Status and Trends Monitoring of Riparian and Aquatic Habitat in the Olympic Experimental State Forest

2015 Hydrology Status Report




N A T U R A L R E S O U R C E S

WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
PETER GOLDMARK | COMMISSIONER OF PUBLIC LANDS

(This page is intentionally left blank.)

ACKNOWLEDGEMENTS

Authors
Rebekah Korenowsky, Hydrologic Modeling Intern for the Olympic Experimental State Forest (OESF), Washington Department of Natural Resources
Warren Devine, OESF Data Management Specialist, Washington Department of Natural Resources

Principal Contributors and Reviewers
Teodora Minkova, Research and Monitoring Manager for the OESF, Washington Department of Natural Resources
Gregory Stewart, Cooperative Monitoring, Evaluation and Research (CMER) Geomorphologist, Northwest Indian Fisheries Commission
Jeff Keck, Natural Resource Scientist 3, State Lands Forest Hydrologist, Washington Department of Natural Resources

Additional Contributors
Erin Martin, TESC MES Faculty, Project Sponsor for this Internship
Ellis Cropper, OESF Field Technician
Mitchel Vowerk, OESF Field Technician

Photo Credits
Cover photos: (top and bottom left) Ellis Cropper; (top and bottom right) Rebekah Korenowsky

Suggested Citation
Korenowsky, R. and W. Devine. 2016. Riparian Status and Trends Monitoring for the Olympic Experimental State Forest. 2015 Hydrology Status Report. DNR Forest Resources Division, Olympia, WA.

Washington State Department of Natural Resources
Forest Resources Division
1111 Washington St. SE
PO Box 47014
Olympia, WA 98504

www.dnr.wa.gov

Copies of this report may be obtained from Teodora Minkova: teodora.minkova@dnr.wa.gov or (360) 902-1175

EXECUTIVE SUMMARY

The purpose of the hydrology status report is to document the initial analysis of the hydrology dataset collected from the hydrologic monitoring basins within the Olympic Experimental State Forest (OESF). Hydrologic monitoring has occurred since October 2013 in 14 basins spread throughout the OESF. The 14 basins were selected to be representative of the ranges of basin size, precipitation zone and reach gradient that exist within the OESF.

Part 1 of this report describes the methods and overall results of this study. Included in part 2 of this report are detailed results from each hydrology monitoring basin in the OESF. These results include plots of the cross-section at each gage station over the past 3 years, histograms of the recording gage and staff gage trends and stage-discharge rating curve models that will be utilized to create hydrographs.

Overall results show that the majority of the hydrology monitoring basins in the OESF have experienced changes in channel shape over the three-year monitoring period. The data also show that, as expected, the discharge measurements that are being taken are occurring when streamflow is relatively low. These two points combined, though anticipated, lead to a limited ability to estimate the full range of stream discharge within the OESF.

Recommendations for future data collection and analysis are included for the overall project. Individual basins may also have specific recommendations which are included in part 2. Major recommendations include an evaluation of the rating curves based on a quantitative metric, additional cross-section stability survey points and additional high-flow discharge measurements.

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

BFW – Bank full width

CMER – Cooperative Monitoring, Evaluation and Research

DNR- Washington state Department of Natural Resources

MES – Masters of Environmental Studies program

OESF – Olympic Experimental State Forest

Q – Stream discharge in cubic feet per second (cfs)

TESC – The Evergreen State College

WY – Water year

KEY TERMS

Adapted from Langbein and Iseri, 1972 unless otherwise indicated.

Aggradation: The accumulation of sediment on a streambed, causing streambed elevation to rise.

Bankfull stage: Stage at which a stream first overflows its natural banks.

Baseflow: Sustained or fair-weather flow, natural flow in a stream.

Channel: An open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water.

Cross-section stability survey: A periodic leveling check at a gaging station to ensure that gages are accurately set to the established gage datum (Minkova et al., 2012).

Common datum: A local site datum (vertical elevation used as a zero point) for comparing staff gage height, recording gage height and cross-sectional elevation data. It is established as the lowest recorded thalweg elevation for each gage cross-section. This datum that is maintained independently of channel aggradation (it may be shifted following channel degradation) and does not correspond to any national geodetic datum (Minkova et al., 2012).

Control: A natural constriction of the channel, a long reach of the channel, a stretch of rapids, or an artificial structure downstream from a gaging station that determines the stage-discharge relation at the gage.

Discharge (also known as “flow” or “streamflow”): The amount of water that passes a given point in a given amount of time. Discharge is the product of the cross-sectional area multiplied by the velocity of the water.

Flood plain: A strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current.

Gage height: The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term stage although gage height is more appropriate when used with a reading on a gage.

Gaging station: A particular site on a stream where systematic observations of stage height and/or discharge are obtained (Minkova et al., 2012).

Hydrograph: Graph showing discharge with respect to time.

Inflection point: Point of change in the slope of the cross-section as measured by the cross-section stability survey (Minkova et al., 2012).

Recording gage: Pressure transducer that collects stage height measurements at a specified interval. All OESF recording gages measure at 15-minute intervals (Minkova et al., 2012).

Stage-discharge rating curve (also known as “rating curve”): A graph showing the relation between the gage height, usually plotted as ordinate, and the amount of water flowing in a channel, expressed as volume per unit of time, plotted as abscissa.

Stage: The height of a water surface above an established datum plane. See also “gage height”.

Staff gage: A graduated scale that is semi-permanently installed in a stream channel to indicate the height of the water.

Stream discharge (also known as “discharge”, “flow” or “streamflow”): The amount of water that passes a given point in a given amount of time. Discharge is the product of the cross-sectional area multiplied by the velocity of the water.

Stream-gaging station (also known as “gage station”): A gaging station where a record of discharge of a stream is obtained. Within the Geological Survey this term is used only for those gaging stations where a continuous record of discharge is obtained.

Thalweg: Lowest point of elevation in the channel cross-section as measured by the cross-section stability survey (Minkova et al., 2012).

Water year: The 12-month period of October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ended September 30, 1959, is called the "1959 water year."

INTRODUCTION

Here we present the preliminary analysis of the hydrologic dataset for the Riparian and Aquatic Status and Trends monitoring project in the Olympic Experimental State Forest (OESF). Data utilized is from the period October 2013-June 2015 in the 14 basins selected for long-term monitoring by the Washington State Department of Natural Resources (DNR) within the OESF (Figure 1). Refer to the project *Status and Trends Monitoring of Riparian and Aquatic Habitat in the Olympic Experimental State Forest* for information on the study plan (Minkova et al. 2012), monitoring protocols (Lovellford et al. in prep, Devine et al. in prep), and maintenance of the hydrology installations (Minkova and Vorwerk 2014, Minkova and Devine, 2015).

The goal of this analysis was to create stage-discharge rating curves for each of the 14 basins to predict discharge across the range of measured discharges. These rating curves will be used in creating hydrographs of continuous discharge estimates for each of the basins. Additionally, the analysis described here was intended to provide a framework for continuing hydrologic analysis in these basins.

Part 1 of this report describes the data analysis methods utilized in rating curve development for each monitoring basin, introduces overall results and provides an overview of the known limitations that may hinder this analysis. Part 1 also discusses key findings and provides recommendations for overall data collection and analysis in the future. Part 2 contains results and recommendations for individual basins. For each basin, Part 2 contains a brief summary of the issues at this site, recommendations for future data collection, descriptions of stream channel change (if present), assessment of the stability of the field instruments and statements of confidence in the rating curve to make accurate predictions of discharge.

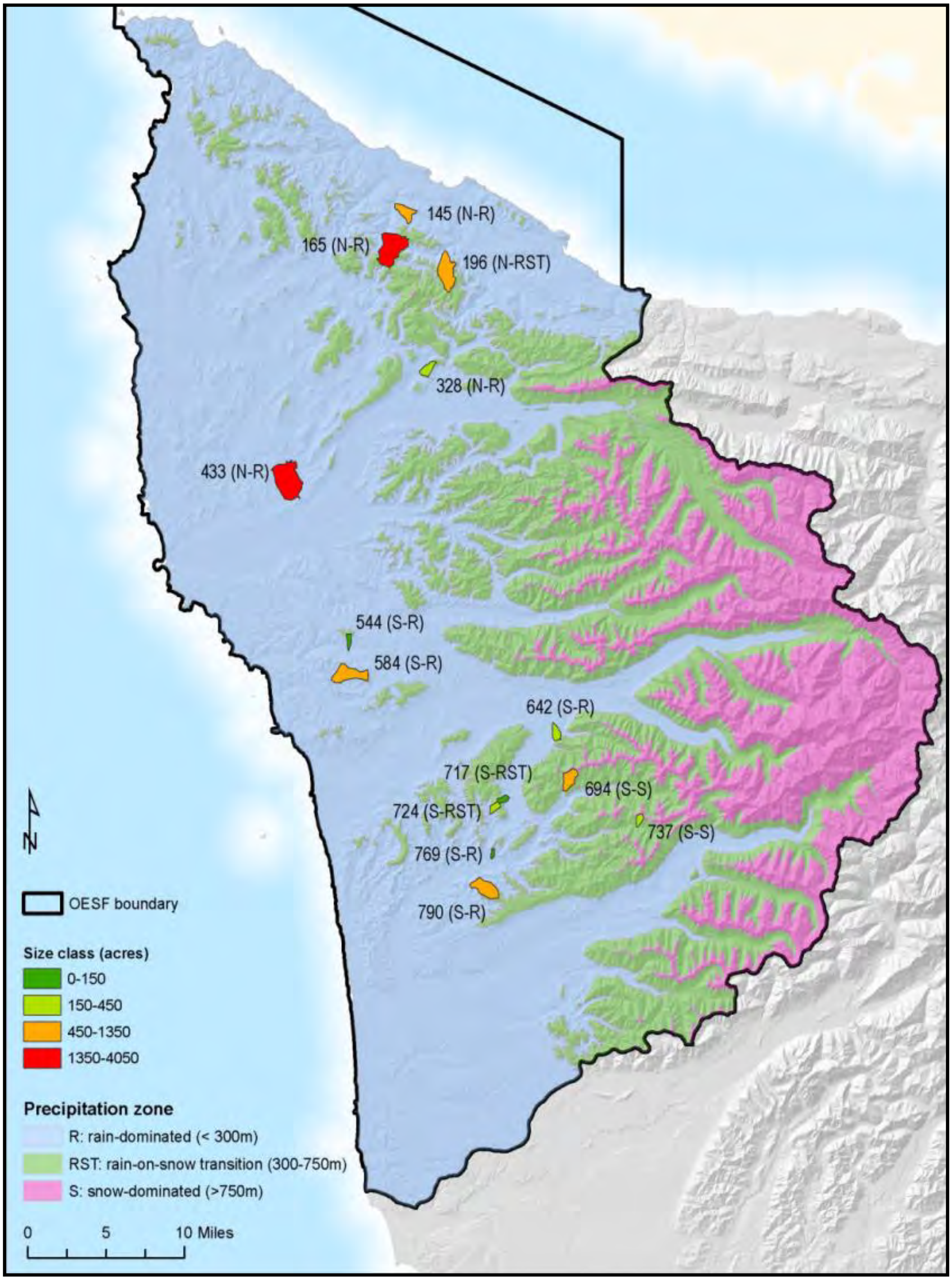


Figure 1 – Hydrologic monitoring basins within the OESF (n=14) classified by size, precipitation zone and rainfall intensity.

PART 1:

Methods, Limitations, Results and Recommendations

METHODS

The hydrologic monitoring protocol for this project includes: stream discharge measurements, staff gage readings, recording gage data from pressure transducers recorded at 15 minute intervals and cross-section profiles of the gage station sites. Refer to Lovellford et al (in prep.) for description of the field monitoring protocol and to Devine et al. (in prep.) for details on the data management.

The 14 basins included in this analysis were selected to represent the range of basin areas, precipitation zones, reach gradients and geographic locations of basins within the OESF (figure 1). Each basin also has varying channel roughness, slope and geometry. As such, each basin was treated individually throughout this analysis.

Described in detail below are the specific methods for each step in the process of creating stage-discharge rating curves for each basin (figure 2). It should be noted that this is often an iterative process, and some steps must be repeated as new insight is obtained from subsequent procedures. Rating curves were evaluated utilizing all the available data to date for the basin. Aside from the thresholds we selected for the correlation coefficient and sample size ($R^2 > 0.95$ and $n > 4$), evaluations of the basin's stability were based on the analysts' interpretation of the changes that occurred within the basin. In future iterations of this analysis, quantitative metrics for establishing significant channel changes may be applied.

Data is managed within the OESF hydrology database in Microsoft Access hosted on DNR servers. Analysis was conducted using JMP, R and Microsoft Excel. All raw data were kept intact in master data tables; data adjustments (e.g., to account for a gage replacement) were made using database queries.

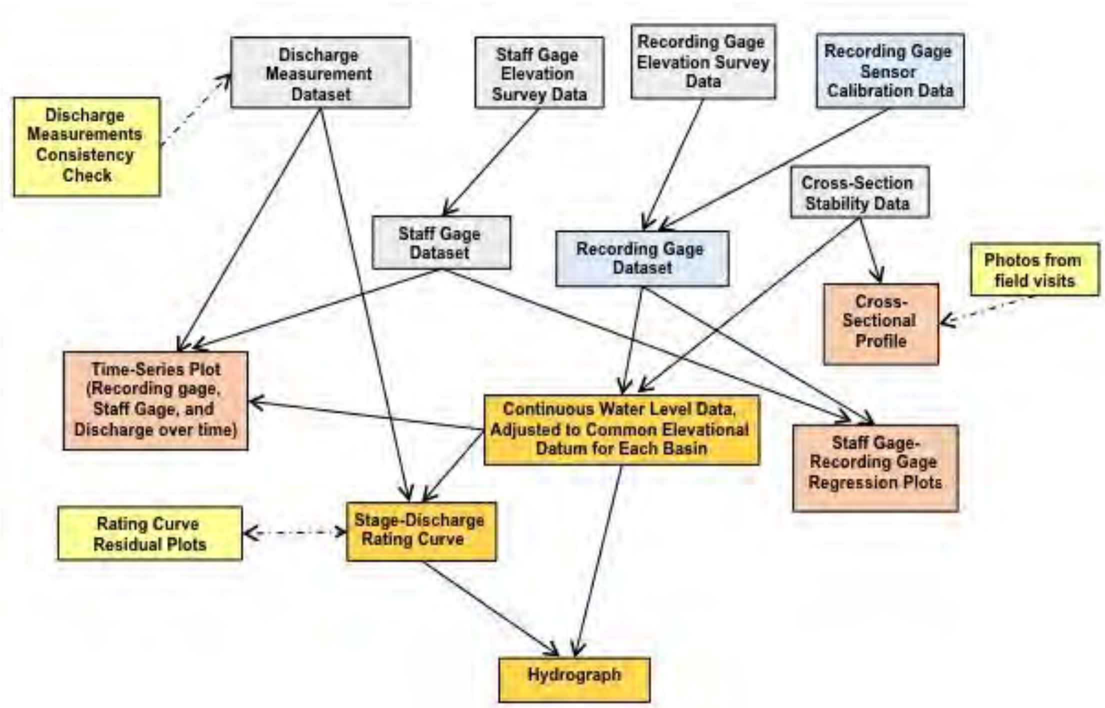


Figure 2 – Conceptual model of datasets and plots utilized in this analysis. Modified from Devine and LovellFord (in prep).

Common Datum

Datasets for staff gage, recording gage and cross-section elevations were set to a common datum established for each basin. This allows for easy comparison of information across different plots to identify areas of concern. The datum was created by adding an adjustment factor to all datasets with elevation components. The common datum's zero elevation was established as the lowest recorded thalweg elevation for each basin cross-section.

Staff Gage Replacement Adjustments

Before the staff gage data could be utilized, it was necessary to apply an adjustment factor to correct for staff gage replacements that happened during the monitoring period. In December 2014 and January 2015 staff gages were replaced at basins 165, 196, 433, 584, 642, 694, 717, 737, 769, and 790. The replacement gages were placed at a new vertical datum, and as such the staff gage readings from the original gages do not match those from the replacement gages. This method of adjustment was created for our purposes, as no appropriate methodology could be found in the literature to support an adjustment for a change in staff gage heights.

