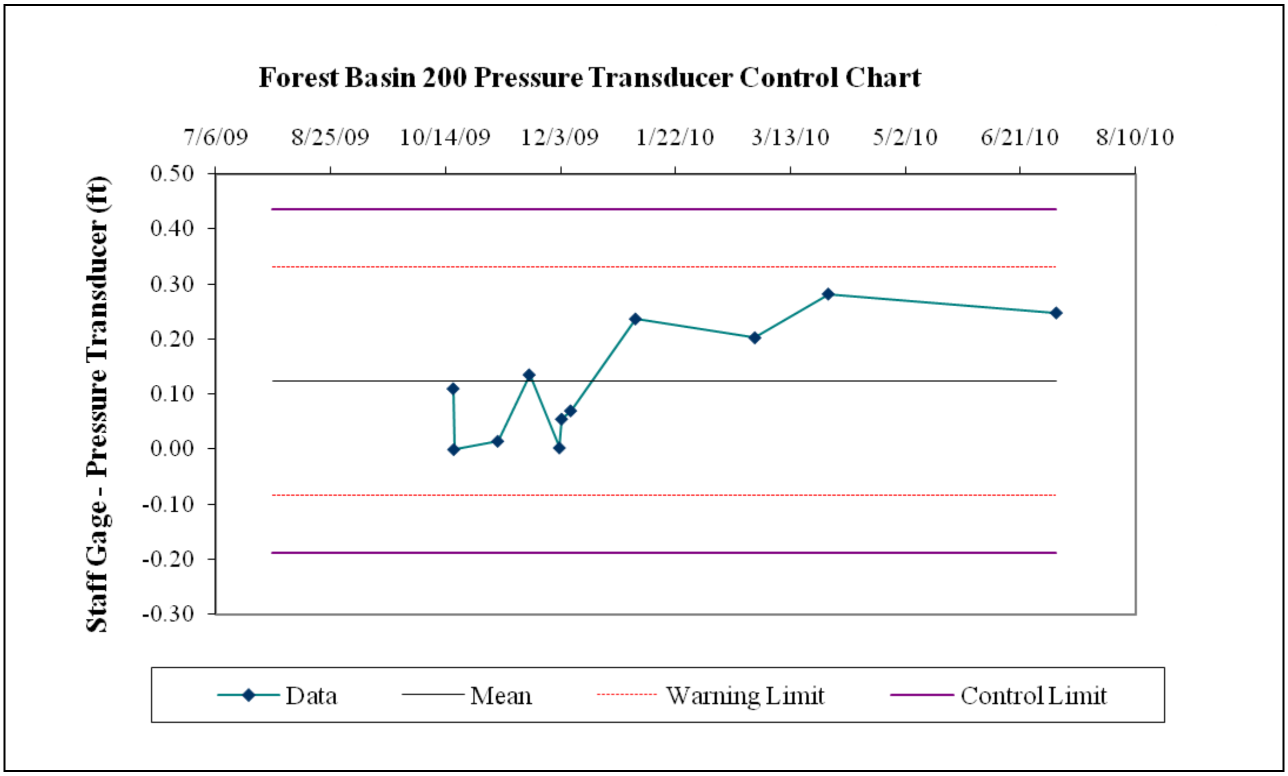


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the FB200 transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a poor quality. Inadequate ventilation in the stilling well caused a partial vacuum to form that affected the data from the start of the study until December 12, 2009, when the issue was finally resolved by drilling ventilation holes in the top of the stilling well. The level data from FB203 was used to model the spurious FB200 level data from August 1, 2009 to December 12, 2009. This process involved creating an adaptive neuro-fuzzy inference system (ANFIS) model that related a high quality portion of the FB203 level data with a high quality portion of the FB200 data. This relationship was then used to overwrite the spurious FB200 data based on the existing FB203 level data for the same period of

Table 2. Hydrologic data correction history for location FB200.

Date of Correction	User	From	To	Comment
1/24/2010 15:46	dyu	7/30/2009 15:28	8/18/2009 13:28	Advanced Correction of (Date/Time Value Diff) (2009-07-30 15:13:120.329 0.088) (2009-08-18 13:28:12-0.136 0.000)
1/24/2010 15:47	dyu	7/30/2009 14:43	7/30/2009 15:13	Delete region
1/24/2010 15:47	dyu	7/30/2009 14:28	7/30/2009 15:28	Interpolate Gap(Linear)
1/24/2010 15:49	dyu	9/29/2009 11:43	10/17/2009 12:58	Drift Correction with Calibration Drift value of 0.119 and Fouling Drift value of 0.000 Feet H2O
1/24/2010 15:51	dyu	10/17/2009 13:13	10/17/2009 18:28	Advanced Correction (Date/Time, Value, Diff) (2009-10-17 13:13:12, 0.817, 0.120) (2009-10-17 18:28:12, 0.615, -0.082)
1/24/2010 20:45	dyu	10/17/2009 18:43	11/5/2009 19:58	Advanced Correction (Date/Time, Value, Diff) (2009-10-17 18:43:12, 0.618, -0.083) (2009-11-05 19:58:12, 0.695, -0.028)
1/24/2010 20:46	dyu	11/5/2009 20:28	11/5/2009 20:28	Delete region
1/24/2010 20:47	dyu	11/19/2009 12:13	11/19/2009 12:58	Delete region
1/24/2010 20:50	dyu	11/5/2009 20:43	11/19/2009 11:58	Advanced Correction (Date/Time, Value, Diff) (2009-11-05 20:43:12, 0.695, 0.066) (2009-11-19 11:58:12, 0.98, 0.250)
1/24/2010 20:50	dyu	11/5/2009 19:58	11/5/2009 20:43	Interpolate Gap(Linear)
1/24/2010 20:52	dyu	11/19/2009 13:13	12/2/2009 15:13	Advanced Correction (Date/Time, Value, Diff) (2009-11-19 13:13:12, 0.98, 0.179) (2009-12-02 15:13:12, 0.6, -0.343)
1/24/2010 20:52	dyu	11/19/2009 11:58	11/19/2009 13:13	Interpolate Gap(Linear)
1/24/2010 20:53	dyu	12/2/2009 15:28	12/2/2009 15:58	Delete region
1/24/2010 20:55	dyu	12/2/2009 16:13	12/3/2009 13:43	Advanced Correction (Date/Time, Value, Diff) (2009-12-02 16:13:12, 0.6, 0.013) (2009-12-03 13:43:12, 0.64, 0.095)
1/24/2010 20:55	dyu	12/2/2009 15:13	12/2/2009 16:13	Interpolate Gap(Linear)
1/24/2010 21:01	dyu	12/3/2009 14:43	12/7/2009 11:43	Advanced Correction (Date/Time, Value, Diff) (2009-12-03 14:28:12, 0.64, 0.087) (2009-12-07 11:43:12, 0.56, 0.098)
1/24/2010 21:02	dyu	12/3/2009 14:13	12/3/2009 14:28	Delete region

Table 2 (continued). Hydrologic data correction history for location FB200.

Date of Correction	User	From	To	Comment
1/24/2010 21:02	dyu	12/3/2009 13:43	12/3/2009 14:43	Interpolate Gap(Linear)
1/24/2010 21:03	dyu	12/7/2009 12:28	1/4/2010 15:58	Advanced Correction (Date/Time, Value, Diff) (2009-12-07 12:28:12, 0.56, 0.086) (2010-01-04 15:58:12, 0.78, 0.234)
1/24/2010 21:04	dyu	12/7/2009 11:58	12/7/2009 12:13	Delete region
1/24/2010 21:04	dyu	12/7/2009 11:43	12/7/2009 12:28	Interpolate Gap(Linear)
3/3/2010 23:09	dyu	1/4/2010 16:13	2/25/2010 12:58	Advanced Correction (Date/Time, Value, Diff) (2010-01-04 16:13:12, 0.78, 0.213) (2010-02-25 12:58:12, 0.58, 0.202)
4/20/2010 17:03	dyu	2/25/2010 13:13	3/29/2010 9:13	Advanced Correction (Date/Time, Value, Diff) (2010-02-25 13:13:12, 0.58, 0.202) (2010-03-29 09:13:12, 0.84, 0.286)
6/2/2010 21:34	dyu	3/29/2010 9:43	5/14/2010 9:28	Advanced Correction (Date/Time, Value, Diff) (2010-03-29 09:28:12, 0.84, 0.283) (2010-05-14 09:28:12, 0.56, 0.188)
6/2/2010 23:19	dyu	3/29/2010 9:28	3/29/2010 9:28	Delete drop
6/2/2010 23:19	dyu	3/29/2010 9:13	3/29/2010 9:43	Interpolate Gap(Linear)
7/29/2010 8:43	dyu	5/14/2010 9:43	5/21/2010 4:58	Offset Correction with value of 0.185 Feet H2O
7/29/2010 10:36	dyu	5/21/2010 13:13	7/6/2010 10:28	Advanced Correction (Date/Time, Value, Diff) (2010-05-21 13:13:12, 0.47, -0.697) (2010-07-06 10:28:12, 0.85, 0.236)
7/29/2010 10:39	dyu	5/21/2010 5:13	5/21/2010 12:58	Delete region
7/29/2010 10:39	dyu	5/21/2010 4:58	5/21/2010 13:13	Interpolate Gap(Linear)
8/10/2010 11:12	dyu	7/6/2010 10:43	8/4/2010 11:28	Advanced Correction (Date/Time, Value, Diff) (2010-07-06 10:43:12, 0.847, 0.241) (2010-08-04 11:28:12, 0, -0.357)
8/26/2010 16:52	dahearn	7/9/2010 15:28	7/10/2010 15:43	Delete spike - no rain during spike
8/26/2010 16:52	dahearn	7/9/2010 15:13	7/10/2010 15:58	Interpolate Gap(Linear) - spike/drop fill

time. The error associated with the model was 7.7 percent. The model assumes that the relationship between water level data at FB200 and FB203 is constant through time. In order to reduce the error associated with this assumption, the FB203 and FB200 hydrographs were compared visually prior to modeling. It was determined from this assessment that the stations hydrographs were similar enough to generate a valid model. The result of this modeling can be seen in Figure 2 and the application of the model is presented in Table 2. Despite the efforts made to improve portions of the FB200 level data with modeling, the resultant FB200 data should be used with caution and flagged as estimates. In addition, any pollutant loading calculations that are based on the FB200 flow data should also be considered estimates.

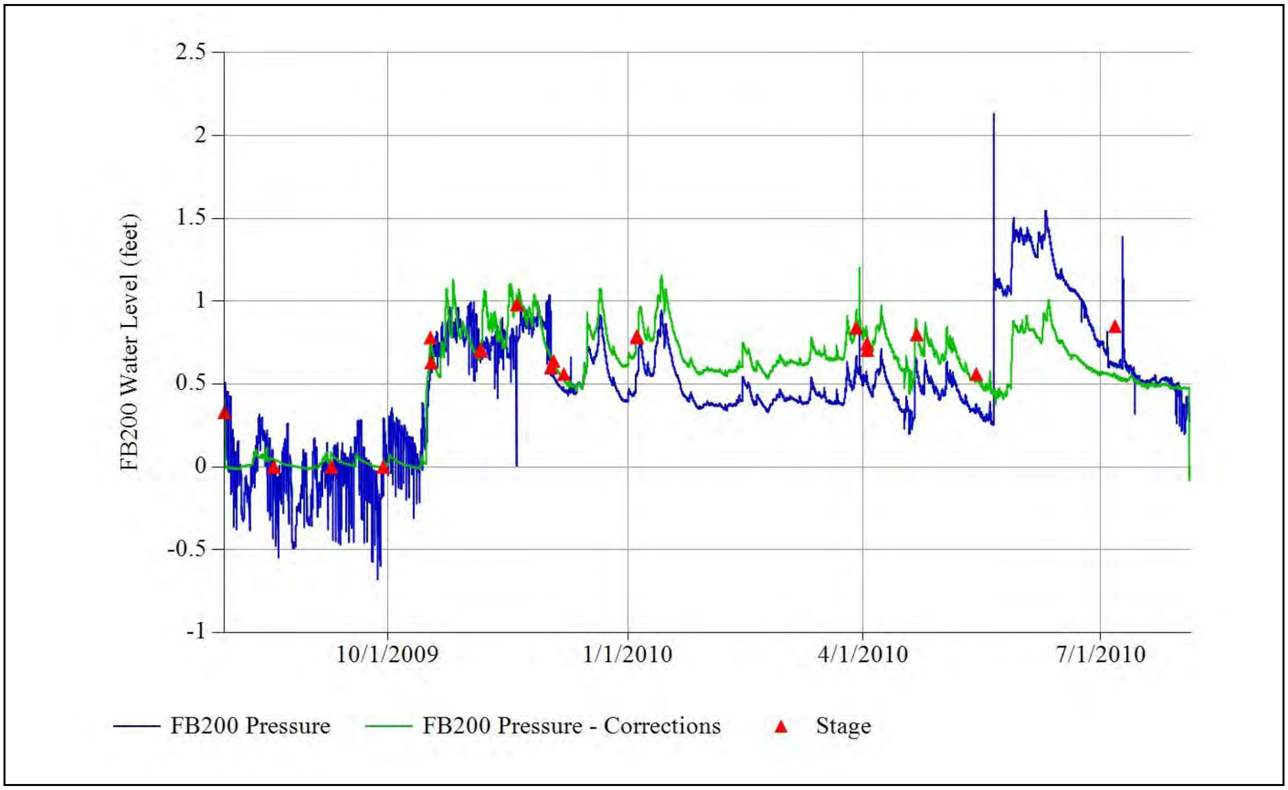
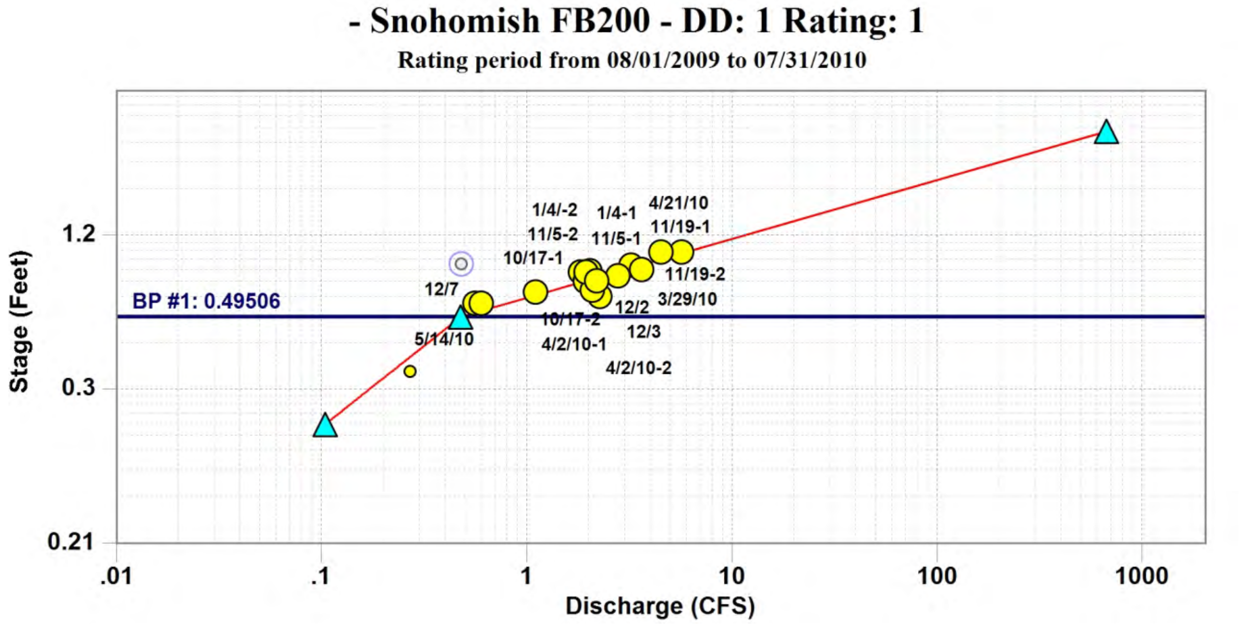


Figure 2. Corrected and raw water level data from location FB200.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location FB200 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Seventeen discharge measurements were collected at location FB200 during the 1-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is 36.7 percent. A measurement on July 6, 2010 was excluded from the rating curve as an outlier because the manual water level and discharge measurements were unrealistically high. Due to the combined uncertainties regarding this rating and the model results based on FB203, all discharge data for this location are qualified as estimates.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location FB200.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At FB200, the highest manually measured flow was 5.7 cfs, while the highest recorded flow was 11.6 cfs. Consequently, the guideline was met.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

To assess if the FB200 hydrograph was representiave of forested basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a forested basin in western Washington. Since there were no existing rain gauges with reliable data records located within the FB200 basin, rainfall and runoff comparisons could not be made. As a result, the FB200 hydrograph was assessed without comparison to rainfall.

