RECLAMATION

Managing Water in the West

Hydraulic Laboratory Technical Memorandum PAP-1118

Hydrokinetic Impact Study Update – 2014 Field Testing

Prepared for Reclamation's Power Resources Office and Science & Technology Program

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Disclaimer

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Introduction

Testing was performed on Reclamation's Roza Main Canal to investigate hydraulic impacts from a hydrokinetic turbine. This testing is part of an ongoing study performed by Reclamation in collaboration with Instream Energy Systems Corp. (Instream) and Sandia National Laboratories (SNL). Measurements were taken by all three organizations including ADCP and ADV velocity measurements, power output, speed, and torque measurements on the hydrokinetic unit, as well as water surface elevations at multiple locations along the canal. While these measurements were used to quantify hydrokinetic turbine performance and near-field hydraulics, this report focuses on hydraulic impacts to the existing operation of the canal, which is Reclamation's primary interest. The analysis herein documents water surface impacts related to 2014 testing. These measurements, as well as additional test measurements planned for 2015, are being used to calibrate a numerical model for predicting hydraulic impacts from hydrokinetic turbines under a range of operating conditions.

Field Measurement Results

Testing occurred over two separate weeks (May 12-16 and August 11-15, 2014) to collect data under different canal flow and depth ranges. More detailed information about the test site, hydrokinetic installation, and measurement locations is available in a previous report (Mortensen 2014). Impacts to canal hydraulics were quantified primarily using water surface elevation and hydrokinetic operating measurements for a range of canal flows.

Water surface elevations were measured with Onset HOBO® submersible water level loggers (model U20-001-01) that were deployed and surveyed by Reclamation (Mortensen 2014). Water level data were collected at 30 second intervals and the overall uncertainty was ±0.032 ft for the May test and ±0.023 ft for the August test, based on surveyed water surface elevations. Generator power output, speed, and torque measurements were made with Instream's data acquisition system at a sample rate of 10 Hz. Canal flowrate data were measured at a rated section near the canal headworks and were downloaded from Reclamation's Hydromet database. These data were compared to determine if there is a correlation between operation of the hydrokinetic unit and change in water level in the canal.

Canal flowrate (Figure 1) and generator power output (Figure 2) are displayed with water surface elevations measured at 66 ft (20 m) upstream from the hydrokinetic turbine. Testing in May involved data collection at more than one flowrate which allowed a greater test range but complicated testing because of fluctuating water surface elevations. Also, difficulty surveying lower water surfaces relative to the top of the canal lining added uncertainty to the water surface elevation measurements.

Testing in August provided a steady canal flow that was near the canal capacity of 2,000 cfs. Water surface elevations were significantly higher in August primarily due to the increased canal roughness caused by significant aquatic growth within the two unlined portions of the canal downstream. Increased hydraulic roughness resulted in a water surface elevation very close to the canal's free board limit.

