MEMO

(External Correspondence)

Houston Engineering Inc.

To:	Mike Hirst LOW SWCD	**From:**	Lisa Odens, EIT Stephanie Johnson, PhD, PE
Date:	June 20, 2013	**Subject:**	LOW Watershed Rating Curve Development
Cc:	Cary Hernandez, MPCA File 7180-002		

Objective

The objectives of the efforts summarized within this memorandum are:

1. Review available data for use in developing rating curves in the Lake of the Woods (LOW) Watershed;
2. Develop continuous flow data records for use in the LOW Watershed Restoration and Protection (WRAP) project; and
3. Identify future data collection needs to facilitate the development of subsequent continuous flow data.

Data Sources

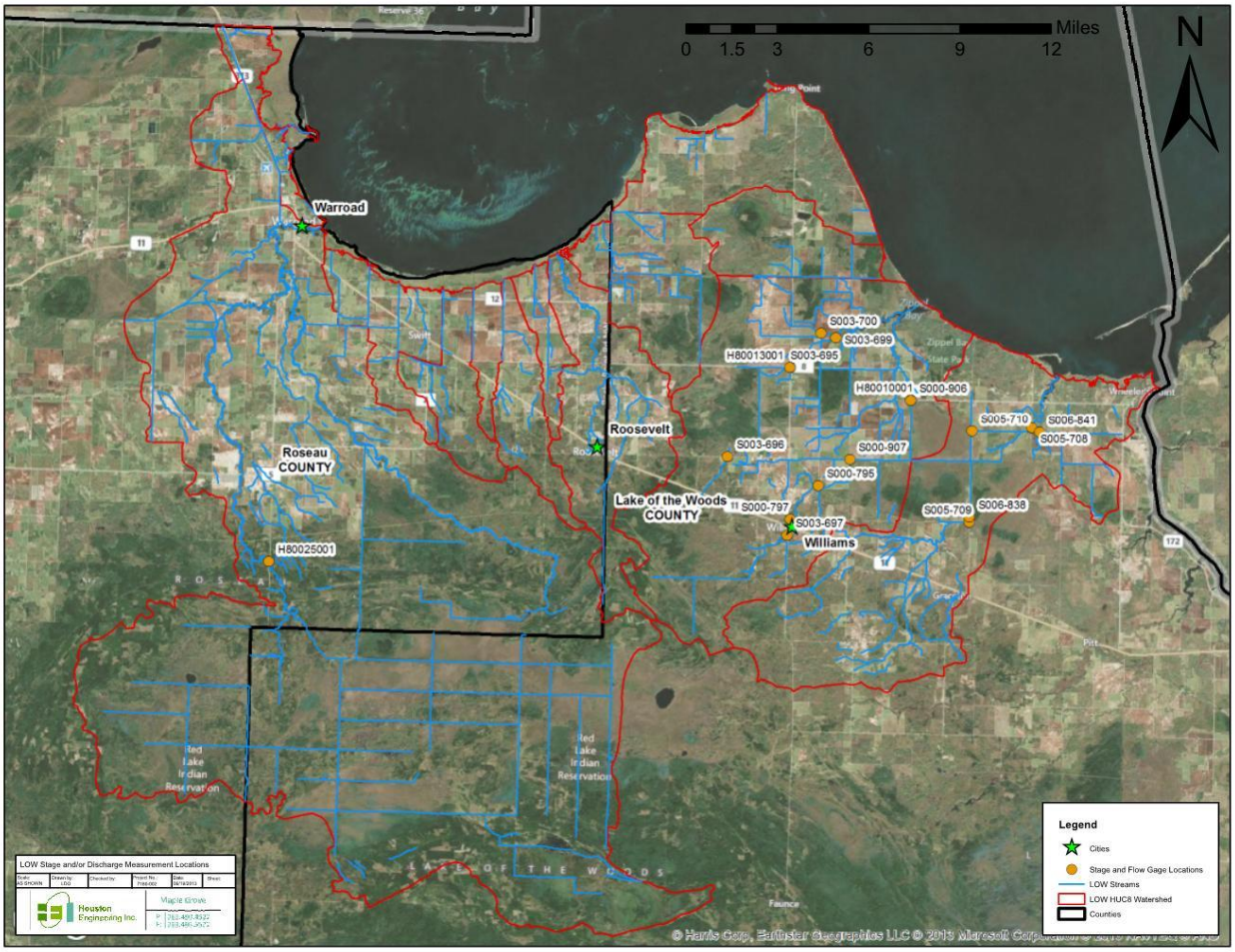
Flow and stage data throughout the LOW Watershed (hydrologic unit code 0903009) have been collected by various agencies, over various time periods, with varied objectives. The following data was assembled for this analysis:

