APPENDIX E

Hydrologic Data Quality Assurance Review of the StormGarden Monitoring Project

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Herrera Environmental Consultants, Inc.

Internal Memorandum

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Subject: Hydrologic Data Quality Assurance Review of Rotondo StormGarden™ Filter TAPE Monitoring Project

INTRODUCTION

This memorandum reviews hydrologic data that were collected from April 20, 2017, through November 22, 2018, and compares the results to data quality indicators that were identified in the quality assurance project plan (QAPP) for the StormGarden™ Filter TAPE Monitoring Project (Herrera 2016). It then provides results that indicate whether or not specific measurement quality objectives (MQOs) for each data quality indicator were met and establishes the overall usability of the data.

Hydrologic monitoring consisted of measurements of water level (for estimating discharge) and precipitation depth. MQOs for these measurements are expressed in terms of precision, bias, representativeness, completeness, and comparability. Data quality for each of these categories is described in the sections that follow. Table 1 presents a list of the equipment that was used to collect the measurements and subsequently tested as part of this evaluation.

Table 1. Project Hydrological Measurement Instrument Characteristics.

Instrument	Make/Model	Serial Number	Station	Deployment
Pressure transducer	Campbell Scientific CS-450L (0-2.9 psi)	20010997	WB-OUT	April 20, 2017, to present
Pressure transducer	Campbell Scientific CS-450L (0-2.9 psi)	20010991	WB-BP	April 20, 2017, to present
Rain Gauge	Hydrological Services TB4	10-568	WALL-RG	April 20, 2017, to present

Precision

Pursuant to the QAPP for the project, the MQO for water level and precipitation depth precision is 5 percent. On September 9, 2016, and prior to initiating monitoring, the precision of the precipitation depth measurements was evaluated by repeatedly releasing a known volume of water (between 400 and 450 milliliters) into the rain gauge's tipping bucket mechanism with a burette and recording the number of tips associated with the volume. The percent error in rain gauge measurements was then computed based on the theoretical number of tips that should have been recorded for each known volume and the actual number of tips (Table 2). The standard deviation of the percent error across the repeated tests was then computed and compared with the MQO. The resultant value (2.25 percent) was less than the MQO for precipitation depth precision identified above; hence, no qualification of the data was necessary based on this measure of quality.

Table 2. Pre-Monitoring Precipitation Precision and Bias Testing.

Water Volume Applied (mL)	Theoretical Number of Tips	Actual Number of Tips	Percent Error	Absolute Percent Error
450	54.6	55	-0.71	0.71
400	48.5	47	3.2	3.2
400	48.5	47	3.2	3.2
Total Bias				**2.37**
Total Precision			**2.25**	

ml = milliliter

To evaluate the precision of water level measurements, both the WB-OUT and WB-BP pressure transducers were placed in a graduated cylinder filled with water for approximately 92 hours. Water level data from each pressure transducer were then recorded on a 5-minute time step over this period. Figure 1 provides a graphical presentation of these results. The coefficient of variation of these repeated measurements at 20 degrees Celsius for the WB-OUT transducer was 0.08 percent, while the coefficient of variation for the WB-BP transducer was 0.05 percent. These values were less than the MQO for water level measurement precision identified above; hence, no qualification of the data was necessary based on this measure of quality.