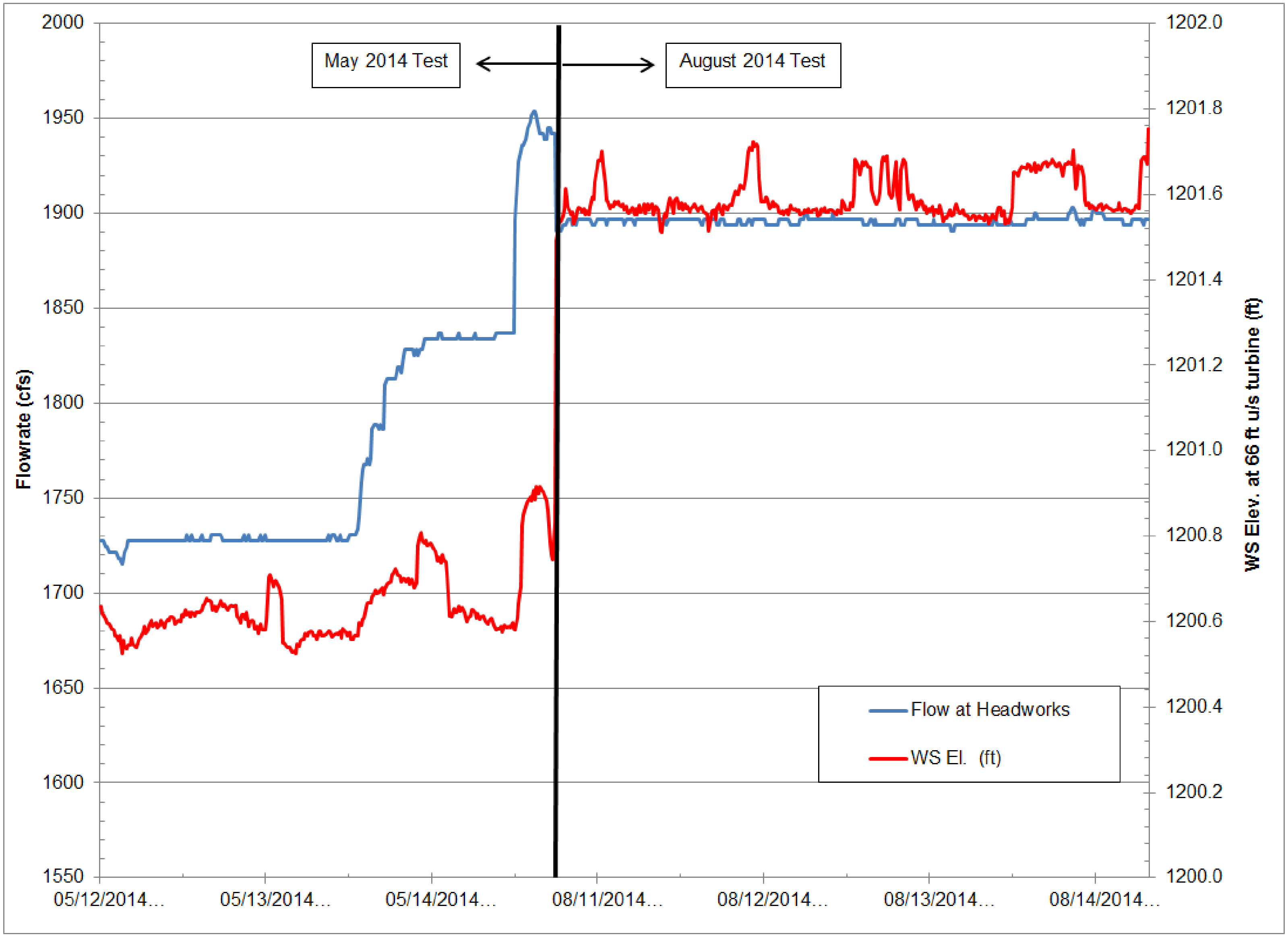

Figure 1. Canal flowrate and water surface elevation data at 66 ft (20 m) upstream from the turbine for both May and August tests.