- HYDSTRA data dump for hydrologic unit code (HUC) 0903009, received 4-24-2013 (Wade Gillingham, MPCA, contact)
- Minnesota Pollution Control Agency (MPCA) EQuIS (Environmental Quality Information System) database dump for HUC 0903009, received 4-24-2013 (Jean Garvin, MPCA, contact)
- 2011 and 2012 HOBO data for gage site S006-841, received 3-31-2013 (Corryn Trask, LOW Soil and Water Conservation District (SWCD), Contact)
- Flowtracker data , received 3-31-2013 (Corryn Trask, LOW SWCD, Contact)
- MPCA data for Zippel South and Zippel West , received 5/23/2013 (Mark Evenson, MN Department of Natural Resources (DNR), Contact)
- MPCA data for S003-695 (2009, 2011, 2012); S000-906 (2009, 2011, 2012); S005-708 (2011, 2012) (Bruce Paakh, MPCA, Contact)

Site Locations

The **Figure 1** shows the location of the stage and/or flow gaging sites in the LOW Watershed.

Figure 1: LOW Watershed Stage and Flow Gage Locations



Due to data collection by different agencies, some sites have multiple gage names. The following sites have multiple names.

- LOW SWCD site BST04E coincides with MPCA site S006-838;
- LOW SWCD site BST0N coincides with MPCA site S006-841;
- MN DNR site H80010001 coincides with MPCA site S000-906 and MPCA regional site 179;
- MN DNR site H80013001 coincides with MPCA site S003-695 and MPCA regional site 178;
- MN DNR site H80025001 coincides with MPCA site S004-290; and
- MPCA site S005-708 coincides with MPCA regional site 180.

For the sake of clarity, in this memorandum the MPCA site number was used to describe a site location when possible. In some cases, the MN DNR site number was also referenced.

General Discussion on Methods for Rating Curve Development

There are two general ways to generate a rating curve:

- Empirical data: Using empirical data to develop a rating curve requires the availability of coincident stage and discharge observations at a set location. The observed data are then plotted against each other and a smooth curve is drawn through the points to develop a relationship between the variables. The more stage and discharge data available for making these plots, the less error involved in the resulting relationship. This method is the ideal approach to creating a rating curve; however it requires numerous observations at a wide range of discharges (i.e., high, low, and mid-range flows).
- Hydraulic model: Hydraulic models, such as HEC-RAS, can also be used to analyze the stream channel and estimate a rating curve. In order to use this approach, cross sections should be surveyed at and downstream from the site and entered into the model. Then, assuming a relatively uniform channel and that the stage (i.e., water height in the channel) is not influenced by structures or other variables outside the model extents, the water surface slope can be calculated for various discharges and a rating curve can be developed. The model should be calibrated to any stage-discharge field measurements available and, as such, the quality of the relationship developed through this approach is also dependent on the amount of data available to inform its development.

As mentioned, regardless of which method is being used, the development of rating curves depends critically on the observed data that's available for the analysis. Ideally, numerous and varied (i.e., taken at high, low, and mid-range flows) paired stage and discharge measurements would be available.

Summary of Existing Stage and Discharge Observations

Table 1 summarizes the stage and discharge data available within the LOW Watershed. Note that the discharge "observations" available at MN DNR sites H80010001 and H80013001 are not actually observed data, but rather were created from observed stage values using the DNR's rating curves at this location. These values are listed under site numbers S000-906 and S003-695.