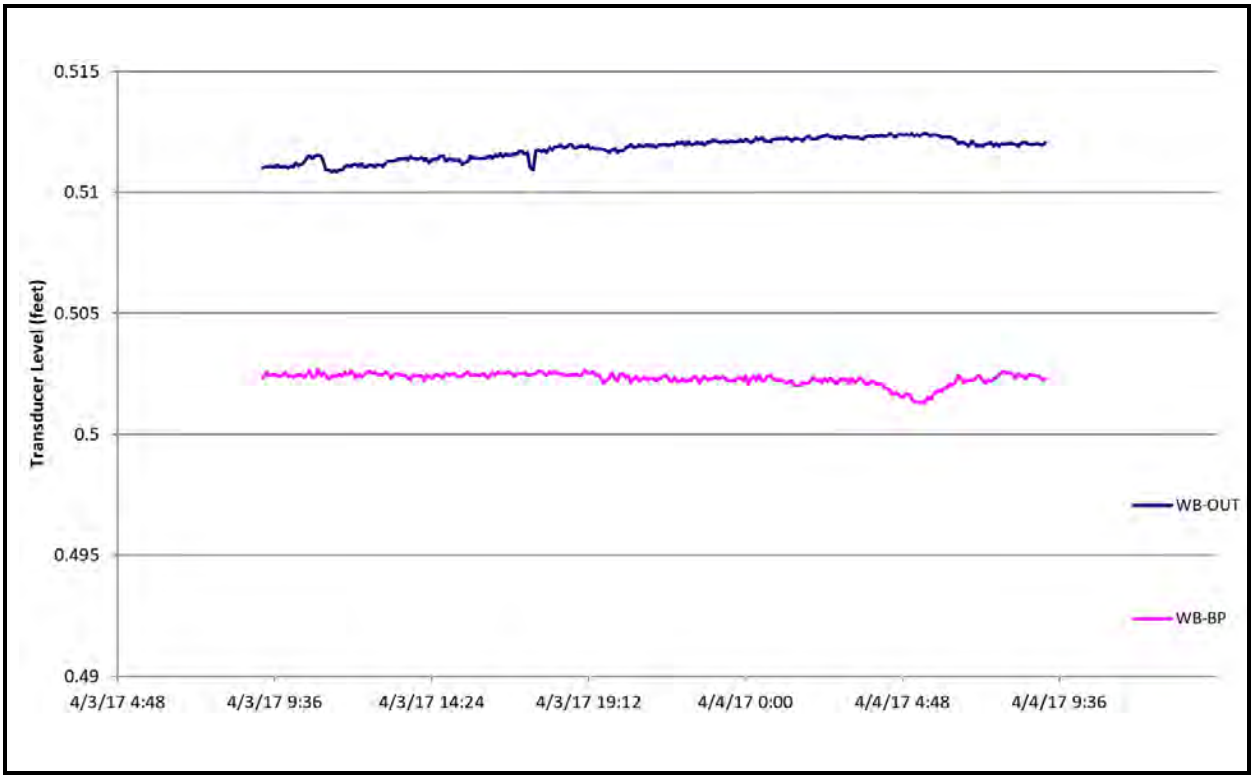

Figure 1. Pressure Transducer Precision Testing Results.

Bias

The MQO for bias in precipitation depth and water level measurements as defined in the QAPP (Herrera 2018) was a difference of no more than 5 percent between recorded measurements and the true value. Bias was assessed by comparing monitoring equipment readings to an independently measured "true" value. For example, bias in precipitation depth data collected through this study was assessed by comparing the rain gauge's actual tip volume to its theoretical tip volume, as specified by the manufacturer. Prior to monitoring, bias was estimated by pouring a known volume of water through the rain gauge in order to generate approximately 50 tips of the gauge. The theoretical number of tips that should have been recorded for each known volume was then compared with the actual number of tips to estimate the percent error in the precipitation depth measurements (Table 2). This process was repeated three times, and the average of the absolute percent error was computed. The resultant value (2.37 percent) was less than the MQO for precipitation depth bias identified above. The bias of the rain gauge was reassessed on August 23, 2018. On this occasion the bias was -3.72 percent, again less than the MQO of 5 percent; hence, no qualification of the data was necessary based on this measure of quality.

Bias in the continuous water level measurement data is introduced from two primary sources: instrument design limitations and calibration or operation errors. To assess if instrument design limitation were contributing to level gauge bias, the pressure transducers were placed in a graduated cylinder filled with water. One inch of water at a time was then added to the graduated cylinder, and the pressure transducer responses were recorded. Pressure transducer depths were then compared to the measured depths to compute the corresponding percent error. This test was conducted before the monitoring period on both of the pressure transducers used during the project. Results from the pressure transducer bias tests are presented in Table 3. This table indicates the average of the percent error for the WB-OUT transducer was -0.9 percent while the average for the WB-BP was -0.7 percent. These values were less than the MQO for water level measurement bias identified above; hence, no qualification of the data was necessary based on this measure of quality.