In all basins with replaced gages except for 165, water surface elevation was measured relative to the new staff gage elevations and the local datum at the time of replacement. Recording gage data during the period of replacement (the time between removal of the original gage and the installation of the new gage) displays no significant change or trend, indicating that the water level was steady during this time. The offset between the original and new staff gage reading was added to the original staff gage readings for each basin so that all adjusted staff gage data is reported in the new staff gage datum. For basin 165, the comparison was conducted from a previous staff gage reading, as the staff gage at this site was blown out and could not be utilized to take a measurement at the time of replacement.

Site visit photos

Photos are taken during site visits: upstream and downstream during the discharge measurement, and at an established photo point near the gaging station.

These photos were also used while evaluating the various datasets, especially cross-sectional profile plots and discharge data.

Staff Gage and Recording Gage Relationships

The relationship between the staff gage measurements and the recording gage readings should be stable over time. Ideally, both instruments should be responding equally to changes in stage height, which would indicate that there are no issues with either gage. To investigate this relationship we used linear regression analysis. The slope of staff gage-recording gage regression equations should be equal to 1, demonstrating a 1:1 relationship between the staff gage and recording gage.

In order to display the range of the recording gage readings and staff gage measurements, the two datasets were presented as histograms plotted side-by-side in the common elevational datum for each basin (Figures 2A and 2B). Histograms of the staff gage and recording gage show the range of the stage heights observed during field visits (staff gage), against the full range of stage heights that are occurring (recording gage). Note that the range of recording gage data set (recorded year-round at a 15-minute interval) is much larger than the staff gage data set, which is limited to field visits.

Cross-sectional Profiles

Cross-sectional profiles for each gage station were surveyed relative to the common elevational datum. These plots are color-coded by year of the survey, to visually represent changes in the cross-section over time. The elevation of maximum recorded stage height is included on each plot, indicating the maximum height of the water level observed by the recording gage. These cross sections must be accurate up to the maximum stage height, to clearly detect changes in channel geometry or cross-sectional area over time.

Cross-sections were evaluated to determine the stability of the stream channel over time. If a change in the channel cross-section is detected, a different rating curve model must be created for the different channel shape.

Stage-Area Curves

To assist in detecting changes in stream cross sections over time, we modeled the cross-sectional area of each profile, in 1.0-cm stage increments, using the cross-section profiles from the three surveys. The results appear in the Appendix.

Staff Gage-Recording Gage Time Series and Regression

Time series plots were created for each basin, extending through the entire monitoring period. These plots show the measurements from the recording gage (recorded at 15-minute intervals), staff gage measurements, and the difference between the staff gage and recording gage measurements at the time of the staff gage reading. The time-series plots display variability in the stream stages, and can potentially highlight issues with the recording gage, or major shifts in the channel.

The line showing the difference between staff gage and recording gage represents the relationship between the two instruments. The staff gage is only used to check the accuracy of the recording gage readings; it is not used for discharge estimation. The difference between the staff gage and recording gage should consistently be 0. If, however, the difference is not equal to 0 for a given set of elevations or times, then it is likely that the accuracy of the recording gage or staff gage is compromised at a given range of stage heights or times. This difference could be due to movement of one of the gages, and/or incorrect gage readings.

Stage-Discharge Rating Curves

The stage-discharge rating curves are least-squares-regression plots of stage height by discharge, depicting the relationship between these two variables. Stage height values are attributed to the recording gage measurement at the time the discharge measurement was taken. The rating curve equations provide a discharge prediction which can then be used to create a hydrograph for the basin. The rating curves utilize the following equation (adapted from Herschy, 1995 and Rantz, 1982):

$$\ln(Q) = \ln(C) + \alpha * \ln(h)$$

where Q = stream discharge; h = effective stage height; C = constant, equal to discharge when effective stage height equals 1 (i.e, ln(0)); and α = slope of the rating curve. Rewritten in linear form the equation becomes:

$$Q = C(h)^{\alpha}$$

The original equation described by Rantz and Herschy includes the variable, a, which equates to the gage height at 0 flow, or the “effective depth of water on the control” (Rantz, 1982). We have not included this measurement here because, as of now, it has not been calculated in our basins due to the variable nature of the channel controls in our reaches.

A preliminary set of stage-discharge rating curves were created using all data collected through July 2015, using methods described in Rantz, 1982 and Gore, 1996. These preliminary curves were used during investigation of the stability of the cross-section over time and/or changes in stage-discharge relationship based on stage height. In many cases, the preliminary curves did not accurately describe the stage-discharge relationship for the entire dataset because the stage-discharge relationship was not constant throughout the data collection period. Where the stage-discharge relationship was not constant, multiple curves were developed for the same basin. There are two types of situations where multiple stage-discharge curve models are required for the same basin:

First, the channel may change over time. This will be evident from the cross-section stability survey, the recording gage time-series plot and the preliminary plot of the rating curve using the full dataset (i.e., data from the full time period and all stage values). For example, if a channel change occurred over time, the cross-section profile shape at “time A” will be different than the profile shape at “time B”. On the rating curve, separate trends in the stage-discharge relationship will be observed for “time A” and “time B” (Figure 3). Also, baseflow observed on the recording gage time-series plot at “time A” will be observed at a different stage height than baseflow at “time B”. Temporal changes in downstream controls will also show similar results to those described here (Rantz, 1982).

Second, multiple rating curves may be required for different stage heights, owing to differing cross-section characteristics that vary with height. This may be evident from the cross-section profile, as well as the preliminary rating curve plots. Significant

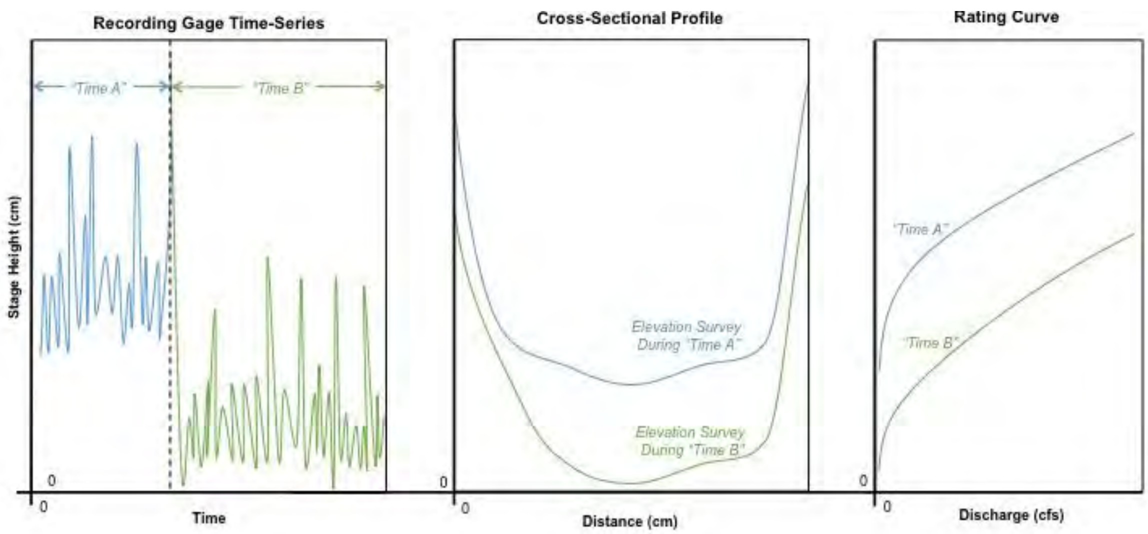


Figure 3 – Idealized example of Recording Gage Time-Series, Cross-Sectional Profile and Rating Curve plots in the event of a channel change over time due to channel erosion. "Time A" is represented in blue and "Time B is represented in green.

channel expansions may be identified through inflection points in the rate of cross-sectional area change as a function of stage. Inflection points may be associated with areas of undercutting, or lateral expansion into the floodplain with little elevation gain. For example, if an inflection point in the stage-discharge relationship is observed at "elevation A" then the stage-discharge relationship will be different for areas above and below "elevation A", and two rating curves will be necessary (Figure 4).

Residual plots, which show relative distances from the regression line for each data point, were also utilized in the analysis of rating curve model quality and in the determination of the rating curve sub-sections. The residual plots are show in Part 2. In future analysis a quantitative metric for evaluating the threshold of residual distances, such as a 5% deviation in random direction described by Rantz, 1982, may be applied.

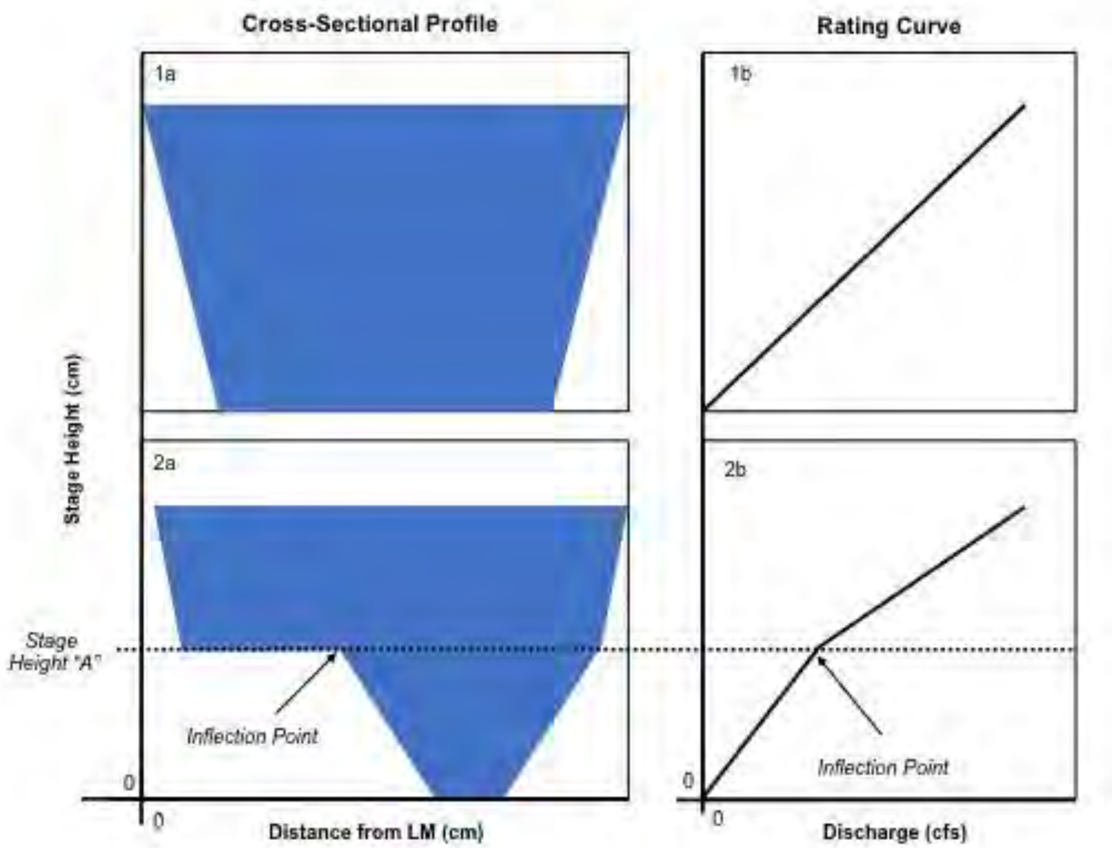


Figure 4 – Idealized example of Cross-Sectional Profile and Rating Curve plots showing how a change in channel geometry will affect the rating curve plot. In 1a the cross-sectional profile of an idealized trapezoidal channel is shown, and it's a rating curve, shown in 1b that displays a perfect 1:1 ratio. In cross-section 2a, an inflection point is present at stage height "A" and a corresponding inflection in the rating curve can be observed in 2b.

In all situations, we only fit stage-discharge curves where there were sufficient data present to create a "reliable" model, defined here as one in which $R^2 > 0.95$ and $n > 4$.

Ranking of Stage-Discharge Rating Curves

Since the rating curves will be utilized in creating basin-specific hydrographs for the monitored basins, an assessment of the rating curves' capacity to accurately predict discharge is essential. Monitoring basins have been separated into 3 categories based on our current ability to create a reliable rating curve model ($R^2 > 0.95$ and $n > 4$) for the monitoring period October 2013-June 2015. Criteria required for each category are defined below.

Category 1 — Accepted

A reliable rating curve model is currently available for the entire range of observed discharges up to June, 2015. Constant baseflow is displayed over the entire monitoring period.

Category 2 — Conditional Based on Time

A reliable rating curve model is available for a subset of time. Constant baseflow is observed during this subset, but not for entire range observed discharges. One or more significant changes in the channel cross-section have occurred.

Category 3 — Conditional Based on Stage Height

One or more reliable rating curve models are available for one or more subsets of stage heights. An inflection point (point of changing slope in the streambed) is observed on the cross-section, which is affecting the relationship between stage and discharge.

Category 4 — Not available

Based on the available data at this time, a reliable rating curve cannot be created.

RESULTS

The results presented in this section represent the overall results of this analysis. Basin-specific results and recommendations are contained in Part 2 of this report.

As expected, our staff gage data resides on the lower end of the stage range. Ideally, the medians and ranges of these the data collected from the recording and staff gages should be equal. The discrepancies between these histograms speak to the rapid time-to-peak of our streams, as there are many spikes in the recording gage data for which we are likely unable to obtain staff gage measurements.

As evident from the cross-section plots, many of the sites experienced channel shifts, due to either aggradation or erosion (note that the scale of the cross-section plots is highly condensed on the horizontal axis). These shifts likely occurred during high-flow events. Events of this nature were experienced in both winters of 2014 and 2015. In basins where constant baseflow is displayed over time (e.g. basins 165 and 737), it is unlikely that a significant shift in the channel has occured. This is also evident from the lack of variation in the cross-section plots from year to year.

Stage-discharge rating curves are presented for each basin for the entire range of observed discharges and stage heights (i.e., the “preliminary curves”). For basins where channel changes have occurred over time or where multiple stage-dependent curves are required, separate rating curves are also presented.

Two basins met the qualifications for the category “1 Accepted”, eight basins were placed in the “2 Conditional (Time)” category and two basins were placed in the “Conditional (Stage Height)” category. Two basins were placed in the “3 Not available” category (see table 1 for category assignments). Refer to the methods section for more detail as to how categories were determined.

Table 1 – Basins categorized according to systems described in methods.

Basin	Category	Based on	Available Range(s)
145	Conditional	Time	1/29/2014 - 10/8/2014
165	Accepted	—	10/14/2013 - 6/16/2015
196	Conditional	Stage Height	< 45 m; 45-65 m
328	Conditional	Time	3/11/2014 - 10/8/2014
433	Not available	—	—
544	Conditional	Time	2/19/2014 - 6/24/2015
584	Conditional	Stage Height	30 - 47 cm
642	Not available	—	—
694	Conditional	Time	2/20/2014 - 6/23/2015; 10/9/2014 removed
717	Conditional	Time	1/27/2014 - 10/6/2014
724	Conditional	Time	2/20/2014 - 10/6/2014
737	Accepted	—	1/9/2014 - 6/18/2015
769	Conditional	Time	4/4/2014 - 10/6/2014
790	Conditional	Time	Data through 10/9/2014

DISCUSSION AND RECOMMENDATIONS

Cross-Section Stability Survey Discrepancies

For many of the basins, the right monuments (RM), which mark the endpoint of the elevation stability survey, do not match up from year to year; left monuments (LM) are artificially snapped to same elevation to allow comparison between surveys. The difference between RM elevation in each basin ranges from 0.5 to 12.0 cm. We hypothesize that the discrepancy between monument elevations is a result of error in the stability survey, which is likely associated with the difficulty of surveying long distances between a basin's reference point and the gage cross-section.

The discrepancies affect the visual interpretation of channel change over time based on the cross-section plots as well as the stage/cross-sectional area relationship. Enhancing the accuracy of the cross-section stability survey will improve the detection of rating-curve-impacting changes in channel geometry. We recommend that elevation measurements be taken both to and from reference points. New gage reference points have been established for the 2016 field season and intended to reduce the error associated with these measurements.