The FB200 hydrograph is presented in Figure 4. There was no base flow or response to rainfall during the dry season. Although base flow is typically observed in a forested basin, the lack of base flow at this site can be explained by the relatively small size of the basin. The flow peaks converged in the wet season indicating flow attenuation and elevated winter base flow. In general, response to rainfall was not immediate or flashy. Taken together, these factors indicate that the FB200 hydrograph is representative of a forested basin.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal (less than 0.1 percent of the record) data gaps during the monitoring period during which there was flow (Table 2). Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

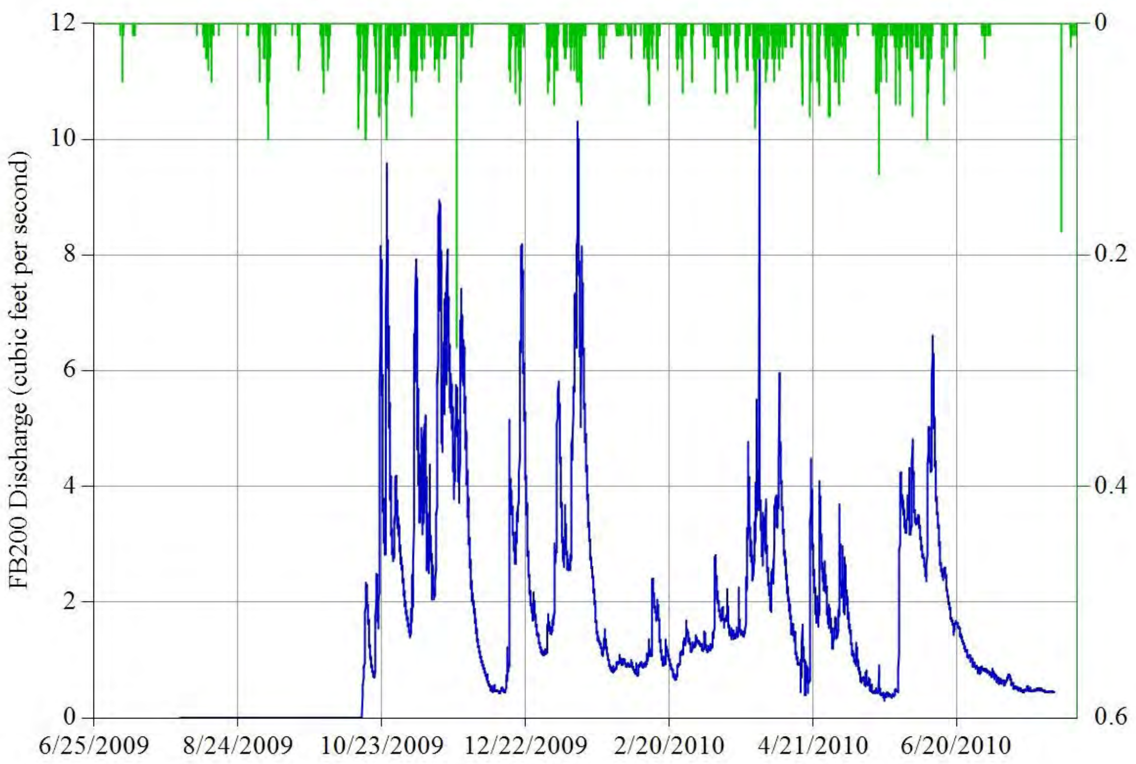


Figure 4. FB200 hydrograph.

Summary

The water level and stream flow data from FB200 have numerous quality assurance issues. The data from August 1, 2009 to December 12, 2009 was noisy and had to be replaced with modeled data from FB203. In addition, the rating had a relatively high degree of error and one erroneous manual discharge measurement had to be excluded from the rating. These factors combine to result is a hydrograph of average quality. After assessing the quality of the hydrologic data at location FB200, it was found that the hydrologic data should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from FB200 should be closely examined to determine if low quality flow data is controlling pollutant loading patterns.

References

Bovee, K., and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

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USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

Herrera Environmental Consultants, Inc.

Memorandum

To Project File 06-03509-002

From Dylan Ahearn, Herrera Environmental Consultants

Date August 8, 2010

Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **FB203**

This memorandum reviews hydrologic data collected at monitoring location FB203 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location FB203 represents forested land use in the Snohomish River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.11 percent to 0.0 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928004).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.398	1.4	-0.11
Post-monitoring	1.000	1.0	0.0

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the level sensors were conducted on 13 occasions during study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift did not exceed the warning limit of plus or minus 1 standard deviation from the mean. The maximum drift at this location was 0.08 feet. To correct for this sensor drift and all drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

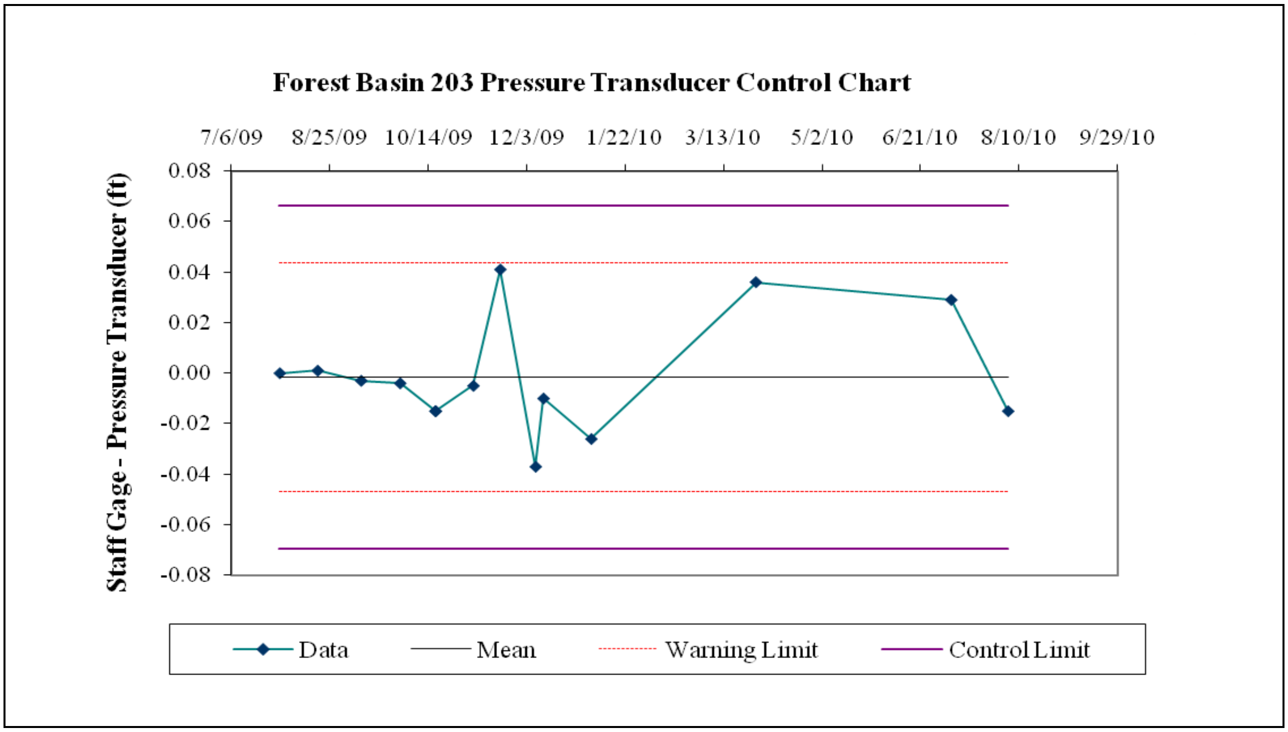


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the FB203 transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a high quality. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias can be introduced by the flow conversion process. A rating curve was developed for location FB203 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS

Table 2. Hydrologic data correction history for location FB203.

Date of Correction	User	From	To	Comment
10/28/2009 10:34	dyu	7/30/2009 8:54	8/18/2009 14:54	Drift Correction with Calibration Drift value of 0.001 and Fouling Drift value of 0.000 Feet H2O
10/28/2009 10:35	dyu	9/9/2009 18:24	9/29/2009 13:24	Drift Correction with Calibration Drift value of -0.004 and Fouling Drift value of 0.000 Feet H2O
11/4/2009 12:49	dyu	9/29/2009 13:39	10/17/2009 10:09	Drift Correction with Calibration Drift value of -0.015 and Fouling Drift value of 0.000 Feet H2O
11/16/2009 9:53	dyu	10/17/2009 10:24	10/17/2009 16:39	Drift Correction with Calibration Drift value of -0.015 and Fouling Drift value of 0.000 Feet H2O
11/16/2009 9:54	dyu	10/17/2009 16:54	11/5/2009 18:39	Drift Correction with Calibration Drift value of -0.005 and Fouling Drift value of 0.000 Feet H2O
12/23/2009 14:33	dyu	12/7/2009 10:54	12/7/2009 10:54	Delete spike
12/23/2009 14:34	dyu	12/7/2009 10:39	12/7/2009 11:09	Interpolate Gap(Linear) - fill deleted spike
12/28/2009 14:35	dyu	11/5/2009 18:54	11/19/2009 10:39	Drift Correction with Calibration Drift value of 0.176 and Fouling Drift value of 0.000 Feet H2O
12/28/2009 14:39	dyu	11/19/2009 10:54	12/7/2009 10:24	Advanced Correction (Date/Time, Value, Diff) (2009-11-19 10:54:46, 2.2, 0.114) (2009-12-07 10:24:46, 1.39, -0.014)
12/28/2009 16:22	dyu	8/18/2009 15:09	9/9/2009 16:54	Advanced Correction (Date/Time, Value, Diff) (2009-08-18 15:09:46, 0.885, 0.000) (2009-09-09 16:54:46, 1.04, 0.158)
1/24/2010 10:42	dyu	12/7/2009 10:39	12/11/2009 9:54	Advanced Correction (Date/Time, Value, Diff) (2009-12-07 10:39:46, 1.39, -0.013) (2009-12-11 09:54:46, 1.33, 0.005)
1/24/2010 10:44	dyu	12/11/2009 10:09	12/11/2009 10:09	Delete spike
1/24/2010 10:44	dyu	12/11/2009 9:54	12/11/2009 10:24	Interpolate Gap(Linear)
1/24/2010 10:46	dyu	12/11/2009 10:24	1/4/2010 17:09	Advanced Correction (Date/Time, Value, Diff) (2009-12-11 10:24:46, 1.33, -0.013) (2010-01-04 17:09:46, 1.6, -0.002)
6/2/2010 21:43	dyu	1/4/2010 17:24	3/29/2010 9:09	Advanced Correction (Date/Time, Value, Diff) (2010-01-04 17:24:46, 1.6, -0.011) (2010-03-29 09:09:46, 1.98, 0.041)

Table 2 (continued). Hydrologic data correction history for location FB203.

Date of Correction	User	From	To	Comment
6/2/2010 21:45	dyu	3/29/2010 9:24	5/14/2010 7:39	Advanced Correction (Date/Time, Value, Diff) (2010-03-29 09:24:46, 1.996, 0.040) (2010-05-14 07:39:46, 1.35, 0.057)
7/28/2010 14:58	dyu	5/14/2010 7:54	7/6/2010 14:24	Advanced Correction (Date/Time, Value, Diff) (2010-05-14 07:54:46, 1.35, 0.060) (2010-07-06 14:24:46, 1.118, 0.041)
8/10/2010 12:36	dyu	7/6/2010 14:54	8/4/2010 13:39	Advanced Correction (Date/Time, Value, Diff) (2010-07-06 14:54:46, 1.122, 0.033) (2010-08-04 13:39:46, 0.899, 0.000)

1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Nineteen discharge measurements were collected at location FB203 during the 1-year study.

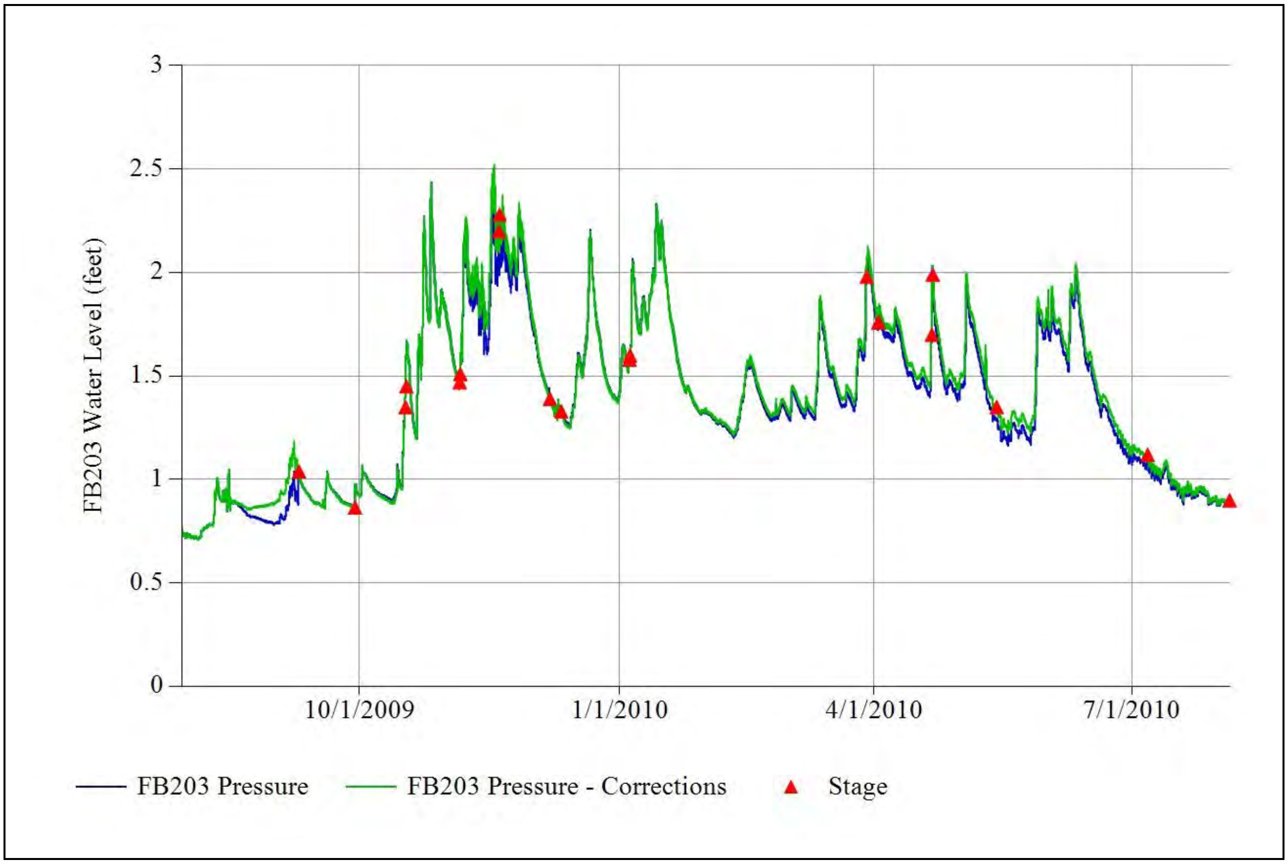
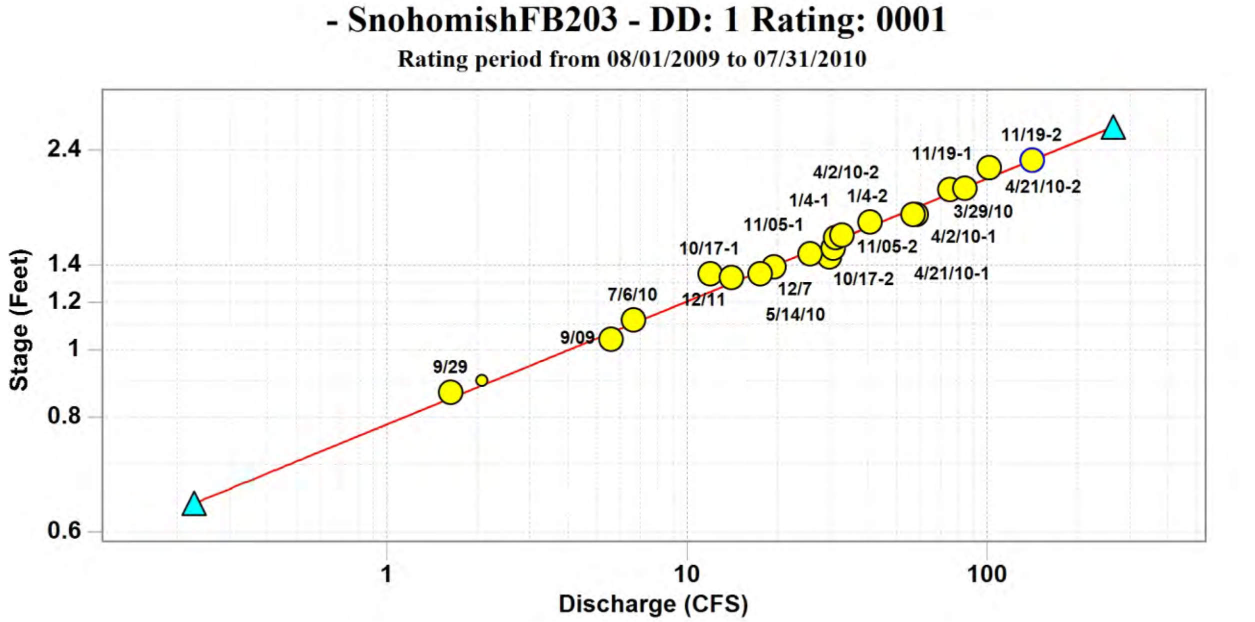


Figure 2. Corrected and raw water level data from location FB203.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is only 12.7 percent. This is lowest rating error in the study and consequently it is recommended that the hydrologic data be used without qualification.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At FB203, the highest manually measured flow was 141.4 cfs, while the highest recorded flow was 204.6 cfs. Consequently, the highest recorded flows were only 1.4 times higher than the highest manually measured flow, well within the guideline of 2.5.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location FB203.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

To assess if the FB203 hydrograph was representative of forested basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a forested basin in western Washington. Since there were no existing rain gauges with reliable data records located within the FB203 basin, rainfall and runoff comparisons could not be made. As a result, the FB203 hydrograph was assessed without comparison to rainfall.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

The FB203 hydrograph is presented in Figure 4. There was minimal base flow and an attenuated response to rainfall events during the dry season. The flow peaks converged in the wet season indicating flow attenuation and elevated winter base flow. Taken together, these results indicate that the FB203 hydrograph is typical (representative) of forested basins in western Washington.