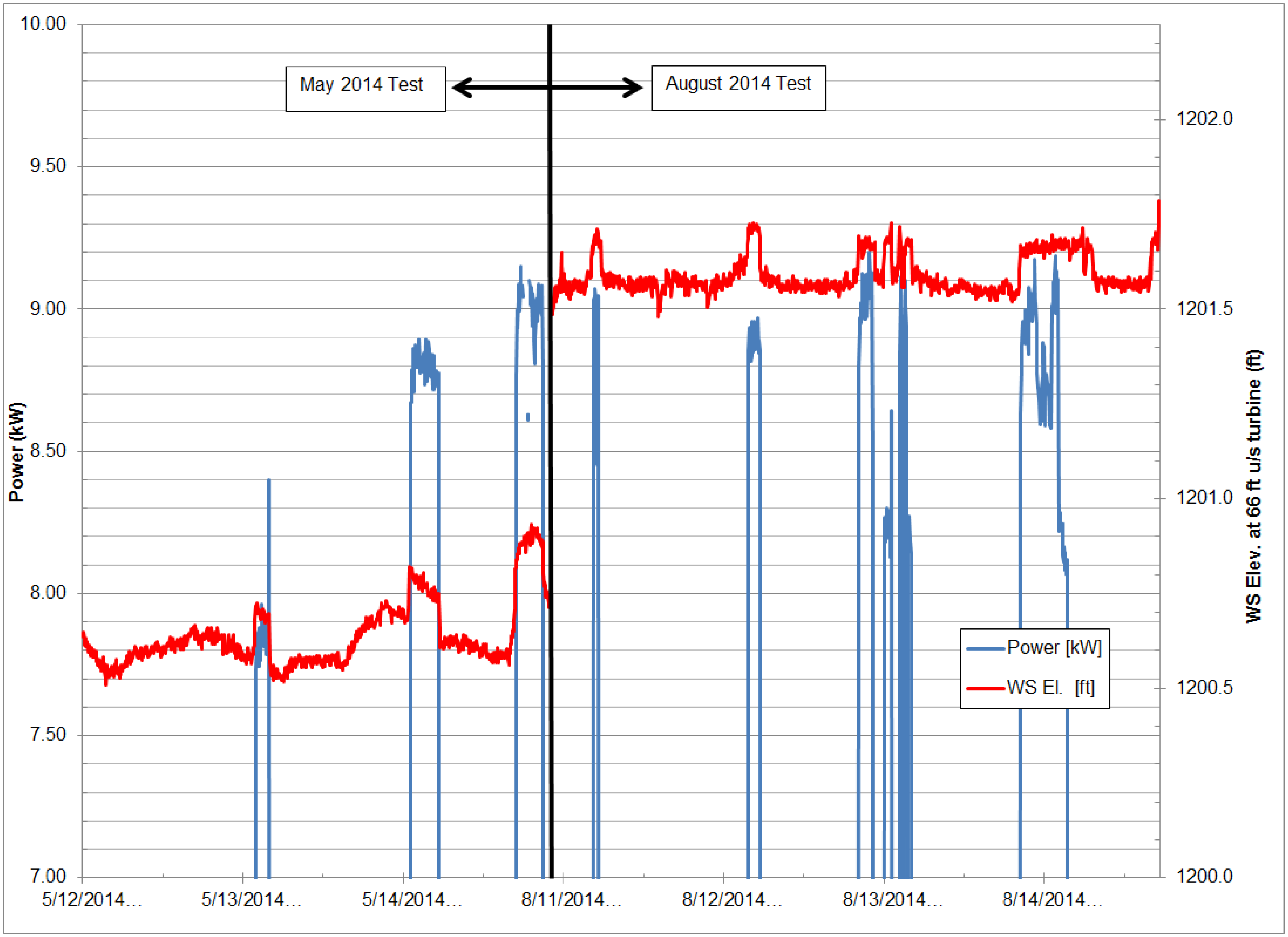

Figure 2. Power and water surface elevation data (5 minute average) at 66 ft (20 m) upstream from the turbine for both May and August tests.

Analysis and Discussion

Test results were analyzed by organizing measurement data into eight different test cases, each with a baseline water surface elevation followed by data with the hydrokinetic turbine operating after at least ½ hour for conditions to stabilize (Table 1). Water surface elevation data for each test case were compared to determine if there was any correlation with hydrokinetic operation. Three of these test cases were performed on 8/14/2014 which compared three operating settings to a single baseline.

Table 1. Test case data sets used to compare water surface elevation changes with hydrokinetic operation.