The 2014 and 2015 cross-sectional stability surveys do not include elevation measurements into the 100-yr floodplain. Future cross-section stability surveys should extend beyond the maximum recorded stage height at each basin. In some basins, this will require extending the surveys into the 100-yr floodplain.

Future work should also include an evaluation of the control reach and effects of objects that are not captured by the cross-sectional profiles (e.g., channel spanning logs such as those shown in photos of basins 145, 328, and 642 in Part 2 of this report).

Currently the effects of the objects in the reach are attributed in the model as unexplained variance around the fitted line. By identifying these effects, it may be possible to correct for them and reduce the variance within our models.

Discharge Measurements

Due to the limited number of discharge measurements, discharge data with a “poor” quality rating had to be used to develop the rating curves for several basins. In the future, however, it will be necessary to investigate the quality of discharge measurements relative to their contributions to the rating curve equations.

Discharge measurements made using the neutrally buoyant object (NBO) method (LovellFord et al (in prep.)) have very weak correlations with the measurements taken using the electronic flow meter. Inclusion of data collected using the NBO method has been numerically ineffective at improving the accuracy of rating curve predictions; therefore, all measurements taken using the NBO method have been excluded from rating curves.

The high flows observed in the recording gage measurements were not observed in discharge measurements or in the staff gage readings. As noted above, these streams are highly “flashy” and have short time-to-peak values, causing the window of opportunity to measure discharge during these high flows to be very small. Additionally, at very high flows, it is not physically possible to measure discharge under our monitoring protocol. We recommend that a method such as the slope-area method (Rantz, 1987) is utilized to extrapolate discharge estimates at high flows. The slope-area method utilizes the Manning equation which takes inputs of cross-sectional area, hydraulic radius, slope and a roughness coefficient to estimate discharge. Future analysis of the hydrology dataset should include slope-area calculations, and field protocol should be updated accordingly to include collection of data required for the equation.

For all basins, there is a large gap in the discharge dataset from early October 2014 to late April 2015. This data gap occurs during the rainy season, and there are a large number of high flow peaks for which we do not have discharge measurements. In water year (WY) 2014 an average of 7 discharge measurements were taken at each basin, whereas in WY 2015 only 3 discharge measurements were taken on average in each basin. Unfortunately, WY 2015 is the time during which many of the basins have expereicned significant changes in their cross-sections, as represented by the green and blue lines on the cross-section profile plots. Because there is little data provided for this time period, it may be difficult to pinpoint which high flow event resulted in the channel changes. This determination will not be able to be made until more data from WY 2015 are analyzed.

Discharge measurements should be taken as close to once a month as possible. Extra effort should be made to collect data during times when the stage-discharge relationship may be altered, either during high flow periods or after a known channel change has occurred.

Gage Stability

The relationships between staff gage and recording gage is much closer to 1:1 at low flows, as shown on the time-series plots and the SG-RG relationship plots for each basin. This can be attributed to a few different factors: lack of precision in the recording gage during quickly rising or falling stage heights (as noted above), lack of precision in staff gage measurements during quickly rising or falling stage heights (turbulent water), a staff gage that is not vertically plumb, lag in the time to fill/empty the PVC pipe with water during changing stages, increased value of error percentage with larger volumes of water, or a combination of two or more of the listed possibilites (Boiten, 1987).

Due to the issues listed above, as well as the difficulties associated with the stability surveys, we made the assumption that the elevations of the recording gages were stable in order to continue with this analysis. In the future, it may be necessary to investigate how reduced precision of the recording gage during rising flood stages may affect the observed relationship between the staff gage and the recording gage and whether this will ultimately affect predictions of discharge.

The recording gage measures stage height at 15-minute intervals, while the staff gage reading can be conducted at any time. Thus, during quickly rising stages the relationship between staff gage and recording gage is likely to be skewed.

Site visit photos

Photos should include a very clear image of the gage cross-section facing downstream, to compare to cross-section plots. Preferably, the tape measure should be included in these photos. Additional photos should also be taken when vegetation blocks the stream in photo point photos.

Data analysis and sensitivity

Utilizing an interactive data visualization program such as JMP has proven to be very effective during active interpretation of data. R was utilized to create the final plots that are incorporated throughout this report. This program allows for consistency in output among basins and over time. Once new data is collected and entered into the database, it can be easily incorporated into the models that have been scripted.

As new data are gathered, analysis should be sensitive to changes in the data that can indicate the necessity to update the rating curve model. Information provided in field observations will also be crucial in determining the necessity for model refinement. Specific "red flags" or changes to look for in future analysis include:

- <u>Cross-sectional changes over time:</u> Cross-sectional profile displays observable erosion or aggradation from year to year. Recording gage data shows a change in baseflow from year to year.
- <u>Cross-sectional changes with elevation:</u> Cross-section displays observable changes in channel geometry above or below a certain elevation. This elevation will likely represent an inflection point on the rating curve, where a new equation will be necessary to relate stage height to discharge. It is important to remember that if two rating curves are necessary—one above and one below the inflection point—each must be built with at least five reliable data points. If insufficient discharge data are present above the inflection point, then the hydrograph can only be built on the rating curve that is created for stage values below the inflection point.

- Changes in relationship between staff and recording gages: Relationship between staff gage and recording gage strays from 1:1 after a certain time or above a certain elevation, indicating that an issue is present with either the recording gage (likely) or the staff gage (much less likely).
- Changes in downstream control: A physical element that controls the relationship between discharge and stage height is known as a downstream control (Rantz, 1982). Commonly there are multiple elements that combine to control the relation. Statisfactory controls are both permanent and sensitive. If the control changes, the stage-discharge relation will also change. Primary causes of changes in downstream control are a result high discharge events that cause high velocity in the stream channel to mobilize or damage the controls (Rantz, 1982). More stable controls, such as bedrock outcrops are less likely to change, while unstable controls, such as sand bars or gravel beds, are more likely to change with increased in-stream velocities. Vegetation growth in the stream channel can also alter the stream control and the stage-discharge relation (Rantz, 1982).

  Controls should also be sensitive enough that changes in discharge at low-flow should produce a significant change in stage height. A change in stage height of 0.003 m should constitute no more than 2 percent of the total discharge for the control to be considered sensitive (Rantz, 1982).

For the sites where one or more of the above criteria apply, it will need to be determined if these shifts represent a change in the stage-discharge relationship. Future analysis should include a quantitative metric for evaluating whether or not a basin has experienced significant changes in channel geometry or downstream control. One such possibility for this quantitative metric is described in Rantz, 1982 in which a discharge measurement of ± 5% deviation from the rating curve line is used to signify the need for a new rating curve model.

LIMITATIONS OF ANALYSIS

In this section, we list the possible issues in discharge estimation that have occurred or may occur throughout the duration of this project and which will limit the reliability of the produced rating curves.

This project monitors small montane basins of varying sizes and flows that are highly dependent on rainfall and as a result are quite susceptible to channel shifting. The accuracy of a rating curve is reduced as a result of channel shifts, which is described in detail in the methods section. Also, the gaging stations are often anchored to organic matter of some type (trees, stream beds, etc.) and do not use engineered anchors such as bridges and roads. This makes them more susceptible to shifts during high flows.

For some of the basins, backwater areas, or areas of little or no current, may be present along the gage cross-section. Backwater areas are affected by downstream channel morphology and are the result of an obstruction in the channel such as large woody debris or boulders. Originally, the gage sites were selected to avoid areas with significant backwater effects, but as changes in the channel occurred over time, backwater may be created. At this point we are not able to quantify this effect. A future calculation of the Froude number may be applicable at sites where backwater effects are of concern (Braca et al., 2008).

Currently, we have very few discharge measurements during high flow. Rating curves are only accurate within the range of measured discharges from which they are built, and thus the range of discharge values that we are able to predict is relatively small. Extrapolation of a stage-discharge relationship outside of the measured range of discharges will likely result in large errors in estimation of discharge and is highly discouraged. This issue arises as a result of a combination of two issues. First, headwater streams have a very rapid time-to-peak, which makes it difficult to conduct field monitoring across many basins during this narrow window of time. Second, because the methods of stream discharge measurement that are utilized in this protocol involve wading in the stream, there is an increased safety risk to measure discharge during over-bankfull flows and during rapid storm surges. Our inability to sample during high flow events limits the amount of high flow data we are able to obtain and consequently limits the range of predicted discharge values.

The 2015 water year has been very dry, with very little rainfall occurring during the summer months, which will cause a number of the steams to become dry. This will limit the amount of data that we are able to use to develop the stage-discharge rating curves. This may also lead to an inability to accurately compare baseflows from year to year.

The currently available data sets have a small number of data points, as this long-term study is still in its early stages. This reduces the confidence in the produced rating curves. It is expected that the predictive capabilities of this analysis will improve as more data are collected.

CONCLUSION

This report summarizes the initial analysis of OESF’s hydrologic monitoring dataset. Due to the unstable nature of streams within this monitoring project, there are many limitations to this analysis. However, preliminary rating curves have been created for all 14 basins and an evaluation of their reliability to accurately predict discharge is discussed. This report documents methodology with which rating curves can be produced, and this method will be enhanced and utilized as more data is collected.

PART 2:

Basin-Specific Results and Recommendations

This basin-by-basin analysis includes narrative and figures (described below). The figures for each basin are first presented in a condensed format - plotted recording gage and staff gage histograms, cross-section elevations stability surveys and discharge-stage relationship - on one page for easy comparison across plots. This is followed by expanded versions of the cross-sections and rating curves and additional plots illustrating the analysis. A photo of the gage station for each basin is included as visual reference.

A: Gage data histograms, cross−section profile, and stage−discharge data

Includes histograms of staff gage and recording gage measurements, cross-section profile and rating curve on same page. A horizontal dashed line on the cross-section represents the maximum recorded stage height (on the recording gage).

B: Cross-section profiles from three surveys

Cross-section abbreviations:
LBF – Left bankfull, highest observed area lacking perennial vegetation on left bank
LEW – Left edge of water, water's edge on left bank
LFP – Left floodplain, measured points located within the floodplain on the left bank
LM – Left monument, rebar indicating cross-section location
RBF – Right bankfull, highest observed area lacking perennial vegetation on right bank
REW – Right edge of water, water's edge on right bank
RFP – Right floodplain, measured points located within the floodplain on the right bank
RM – Right monument, rebar indicating cross-section location
TH – Thalweg, deepest point (lowest elevation) in the cross-section at time of current survey

The cross sectional profiles show the elevation of points along the gage station cross-section, color-coded by date of survey.
The two horizontal dotted lines represent the highest and lowest stage height recorded for which a discharge measurement was taken and the horizontal dashed line represents the maximum recorded stage height.

Note that right monuments (RM) do not match up from year to year. Left monuments (LM) have been artificially snapped to the same elevation for comparison, shifting error to the right side of the channel.

C: Stage Data Time Series

Time-series plots display the recording gage and staff gage values over time, the staff gage-recording gage difference, as well as dates of discharge measurements.

The two black horizontal dotted lines are the maximum and minimum stage heights recorded for which we have a discharge measurement.

The horizontal dashed line at 0 is provided for reference when evaluating the staff gage-recording gage difference.

The black triangles represent dates during which discharge was taken, but have no meaningful y-value.

D: Recording gage vs staff gage

The staff gage-recording gage regression displays the relationship between the two gages. Ideally this relationship should be equal to 1. Black line is the line of fit for the model. Grey line is a reference line with slope of 1.

E: Stage−discharge curve and residuals

Rating curves are presented including all available measured discharges and associated stage heights for that basin. Any subsequent rating curve models present are a product of the temporal or spatial breakdown for that basin. The range of dates or stage heights included in the presented model is indicated on the plot. Coefficients for the model equations and R^2 values are presented in Table 2-1.

Log-log model and residual plots for the same data are presented. Note the different log and linear axes on this page. Points are labeled with the quality of the discharge measurement as described in the field and are color coded based on the year of measurement.

Table 2-1 . Coefficients for stage-discharge curves for 14 basins, using stage data from recording gages. Model is: ln(Discharge) = ln(Stage)* x_1 + x_2

Basin	Model data	x_1	x_2	R^2
145	All data	5.8631	-20.9170	0.8243
145	1/29/2014 - 10/8/2014	6.8939	-23.3000	0.9928
165	All data	7.8220	-32.0900	0.9745
196	All data	8.7405	-36.7420	0.9593
196	< 45 cm elevation only	16.6010	-65.4490	0.9299
196	45 - 65 cm elevation only	4.6199	-20.0210	0.9912
328	All data	6.6581	-24.9110	0.5714
328	3/11/2014 - 10/8/2014	10.0060	-34.8550	0.9841
433	All data	2.9167	-11.8900	0.4672
433	2/19/2014 - 10/7/2014	6.5120	-24.3710	0.7666
433	6/28/2014 - 10/7/2014	1.7787	-9.5964	0.9658
544	All data	9.3474	-33.1650	0.9456
544	2/19/2014 and after	9.4161	-33.4930	0.9617
584	All data	7.5722	-30.1410	0.8708
584	30 - 47 cm elevation only	9.2501	-36.0110	0.9739
642	All data	5.4378	-20.5850	0.4859
694	All data	6.0027	-22.4210	0.9524
694	2/20/2014 and after	5.9987	-22.5020	0.9852
694	2/20/2014 and after; 10/9/2014 removed	5.9139	-22.1890	0.9893
717	All data	3.1616	-14.0190	0.1960
717	1/27/2014 - 10/6/2014	8.8078	-30.5020	0.8462
717	1/27/2014 - 10/6/2014; two zero discharge readings removed	7.9449	-27.6480	0.9766
724	All data	0.6798	-5.8573	0.1001
724	Data prior to 10/6/2014	7.7744	-26.7890	0.9319
724	2/20/2014 - 10/6/2014	8.5657	-29.0590	0.9574
737	All data	8.0229	-31.3770	0.9483
737	Removed one point from 6/18/2014	8.2999	-32.3620	0.9577
769	All data	4.5946	-15.5530	0.4888
769	4/4/2014 - 10/6/2014	8.0748	-22.5350	0.9709
790	All data	4.0658	-15.7340	0.8917
790	Data through 10/9/2014	4.9057	-18.6960	0.9853

Basin 145

Summary

Channel change occurred in January 2014 and during high flow season of WY 2015.

Category 2c
Conditional – Time

Recommendations for future data collection

Discharge during high-flow. Need at least 4 more discharge readings to create rating curve for period after 04/28/2015. More cross-section elevations.

Histograms

This basin shows correlation between range of recording gage readings and range of staff gage measurements.

Cross-sectional Profiles

Channel is wide with relatively steep banks. No flows have been observed into the floodplain.
Cross-section geometry has changed over 3 years. The 2013 cross-section (red) is substantially different than 2014 (blue) and 2015 (green) cross-sections. Sediment was moved during a high flow between the 2013 and 2014 surveys, evident by large scour near the thalweg and a narrower, deeper channel in 2013.

Roughly 5 cm of aggradation was observed from 2014 to 2015, near the REW up to RBF. Alternatively, roughly 5 cm of erosion was observed from 2014 to 2015 near LEW up to LBF. This sediment has very likely been mobilized and re-arranged during late-2014/early-2015 high flows.

Maximum recorded stage height (~50cm) occurs well above bankfull but below both the left and right monuments. More elevational data collected between bankfull and the monuments in the future may improve our ability to model cross-sectional area by stage height.