Table 1: Summary of Stage and Discharge Data within the LOW Watershed

	Discharge				Stage			
Site	**Observation Count[1]**	**Min Date**	**Max Date**	**Unique Dates**	**Observation Count[1]**	**Min Date**	**Max Date**	**Unique Dates**
S000-795	2	6/21/1984	8/27/2007	2	8	8/25/2006	9/6/2007	8
S000-797	2	2/25/1982	6/21/1984	2				
S000-906	21,023 (20,985[2])	6/21/1984	6/2/2011	328	79,672	5/23/2000	10/11/2012	1,555
S000-907	1	6/21/1984	6/21/1984	1	7	7/6/2007	9/6/2007	7
S003-695	63,755 (63,727[2])	4/28/2000	6/1/2011	1,178	85,354	4/28/2000	10/11/2012	1,646
S003-696					20	8/25/2006	9/23/2009	20
S003-697					32	8/25/2006	9/23/2009	32
S003-699	2	6/1/2011	6/16/2011	2	35	5/23/2006	9/23/2009	35
S003-700					1	5/23/2006	5/23/2006	1
S004-290					13,512	9/19/2012	2/7/2013	142
S005-708					14,032	5/23/2006	20/11/2012	339
S005-709					2	5/23/2006	7/11/2007	2
S005-710					2	5/23/2006	6/19/2006	2
S006-838	3	4/28/2011	6/2/2011	3				
S006-841	3	4/28/2011	6/2/2011	3	23,905	5/24/2011	9/18/2012	251

[1] *observations are reported on a per event basis; if multiple readings were taken during a single monitoring event, they are reported as one observation.*

[2] *discharges estimated from MN DNR rating curves and observed stage; these are not actual flow observations.*

As mentioned above, for field observations to be applicable in rating curve development there must be coincident flow and discharge data available. Sites S000-906, S003-695 and S006-841 have observations that fit this criterion. **Table 2** shows all the known coincident (observed) stage-discharge measurements at sites S000-906, S003-695 and S006-841.

Table 2: Stage-Discharge Observations at Sites S000-906, S003-695 and S006-841

Site	Date	Discharge (cfs)	Stage (ft)
S000-906	10/31/2000	21.54	5.08
S000-906	5/23/2001	64.41	6.2
S000-906	6/18/2001	17.26	5.1
S000-906	6/25/2001	15.01	4.92
S000-906	7/3/2001	3.92	4.47
S000-906	7/13/2001	1.74	4.25
S000-906	8/7/2001	35.22	5.59
S000-906	8/10/2001	12.42	4.85
S000-906	5/14/2002	32	5.55
S000-906	5/18/2004	66.099	6.28
S000-906	6/8/2004	88.955	6.95
S000-906	9/16/2004	17.745	6.23
S000-906	10/28/2004	39.146	6.58
S000-906	5/10/2005	14.329	5.96
S000-906	8/18/2005	66.933	6.98
S000-906	4/25/2006	25.056	6.3
S000-906	6/22/2006	0.92	5.41
S000-906	5/10/2007	2.291	5.3
S000-906	7/9/2007	1.331	5.31
S000-906	7/10/2007	10.666	5.92
S000-906	7/10/2007	10.7	5.87
S000-906	7/10/2007	19.08	6.3
S000-906	9/10/2007	0.574	5.08
S000-906	11/15/2007	3.444	5.33
S000-906	6/3/2008	12.098	5.95
S000-906	7/8/2008	9.54	5.86
S000-906	8/12/2008	1.576	5.53
S000-906	9/15/2008	7.526	5.85
S000-906	10/30/2008	18.103	6.11
S000-906	6/23/2009	8.494	1.705
S000-906	7/8/2009	1.859	1.37
S000-906	7/21/2009	1.132	1.36
S000-906	8/26/2009	0.469	1.25
S003-695	9/19/2001	5.7	5.18
S003-695	5/18/2004	73.414	6.43
S003-695	6/8/2004	50.675	6.27
S003-695	7/13/2004	6.095	5.38
S003-695	8/4/2004	2.319	5.14
S003-695	9/16/2004	13.747	5.51
S003-695	10/28/2004	18.297	5.71
S003-695	5/10/2005	12.992	5.5
S003-695	4/26/2006	27.675	5.84
S003-695	4/26/2006	28.974	5.89
S003-695	6/22/2006	1.08	4.9
S003-695	7/9/2007	2.715	5.02
S003-695	7/10/2007	15.889	5.53

Site	Date	Discharge (cfs)	Stage (ft)
S003-695	9/10/2007	0.755	4.88
S003-695	11/15/2007	3.737	5.03
S003-695	6/3/2008	12.456	5.39
S003-695	7/8/2008	8.452	5.31
S003-695	8/12/2008	3.075	5.04
S003-695	9/15/2008	3.579	5.07
S003-695	10/30/2008	14.828	5.43
S003-695	5/20/2009	24.008	5.8
S003-695	6/23/2009	6.924	5.35
S003-695	7/8/2009	2.429	5.14
S003-695	7/21/2009	1.565	5.1
S003-695	8/26/2009	0.995	4.95
S003-695	5/2/2011	2.03	6.34
S003-695	5/18/2011	0.5	5.49
S003-695	6/1/2011	1.09	5.9
S006-841	6/2/2011	0.12	1.56