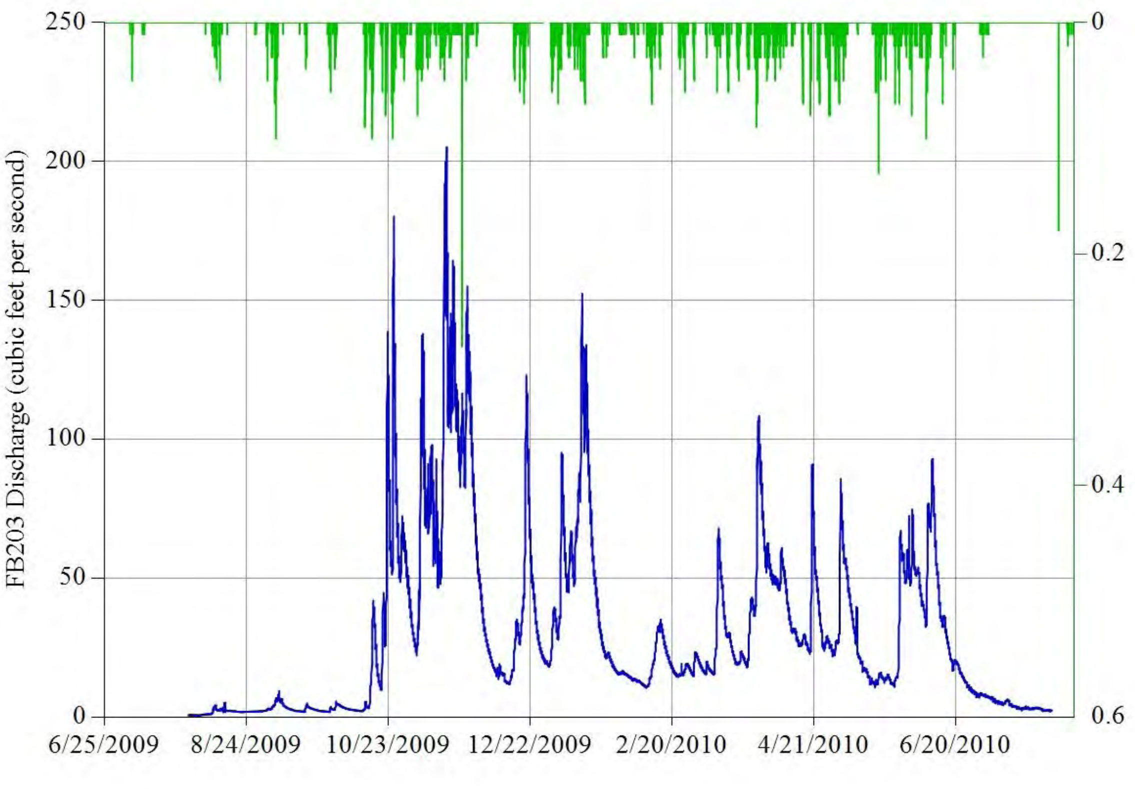


Figure 4. FB203 hydrograph.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal (less than 0.1 percent of the record) data gaps during the monitoring period during which there was flow (Table 2). Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location FB203. There were no major data gaps or shifts in the rating curve, and the rating curve error was very low. After assessing the quality of the hydrologic data at location FB203 it was found that the data can be used without qualification. The error associated with the hydrograph from this station is accounted for in the final pollutant loading values by reporting the data as a range between the 25th and 75th percentile.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

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Herrera Environmental Consultants, Inc.

Memorandum

To Project File 06-03509-002

From Dylan Ahearn, Herrera Environmental Consultants

Date August 8, 2010

Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **FB372**

This memorandum reviews hydrologic data collected at monitoring location FB372 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location FB372 represents forested land use in the Puyallup River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -1.44 percent to -2.7 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928014).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.377	1.4	-1.44
Post-monitoring	0.971	1.0	-2.7

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the level sensors were conducted on 14 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift did not exceed the warning limit of plus or minus 1 standard deviation from the mean. The maximum drift at this location was 0.07 feet. To correct for this drift, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

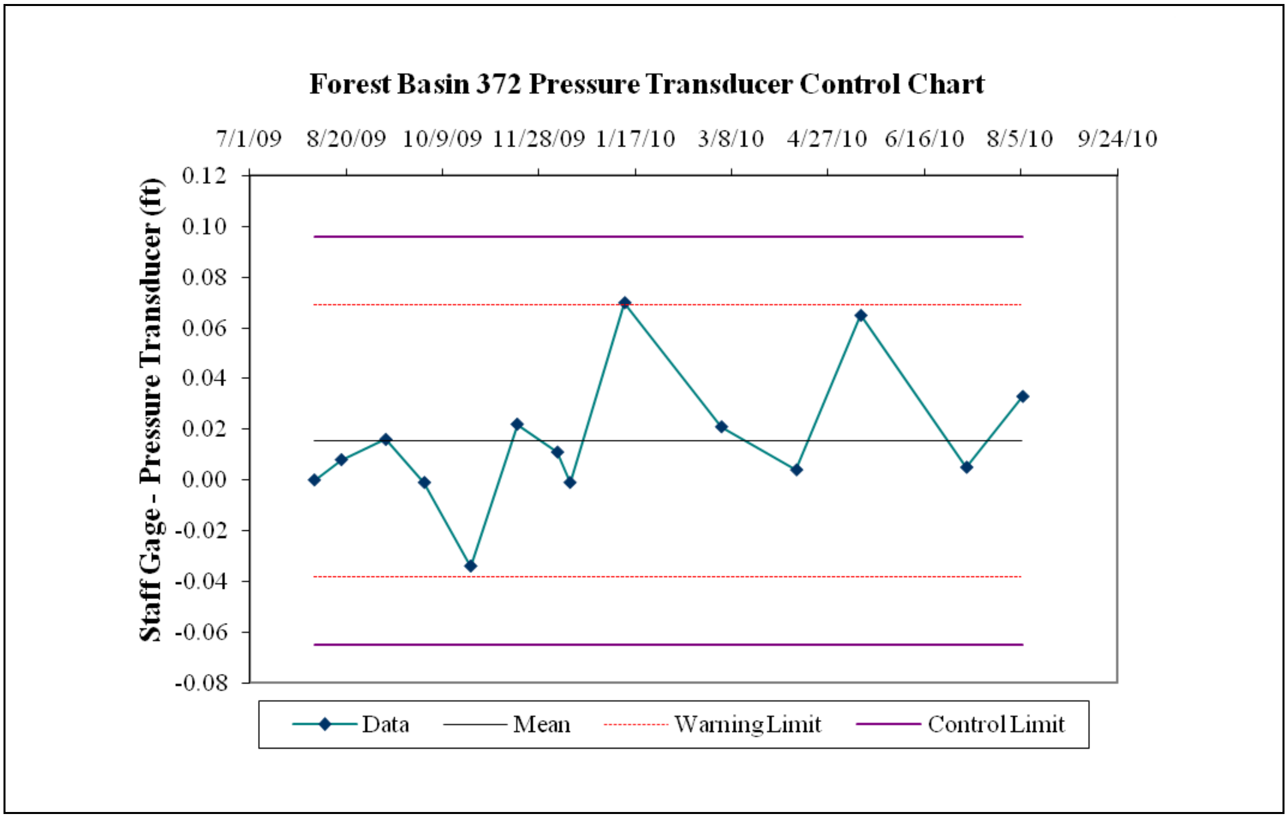


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the FB372 transducer are presented in Table 2 and Figure 2. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was not a factor.

Flow Conversion

Because discharge is calculated using water level and water level converted to flow, bias can be introduced by both water level data and the flow conversion process. A rating curve was

Table 2. Hydrologic data correction history for location FB372.

Date of Correction	User	From	To	Comment
1/24/2010 21:14	dyu	8/17/2009 10:16	8/17/2009 10:16	Delete spike
1/24/2010 21:16	dyu	8/3/2009 11:46	8/17/2009 11:16	Advanced Drift Correction
1/24/2010 21:17	dyu	8/17/2009 10:01	8/17/2009 10:31	Interpolate Gap(Linear)
1/24/2010 21:19	dyu	8/17/2009 11:31	9/9/2009 13:16	Advanced Drift Correction
1/24/2010 21:23	dyu	9/29/2009 11:31	10/23/2009 12:31	Advanced Drift Correction
1/24/2010 21:26	dyu	9/9/2009 13:31	9/29/2009 11:16	Advanced Drift Correction
1/24/2010 21:29	dyu	10/23/2009 12:46	11/16/2009 14:46	Drift Correction with Calibration Drift value of 0.012
1/24/2010 21:30	dyu	11/16/2009 3:01	12/7/2009 12:46	Drift Correction with Calibration Drift value of 0.000
1/24/2010 21:32	dyu	12/7/2009 13:01	12/14/2009 0:01	Drift Correction with Calibration Drift value of 0.047
1/24/2010 21:34	dyu	12/14/2009 0:16	1/11/2010 10:01	Advanced Drift Correction
4/15/2010 10:58	dyu	1/11/2010 10:16	3/2/2010 13:16	Advanced Drift Correction
4/15/2010 11:00	dyu	3/2/2010 13:31	4/10/2010 11:31	Advanced Drift Correction
6/2/2010 22:02	dyu	4/10/2010 12:01	5/13/2010 18:01	Advanced Drift Correction
6/2/2010 22:02	dyu	4/10/2010 11:46	4/10/2010 11:46	Delete drop
6/2/2010 22:03	dyu	4/10/2010 11:31	4/10/2010 12:01	Interpolate Gap(Linear)
6/2/2010 22:02	dyu	4/10/2010 11:46	4/10/2010 11:46	Delete drop
6/2/2010 22:03	dyu	4/10/2010 11:31	4/10/2010 12:01	Interpolate Gap(Linear)
7/15/2010 10:58	dyu	5/13/2010 18:31	7/7/2010 13:31	Advanced Correction (Date/Time, Value, Diff) (2010-05-13 18:31:43, 0.633, 0.070) (2010-07-07 13:31:43, 0.55, 0.025)
7/15/2010 10:59	dyu	5/13/2010 18:01	5/13/2010 18:16	Delete region
7/15/2010 10:59	dyu	5/13/2010 17:46	5/13/2010 18:31	Interpolate Gap(Linear)
7/15/2010 11:01	dyu	4/10/2010 12:16	5/13/2010 18:31	Advanced Correction (Date/Time, Value, Diff) (2010-04-10 12:01:43, 0.73, 0.010) (2010-05-13 18:31:43, 0.63, -0.003)
8/10/2010 13:02	dyu	7/7/2010 13:46	8/5/2010 14:31	Offset Correction with value of 0.026 Feet H2O
8/10/2010 13:03	dyu	7/7/2010 14:16	8/5/2010 14:31	Drift Correction with Calibration Drift value of 0.013

developed for location FB372 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Nineteen discharge measurements were collected during the 1-year study.

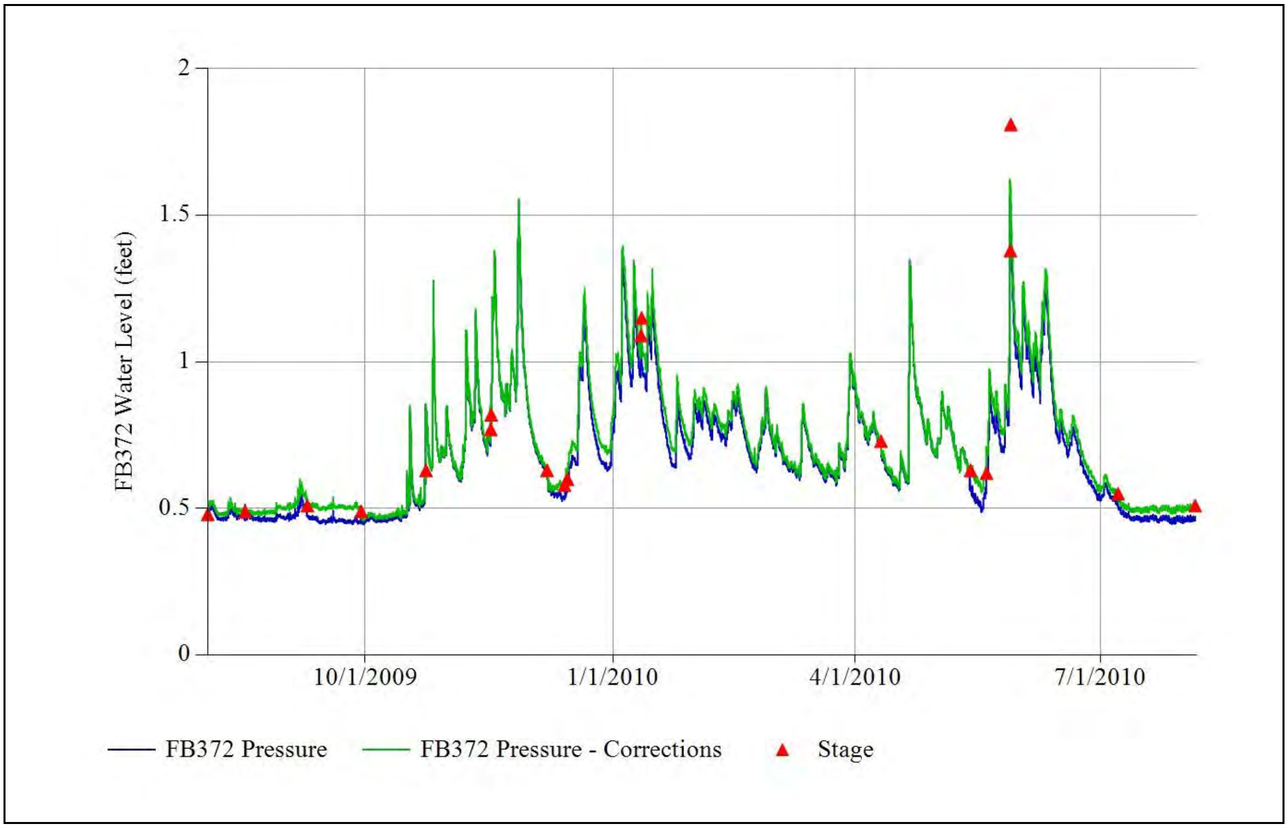
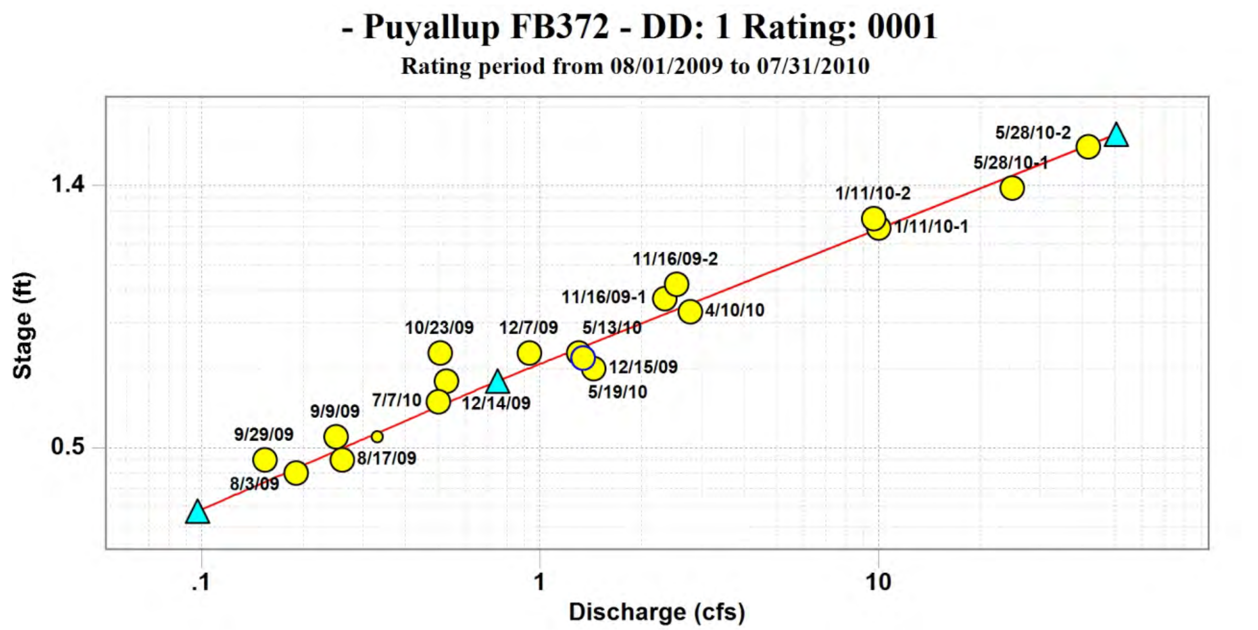


Figure 2. Corrected and raw water level data from location FB372.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is 26.3 percent. The project QAPP (Herrera 2009) did not provide an MQO for the rating curve bias, but given the error inherent in manual discharge estimation, water level sensing, and gauging in a dynamic fluvial environment, the rating curve shown in Figure 3 is considered excellent.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At FB372, the highest manually measured flow was 41.7 cfs, while the highest recorded flow was 34.4 cfs. The highest manually measured flow exceeded the highest recorded flow during a large storm event in May 2010 (see Figure 2) because the staff gauge was read at a peak in storm flow that exceeded the maximum 15-minute average water level recorded during the storm.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location FB372.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

To assess if the FB372 hydrograph was representative of forested basins in western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a forested basin in western Washington. Since there were no existing rain gauges with reliable data records located within the FB372 basin, rainfall and runoff comparisons could not be made. As a result, the FB372 hydrograph was assessed without comparison to rainfall.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

The FB372 hydrograph is presented in Figure 4. There was discernable base flow during the dry season. In addition, the flow peaks tend to converge in the wet season indicating flow attenuation and elevated winter base flow. There are no erroneous flow spikes and the hydrograph form looks natural (i.e., no anthropogenic influence). Taken together, these results indicate that the FB372 hydrograph is typical (representative) of forested basins in western Washington.