Staff Gage-Recording Gage Time Series and Regression

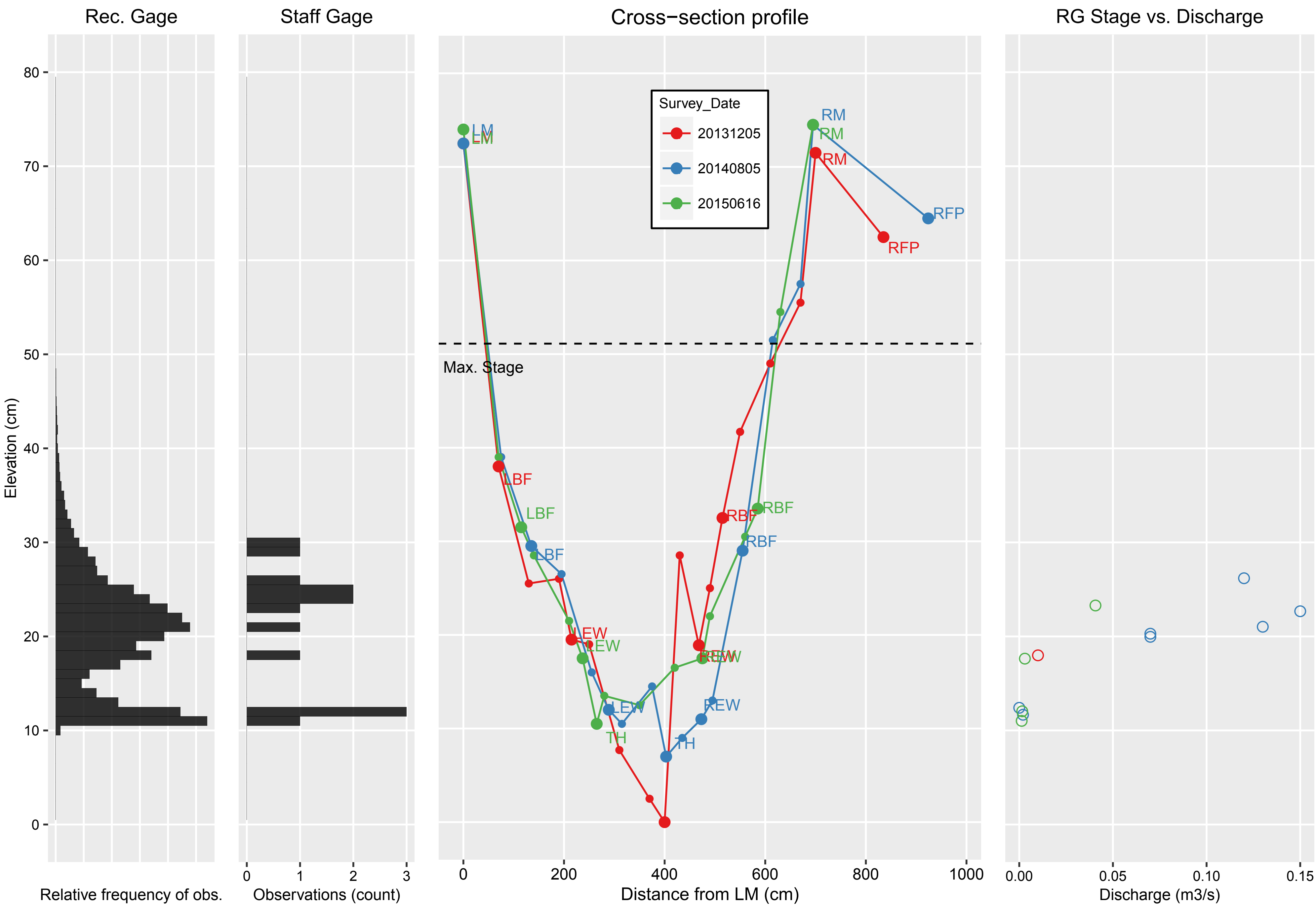
2015 low flows were not as low as 2014 low flows, which is consistent with the channel erosion/aggradation explained above. Relationship between staff gage and recording gage (blue line) is much closer to 1:1 at low flows than at high flows. Variation in the difference between staff gage and recording gage ranges from 0-4 cm.

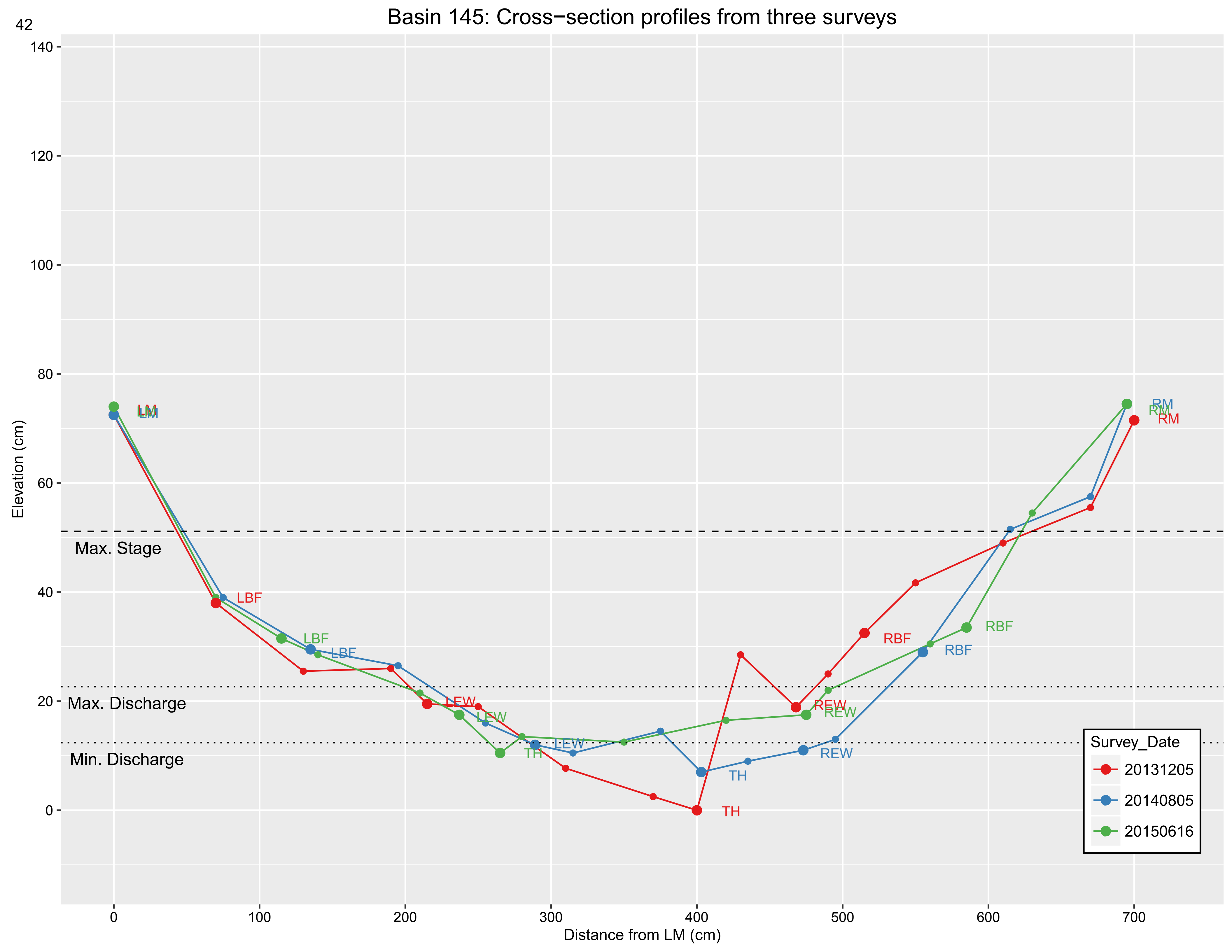
Stage-Discharge Rating Curve(s)

Due to changes in channel geometry over time, the rating curve for this basin must be divided into three distinct sections: Start of monitoring to 01/07/2014; 01/29/2014 to 10/08/20104 and 04/28/2015 to present. At this current point in time, the middle section is the only section where enough data are available to draw a reliable rating curve.

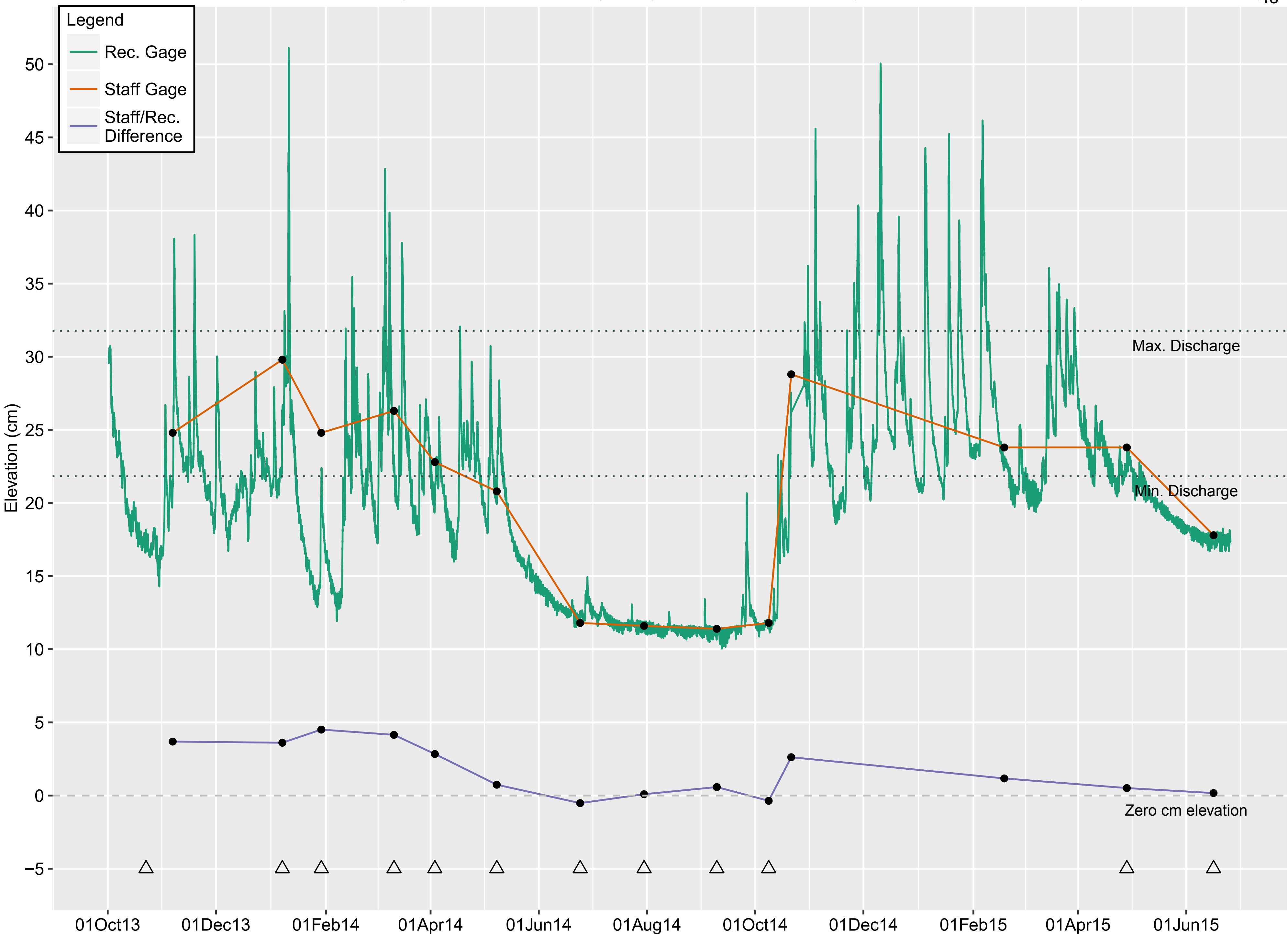
Stream gage station in basin 145 at mid flow (the removable staff gage is not shown).

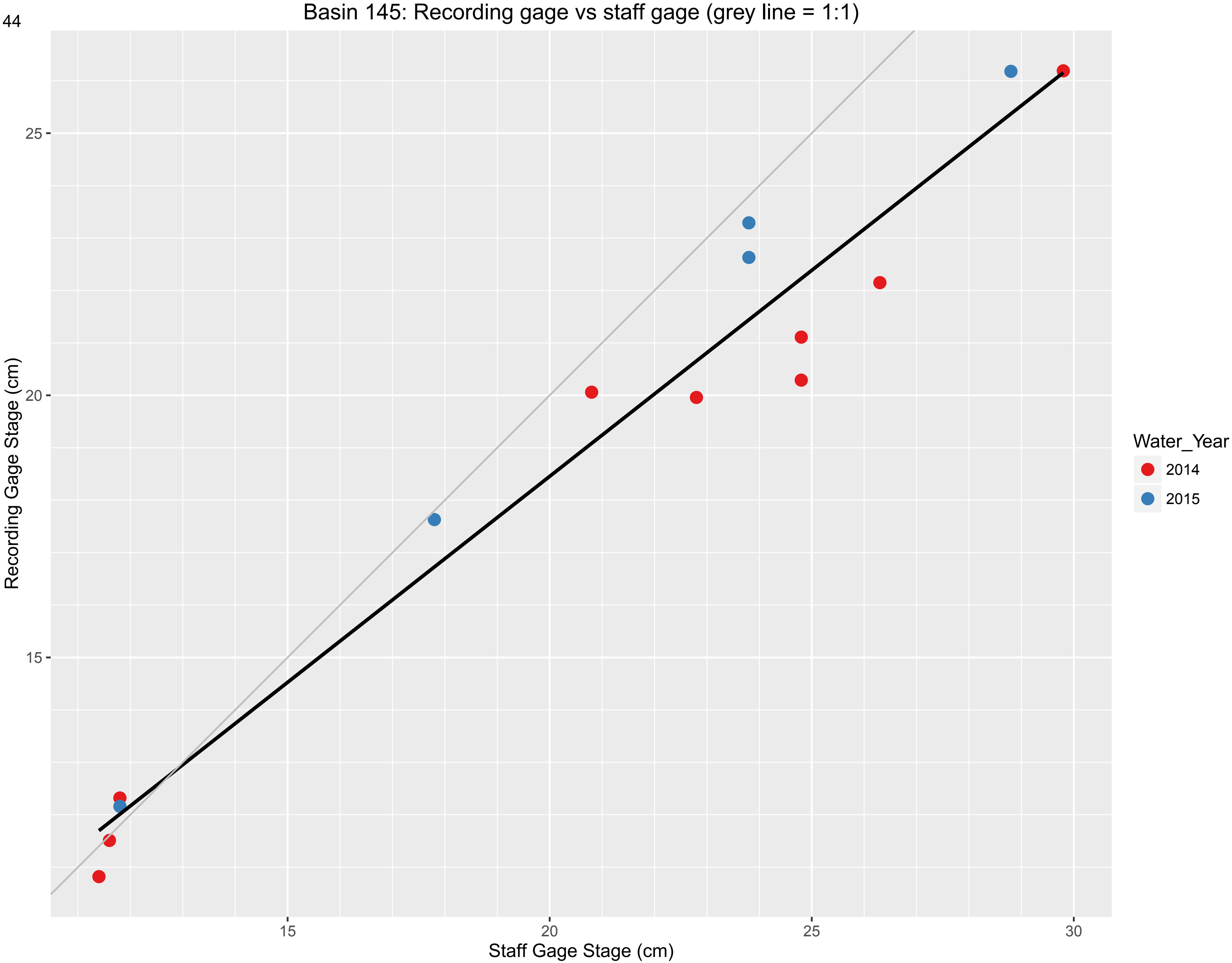
Basin 145: Gage data histograms, cross−section profile, and stage−discharge data




Basin 145: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131205
20140805
20150616
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700