Existing Rating Curves

Rating curves have been developed by the DNR at sites H80013001 and H80010001 (S000-906 and S003-695). The following paragraph, provided by the MN DNR (Bergman, Andrea Email 5-22-2013) summarizes their rating curve development methodology:

> *When developing a rating for a site, the hydrologist first attempts to create a best fit line through all good quality measurements with clear control. The hydrologist reviews the control condition at [the] time of each measurement and the quality of each measurement when deciding whether or not to use that measurement as a guide for the curve. It is common to intentionally bypass a measurement if control conditions warrant this, and apply short-term rating shifts rather than forcing the curve to intersect each measurement. For example, if debris is noted at the time of a flow measurement (i.e. a beaver dam), it would be expected that this measurement would fall above the curve. Similarly, channel scouring is common shortly after a large rain event, and it is reasonable to expect a measurement shortly after such an event to fall below the curve. Measurement quality is another factor in choosing where to put the rating. Measurements may not fall in line with others and measurement quality is used as a guide whether or not to use that measurement as an anchor point for the rating curve.*

Figure 2 and **Figure 3** show the rating curves developed for sites H80010001 and H80013001 (by the MN DNR). Conversations with Mark Evenson (MN DNR) indicate that the watercourses containing these sites have undergone construction projects in recent years and also had significant storms scour the channel. As such, it's likely that the MN DNR's rating curves at these locations may no longer be accurate. The timeframe of the construction and scour corresponds with the DNR's discontinued use of the rating curves (2009 and 2008, respectively).

Figure 2: MPCA/DNR H80010001 Rating Curve (Site S000-906)

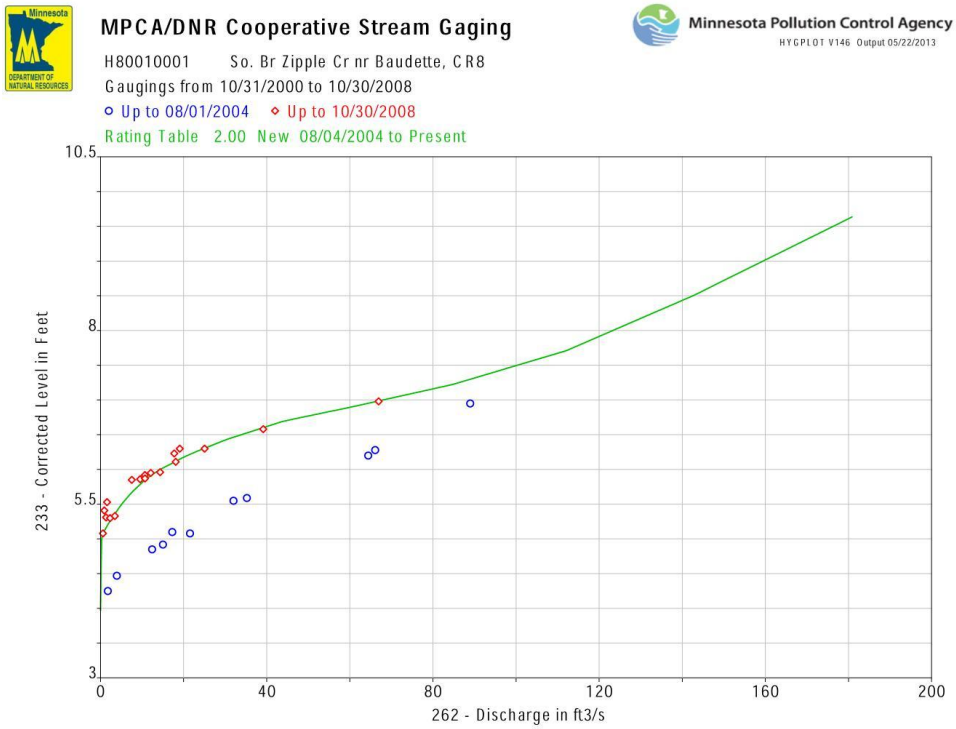
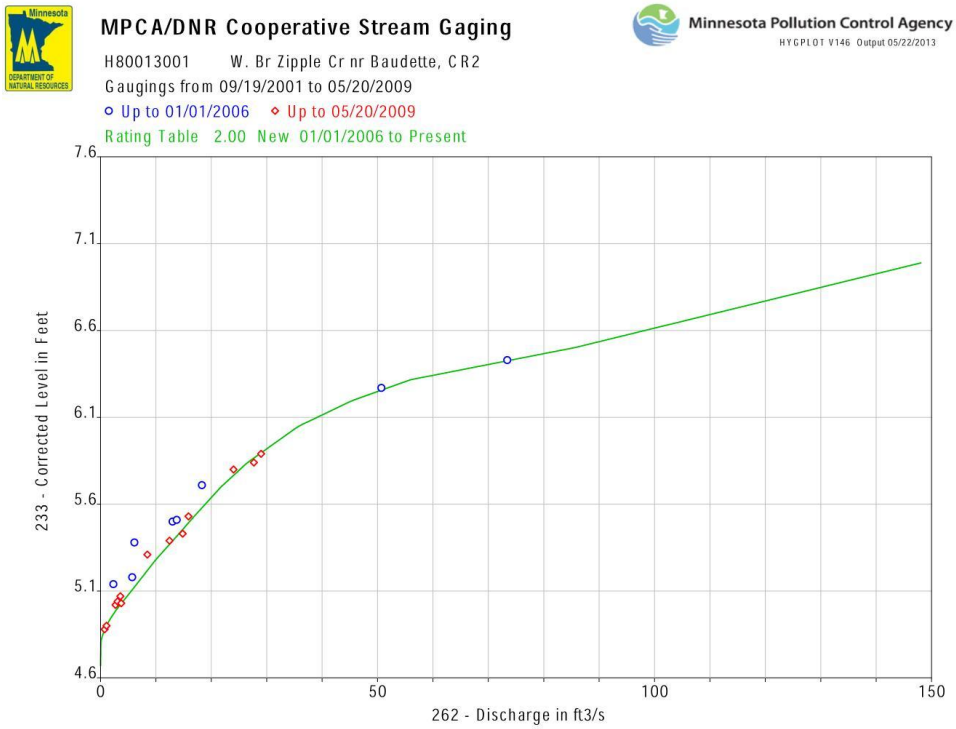