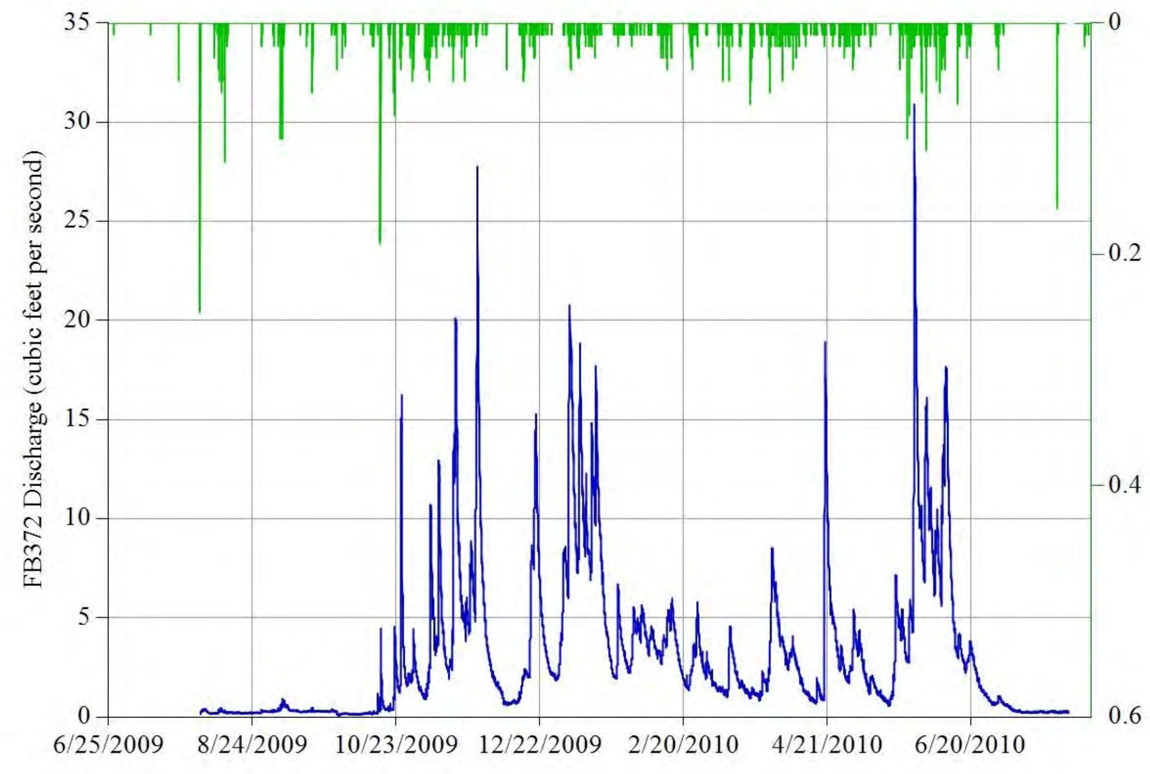


Figure 4. FB372 hydrograph.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal data gaps during the monitoring period (Tables 2), and the majority of gaps were sufficiently short in duration that they could be filled by interpolation. Data gaps represent 0.1 days of the 365 days of monitoring, or 0.027 percent of the data. Therefore, the MQO for completeness of hydrological data was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location FB372. There were no major data gaps or shifts in the rating curve, and the rating curve error was reasonably low. After assessing the quality of the hydrologic data at location FB372 it was found that the data can be used without qualification. The error associated with the hydrograph from this station is accounted for in the final pollutant loading values by reporting the data as a range between the 25th and 75th percentile.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

Herrera Environmental Consultants, Inc.

Memorandum

To	Project File 06-03509-002
From	Dylan Ahearn, Herrera Environmental Consultants
Date	August 8, 2010
Subject	Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **RB53**

This memorandum reviews hydrologic data collected at monitoring location RB53 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location RB53 represents residential land use in the Puyallup River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves.

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers are programmed with algorithms that convert electromagnetic resistance values to water level. In

theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.3 percent to 0.4 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928010).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.397	1.4	-0.3
Post-monitoring	1.005	1.0	0.4

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the level sensors were conducted on 15 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift exceeded the warning limit of plus or minus 1 standard deviation from the mean on two occasions. However, the maximum drift at this location was only 0.08 feet, so the data were minimally affected after the drift was corrected. To correct for sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

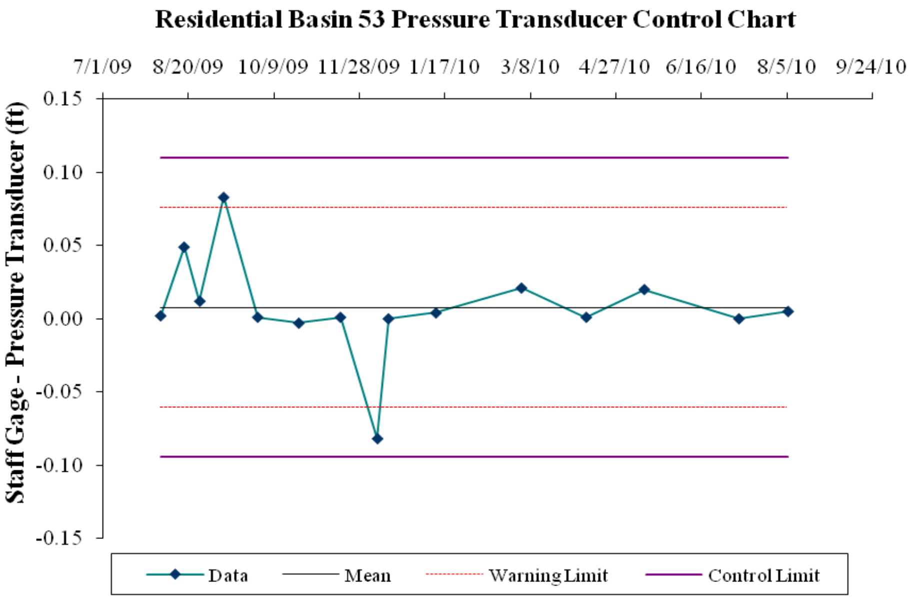


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the RB53 transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a poor quality. Inadequate ventilation in the stilling well caused a partial vacuum to form, which affected the data from the start of the study until December 7, 2009, when the issue was resolved by drilling ventilation holes in the top of the stilling well. In addition, a large gap exists in the data from April 1, 2010 to April 29, 2010. This data gap was the result of sensor failure and subsequent replacement. Finally, the level data became noisy on May 30, 2010 and remained that way through the end of the study.

To improve the quality of the level data a few measures were taken. First, the level data from FB372 was used to model the missing RB53 level data from the April gap. This process involved

Table 2. Hydrologic data correction history for location RB53.

Date of Correction	User	From	To	Comment
8/31/2009 9:57	dyu	8/3/2009 15:00	8/17/2009 7:45	Drift Correction with Calibration Drift value of 0.049 and Fouling Drift value of 0.000 Feet H2O
12/14/2009 15:00	dyu	11/8/2009 16:33	11/8/2009 16:33	Delete region
12/14/2009 15:01	dyu	11/8/2009 16:18	11/8/2009 16:48	Interpolate Gap(Linear)
12/28/2009 16:31	dyu	8/17/2009 7:45	8/26/2009 12:30	Advanced Correction (Date/Time, Value, Diff) (2009-08-17 08:00:16, 0.668, 0.152) (2009-08-26 12:30:16, 0.57, 0.059)
1/24/2010 11:29	dyu	12/7/2009 14:18	12/8/2009 11:18	Drift Correction with Calibration Drift value of -0.006 and Fouling Drift value of 0.000 Feet H2O
1/24/2010 11:33	dyu	12/8/2009 11:33	12/8/2009 12:33	Delete spike
1/24/2010 11:35	dyu	12/8/2009 12:48	12/14/2009 19:48	Advanced Correction (Date/Time, Value, Diff) (2009-12-08 12:48:34, 0.74, -0.012) (2009-12-14 19:48:34, 0.771, -0.004)
1/24/2010 11:35	dyu	12/8/2009 11:18	12/8/2009 12:48	Interpolate Gap(Linear)
3/3/2010 23:51	dyu	1/11/2010 14:03	1/11/2010 14:03	Delete region
3/3/2010 23:51	dyu	1/11/2010 13:48	1/11/2010 14:18	Interpolate Gap(Linear)
4/15/2010 11:14	dyu	3/2/2010 14:18	4/1/2010 14:18	Offset Correction with value of 0.578 Feet H2O
4/15/2010 11:15	dyu	3/2/2010 14:03	3/2/2010 14:03	Advanced Correction (Date/Time Value Diff) (2010-03-02 14:03:34, 1, 0.024)
7/15/2010 10:22	dyu	4/29/2010 12:30	5/13/2010 10:00	Drift Correction with Calibration Drift value of 0.021 and Fouling Drift value of 0.000 Feet H2O
7/15/2010 10:24	dyu	5/13/2010 10:15	7/7/2010 17:45	Advanced Correction (Date/Time, Value, Diff) (2010-05-13 10:15:00, 0.67, 0.020) (2010-07-07 17:45:00, 0.56, 0.000)
8/30/2010 14:33	dahearn	8/4/2009 7:45	12/11/2009 16:03	Fill Region with modeling:[Name = ANUntitled][Type = ANFIS][Target Name = RB53 Pressure][Error = 0.160][Number of Surr. = 1][#1: FB372 Pressure]
8/30/2010 14:34	dahearn	4/1/2010 21:33	4/30/2010 13:30	Fill Region with modeling:[Name = ANUntitled][Type = ANFIS][Target Name = RB53 Pressure][Error = 0.160][Number of Surr. = 1][#1: FB372 Pressure]
8/30/2010 14:54	dahearn	8/3/2009 14:00	11/17/2009 3:03	Advanced Correction (Date/Time, Value, Diff) (2009-08-03 14:00:16, 0.81, 0.302) (2009-11-17 03:03:34, 1.758, 0.150)

Table 2 (continued). Hydrologic data correction history for location RB53.

Date of Correction	User	From	To	Comment
8/30/2010 14:56	dahearn	9/29/2009 11:18	10/16/2009 13:33	Advanced Correction (Date/Time, Value, Diff) (2009-09-29 11:18:34, 0.596, 0.265) (2009-10-16 13:33:34, 0.64, 0.195)
8/30/2010 14:56	dahearn	9/29/2009 10:48	9/29/2009 11:18	Interpolate Gap(Linear) - spike/drop fill
8/30/2010 14:58	dahearn	4/1/2010 21:33	4/30/2010 13:30	Advanced Correction (Date/Time, Value, Diff) (2010-04-01 21:33:41, 1.096, -0.225) (2010-04-30 13:30:00, 0.703, -0.382)
8/30/2010 14:59	dahearn	4/1/2010 14:18	7/5/2010 20:30	Interpolate Gap(Linear) - noisy signal smooth

creating an adaptive neuro-fuzzy inference system (ANFIS) model that related a high quality portion of the FB372 level data with a high quality portion of the RB53 data. This relationship was then used to fill the gap in the RB53 data based on the existing FB372 level data for the same period of time that the gap occurred. The same ANFIS model was used to replace the RB53 level data affected by the stilling well venting issue from August 1, 2009 to December 12, 2009. The error associated with the model was 16 percent. The model assumes that the relationship between water level data at RB53 and FB372 is constant through time. In order to reduce the error associated with this assumption the FB372 and RB53, hydrographs were compared visually prior to modeling. It was determined from this assessment that the stations hydrographs were similar enough to generate a valid model. The result of this modeling can be seen in Figure 2 and the application of the model is presented in Table 2.

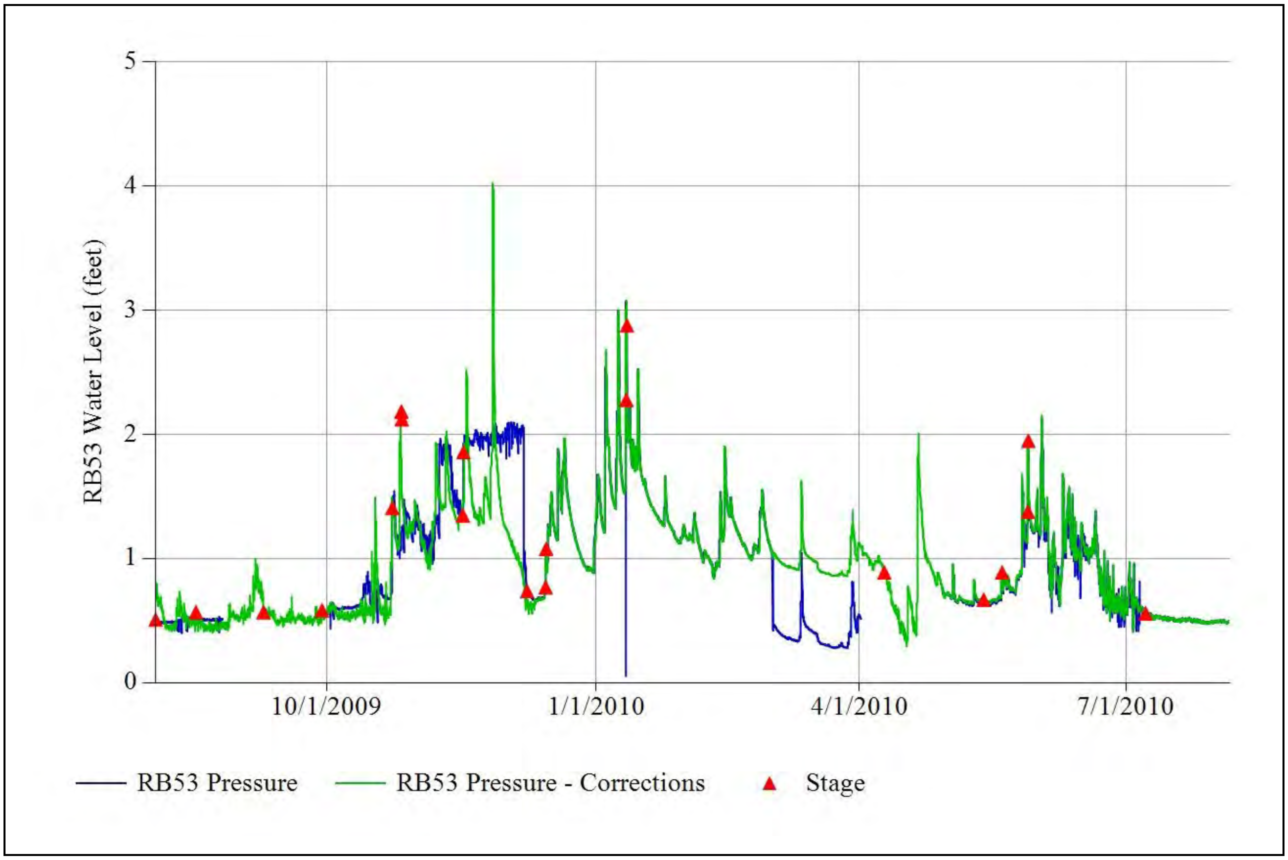
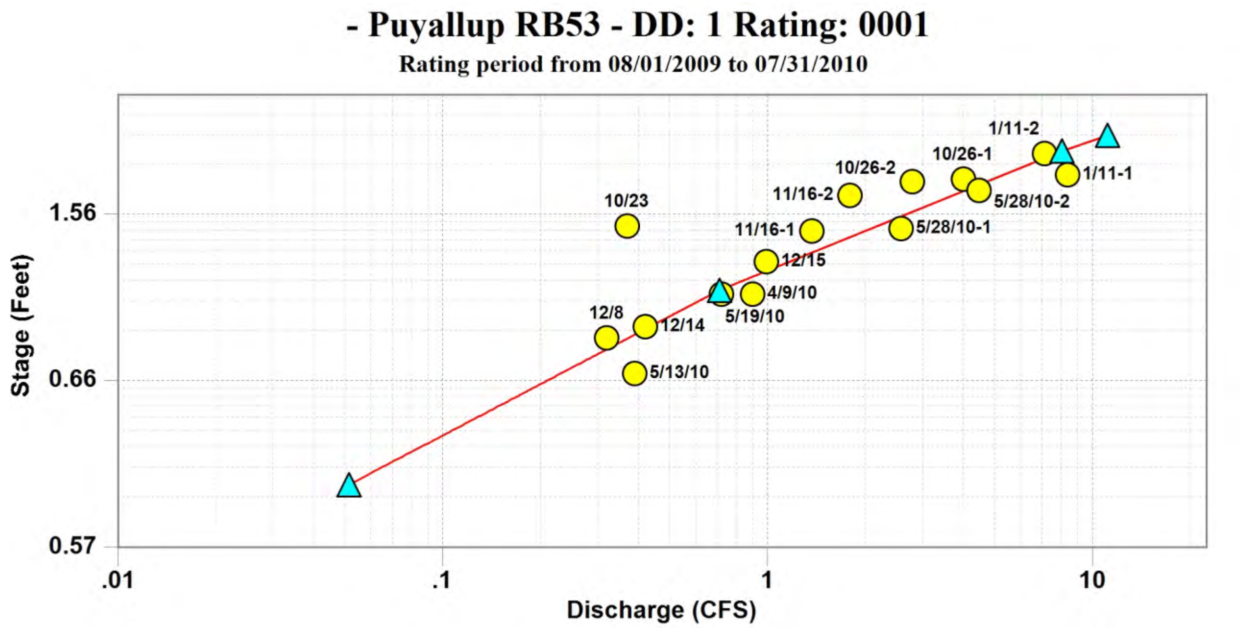


Figure 2. Corrected and raw water level data from location RB53.