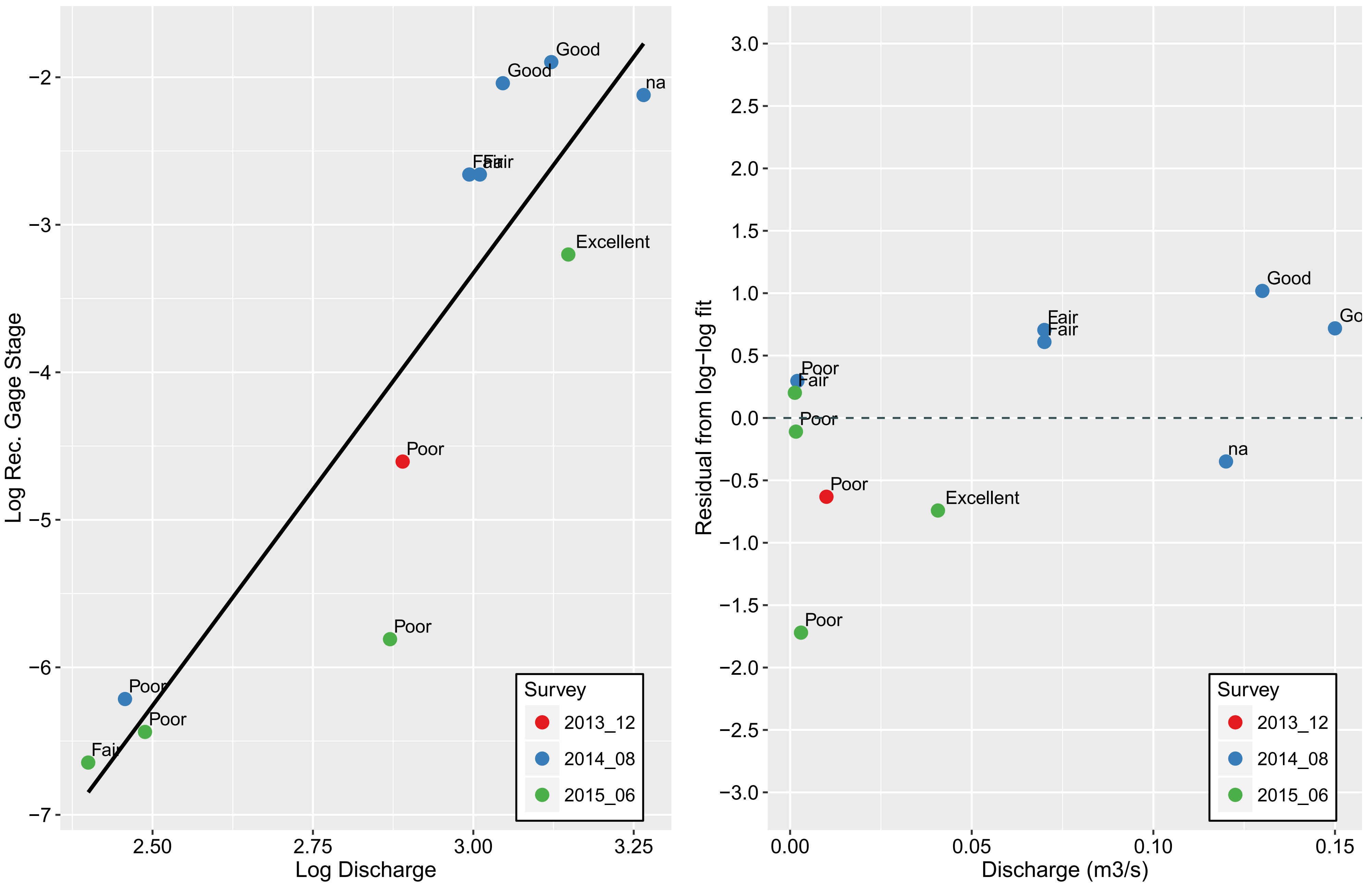
Basin 145: Stage data time series (triangles indicate discharge measurement dates)

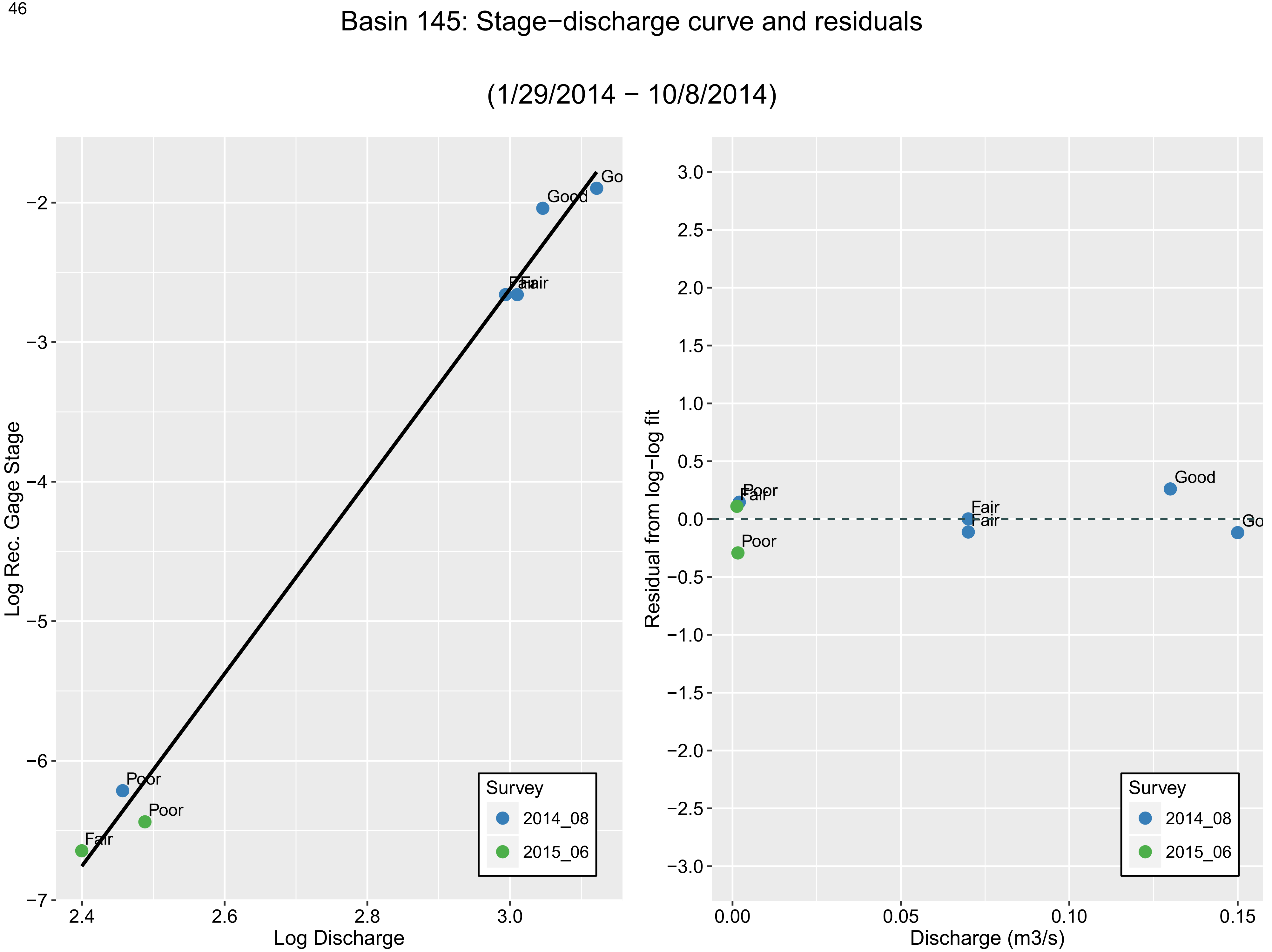



Basin 145: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
25
20
15
15
20
25
30
Water_Year
2014
2015

Basin 145: Stage−discharge curve and residuals

All available data





Basin 145: Stage−discharge curve and residuals
(1/29/2014 − 10/8/2014)
Log Rec. Gage Stage
Log Discharge
Residual from log−log fit
Discharge (m3/s)
Good
Fair
Poor
Survey
2014_08
2015_06

Basin 165

Summary
Rating curve is reliable for all measurements of discharge.

Category:
Accepted

Recommendations for future data collection
Discharge during high-flow. Cross-section stability survey above bankfull stage.

Note

Staff gage blown out by high flow in December 2014, replaced shortly thereafter. An adjustment factor was applied to all data that was collected before the replacement was made. See methods section for more details.

Histograms

This basin shows correlation between range of recording gage readings and range of staff gage measurements, especially near the median flow range. However, there are peaks in recording gage readings that have not observed on the staff gage.

Cross-sectional Profiles

Channel is relatively wide with a steep right bank and a gradual slope on the left bank.

The maximum recorded stage height occurs above the RM. Thus, at present, a stage/cross-sectional area relationship cannot be fully characterized up to the maximum recorded stage height.

Large change in 2015 cross section near right monument. This is likely due to an error in data collection or recording, as this point is located lower in elevation than the indicated TH. If the data point is accurate, then a large amount of scour has occurred near the REW.

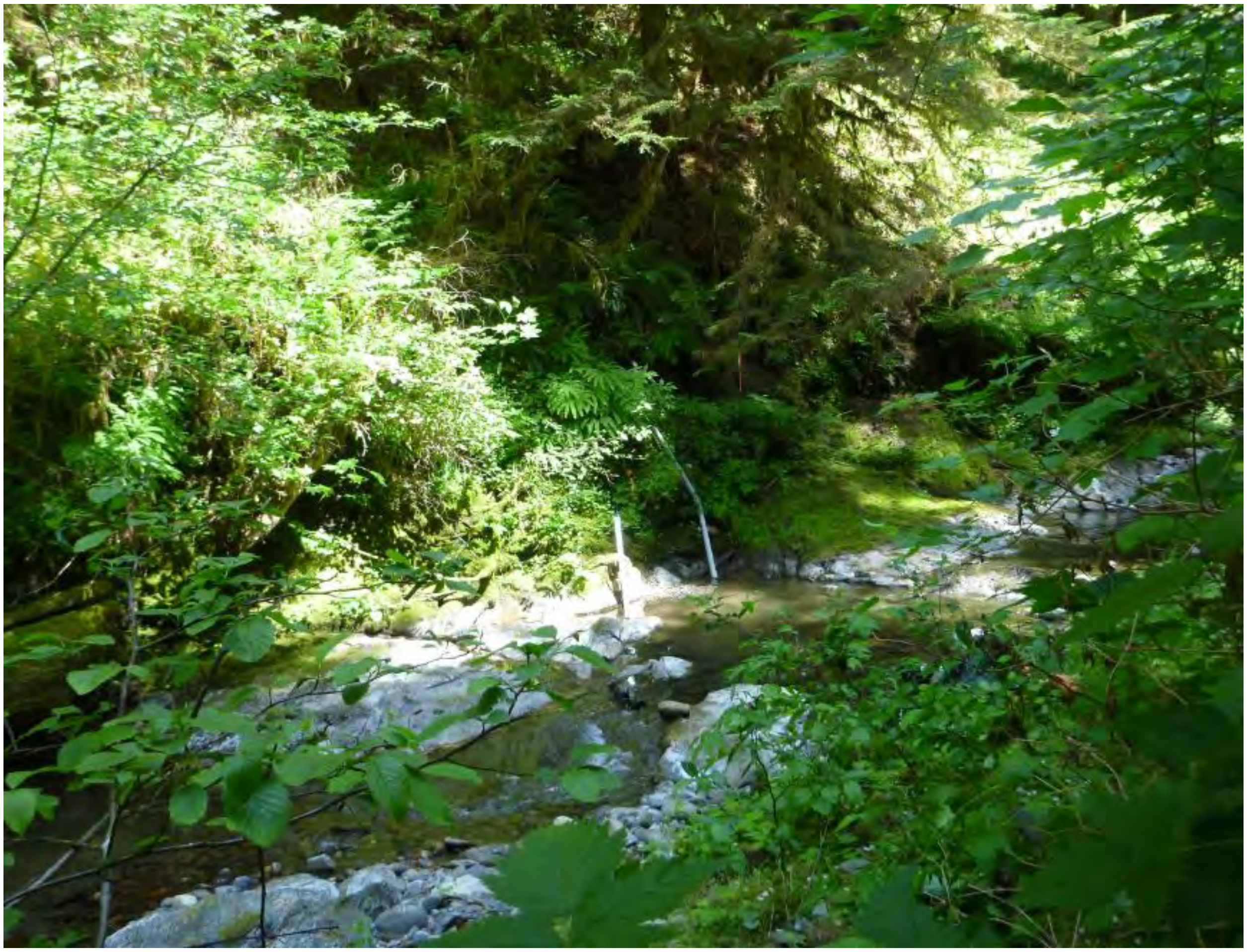
Staff Gage-Recording Gage Time Series and Regression

Constant baseflow is displayed over time, indicating that it is unlikely that a significant shift in the channel has occured.

On the line depicting the difference between staff gage and recording gage, the data point on 01/07/2014 shows a much larger difference in the response of the recording gage and the staff gage to a high discharge. This point occurs on the rising limb of the largest peak in stage height in 2014. When this point is removed from staff gage-recording gage regression the relationship is strongly correlated (R^2=) with a slope near 1. When this point is included, the relationship is not strongly correlated (R^2=?). This difference can likely be attributed to the lack of precision in the recording gage data during rapidly rising flows as explained in the discussion section of part 1.