Figure 3: MPCA/DNR H80013001 Rating Curve (Site S003-695)



After the DNR's discontinued use of their rating curves, the MPCA developed rating curves for South and West Zippel Creeks (sites S000-906 and S003-695 respectively) using 2009 data. **Figure 4** and **Figure 5** show the 2009 rating curves received from the MPCA. Note that the shape of the MN DNR and MPCA-developed curves at these locations are significantly different.

Figure 4: MPCA 2009 South Zippel Rating Curve (Site S000-906)

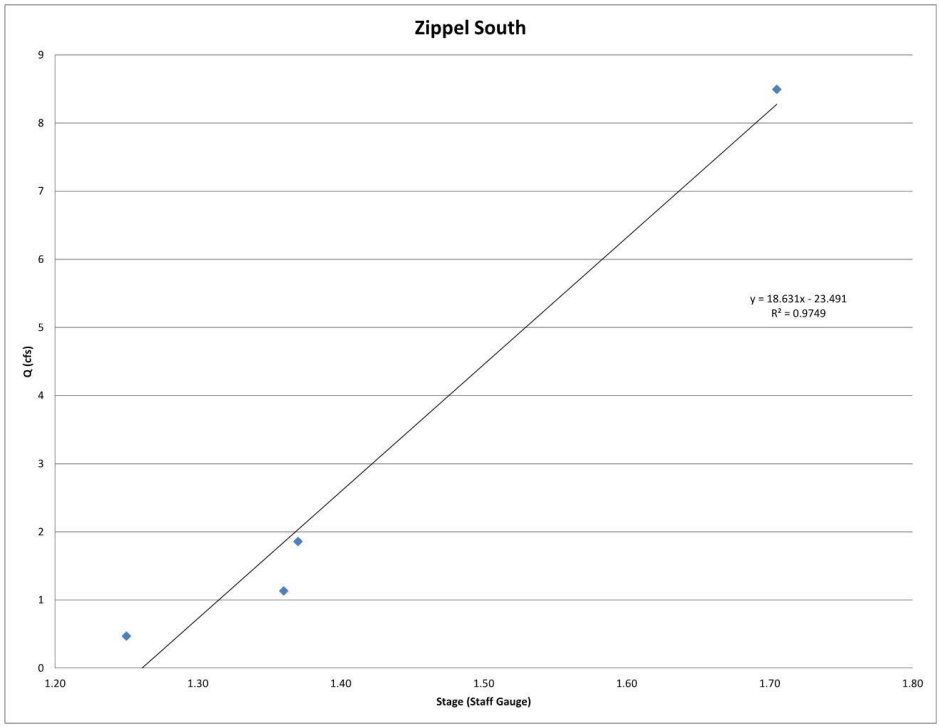
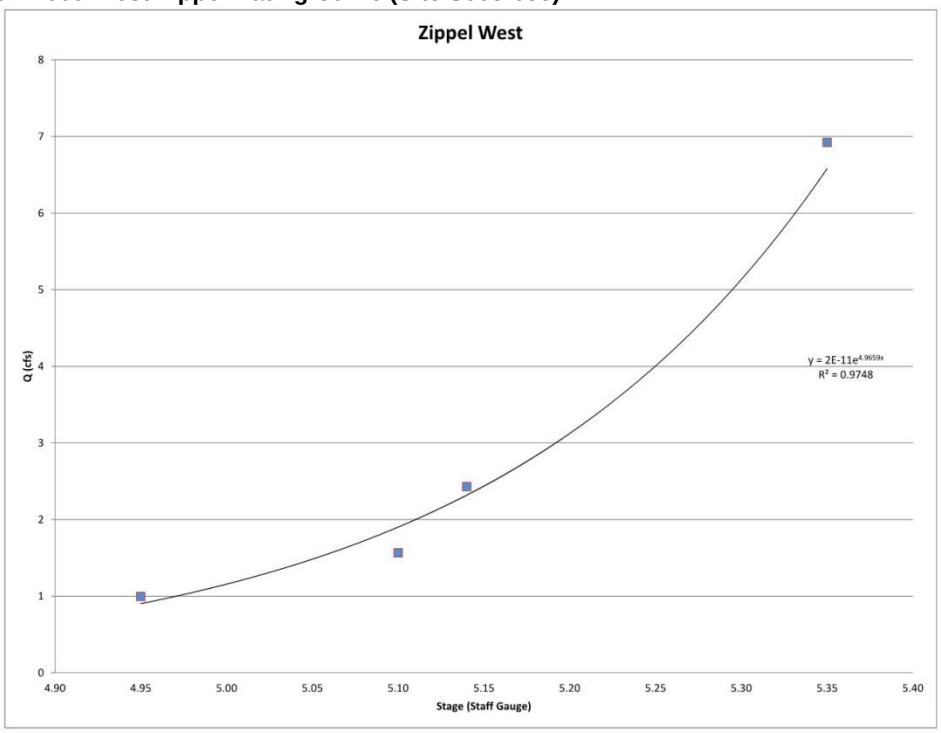


Figure 5: MPCA 2009 West Zippel Rating Curve (Site S003-695)



The US Department of Agriculture – Natural Resources Conservation Service (NRCS) has developed rating curves at 3 sites in the LOW Watershed: S000-906, S003-965, and a site on Bostic Creek (presumed S005-708). The rating curves were developed using a HEC-RAS model with surveyed cross sections. These rating curves could be further refined with more field observation at the sites. **Figure 6** through **Figure 8** shows the NRCS rating curves. The local datum conversion used in these rating curves is uncertain.