Test Case	Condition	Pacific Time		Average Power	Power Standard Deviation	Average Canal Flow
		Start	*End*	*kW*	*kW*	*cfs*
5/13/2014	Baseline	12:51	16:00	-	-	1,728
	HK Operating	16:32	18:22	7.84	0.06	
5/14/2014	Baseline	11:51	15:00	-	-	1,829
	HK Operating	15:36	19:46	8.79	0.06	
5/15/2014 *	Baseline	0:00	7:17	-	-	1,888 *
	HK Operating	8:27	12:22	8.99	0.12	
8/12/2014	Baseline	05:37	15:27	-	-	1,896
	HK Operating	17:44	19:24	8.88	0.05	
8/13/2014	Baseline	00:00	09:21	-	-	1,897
	HK Operating	10:15	12:20	9.01	0.15	
8/14/2014	Baseline	03:42	10:00	-	-	
	HK Operating - a	10:27	13:17	8.93	0.17	1,896
	HK Operating - b	15:27	16:22	9.08	0.05	1,896
	HK Operating - c	16:32	17:47	8.17	0.07	1,896

* 5/15 HK Operating results were biased due to a significant flow increase (1,836 to 1,945 cfs) at about the same time operation began.

The average change in water surface elevations at multiple locations upstream and downstream from the hydrokinetic turbine are compared in Figure 3 for each test case. For the upstream data, the water surface elevation increased by 0.05 to 0.15 ft with an average of 0.11 ft for distances less than 200 ft upstream (Table 2). The increase is slightly less for measurements made further away at 1,444 and 2,400 ft upstream which would be expected due to the backwater effect. Still, this is a small variation in water surface increase with distance upstream from the turbine, which may be due to the mild canal slope (0.0004 ft/ft). The water surface increase at 2,400 ft upstream from the turbine was 0.03 ft on average in May and 0.08 ft in August. These results indicate that the spacing between measurement locations could potentially be increased for testing in 2015.

There is some variability in upstream water surface results but it is not significant (with the exception of results from 5/15/2014). This variability may be due to differences in canal flows from May to August, as well as unsteady flows and additional water surface elevation uncertainty in May.

Table 2. 2014 average water surface elevation changes (ft) at 8 different locations upstream from the hydrokinetic turbine.

Location - Distance u/s from Turbine (ft)	**5/13**	**5/14**	**5/15***	**8/12**	**8/13**	**8/14 - a**	**8/14 - b**	**8/14 - c**	**Location Average**
-2,400	0.05	0.02	0.23	0.10	0.07	0.07	0.09	0.09	**0.07**
-1,444	0.05	0.04	0.24	0.10	0.08	0.09	0.11	0.11	**0.08**
-164	0.10	0.07	0.27	0.14	0.10	0.12	0.13	0.13	**0.11**
-131	0.09	0.07	0.27	0.14	0.10	0.11	0.13	0.12	**0.11**
-98	0.10	0.07	0.26	0.14	0.10	0.11	0.12	0.12	**0.11**
-66	0.10	0.07	0.27	0.15	0.11	0.11	0.12	0.13	**0.11**
-33	0.10	0.07	0.26	0.14	0.10	0.11	0.13	0.13	**0.11**
-16	0.08	0.06	0.26	0.13	0.09	0.10	0.11	0.11	**0.10**
Test Case Average	**0.08**	**0.06**	**0.26**	**0.13**	**0.09**	**0.10**	**0.12**	**0.12**	

* Water surface elevation changes on 5/15/2014 are not used in the location average calculation as they were biased by a flowrate increase at the time of the test.

For water surface elevations downstream of the turbine, there was a significant difference in the May and August data (Figure 3). Most water surface elevations in August returned to the baseline condition within 200 ft downstream from the turbine while those from May required a greater distance to recover. This may be due to the difference in submergence of the turbine rotor which was almost one foot greater in August due to the higher water surface elevation. In theory, a higher water surface elevation would increase the total flow area and decrease the percentage of effective area that is blocked by the turbine rotor, reducing the head drop across the rotor as a result. While there is insufficient data in this report to support this conclusion, further analysis of velocity data collected by SNL may shed some light on the differences in downstream water level results.

The recovery of the downstream water surface elevation may have been influenced by the canal expansion at that location which naturally raises the water surface. It is likely that the downstream water surface would require a greater distance to recover in a constant canal section. This would be important to determine in the future, if testing at a different test site further upstream becomes possible.