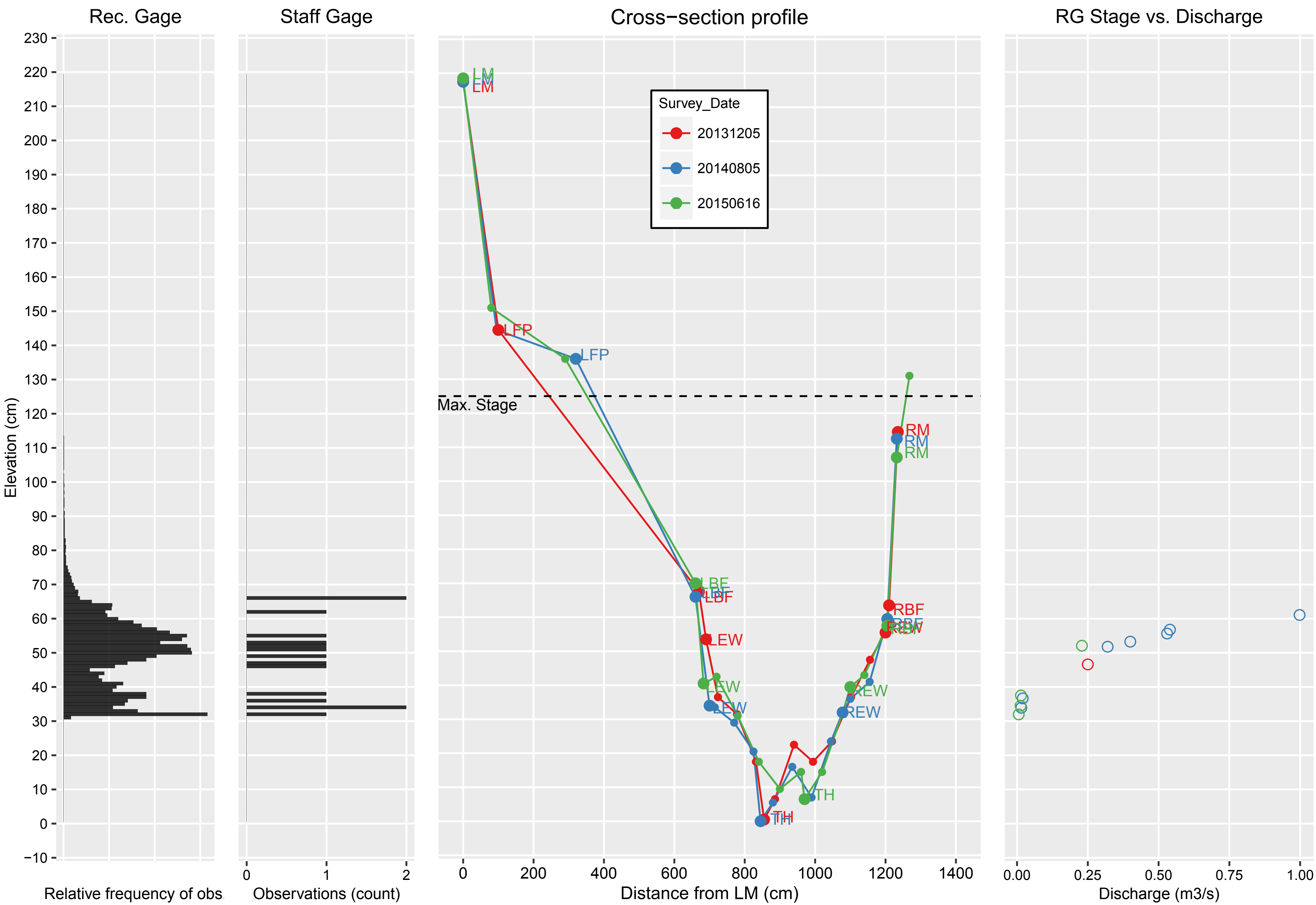
Stage-Discharge Rating Curve

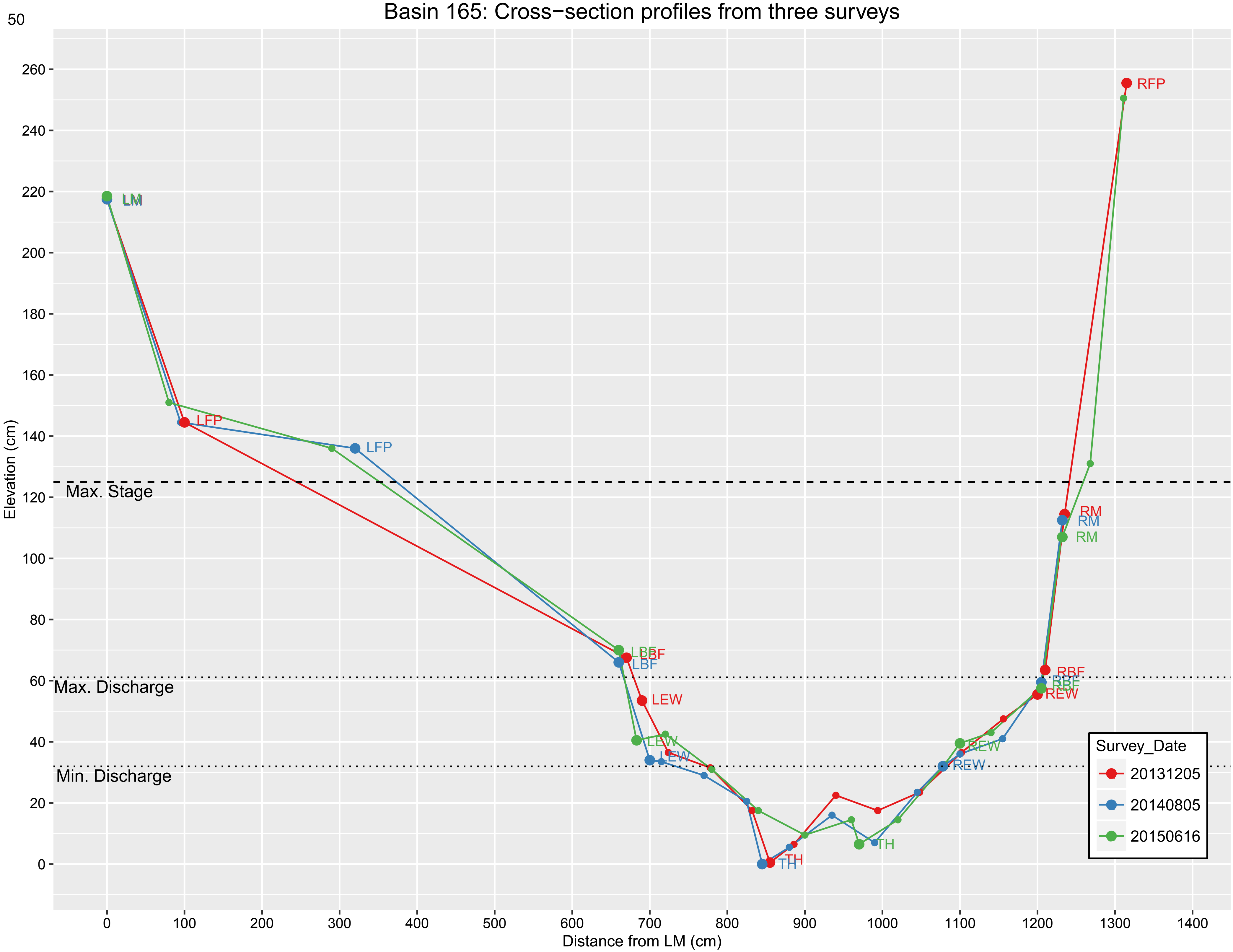
Rating curve displays a strong correlation between discharge and stage height for entire period of monitoring. Highest measured discharge occurs at 61.08 cm relative elevation, which is roughly the median flow value.



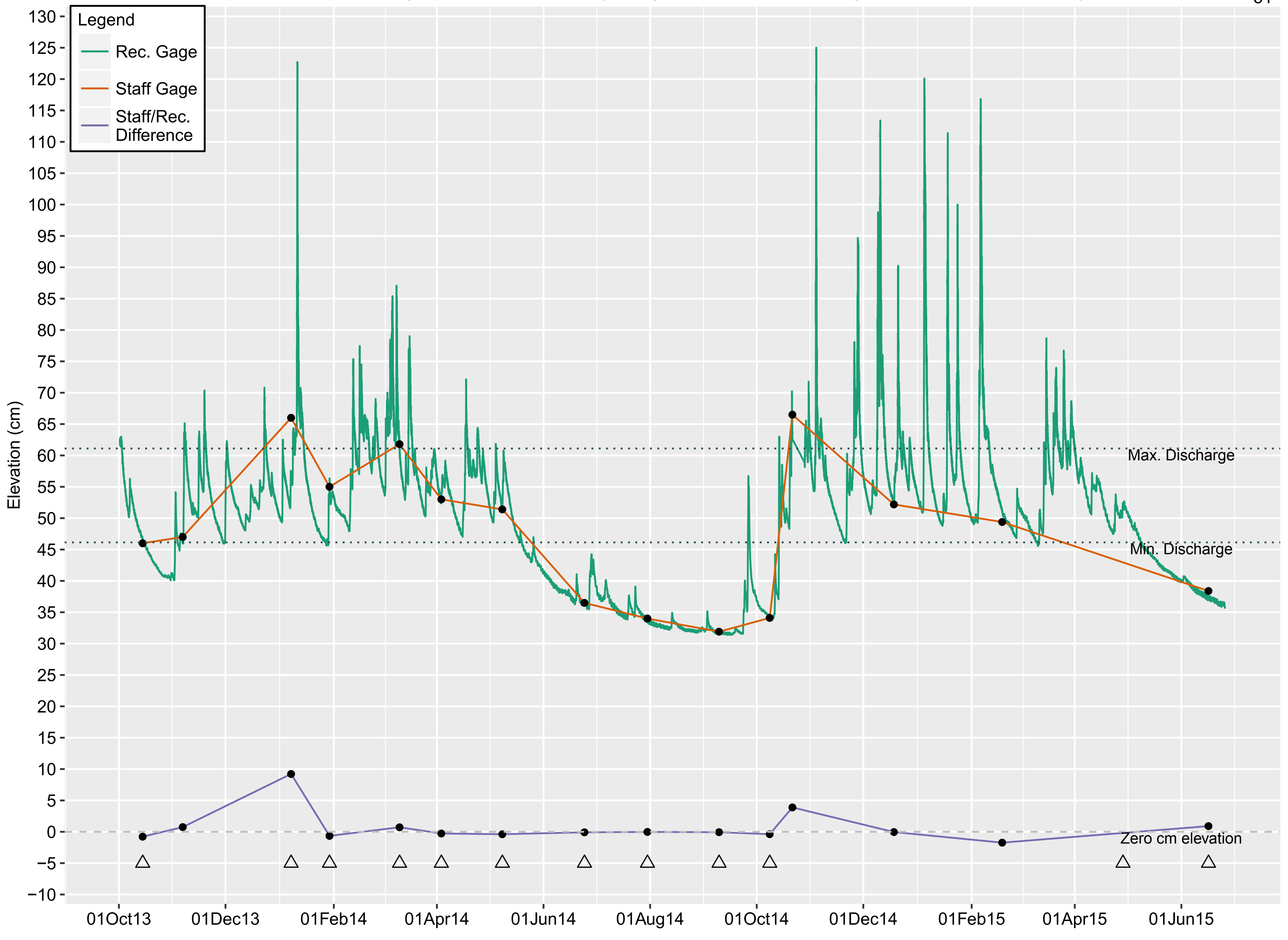
Stream gage station in basin 165 at low flow.

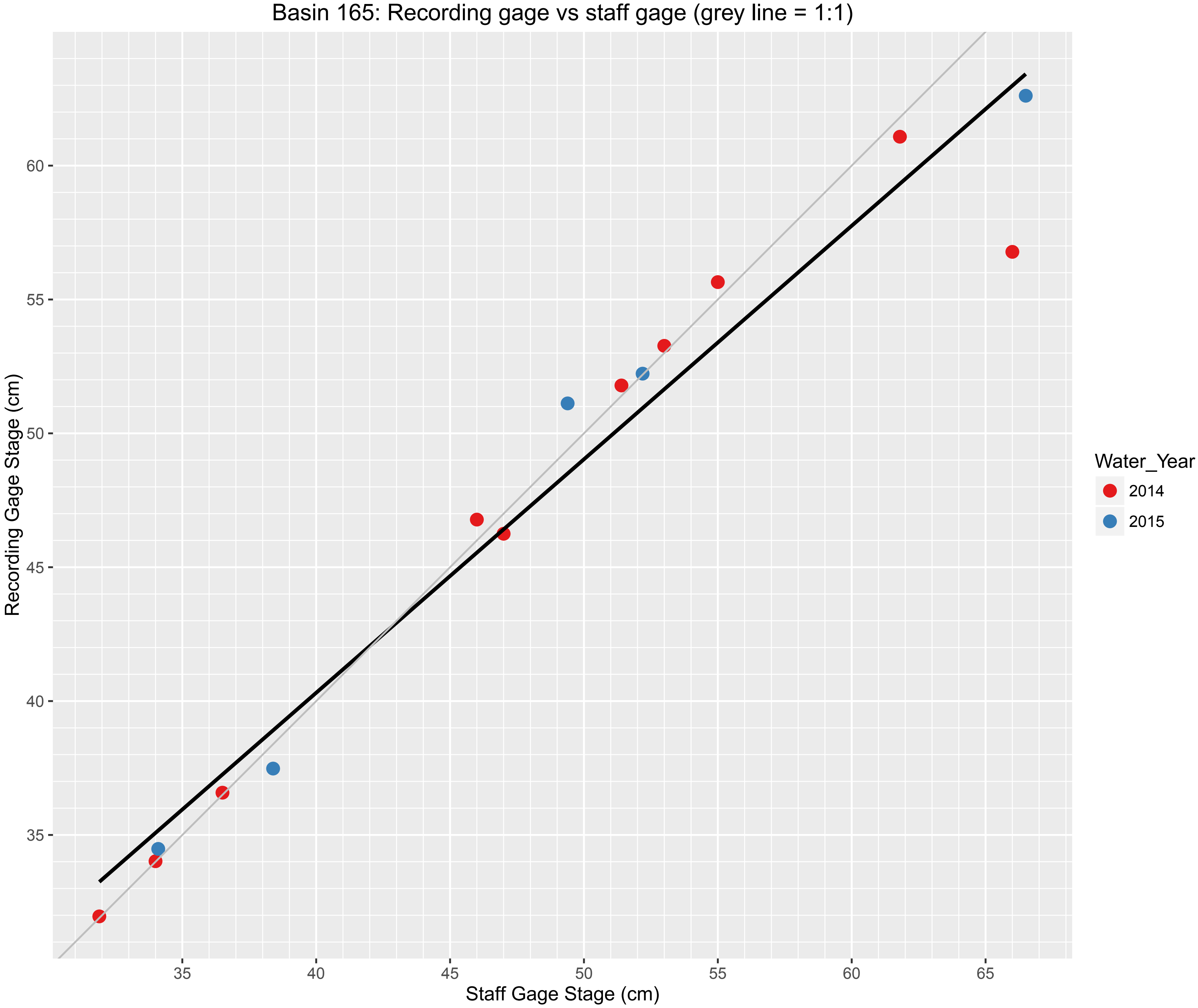
Basin 165: Gage data histograms, cross−section profile, and stage−discharge data

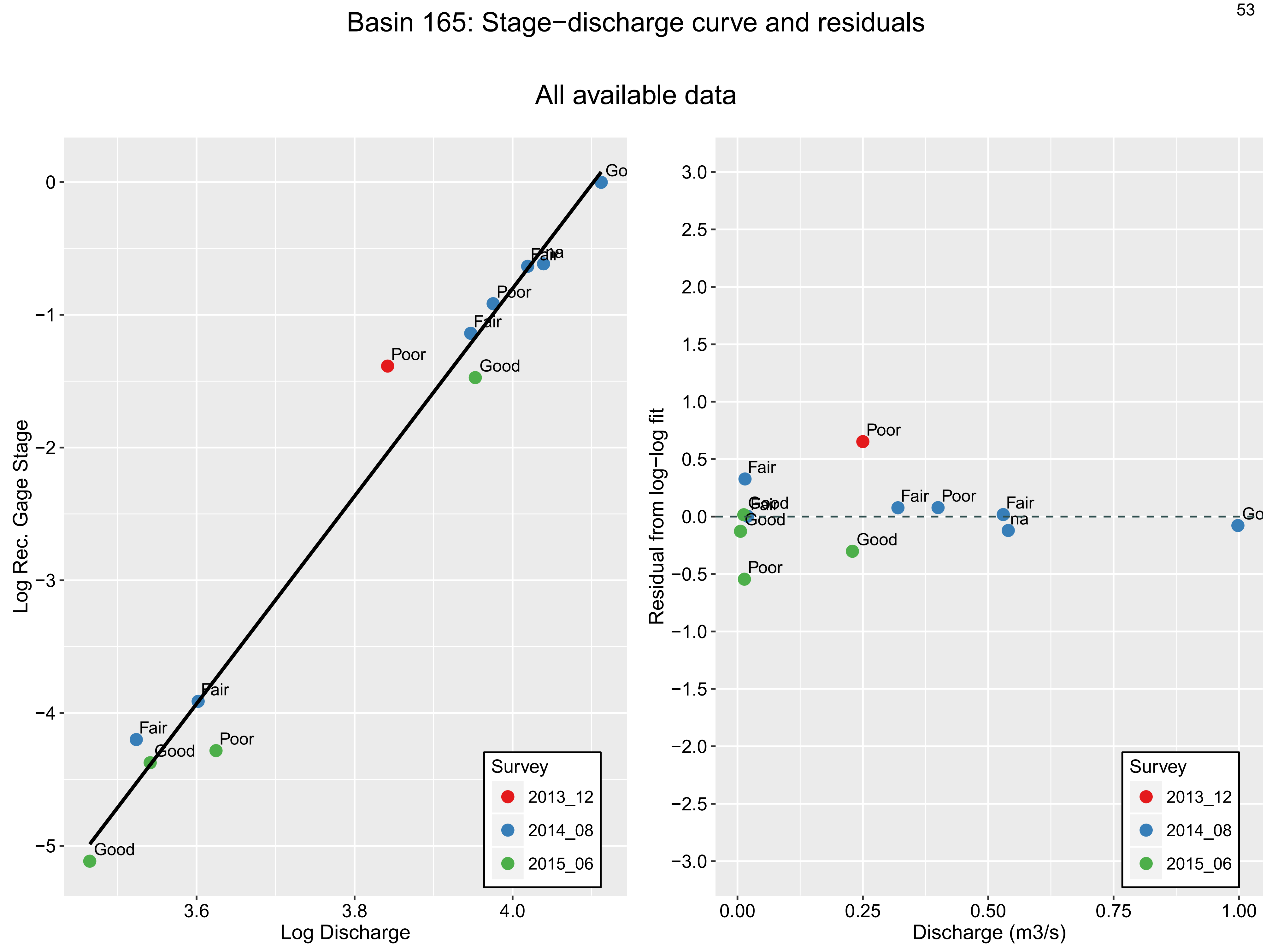



Basin 165: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
LM
LFP
LFP
LBF
LBF
LBF
LEW
LEW
LEW
TH
TH
TH
REW
REW
REW
RBF
RBF
RBF
RM
RM
RM
RFP
Max. Stage
Max. Discharge
Min. Discharge
Survey_Date
20131205
20140805
20150616

Basin 165: Stage data time series (triangles indicate discharge measurement dates)




Basin 165: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
35
40
45
50
55
60
65
Water_Year
2014
2015


Basin 165: Stage−discharge curve and residuals
All available data
Log Rec. Gage Stage
Log Discharge
Residual from log−log fit
Discharge (m3/s)
Survey
2013_12
2014_08
2015_06
Good
Fair
Poor
na

Basin 196

Summary
Two side channels on right bank. Limited changes in cross-section from 2014 to 2015.