Figure 6: NRCS Bostic Creek Rating Curve

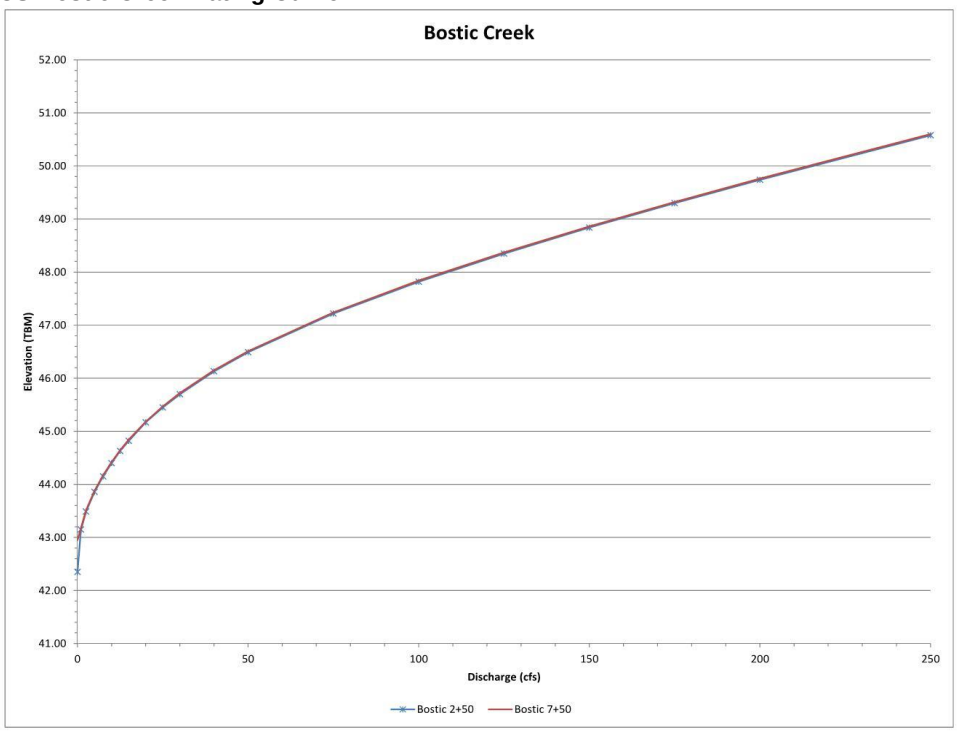


Figure 7: NRCS South Zippel Creek