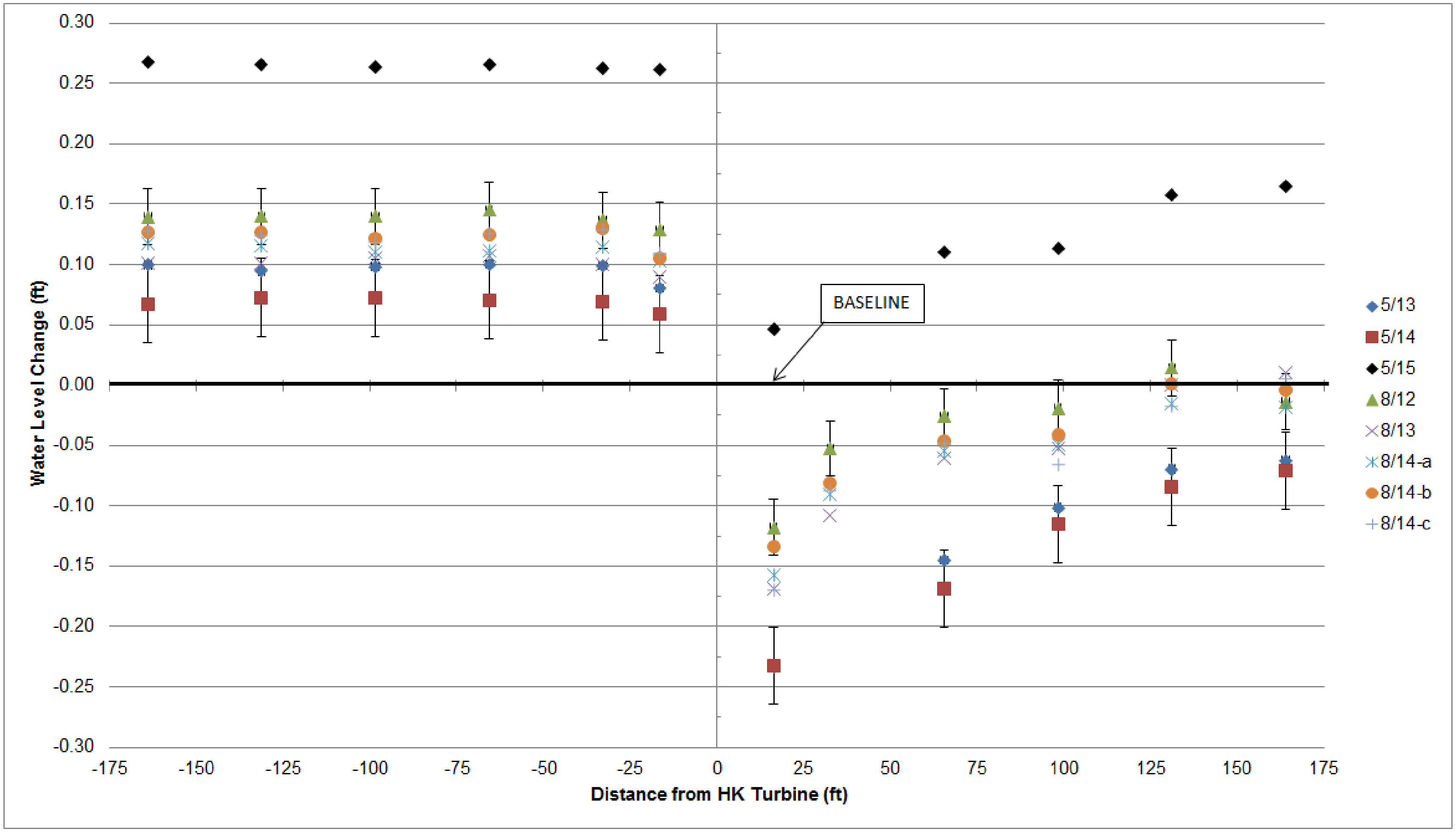

Figure 3. Plot of change in water surface elevation caused by hydrokinetic turbine operation. Negative distance is upstream and positive is downstream from the turbine. Error bars indicate the water level measurement uncertainty for two representative data sets.