Table 3. Results from Pressure Transducer Bias Testing at WB-OUT and WB-BP.

Date	Depth (inches)	WB-OUT Transducer Depth (inches)	WB-Out Percent Error	WB-BP Transducer Depth (inches)	WB-BP Percent Error
7/13/2016	1	0.984	-1.6	0.984	-1.6
7/13/2016	1	1.008	0.8	0.996	-0.4
7/13/2016	1	0.984	-1.6	0.996	-0.4
7/13/2016	3	2.964	-1.2	2.988	-0.4
Total Bias			**-0.9**		**-0.7**

Despite this result, bias can still be introduced into the water level measurements when the pressure transducers are deployed and operated in the field. This bias is usually due to calibration, operation, or configuration errors. Routine field calibrations of the pressure transducers were conducted before each targeted sampling event. Occasionally, these calibrations could not be conducted because water flows were too high to accurately calibrate the pressure transducers. During the 12-month monitoring period, the WB-OUT and WB-BP pressure transducers were both calibrated 8 times. The Aquarius software package for managing continuous time series data (Version 4.10) was used to assess transducer measurement drift between each calibration. Sensor drift was corrected on two occasions at WB-OUT and 3 occasions at WB-BP.

The Aquarius software package was also used to delete anomalous spikes and fill small data gaps. All edits to the continuous record from the WB-OUT pressure transducer are presented in Table 4; edits to the record for the WB-BP pressure transducer are presented in Table 5. Finally, edits to the continuous record for the Wall-RG rain gauge are presented in Table 6.

Table 4. Hydrologic Data Correction History for Station WB-OUT.					
Date of Correction	User	From	To	Points Modified	Comment
9/18/2017 13:06	dahearn	4/20/2017 7:05	5/12/2017 13:30	6414	Multi-Point Drift Correction
1/22/2018 15:17	dahearn	10/10/201 7 12:15	10/10/201 7 12:35	3	Fill Data Gaps (Linear) with gap resample rate of 5.00 min
1/22/2018 15:23	dahearn	11/2/2017 11:53	11/10/201 7 15:06	2343	Drift Correction with Calibration Drift value of -0.01000ft
1/22/2018 15:24	dahearn	11/11/201 7 17:11	12/28/201 7 14:16	13501	Drift Correction with Calibration Drift value of 0.01200ft
1/3/2019 12:01	dahearn	9/12/2018 8:20	11/6/2018 14:10	14436	Offset Correction with value of -0.03000ft - correct bad calibration
1/3/2019 12:04	dahearn	4/28/2018 3:15	7/29/2018 21:50	26720	Offset Correction with value of 0.05000ft

Table 5. Hydrologic Data Correction History for Station WB-BP.					
Date of Correction	User	From	To	Points Modified	Comment
9/18/2017 13:12	dahearn	4/20/2017 6:00	5/12/2017 11:55	6408	Drift Correction with Calibration Drift value of 0.02244ft
1/22/2018 15:35	dahearn	10/10/2017 12:40	11/10/2017 9:55	8896	Drift Correction with Calibration Drift value of 0.00780ft
1/22/2018 15:36	dahearn	11/10/2017 4:40	12/28/2017 14:15	13940	Drift Correction with Calibration Drift value of 0.00700ft
3/23/2018 13:44	dahearn	4/20/2017 6:55	4/20/2017 7:05	1	Fill Data Gap - short gap
3/23/2018 13:44	dahearn	4/25/2017 1:00	4/25/2017 1:10	1	Fill Data Gap - short gap