Finally, the worst portions of the noisy data, from April 1, 2010 to July 5, 2010, were smoothed using linear interpolation. Despite this correction measure and the efforts made to fill data gaps and improve portions of the RB53 level data with modeling, the resultant RB53 data should be used with caution and flagged as estimates. In addition, any pollutant loading calculations that are based on the RB53 flow data should also be flagged as estimates.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location RB53 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Fifteen discharge measurements were collected at location RB53 during the 1-year study.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location RB53.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is 45.5 percent. This is a relatively high degree of error that is carried through into estimates of discharge and, consequently, all flow data for this location are qualified as estimates.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At RB53, the highest manually measured flow was 3.2 cfs, while the highest recorded flow was 10.7 cfs. Thus, the highest recorded flows were 3.3 times higher than the highest manually measured flow, exceeding the 2.5 guideline and providing additional reason to flagged data as estimates for high flow periods.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

To assess if the RB53 hydrograph was representative of residential basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a residential basin in western Washington. Since there were no existing rain gauges with reliable data records located within the RB53 basin, rainfall and runoff comparisons could not be made. As a result, the RB53 hydrograph was assessed without comparison to rainfall.

The RB53 hydrograph is presented in Figure 4. There was no base flow or a response to rainfall events during the dry season. The flow peaks converged in the wet season indicating flow attenuation and elevated winter base flow. The flows were not very flashy at this location, an indication of low impervious area in the basin. Consequently, the hydrograph is representative of a low density residential basin.

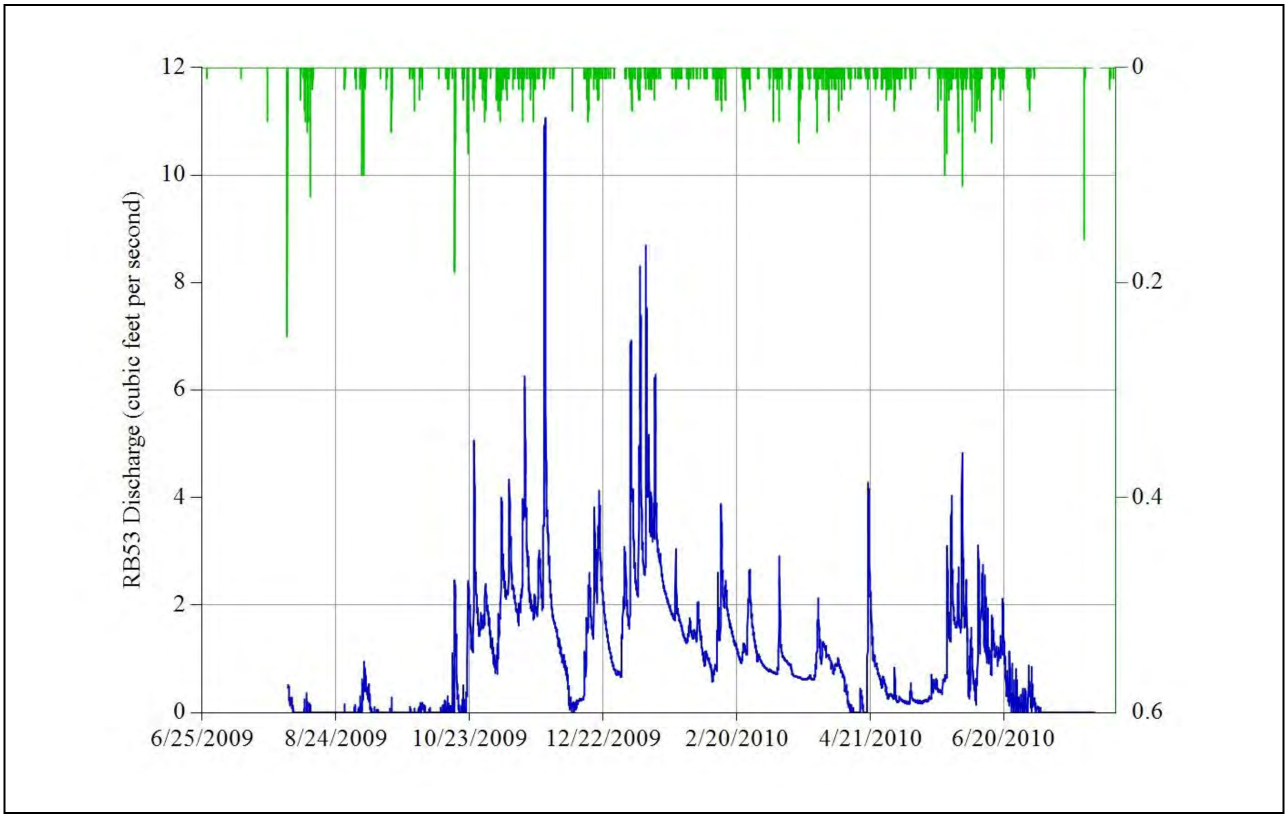


Figure 4. RB53 hydrograph.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There was a 28-day data gap from April 1, 2010 to April 29, 2010 (Figure 2). The gap was filled with modeled data, but even if it was not, it would have only constituted 7.6 percent of the record. Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

The water level and stream flow data from RB53 had numerous quality assurance issues. Noisy data from August 1, 2009 to December 12, 2009 was replaced with modeled data from FB372, and a data gap from April 1, 2009 to April 29, 2009 was also filled with modeled data from

FB372. The remaining data had intermittent issues with noise. The rating curve for RB53 was extrapolated by a factor of 3.3 and the total error is the rating was high. All of these factors combine to result is a hydrograph of poor quality. After assessing the quality of the hydrologic data at location RB53, it was found that all of the hydrologic data should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from RB53 should be closely examined to determine if low quality flow data is controlling pollutant loading patterns.

References

Bovee, K., and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T. J. Buchanan and W. P. Somers. U.S. Government Printing Office, Denver, Colorado.

Herrera Environmental Consultants, Inc.

Memorandum

To Project File 06-03509-002

From Dylan Ahearn, Herrera Environmental Consultants

Date August 8, 2010

Subject Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **RB111**

This memorandum reviews hydrologic data collected at monitoring location RB111 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location RB111 represents residential land use in the Snohomish River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers

are programmed with algorithms that convert electromagnetic resistance values to water level. In theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from -0.56 percent to 0.38 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928016).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.388	1.4	-0.56
Post-monitoring	1.002	1.0	0.38

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the level sensors were conducted on 11 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, the sensor drift did not exceed the warning limit of plus or minus 1 standard deviation from the mean. However, the maximum drift at this location was 0.28 feet. To correct for this sensor drift and all drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

Data Processing

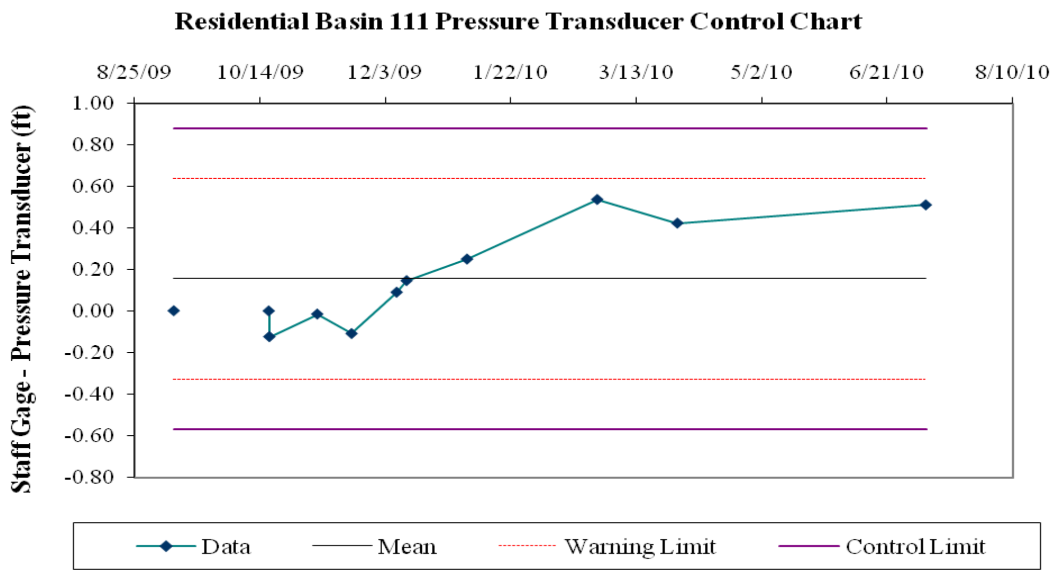
Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the RB111 transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a high quality. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location RB111 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Sixteen discharge measurements were collected at location RB111 during the one-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The rating curve for this location included a shift that occurred due to scour following high flow conditions on January 12, 2010. The shift was applied to data collected after this date (see blue line in Figure 3). The standardized root mean square (SRMS) error for the primary rating is 13.8 percent (red line in Figure 3), while the SRMS for the shifted portion of the rating is 22.9 percent. The error introduced into the data from an unstable channel morphology was reduced by introducing a shift into the rating curve. This resulted in an overall rating that was of an acceptable quality given the conditions in the field.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At RB111, the highest manually measured flow was 17.6 cfs, while the highest recorded flow was 22.0 cfs. Consequently, the highest recorded flows were only 1.25 times higher than the highest manually measured flow, well within the guideline of 2.5.



Note: gap in data indicates period of no flow

Figure 1. Difference between transducer and staff gauge measurements before each calibration.

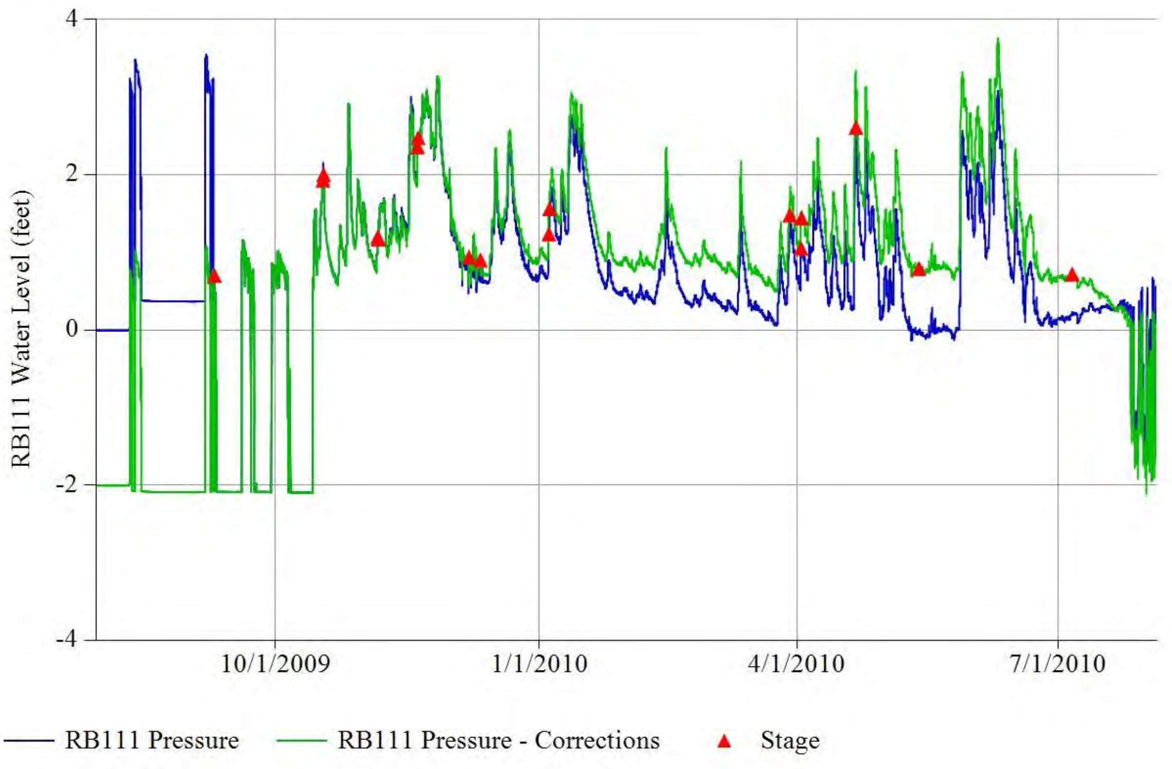
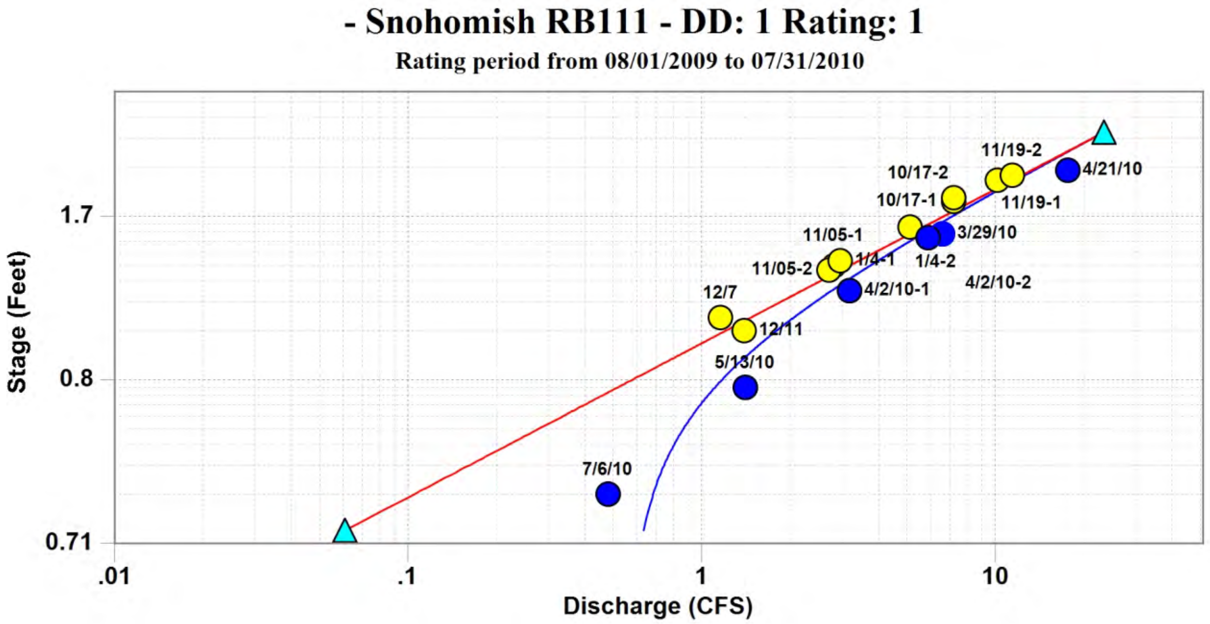


Figure 2. Corrected and raw water level data from location RB111.

Table 2. Hydrologic data correction history for location RB111.