Changes in the water surface elevation were compared with hydrokinetic operating data to determine the hydraulic impact to the canal. Test results obviously show that the hydrokinetic turbine does have an effect on both the upstream and downstream water surface elevation. This was previously shown by the increase in upstream and decrease in downstream water levels when the unit was operating. However, data in Figure 4 indicate that generator power output, within a range of 7.5 to 9.5 kW, has no impact on upstream water surface elevation. This was the full power output range of the hydrokinetic unit. Table 3 shows correlation coefficients of the water surface time-series data with power and turbine speed data which show there is no correlation between these variables. This may be due to the large variation in power output for each case (Figure 4). In Figure 5 average torque and turbine rotational speed data for each test case were compared to water surface changes upstream which also suggest that there is no correlation between the upstream water surface and hydrokinetic operation within the test range.

Table 3. Correlation coefficients of water surface elevation data at 66 ft (20 m) u/s from the turbine compared to power and turbine speed data over the same time period.

	5/13	**5/14**	**5/15**	**8/12**	**8/13**
Power	-0.085	-0.066	-0.026	0.212	-0.093
Turbine Speed	-0.100	-0.065	-0.083	0.207	-0.089
Correlation of time series data at 30 second time intervals.					
Power and turbine speed data (10 Hz) averaged over 30 second intervals.					

Finding a correlation between the hydrokinetic unit operation and hydraulic impacts is important to accurately predict the impacts of other installations and to calibrate the numerical model. Additional testing is planned in 2015 with a larger turbine rotor installed at the existing test site. The new rotor is designed to produce 25 kW which will likely cause a greater change to the water surface elevation than the unit tested in 2014. It is anticipated that a change in power output would have the strongest correlation to a change in water surface elevation since that will likely have the greatest impact to the energy grade line of the canal flow. A larger range of power output data will hopefully allow this correlation to be determined. Additional analyses that include the velocity data will help determine the kinetic energy loss across the turbine which may have a significant effect on the correlation between hydrokinetic operation and hydraulic impacts. Other hydrokinetic variables that may influence canal hydraulics include torque, turbine rotation speed and the submerged cross-sectional area of the rotor which will also be tested and analyzed using the larger rotor in 2015.