Table 6. Hydrologic Data Correction History for Station Wall-RG.					
Date of Correction	User	From	To	Points Modified	Comment
1/23/2018 14:28	dahearn	11/23/2017 0:15	11/24/2017 14:20	458	Copy and Paste from Precip.RG3 Rain - Data Gap
1/23/2018 14:29	dahearn	12/4/2017 6:50	12/22/2017 2:50	5137	Copy and Paste from Precip.RG3 Rain - Data Gap
1/3/2019 14:45	dahearn	8/22/2018 23:45	9/12/2018 15:45	5953	Copy and Paste from Precip.RG3 Rain@StormGarden
1/3/2019 14:45	dahearn	9/18/2018 17:00	9/25/2018 20:10	2055	Copy and Paste from Precip.RG3 Rain@StormGarden
1/3/2019 14:46	dahearn	4/4/2018 23:25	4/6/2018 17:35	507	Copy and Paste from Precip.RG3 Rain@StormGarden
1/3/2019 14:47	dahearn	5/2/2018 23:00	5/16/2018 23:50	4043	Copy and Paste from Precip.RG3 Rain@StormGarden

Bias can also result when primary measurement devices (i.e., weirs) are incorrectly designed or installed in non-ideal conditions. The dimensions of the WB-OUT and WB-BP weirs (both Thel-Mar volumetric pipe weirs [Thel-Mar weirs]) were measured by hand to ensure that the weir equations were appropriate; results from these measurements indicated the weirs appeared to be built to specifications.

However, because past experience has shown Thel-Mar weirs can still produce biased measurements despite being built to specifications (due to elevated approach velocities in sloped pipes), an additional field test was performed to independently check for potential bias in the discharge estimates made at each station. Specifically, field technicians conducted a dynamic flow tests at WB-OUT and WB-BP on April 20, 2017. For this test, a fire hose was attached to a nearby fire hydrant, and flows from the hydrant were assessed using a graduated bucket and timer and a closed channel flow meter (Master Meter 3″ FHM). These known flows were then used as the standard for adjusting the weir rating curves. First, the closed channel flow meter was used to discharge a flow rate of 5 gpm. The flow was held at this rate for 5 minutes until a constant and stable water level reading was recorded at the weir's pressure transducer. These values (known flow rate and water level behind the weir) were recorded and then the process was repeated at 10 gpm, 20 gpm, 50 gpm, and 80 gpm. This process was completed for both the WB-OUT and WB-BP weirs. As shown in Figure 2, results from these tests show the WB-OUT and WB-BP weirs were underestimating flows by 15 percent each.