Category:
Conditional – Stage Height

Recommendations for future data collection
Discharge above 65 cm relative elevation. Cross-section stability survey above bankfull, especially on the right bank. Cross-section stability to better identify elevation of RM.

Histograms

Staff gage and recording gage ranges well correlated within the median range of flows. However, there are peaks in recording gage readings that are not measured on the staff gage.

Cross-sectional Profiles

Channel is relatively narrow with a steep left bank and gradual right bank. A side channel is present the right bank.

Overall channel geometry is relatively stable since monitoring began, most notably on the left bank. Some scour/erosion occurred on right bank and TH from 2013 (red) to 2014 (blue). Notable scour occurred on the right bank from 2013 to 2014. Scour between 2014 and 2015 (green) at this location is undetectable due to lack of data in 2015. More data between the RBF and RM would help to determine if the right bank and experienced additional scour/erosion from 2014 to 2015.

Outlying data point at roughly 450 cm from LM on 2015 cross-section may potentially be due to a data collection or recording error. Or perhaps, there is now (as of 2015) a cobble just above RBF that was not present before that is 40 cm high and 50 cm wide.

Staff Gage-Recording Gage Time Series and Regression

Constant baseflow is displayed over time, indicating that it is unlikely that a significant shift in the channel has occured. Relationship between staff gage and recording gage (blue line) is much closer to 1:1 at low flows. This may be attributed to a few different factors including the lack of precision in the recording gage during quickly rising or falling stage heights.

Data point at 01/29/2015 peak has a higher staff gage reading than the highest recording gage data point in the peak. Close up detail on the recording gage time-series shows that the point is located on the falling limb of the peak, but also that the sensor gage fluctuates up and down within the falling peak by ~2cm which is also the distance it plots away from the regression line.

Regression of staff gage-recording gage relationship after 09/09/2014 shows a strong correlation and slope closer to 1 than for the entire dataset. This includes data at the upper and lower ends of the flow regime, for almost an entire year. This suggests that the relationship between staff gage and recording gage has potentially improved in 2015. This could potentially be due to better data collection and/or staff gage replacement and associated adjustment factor.

Stage-Discharge Rating Curve

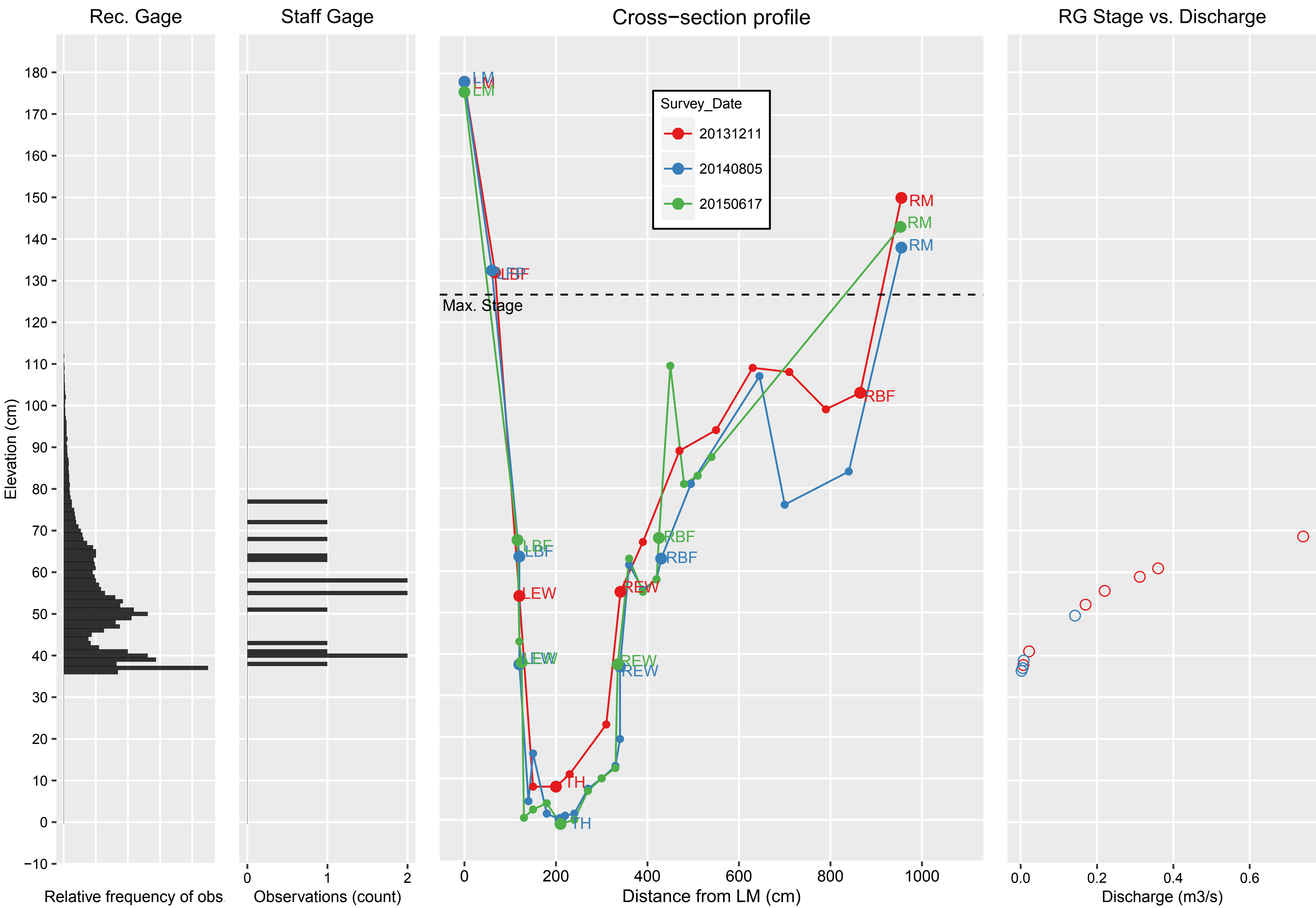
The geometry of the channel above the highest recorded stage for which a discharge measurement was taken (approximately 68 cm) is very different from the one within the range of discharge measurements (37 to 68 cm). Therefore the preliminary rating curve cannot be applied for these high flows.

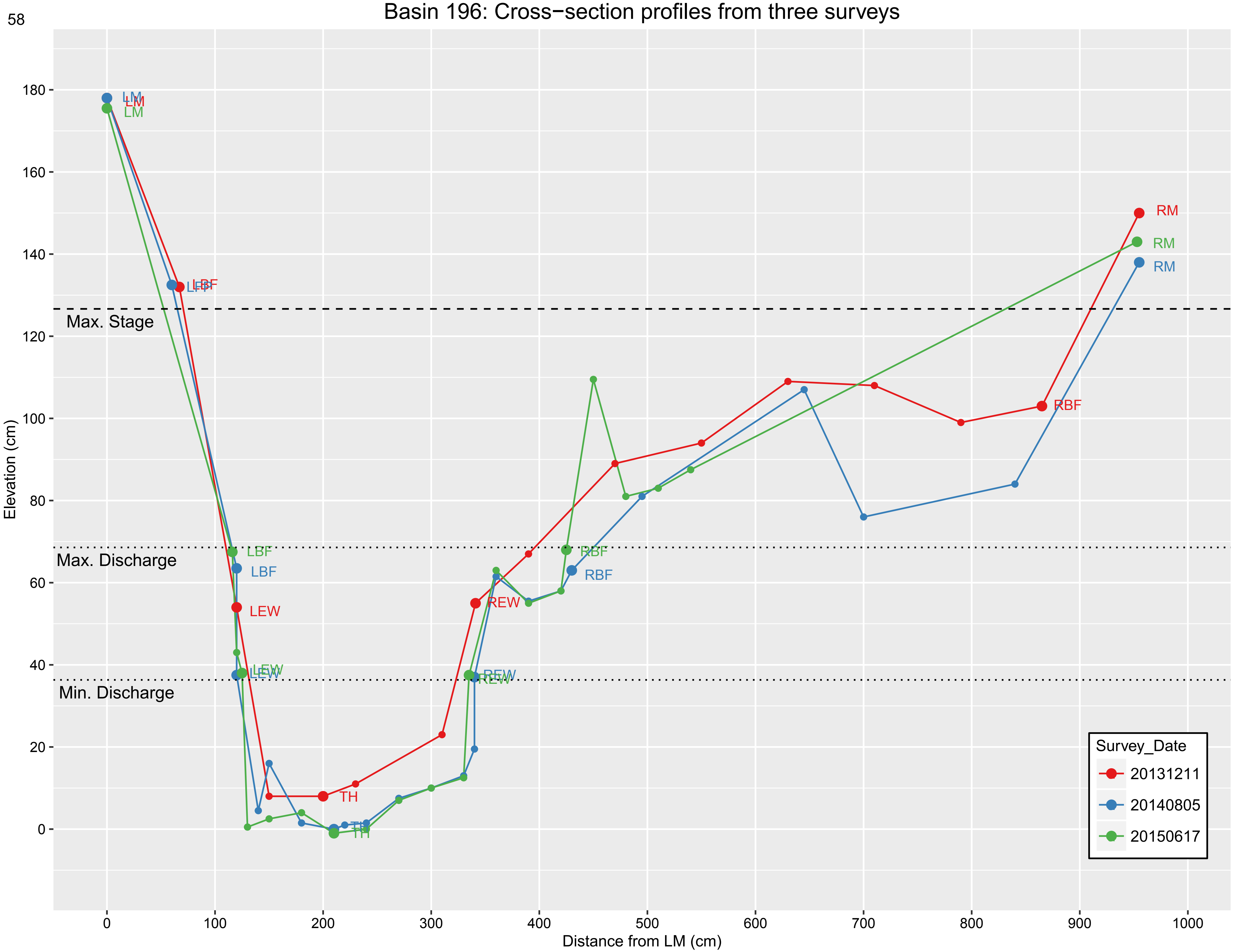
The rating curve model that used all data points showed a log-log relationship that was not linear. After further analysis, three sub-sections of rating curves were created based on elevation, below 45 cm, between 45 and 65 cm and above 65 cm. Discharge below 45 cm is likely influenced by undercutting on the left bank.

2015 data may need a new rating curve, but that is difficult to determine with so few data points at this time.

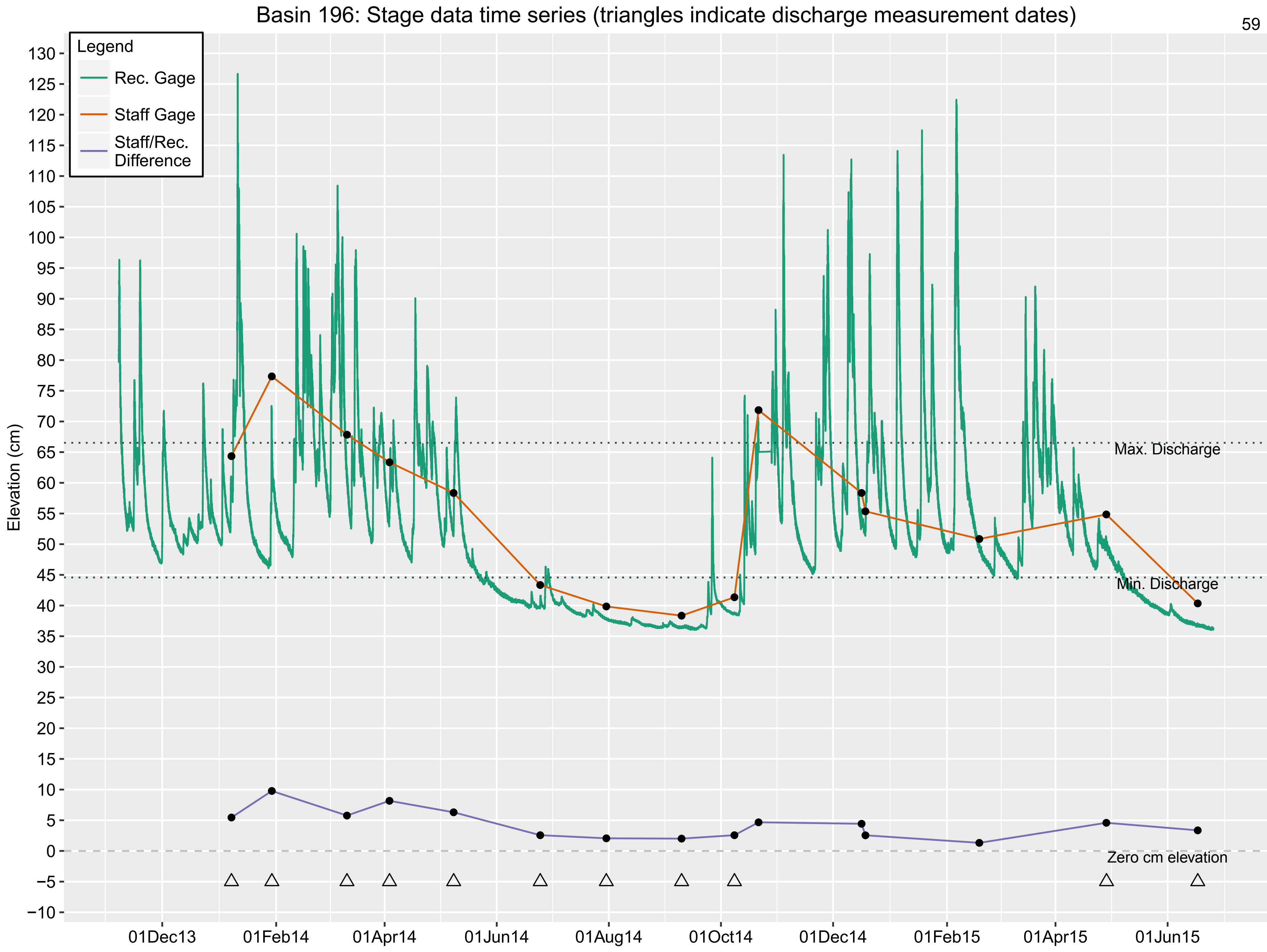
Stream gage station in basin 196 at low flow.