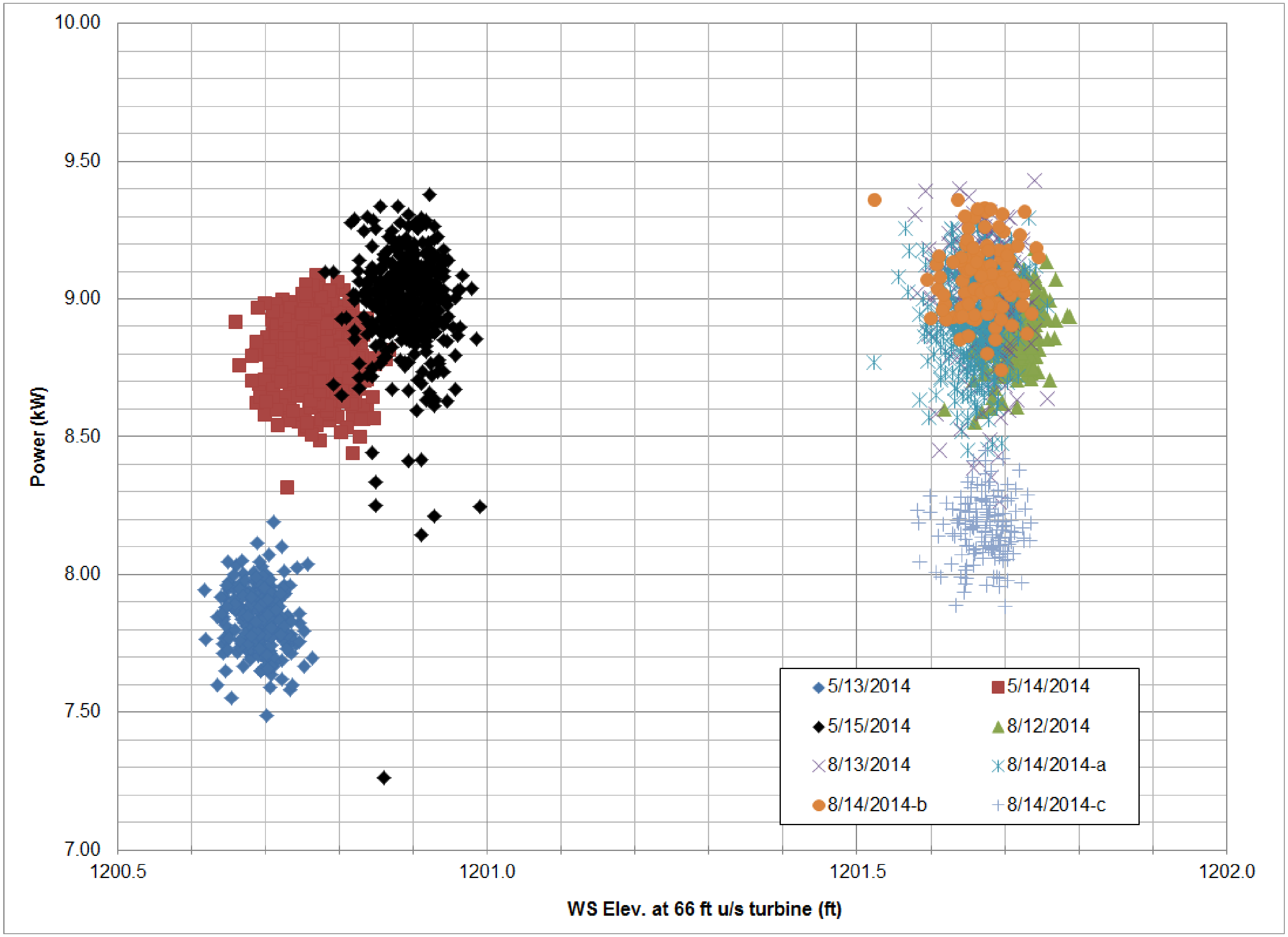

Figure 4. Power output data averaged over 30 second intervals versus water surface elevation data at 66 ft (20 m) upstream from the turbine.