Rating Curve (Site S000-906)

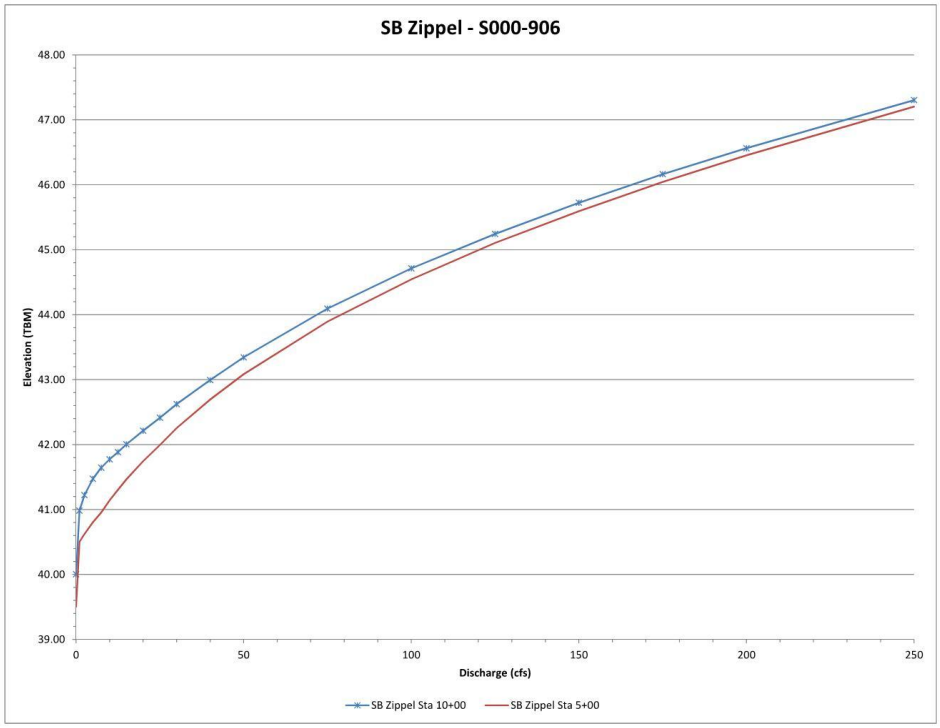
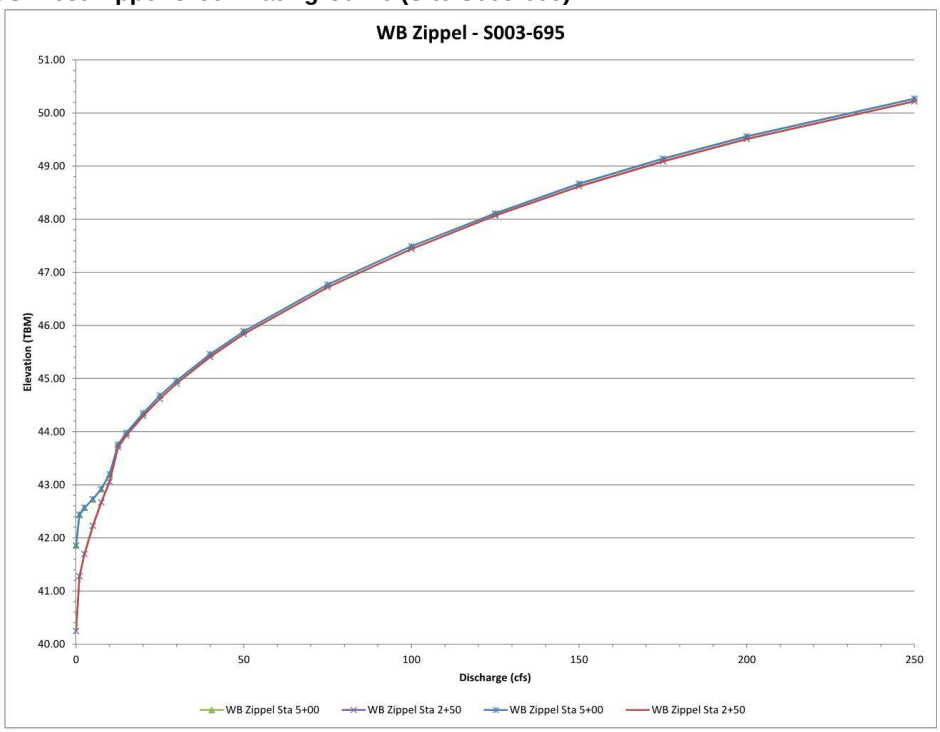