Date of Correction	User	From	To	Comment
10/7/2009 9:14	dyu	8/18/2009 14:14	9/9/2009 15:44	Drift Correction with Calibration Drift value of 0.001 and Fouling Drift value of 0.000 Feet H2O
11/16/2009 9:46	dyu	10/17/2009 19:28	11/5/2009 21:13	Drift Correction with Calibration Drift value of -0.015 and Fouling Drift value of 0.000 Feet H2O
11/21/2009 9:47	dyu	10/17/2009 13:43	10/17/2009 19:13	Drift Correction with Calibration Drift value of -0.124 and Fouling Drift value of 0.000 Feet H2O
11/21/2009 9:48	dyu	11/5/2009 21:28	11/19/2009 13:43	Drift Correction with Calibration Drift value of -0.109 and Fouling Drift value of 0.000 Feet H2O
12/10/2009 10:48	dyu	11/19/2009 13:58	12/7/2009 12:58	Drift Correction with Calibration Drift value of 0.09 and Fouling Drift value of 0.000 Feet H2O
12/11/2009 13:01	dyu	7/30/2009 12:59	8/11/2009 8:59	Offset Correction with value of -2.000 Feet H2O
12/11/2009 13:06	dyu	8/11/2009 9:29	9/9/2009 15:44	Offset Correction with value of -2.459 Feet H2O
12/11/2009 13:15	dyu	8/11/2009 9:14	8/11/2009 9:14	Delete region
12/11/2009 13:15	dyu	8/11/2009 8:59	8/11/2009 9:29	Interpolate Gap(Linear)
1/21/2010 14:56	dyu	12/7/2009 13:13	12/11/2009 12:13	Drift Correction with Calibration Drift value of 0.204 and Fouling Drift value of 0.000 Feet H2O
3/3/2010 22:57	dyu	12/11/2009 12:28	1/4/2010 14:58	Advanced Correction (Date/Time, Value, Diff) (2009-12-11 12:28:03, 0.9, 0.083) (2010-01-04 14:58:03, 1.56, 0.251)
3/3/2010 22:59	dyu	1/4/2010 15:13	2/25/2010 12:28	Advanced Correction (Date/Time, Value, Diff) (2010-01-04 15:13:03, 1.56, 0.243) (2010-02-25 12:28:03, 0.91, 0.538)
4/20/2010 16:52	dyu	2/25/2010 12:58	3/29/2010 9:43	Advanced Correction (Date/Time, Value, Diff) (2010-02-25 12:43:03, 0.91, 0.537) (2010-03-29 09:43:03, 1.47, 0.423)
4/20/2010 16:52	dyu	2/25/2010 12:43	2/25/2010 12:43	Delete region
6/2/2010 21:22	dyu	3/29/2010 9:58	5/14/2010 10:58	Advanced Correction (Date/Time Value Diff) (2010-03-29 09:58:03, 1.47, 0.420) (2010-05-14 10:58:03, 0.79, 0.851)
7/28/2010 14:38	dyu	5/14/2010 11:13	7/6/2010 11:28	Advanced Correction (Date/Time, Value, Diff) (2010-05-14 11:13:03, 0.79, 0.851) (2010-07-06 11:28:03, 0.72, 0.509)
8/10/2010 11:00	dyu	7/6/2010 11:43	8/4/2010 11:58	Advanced Correction (Date/Time, Value, Diff) (2010-07-06 11:43:03, 0.72, 0.513) (2010-08-04 11:58:03, -0.564, -0.482)



Note: red line and yellow circles for rating data before 1/12/10, blue line and blue circles for rating data after 1/12/10, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location RB111.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

To assess if the RB111 hydrograph was representative of residential basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a residential basin in western Washington. Since there were no existing rain gauges with reliable data records located within the RB111 basin, rainfall and runoff comparisons could not be made. As a result, the RB111 hydrograph was assessed without comparison to rainfall.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

The RB111 hydrograph is presented in Figure 4. There was minimal base flow and a flashy response to large rain events during the dry season. The flow peaks converged in the wet season indicating flow attenuation and elevated winter base flow. The resultant hydrograph is similar to what would be seen in a forested basin except that the response to rainfall was more immediate (spiky flows). Given this, the hydrograph is responsibly representative of what would be expected from a low-density residential basin.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal (less than 0.1 percent of the record) data gaps during the monitoring period during which there was flow (Table 2). Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location RB111. There was one shift in the rating curve and the rating curve errors were reasonably low. After assessing the quality of the hydrologic data at location RB111, it was found that the data can be used without qualification. The error associated with the hydrograph from this station is accounted for in the final pollutant loading values by reporting the data as a range between the 25th and 75th percentile.

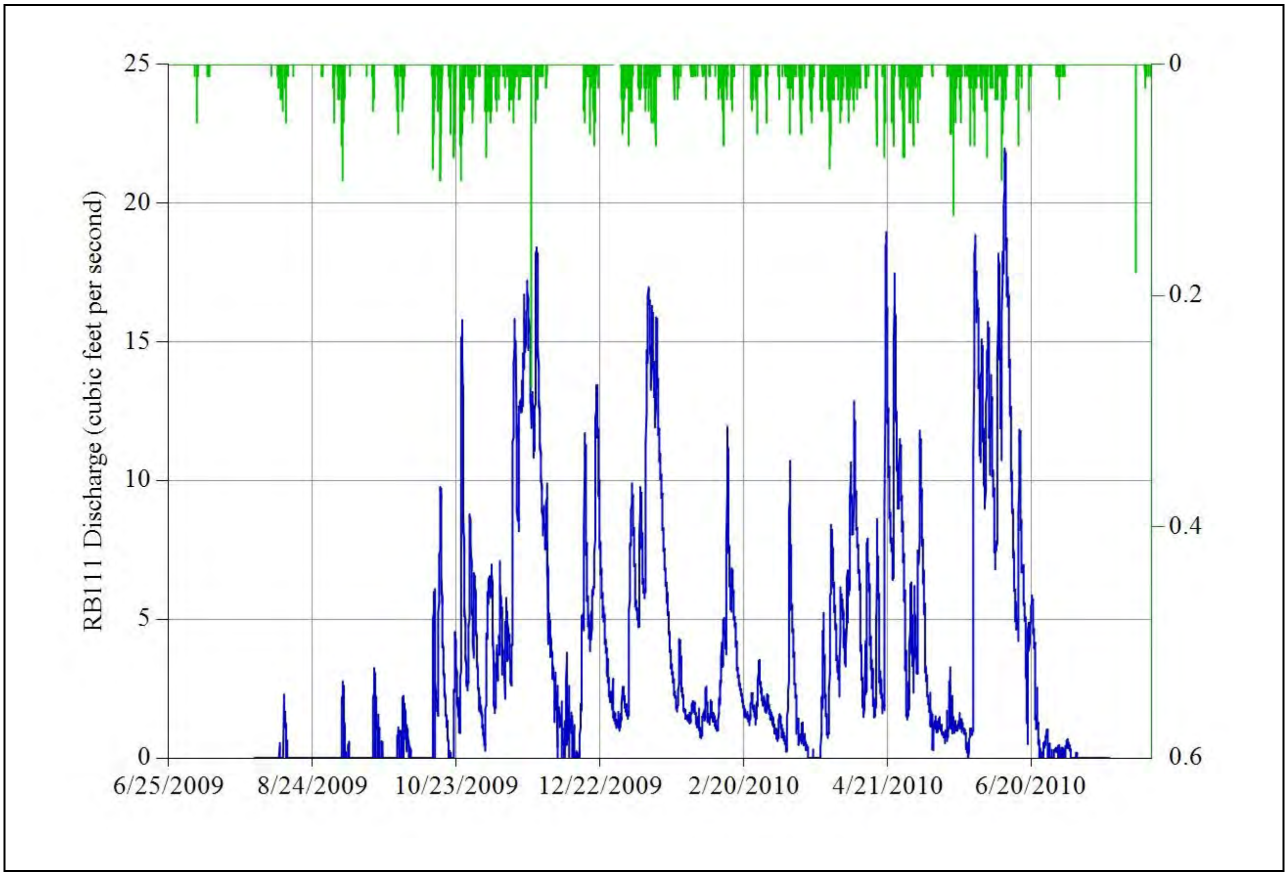


Figure 4. RB111 hydrograph.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

USGS. 1969. Chapter A8: Discharge Measurements at Gaging Stations. Techniques of Water-Resources Investigations of the United States Geological Survey. T.J. Buchanan and W.P. Somers. U.S. Government Printing Office, Denver, Colorado.

Herrera Environmental Consultants, Inc.

Memorandum

To	Project File 06-03509-002
From	Dylan Ahearn, Herrera Environmental Consultants
Date	August 8, 2010
Subject	Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **RB202**

This memorandum reviews hydrologic data collected at monitoring location RB202 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location RB202 represents forested land use in the Snohomish River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers

are programmed with algorithms that convert electromagnetic resistance values to water level. In theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from 0.38 percent to 0.57 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928008).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.407	1.4	0.57
Post-monitoring	1.002	1.0	0.38

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the level sensors were conducted on 15 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift exceeded the warning limit of plus or minus 1 standard deviation from the mean on two occasions. The maximum drift at this location was 0.15 feet. To correct for this sensor drift and all drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the RB202 transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a high quality. Because the flow record was nearly complete and of a high quality, there was no need to model any sections of the flow record; therefore, model bias was not a factor. Table 2 shows that the deleted spikes and interpolated gaps were of a short duration and infrequent; therefore, data processing bias was minimal.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location RB202 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge value was then regressed against the measured water level at the time of the discharge measurement to develop a rating curve (Figure 3). Twenty discharge measurements were collected at location RB202 during the 1-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The rating curve for this location included two shifts that occurred due to aggradation following November 19, 2009 and subsequent scour following June 16, 2010. The first shift applies to the data collected from November 19, 2009 to June 16, 2010, the second shift applies to the data collected after June 16, 2010. The standardized root mean square (SRMS) error for the primary rating is 25.5 percent, the SRMS for the first shift (blue line in Figure 3) portion of the rating is 19.3 percent, and the SRMS for the second shift (green line in Figure 3) is 0.1 percent. The error introduced into the data from unstable channel morphology was reduced by introducing these shifts in the rating curve. This resulted in an overall rating that was of an acceptable quality given the unstable channel conditions.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At RB202, the highest manually measured flow was 30.65 cfs, while the highest recorded flow was 57.2 cfs. Consequently, the highest recorded flows were only 1.87 times higher than the highest manually measured flow, which is within the guideline of 2.5.

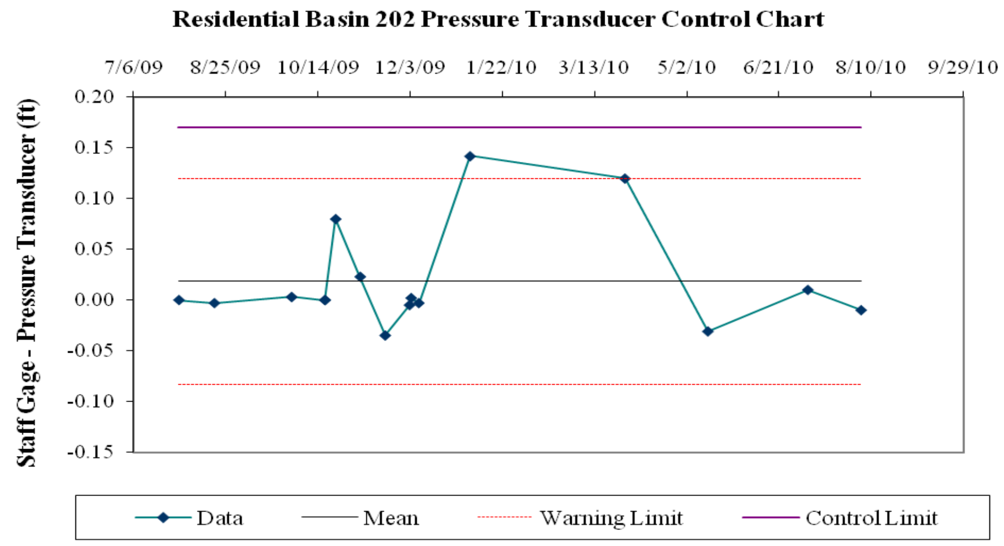


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

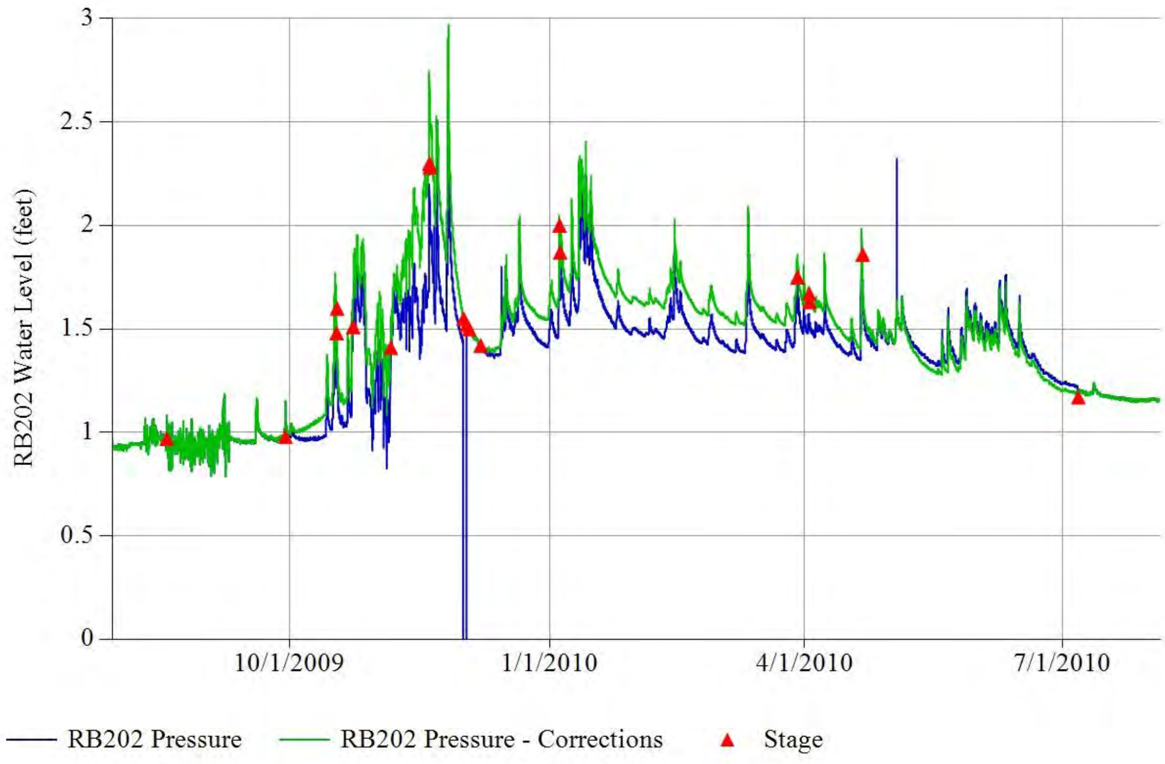


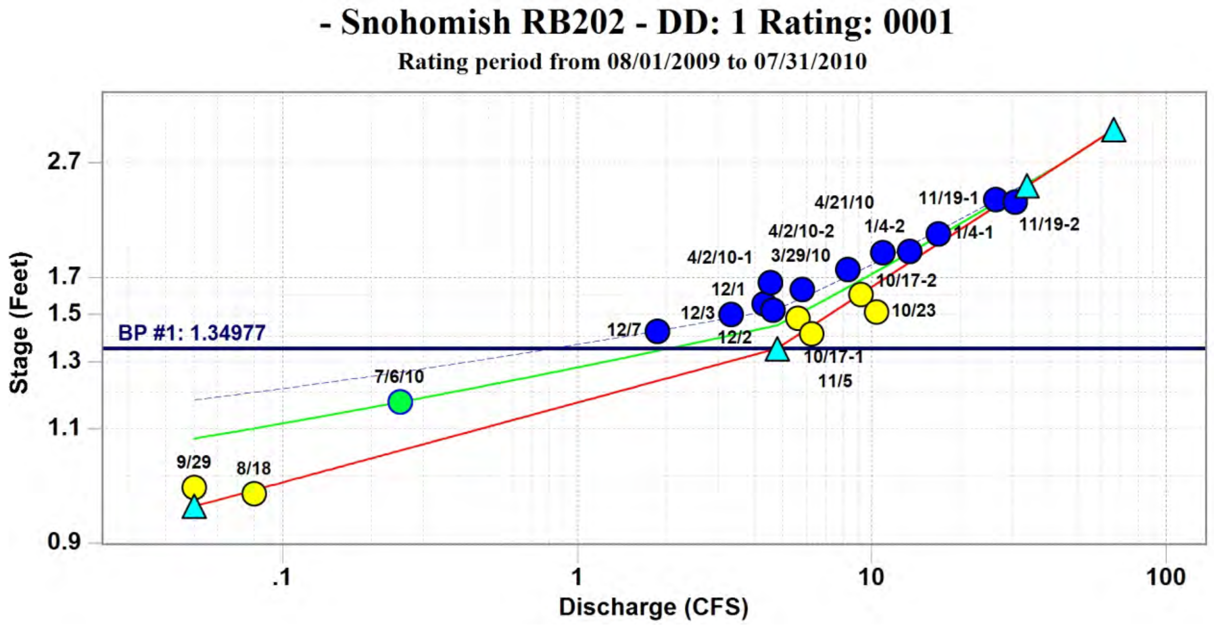
Figure 2. Corrected and raw water level data from location RB202.

Table 2. Hydrologic data correction history for location RB202.