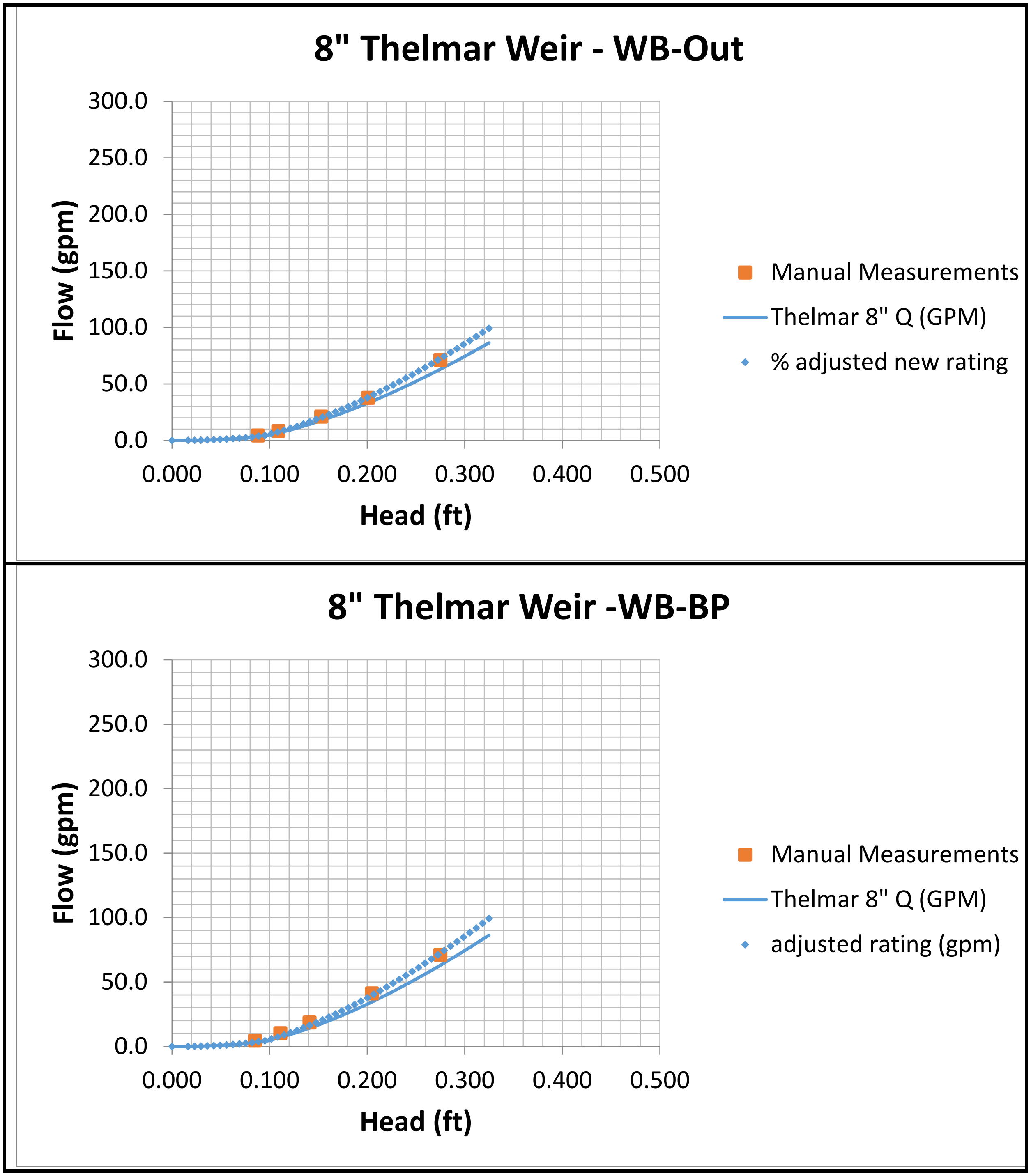

Figure 2. Rating Curve and Thel-Mar Weir Equation for Stations WB-OUT and WB-BP – April 20, 2017.

Representativeness

The representativeness of the hydrologic data was ensured by properly selecting and installing all associated monitoring equipment. Rainfall patterns, stormwater conveyance features, and surrounding land uses were also considered when identifying monitoring locations and sampling frequencies, to ensure that representative data were obtained.

Due to progressive clogging of the 6-inch valve leading to the WB test system, the hydrograph form was not always correlated with the hyetograph form (see the individual storm report—Appendix I—for the May 15, 2017, event as an example). This resulted in a sample distribution across the hydrograph which is more skewed toward the beginning of the storm when the valve was not clogged. Because both the inlet and outlet samplers were pacing off the same flow data they were equally affected by this bias. Though the event hydrographs were not always representative of what a "free-flowing" hydrograph would be from the same basin, the comparison of the chemistry in the inlet and outlet hydrographs was the focus of this study, so this issue with the data representativeness was deemed acceptable.

Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all hydrologic monitoring locations. The associated MQO requires that less than 10 percent of the total data record be missing due to equipment malfunction or other operational problems. During the monitoring period, there were minimal data gaps (Tables 4, 5, and 6), and the majority of those gaps that did occur were sufficiently short in duration that they could be filled by interpolation. Approximately 5.8, 5.8, and 10.8 percent of the record was missing at WB-OUT, WB-BP, and Wall-RG, respectively. These gaps were all filled by linear interpolation from measured values before and after the gap or, as was the case for Wall-RG, with copy and paste fills from City of Seattle rain gauge RG3. The MQO of less than 10 percent was met at WB-OUT and WB-BP, but was slightly exceeded at Wall-RG. Because the gaps frequently occurred during periods of no rain and because they were filled with rainfall from a nearby gauge, the impact of the gaps on the overall quality of the data was deemed acceptable.

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.

References

Herrera. 2016. Quality Assurance Project Plan: StormGarden™ Modular Stormwater Biofiltration System Performance Certification Project. Prepared for Rotondo Environmental Solutions by Herrera Environmental Consultants, Inc., Seattle, Washington.