Figure 8: NRCS West Zippel Creek Rating Curve (Site S003-695)



Implications for Additional Rating Curve Development and Future Data Collection Efforts

The following outlines the impact of the findings of this analysis on the ability to develop/update rating curves in the watershed and also on developing continuous flow records. Implications for future data collection efforts are also discussed.

Sites S000-906 and S003-965 (H8001001 and H80013001) have had the most data consistently collected, in the watershed. Multiple rating curves have been developed, by multiple agencies, using different techniques; the NRCS used HEC-RAS to develop curves, while the MN DNR and MPCA based their curves on empirical data. The MN DNR rating curves at these locations are likely outdated due to channel scour and construction. The MPCA curves contain limited data (observations from 2009 only), but could be updated with more recent observations to strengthen their relationships. However, the 2010-2012 data at these locations were primarily collected at low flows due to limitations with the LOW SWCD's flow tracking equipment; future observations at higher discharges are needed to strengthen the curves' accuracy. Alternatively, observations since 2009 can be compared with the modeled rating curves developed by the NRCS and the HEC-RAS model could, potentially, be used to expand the rating curve to higher discharges. In this case, gathering observed data at higher flows would still benefit the model.

Sites S005-708 and S006-841 have continuous stage data which could be converted to flow, if a rating curve were developed. However, at this time there is not sufficient data to develop rating curves due to a lack of observed discharges. Future efforts should be put towards collecting numerous stage-discharge measurements for a broad range of flows at these locations. With sufficient data collection, rating curves could be developed using either the empirical or modeled approach. If the channel has been fairly stable

over time, these rating curves could then be used to estimate discharges from the existing continuous stage data.

H80025001 is a new gage station, as of September 2012, operated by the MN DNR. It is unknown if the DNR has plans to collect stage/discharge data or develop a rating curve at this site.

S003-696, S003-697, S003-700, S005-709, and S005-710 have only occasional stage measurements. These stage observations coincide with water quality data collections and are not intended for use in rating curve development.

S000-795, S000-797, S000-907, S003-699, and S006-838 have had discharge data collected recently that does not coordinate with stage data. Without paired stages, this flow data is not useful for developing rating curves. If rating curves are the objective of these collections, stage data should also be recorded and more observations should be made at higher discharges.

In summary, to develop/strengthen the rating curves in the LOW Watershed, future data collection efforts should be concentrated at the sites where continuous flow data is most desired. For purposes of watershed-wide water quality analysis, it is recommended that these collections concentrate on the largest systems in the watershed: the Warroad River, Zippel Creek, and Bostic Creek. Since the Warroad River has no recent data available for it (and it is the largest of the three), this system is a high priority. Collecting more comprehensive data in Bostic Creek and continuing collections in Zippel Creek is also suggested. In all cases, flow observations should be made for a wide range of discharges and coincident stage values should be recorded.

An additional recommendation from this work is that the LOW SWCD obtain more flexible flow tracking equipment, allowing for the observation of discharge under high-flow conditions. As stated, the ability to develop good rating curves is largely dependent on having coincident stage-discharge data under a variety of hydrologic conditions.