Date of Correction	User	From	To	Comment
11/4/2009 12:41	dyu	7/30/2009 10:51	8/18/2009 17:06	Drift Correction with Calibration Drift value of -0.003 and Fouling Drift value of 0.000 Feet H2O
11/4/2009 12:42	dyu	8/18/2009 17:06	9/29/2009 14:36	Drift Correction with Calibration Drift value of 0.003 and Fouling Drift value of 0.000 Feet H2O
12/28/2009 13:41	dyu	9/29/2009 14:51	10/17/2009 14:21	Drift Correction with Calibration Drift value of 0.132 and Fouling Drift value of 0.000 Feet H2O
12/28/2009 13:43	dyu	10/17/2009 14:36	10/17/2009 19:21	Advanced Correction (Date/Time, Value, Diff) (2009-10-17 14:36:16, 1.587, 0.125) (2009-10-17 19:21:16, 1.6, 0.098)
12/28/2009 13:48	dyu	10/17/2009 19:36	10/23/2009 12:51	Advanced Correction (Date/Time, Value, Diff) (2009-10-17 19:36:16, 1.563, 0.100) (2009-10-23 12:51:16, 1.55, 0.126)
12/28/2009 15:33	dyu	10/23/2009 13:06	11/5/2009 19:51	Advanced Correction (Date/Time, Value, Diff) (2009-10-23 13:06:16, 1.55, 0.133) (2009-11-05 20:06:16, 1.4, 0.264)
12/28/2009 15:35	dyu	11/5/2009 20:36	11/19/2009 9:21	Advanced Correction (Date/Time Value Diff) (2009-11-05 20:21:16, 1.4, 0.036) (2009-11-19 09:21:16, 2.25, 0.565)
12/28/2009 15:36	dyu	11/19/2009 9:36	12/1/2009 13:51	Advanced Correction (Date/Time, Value, Diff) (2009-11-19 09:36:16, 2.25, 0.552) (2009-12-01 13:36:16, 1.55, 0.115)
12/28/2009 15:40	dyu	12/2/2009 13:51	12/3/2009 12:19	Advanced Correction (Date/Time, Value, Diff) (2009-12-02 13:51:16, 1.52, 0.009) (2009-12-03 12:19:27, 1.5, 0.003)
1/24/2010 10:06	dyu	11/5/2009 20:06	11/5/2009 20:21	Delete drop
1/24/2010 10:06	dyu	11/5/2009 19:51	11/5/2009 20:36	Interpolate Gap(Linear)
1/24/2010 10:09	dyu	12/1/2009 13:51	12/1/2009 13:51	Delete region
1/24/2010 10:10	dyu	12/1/2009 13:36	12/2/2009 14:34	Interpolate Gap(Linear)
1/24/2010 10:16	dyu	12/7/2009 14:49	1/4/2010 10:34	Drift Correction with Calibration Drift value of 0.155 and Fouling Drift value of 0.000 Feet H2O
1/24/2010 10:16	dyu	12/15/2009 1:34	12/15/2009 1:34	Delete spike
1/24/2010 10:16	dyu	12/15/2009 1:19	12/15/2009 1:49	Interpolate Gap(Linear) - fill deleted spike

Table 2 (continued). Hydrologic data correction history for location RB202.

Date of Correction	User	From	To	Comment
4/20/2010 16:56	dyu	1/4/2010 10:49	3/29/2010 10:34	Advanced Correction (Date/Time, Value, Diff) (2010-01-04 10:49:27, 2.019, 0.160) (2010-03-29 10:34:27, 1.75, 0.127)
6/2/2010 23:16	dyu	11/21/2009 9:21	11/21/2009 9:51	Delete spike
6/2/2010 23:16	dyu	11/21/2009 9:06	11/21/2009 10:06	Interpolate Gap(Linear)
6/2/2010 23:16	dyu	11/22/2009 11:51	11/22/2009 11:51	Delete spike
6/2/2010 23:17	dyu	11/22/2009 11:36	11/22/2009 12:06	Interpolate Gap(Linear)
6/2/2010 23:17	dyu	11/25/2009 21:21	11/25/2009 21:21	Delete spike
6/2/2010 23:17	dyu	11/25/2009 21:06	11/25/2009 21:36	Interpolate Gap(Linear)
7/28/2010 14:42	dyu	3/29/2010 10:49	5/13/2010 12:04	Advanced Correction (Date/Time, Value, Diff) (2010-03-29 10:49:27, 1.755, 0.150) (2010-05-13 12:04:27 1.33, -0.045)
7/28/2010 14:43	dyu	5/3/2010 16:49	5/3/2010 16:49	Delete region
7/28/2010 14:43	dyu	5/3/2010 16:34	5/3/2010 17:04	Interpolate Gap(Linear)
7/28/2010 14:45	dyu	5/13/2010 12:34	7/6/2010 16:19	Advanced Correction (Date/Time, Value, Diff) (2010-05-13 12:19:27, 1.328, -0.043) (2010-07-06 16:19:27, 1.18, -0.033)
7/28/2010 14:45	dyu	5/13/2010 12:19	5/13/2010 12:19	Delete region
7/28/2010 14:45	dyu	5/13/2010 12:04	5/13/2010 12:34	Interpolate Gap(Linear)



Note: red line and yellow circles for rating data before 11/19/09, blue line and circles for rating data between 11/19/09 and 6/16/10, green line and circles for rating data after 6/16/10, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location RB202.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

To assess if the RB202 hydrograph was representative of residential basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a residential basin in western Washington. Since there were no existing rain gauges with reliable data records located within the RB202 basin, rainfall and runoff comparisons could not be made. As a result, the RB202 hydrograph was assessed without comparison to rainfall.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

The RB202 hydrograph is presented in Figure 4. There was minimal base flow and little response to rain events during the dry season. The flow peaks converged in the wet season indicating flow attenuation and elevated winter base flow. The resultant hydrograph is similar to what would be seen in a forested basin, which suggest that residential development has a small impact on stream hydrology in this basin.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal (less than 0.1 percent of the record) data gaps during the monitoring period during which there was flow (Table 2). Consequently, the completeness MQO was met.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

All hydrologic MQOs identified in the project QAPP (Herrera 2009) were met for the water level and stream discharge data collected at location RB202. There were two shifts in the rating curve and the rating curve errors were relatively low. After assessing the quality of the hydrologic data at location RB202 it was found that the data can be used without qualification. The error associated with the hydrograph from this station is accounted for in the final pollutant loading values by reporting the data as a range between the 25th and 75th percentile.

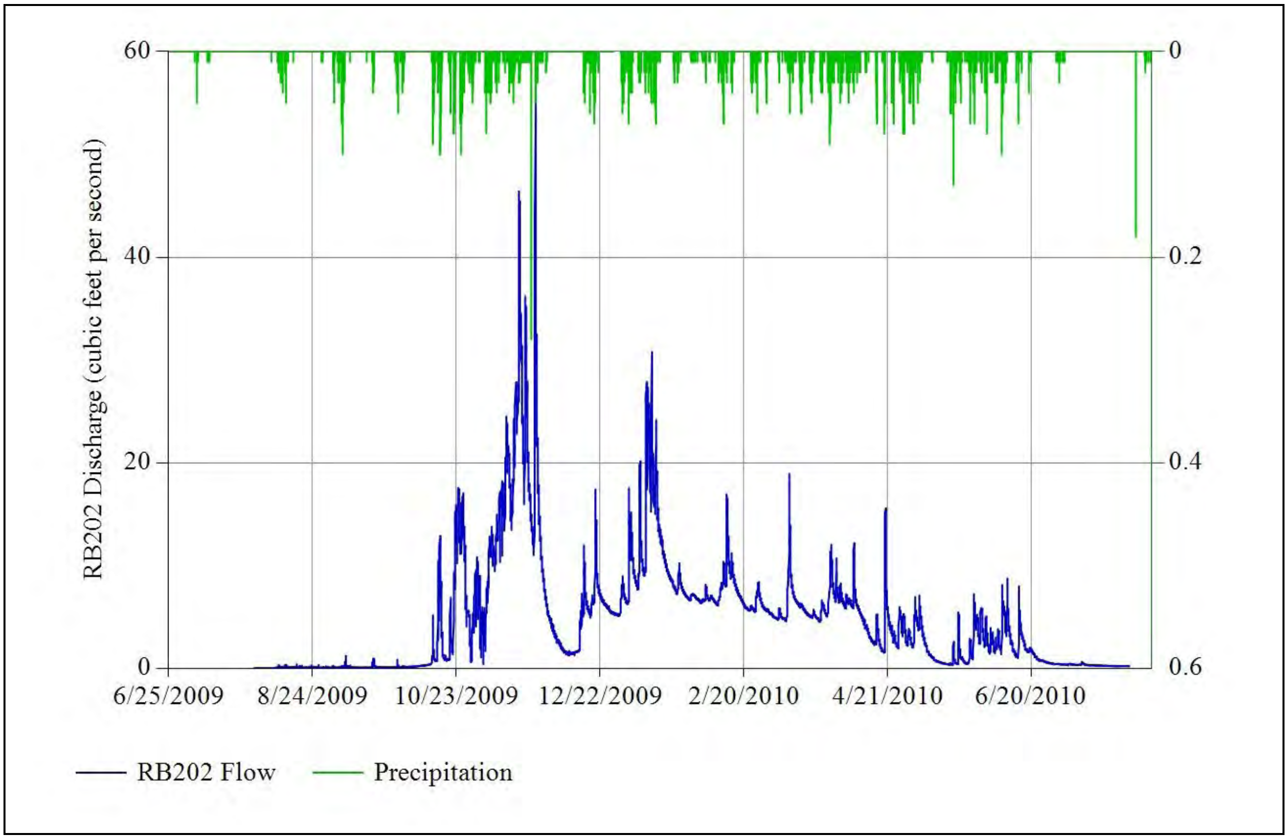


Figure 4. RB202 hydrograph.

References

Bovee, K. and R. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C.

Herrera. 2009. Quality Assurance Project Plan: Control of Toxic Chemicals in Puget Sound Phase 3 – Characterization of Loadings via Surface Runoff. Prepared for Washington State Department of Ecology by Herrera Environmental Consultants, Inc., Seattle, Washington.

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Herrera Environmental Consultants, Inc.

Memorandum

To	Project File 06-03509-002
From	Dylan Ahearn, Herrera Environmental Consultants
Date	August 8, 2010
Subject	Characterization of Loadings to Puget Sound via Surface Runoff: Hydrologic Data Quality Assurance Review of Location **RB209**

This memorandum reviews hydrologic data collected at monitoring location RB209 from August 1, 2009 to July 30, 2010 as part of the Characterization of Loadings to Puget Sound via Surface Runoff Study. Location RB209 represents residential land use in the Puyallup River Watershed. This review was conducted to establish the usability of data from this monitoring location. Results were evaluated using data quality indicators identified in the quality assurance project plan (QAPP) for the project (Herrera 2009). This memorandum also identifies which specific measurement quality objectives (MQOs) were met for each data quality indicator.

Hydrologic monitoring consisted of measuring water levels and converting those levels to estimates of stream discharge using a rating curve developed for each monitoring location. MQOs for these measurements are expressed in terms of bias, representativeness, completeness, and comparability, and are evaluated below.

Bias

Bias can be introduced into discharge data by:

- Inaccurate water level sensor response (linearity)
- Water level sensor drift over time or displacement between calibrations
- Deletion of water level sensor spikes or other erroneous readings and filling of data gaps during data processing
- Conversion of water level to discharge using rating curves

Those sources of bias are assessed separately below.

Sensor Response

Bias can be introduced if the water level sensor (Instrumentation Northwest PT2X 0-5 psi pressure transducer) does not accurately respond to changes in water level. Pressure transducers

are programmed with algorithms that convert electromagnetic resistance values to water level. In theory, there should be a linear relationship between the two variables. Laboratory tests were conducted to test this linearity using the following process:

1. Pressure transducers were placed in a 1-liter graduated cylinder.
2. A reading was taken with no water in the cylinder.
3. Water was added to the cylinder.
4. Five measurements were taken with the pressure transducer, and the results were averaged.
5. The average measured depth was compared with the manually measured depth to determine the percent error.

This test was conducted at different depths before and after the monitoring period. Results from the sensor (pressure transducer) response tests are presented in Table 1. Percent error ranged from 0.16 percent to 0.23 percent. The MQO defined in the project QAPP (Herrera 2009) for sensor testing is less than a 5 percent change in water level readings. Therefore, the measured bias was within acceptable limits.

Table 1. Pressure transducer bias testing results (serial # 2928007).

Test	Transducer Depth (feet)	Measured Depth (feet)	Percent Error (%)
Pre-monitoring	1.404	1.4	0.23
Post-monitoring	1.001	1.0	0.16

Sensor Drift

Bias can be introduced into the level signal when the instrument is operated over time in the field. This bias is usually due to sensor drift, operation, or configuration errors. Routine field calibrations of the level sensors were conducted on 15 occasions during the study. Sensor drift between calibrations was assessed by comparing sensor readings to manual readings from staff gauges installed at each monitoring location. If the sensor was not affected by drift or other operational problems, the difference between the sensor reading and the manual measurement of water level (i.e., sensor drift value) would remain at zero over time and varying water depths. Therefore, sensor bias can be assessed based on the change in the sensor drift value. A change in the sensor drift value of plus or minus 2 standard deviations relative to the mean of all previous measurements was used as a threshold (control limit) and established as an MQO to assess sensor function. If the sensor drifted past the control limit then the sensor was removed, assessed for damage, and recalibrated. If the sensor drifted past a warning limit of 1 standard deviation then the sensor was checked by field technicians and recalibrated during the next field visit.

Figure 1 presents sensor drift values as the difference between the staff gauge and pressure transducer measurements recorded prior to each sensor calibration relative to the warning and

control limits. As shown in Figure 1, sensor drift exceeded the control limit of plus or minus 2 standard deviations from the mean on one occasion. However, the maximum drift at this location was only 0.05 feet, so the data were minimally affected after the drift was corrected. To correct for sensor drift between calibrations, the data were processed using the advanced correction feature of Aquarius Version 2.5. A prorated drift correction was applied to the data between each calibration point. Aquarius was also used to fill data gaps, delete erroneous spikes, and model water level data for sections of missing or spurious data. The potential bias introduced by these actions is addressed below.

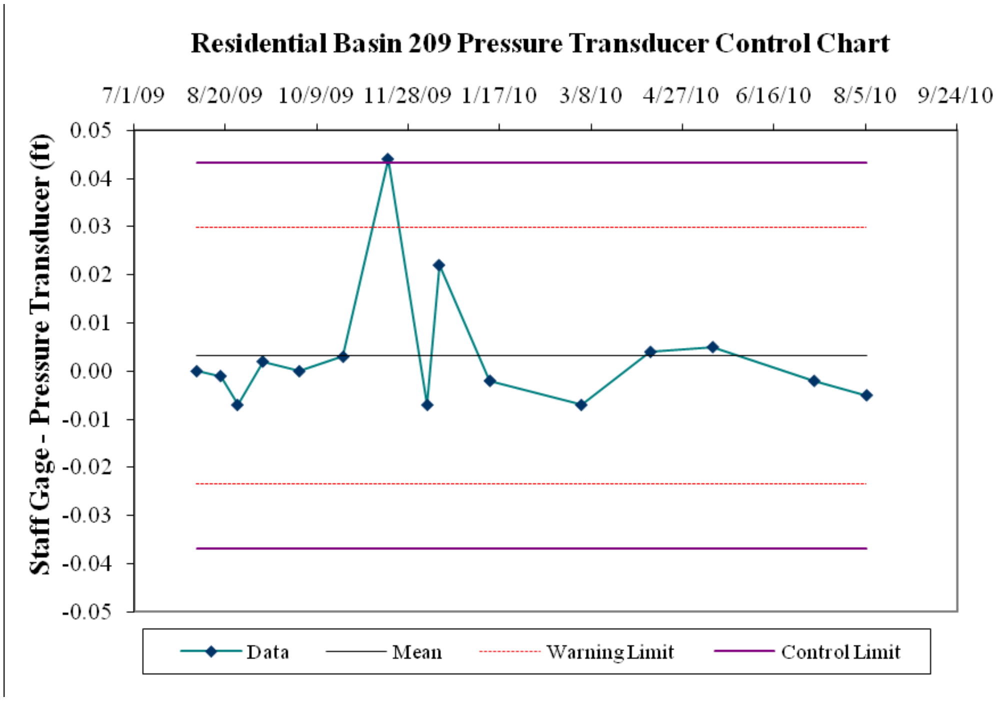


Figure 1. Difference between transducer and staff gauge measurements before each calibration.

Data Processing

Aquarius was used to delete spikes and fill small data gaps, which are also potential sources of bias. All edits to the continuous record from the RB209 transducer are presented in Table 2 and Figure 2. The hydrologic record at this location was of a poor quality. Inadequate ventilation in the stilling well caused a partial vacuum to form which affected the data from the start of the study until November 3, 2009, when the issue was resolved by drilling ventilation holes in the top of the stilling well. The level data from FB372 was used to model the spurious RB209 level data from August 1, 2009 to November 3, 2009. This process involved creating an adaptive neuro-fuzzy inference system (ANFIS) model that related a high quality portion of the FB372 level data with a high quality portion of the RB209 data. This relationship was then used to overwrite the spurious RB209 data based on the existing FB372 level data for the same period of time. The error associated with the model was 7.8 percent. The model assumes that the relationship between water level data at RB209 and FB372 is constant through time. In order to

Table 2. Hydrologic data correction history for location RB209.