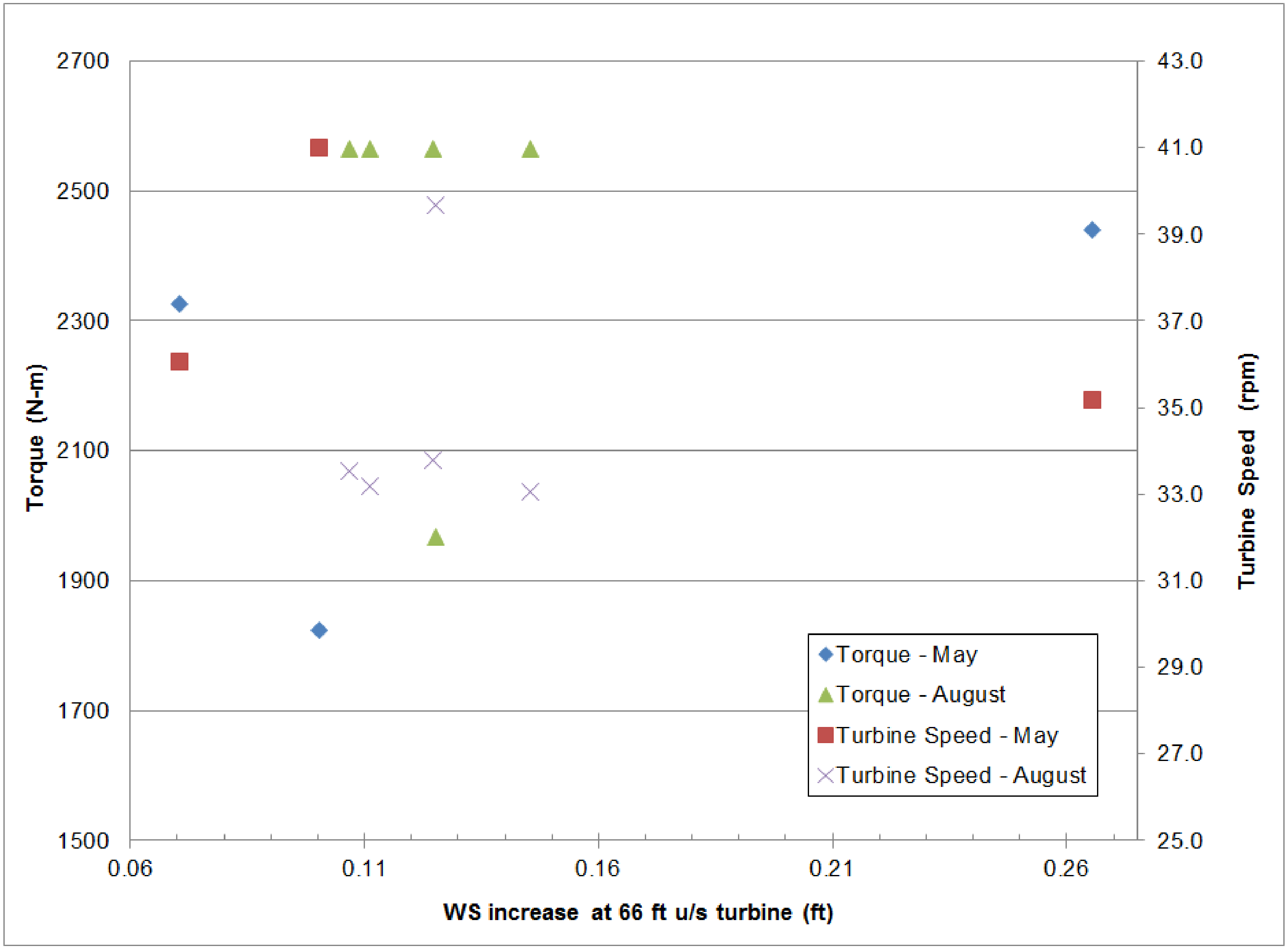

Figure 5. 2014 average torque and turbine speed output versus water level increases at 66 ft (20 m) upstream from the turbine.

Conclusions

Measurements taken during two separate weeks of testing in 2014 were used to identify hydraulic impacts to the Roza Main Canal from a hydrokinetic turbine. Water surface elevation and hydrokinetic operating data from eight different test cases were analyzed. Measurements showed a difference in downstream water surface elevations for the May and August tests which may be due to the difference in submergence of the turbine rotor during the two test periods. Most downstream water levels recovered within about 200 ft of the turbine to match baseline water surface elevations. Upstream water surfaces increased by about 0.10 ft and were similar for all distances from 16 to 165 ft upstream from the turbine and decreased only slightly at distances up to 2,400 ft upstream. There was no correlation between water surface elevation increases and the power outputs within a range of 7.5 to 9.4 kW. Additional testing is planned in 2015 using a larger hydrokinetic turbine rotor capable of producing 25 kW.

It is anticipated that the larger rotor will cause greater changes to canal water surface elevations which could help identify a correlation between canal hydraulics and hydrokinetic operations. The final analysis will include velocity results to identify the total energy loss across the turbine which may help determine the correlation between hydrokinetic operation and hydraulic impacts. This correlation is necessary for numeric model calibration in order for it to be used as a predictive tool for hydraulic impacts. Once this correlation is determined with additional field measurements, a more accurate calibration of the numerical model can be made.

Reference

Mortensen, J. D. (2014). Evaluation of Hydro-Kinetic Impacts to Existing Water Delivery & Hydropower Systems. *HydroVision 2014 Conference Proceedings.* Nashville, TN July 22-25, 2014.