Date of Correction	User	From	To	Comment
8/31/2009 9:57	dyu	8/3/2009 15:00	8/17/2009 7:45	Drift Correction with Calibration Drift value of 0.049 and Fouling Drift value of 0.000 Feet H2O
12/14/2009 15:00	dyu	11/8/2009 16:33	11/8/2009 16:33	Delete region
12/14/2009 15:01	dyu	11/8/2009 16:18	11/8/2009 16:48	Interpolate Gap(Linear)
12/28/2009 16:31	dyu	8/17/2009 7:45	8/26/2009 12:30	Advanced Correction (Date/Time, Value, Diff) (2009-08-17 08:00:16, 0.668, 0.152) (2009-08-26 12:30:16, 0.57, 0.059)
1/24/2010 11:29	dyu	12/7/2009 14:18	12/8/2009 11:18	Drift Correction with Calibration Drift value of -0.006 and Fouling Drift value of 0.000 Feet H2O
1/24/2010 11:33	dyu	12/8/2009 11:33	12/8/2009 12:33	Delete spike
1/24/2010 11:35	dyu	12/8/2009 12:48	12/14/2009 19:48	Advanced Correction (Date/Time, Value, Diff) (2009-12-08 12:48:34, 0.74, -0.012) (2009-12-14 19:48:34, 0.771, -0.004)
1/24/2010 11:35	dyu	12/8/2009 11:18	12/8/2009 12:48	Interpolate Gap(Linear)
3/3/2010 23:51	dyu	1/11/2010 14:03	1/11/2010 14:03	Delete region
3/3/2010 23:51	dyu	1/11/2010 13:48	1/11/2010 14:18	Interpolate Gap(Linear)
4/15/2010 11:14	dyu	3/2/2010 14:18	4/1/2010 14:18	Offset Correction with value of 0.578 Feet H2O
4/15/2010 11:15	dyu	3/2/2010 14:03	3/2/2010 14:03	Advanced Correction (Date/Time, Value, Diff) (2010-03-02 14:03:34, 1 0.024)
7/15/2010 10:22	dyu	4/29/2010 12:30	5/13/2010 10:00	Drift Correction with Calibration Drift value of 0.021 and Fouling Drift value of 0.000 Feet H2O
7/15/2010 10:24	dyu	5/13/2010 10:15	7/7/2010 17:45	Advanced Correction (Date/Time, Value, Diff) (2010-05-13 10:15:00, 0.67, 0.020) (2010-07-07 17:45:00, 0.56, 0.000)
8/30/2010 14:33	dahearn	8/4/2009 7:45	12/11/2009 16:03	Fill Region with modeling:[Name = ANUntitled][Type = ANFIS][Target Name = RB209 Pressure][Error = 0.160][Number of Surr. = 1][#1: FB372 Pressure]
8/30/2010 14:34	dahearn	4/1/2010 21:33	4/30/2010 13:30	Fill Region with modeling:[Name = ANUntitled][Type = ANFIS][Target Name = RB209 Pressure][Error = 0.160][Number of Surr. = 1][#1: FB372 Pressure]
8/30/2010 14:54	dahearn	8/3/2009 14:00	11/17/2009 3:03	Advanced Correction (Date/Time, Value, Diff) (2009-08-03 14:00:16, 0.81, 0.302) (2009-11-17 03:03:34, 1.758, 0.150)
8/30/2010 14:56	dahearn	9/29/2009 11:18	10/16/2009 13:33	Advanced Correction (Date/Time, Value, Diff) (2009-09-29 11:18:34, 0.596, 0.265) (2009-10-16 13:33:34, 0.64, 0.195)
8/30/2010 14:56	dahearn	9/29/2009 10:48	9/29/2009 11:18	Interpolate Gap(Linear) - spike/drop fill
8/30/2010 14:58	dahearn	4/1/2010 21:33	4/30/2010 13:30	Advanced Correction (Date/Time, Value, Diff) (2010-04-01 21:33:41, 1.096, -0.225) (2010-04-30 13:30:00, 0.703, -0.382)
8/30/2010 14:59	dahearn	4/1/2010 14:18	7/5/2010 20:30	Interpolate Gap(Linear) - noisy signal smooth

reduce the error associated with this assumption the FB372 and RB209 hydrographs were compared visually prior to modeling. It was determined from this assessment that the hydrographs were similar enough to generate a valid model. The result of this modeling can be seen in Figure 2 and the application of the model is presented in Table 2. Despite the efforts made to improve portions of the RB209 level data with modeling, the resultant RB209 data should be used with caution and flagged as estimates. In addition, any pollutant loading calculations that are based on the RB209 flow data should also be considered estimates.

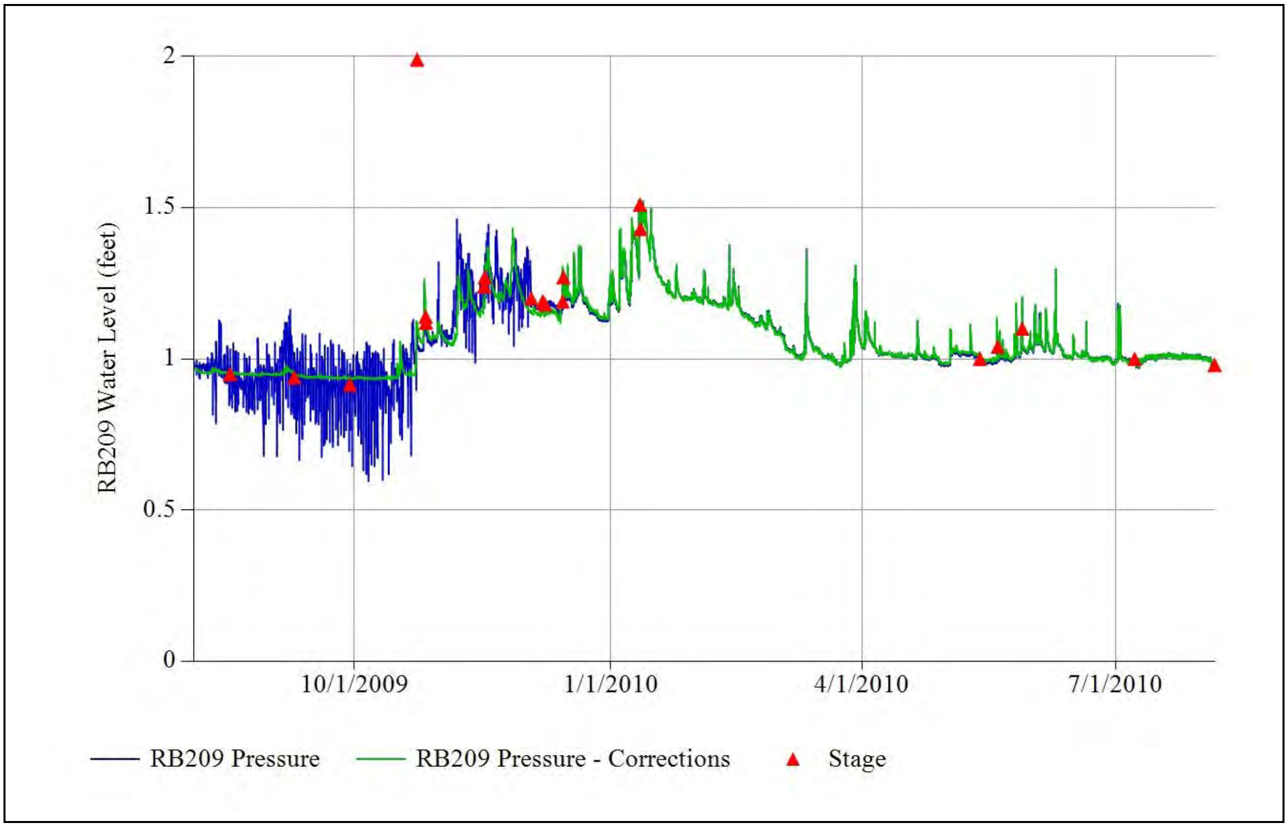
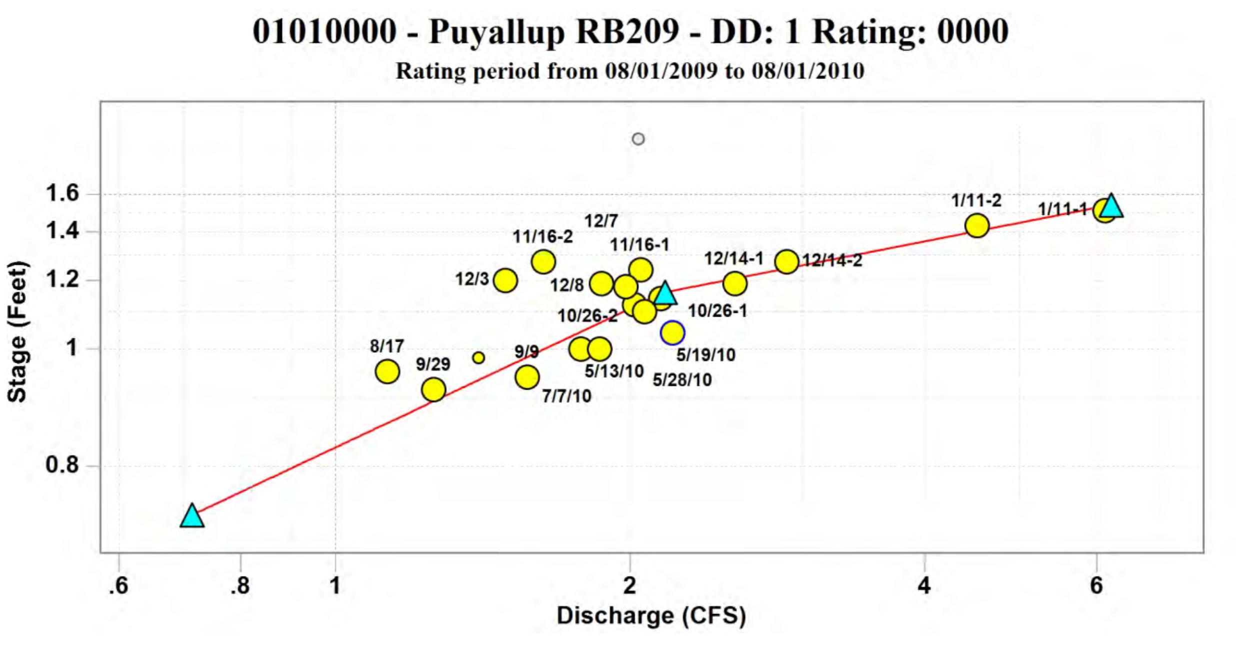


Figure 2. Corrected and raw water level data from location RB209.

Flow Conversion

Because discharge is calculated using water levels and rating curves, bias also can be introduced by the flow conversion process. A rating curve was developed for location RB209 to convert water level to flow. Discharge was manually measured using the mid-point velocity method (USGS 1969) and a Marsh McBirney Flo-Mate velocity meter. The resulting discharge values were then regressed against the water levels measured at the time of the discharge measurement to develop a rating curve (Figure 3). Nineteen discharge measurements were collected at location RB209 during the 1-year study.

As shown in Figure 3, all measured points do not fall on the best fit line. Consequently, there is error associated with the rating. The standardized root mean square (SRMS) error for this rating is 19.6 percent. Although this is a relatively low SRMS, one rating point was excluded prior to calculation because it was an extreme outlier (see grey dot in Figure 3). Inaccuracy of the rating may have been caused by a frequently shifting of the sandy channel bottom. A sand and gravel mine is located upstream from this location that may have exported fine sediments, which accumulated in the stream and then rapidly aggraded and incised during high flow events. Due to the unstable channel cross-section, all discharge data for this location are qualified as estimates.



Note: red line and yellow circles for all rating data, and triangles for artificial breakpoints or endpoints.

Figure 3. Water level (stage) discharge relationship (rating curve) for monitoring location RB209.

An important guideline for developing rating curves is that the highest discharge recorded during the monitoring period should not be more than 2.5 times the highest manual discharge measurement (Bovee and Milhous 1978). At RB209, the highest manually measured flow was 6.1 cfs, while the highest recorded flow was 6.0 cfs. Consequently, the guideline was met.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing monitoring equipment (see equipment installation information presented separately). Rainfall patterns, channel stability, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies.

A hydrologist should visually assess data to evaluate the quality of any hydrologic record. Stream flow from various land uses and watersheds will have a unique and discernable pattern. For example, flows from highly impervious basins have minimal base flow and a rapid response to rainfall, while flows from an undeveloped basin have higher base flow levels and more attenuated flow peaks. Table 3 provides characteristics of second-order stream flow from various land use types in the Pacific Northwest. Stream flow from unregulated, rainfall dominated second-order forested basins are characterized by attenuated peaks, a lag between the maximum rainfall intensity and the peak discharge, discernable base flow, and minimal response to rainfall during the dry season.

Table 3. Generalized characteristics of stream flow from unregulated, rainfall dominated second-order streams in western Washington.

Land Use	Flow Characteristics
Forested	Attenuated flow peaks, lag between rain and flow, base flow, minimal response to rain during the dry season, no flow peaks during periods of no rain.
Agricultural	Less attenuated flow peaks, small lag between rain and flow, base flow elevated during irrigation season, minimal response to rain during the dry season, occasional flow peaks during periods of no rain due to irrigation.
Commercial/Industrial	Spiky flow peaks, no lag between rain and flow, no or minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.
Residential	Minimally attenuated flow peaks, minimal lag between rain and flow, minimal base flow, measurable response to rain during the dry season, occasional flow peaks during periods of no rain due to anthropogenic discharges.

To assess if the RB209 hydrograph was representative of residential basins in the western Washington, a visual analysis of the hydrograph was conducted and results were compared to a typical hydrograph from a residential basin in western Washington. Since there were no existing rain gauges with reliable data records located within the RB209 basin, rainfall and runoff comparisons could not be made. As a result, the RB209 hydrograph was assessed without comparison to rainfall.

The RB209 hydrograph is presented in Figure 4. There was base flow and minimal response to rainfall during the dry season. The flow peaks converged in the wet season indicating flow attenuation and elevated winter base flow. The flows were not very flashy at this location, which is an indication of low impervious area in the basin. Consequently, the hydrograph is quite similar to a forested basin and generally representative of a low density residential basin.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous hydrological data. The MQO for completeness requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. There were minimal (less than 0.1 percent of the record) data gaps during the monitoring period during which there was flow (Table 2). Consequently, the completeness MQO was met.

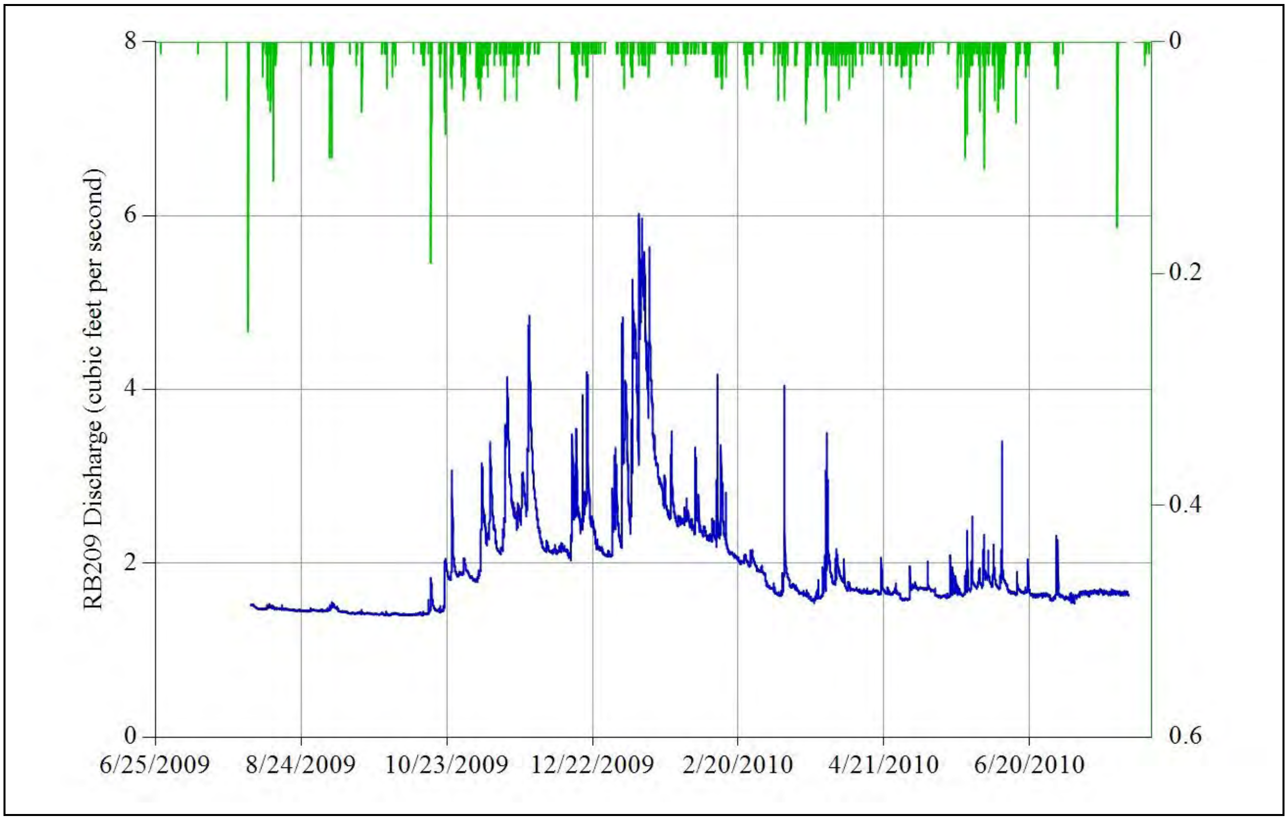


Figure 4. RB209 hydrograph.

Comparability

Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Summary

The water level and stream flow data from RB209 had numerous quality assurance issues. The data from August 1, 2009 to November 3, 2009 was noisy and replaced with modeled data from FB372. In addition, the channel bottom was sandy and unstable, which contributed to a relatively inaccurate rating curve. The combination of these factors resulted in a hydrograph of poor quality. After assessing the quality of the hydrologic data at location RB209, it was found that the hydrologic data should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from RB209 should be closely examined to determine if low quality flow data is controlling pollutant loading patterns.

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