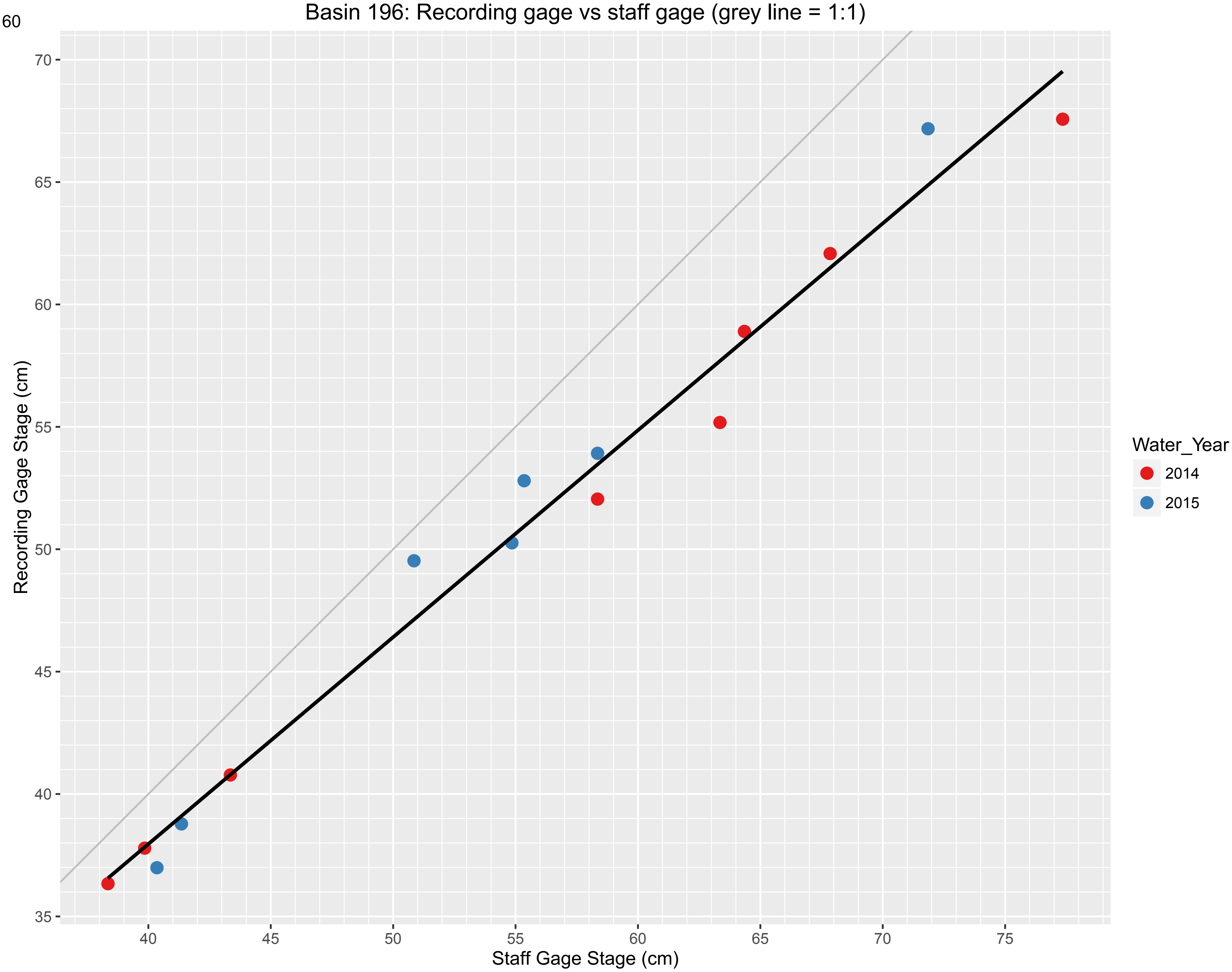
Basin 196: Gage data histograms, cross−section profile, and stage−discharge data





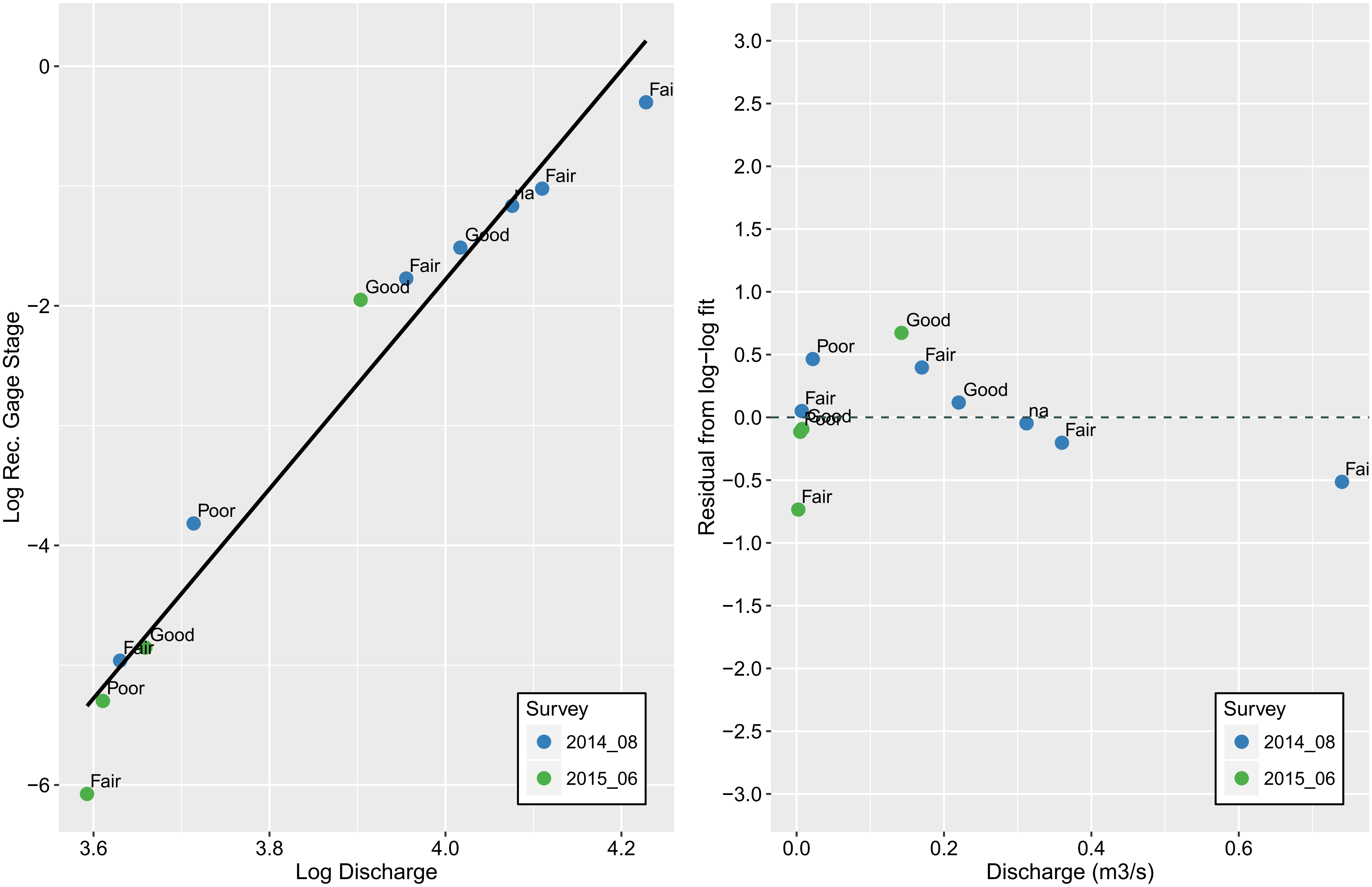
Basin 196: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131211
20140805
20150617

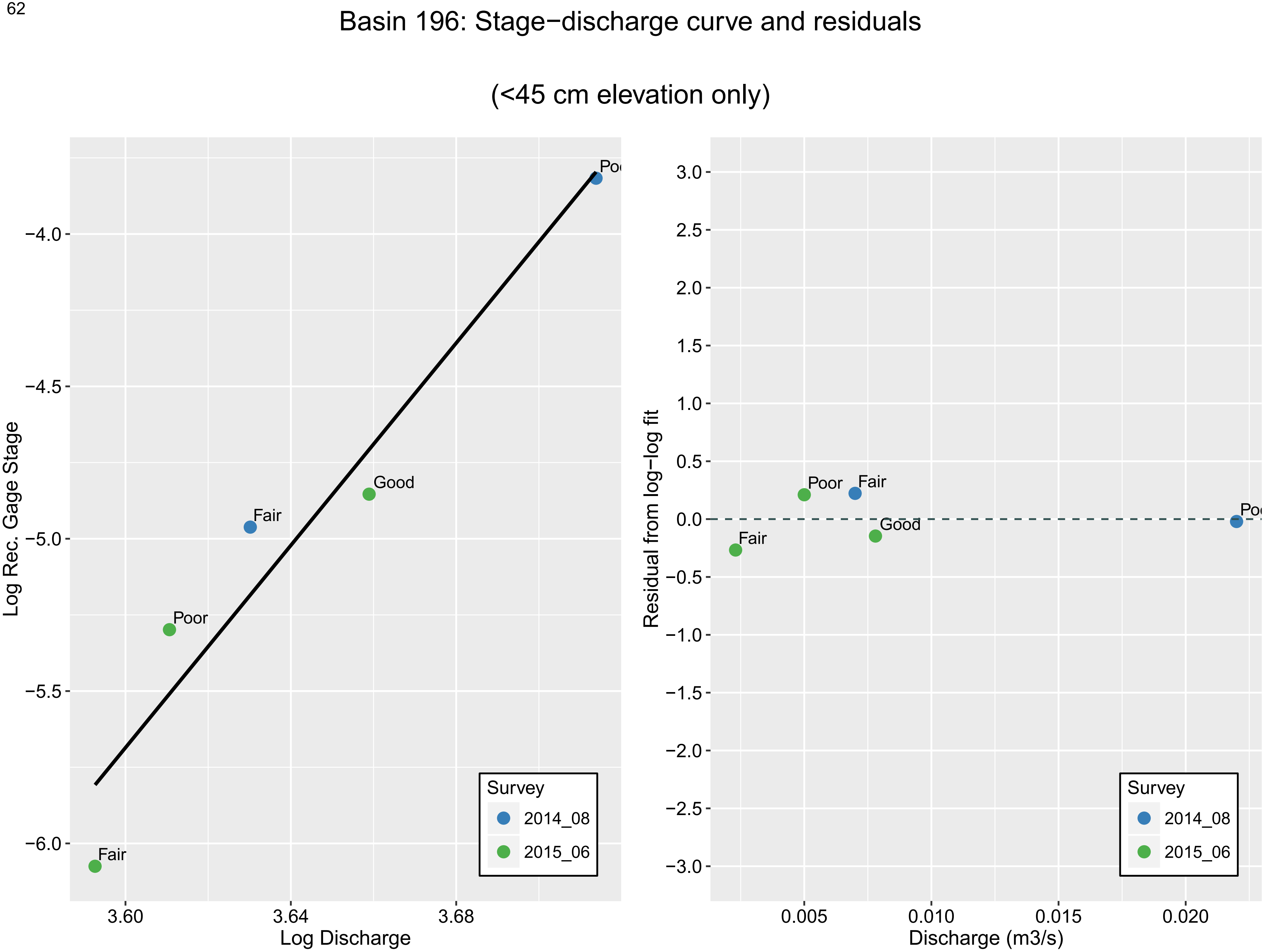

Basin 196: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec. Difference
Elevation (cm)
Max. Discharge
Min. Discharge
Zero cm elevation
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
−10
01Dec13
01Feb14
01Apr14
01Jun14
01Aug14
01Oct14
01Dec14
01Feb15
01Apr15
01Jun15


Basin 196: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
Water_Year
2014
2015
35
40
45
50
55
60
65
70
75

Basin 196: Stage−discharge curve and residuals

All available data

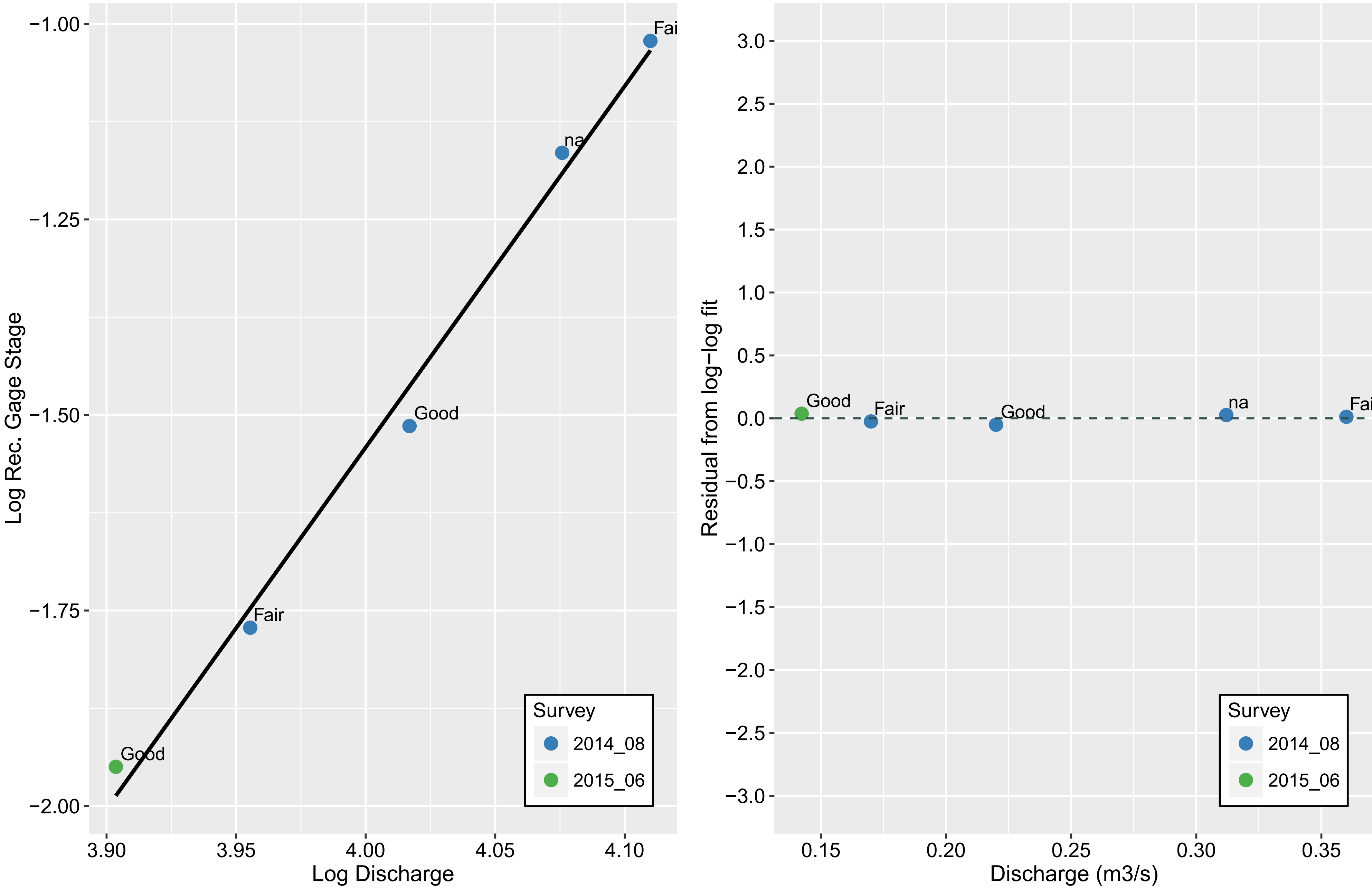




Basin 196: Stage−discharge curve and residuals
(<45 cm elevation only)
Log Rec. Gage Stage
Log Discharge
−4.0
−4.5
−5.0
−5.5
−6.0
3.60
3.64
3.68
Poo
Good
Fair
Poor
Fair
Survey
2014_08
2015_06
Residual from log−log fit
Discharge (m3/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
0.005
0.010
0.015
0.020
Poor
Fair
Good
Fair
Poo
Survey
2014_08
2015_06

Basin 196: Stage−discharge curve and residuals

(45 − 65 cm elevation only)



Basin 328

Summary

High flows in 2015 buried recording gage intake and shifted main channel towards the right bank. Rating curve available for low flows of 2014.

Category:
Conditional — Time

Recommendations for future data collection

Before any additional data can be utilized, gage intake needs to be uncovered and located in main channel.
Discharge during high-flow.
Need at least 4 more points to create rating curve for period after 10/8/2014.

Histograms

This basin shows correlation between range of recording gage readings and range of staff gage measurements, especially near the median flow range. However, there are peaks in recording gage readings that are not observed on staff gage measurements.

Cross-sectional Profiles

Large change in cross-section elevation from 2013 (red) to 2014 (blue), indicating that ~10 cm of aggradation occurred across the entire channel bottom. However, this aggradation seems to be uniform throughout the channel and potentially did not alter the channel geometry. LBF and RBF heights significantly higher in 2013; which is likely associated with the fact that the 2013 survey was conducted during high flow.

A significant amount of scour occurred between 2014 (blue) and 2015 (green) surveys near the REW, shifting the TH from left to right. Potential aggradation may have occurred from 2014 to 2015 on the left bank, and the gage intake is now being reported as out of the main channel and buried. This is well represented on the recording gage time series by the increase in baseflow from 2014 to 2015.

Staff Gage-Recording Gage Time Series and Regression

In 2015, the observed baseflow occurs at a higher elevation than the observed 2014 baseflow. Notes from field visits in 2015 indicate that both gages are out of the main channel and that the intake of the recording gage is buried. It is not clear from the time-series data during which 2015 high-flow event the channel shift occurred.

Recording gage data is missing directly after a staff gage reading was taken between 10/22 – 10/29/2014. The staff gage-recording gage relationship on

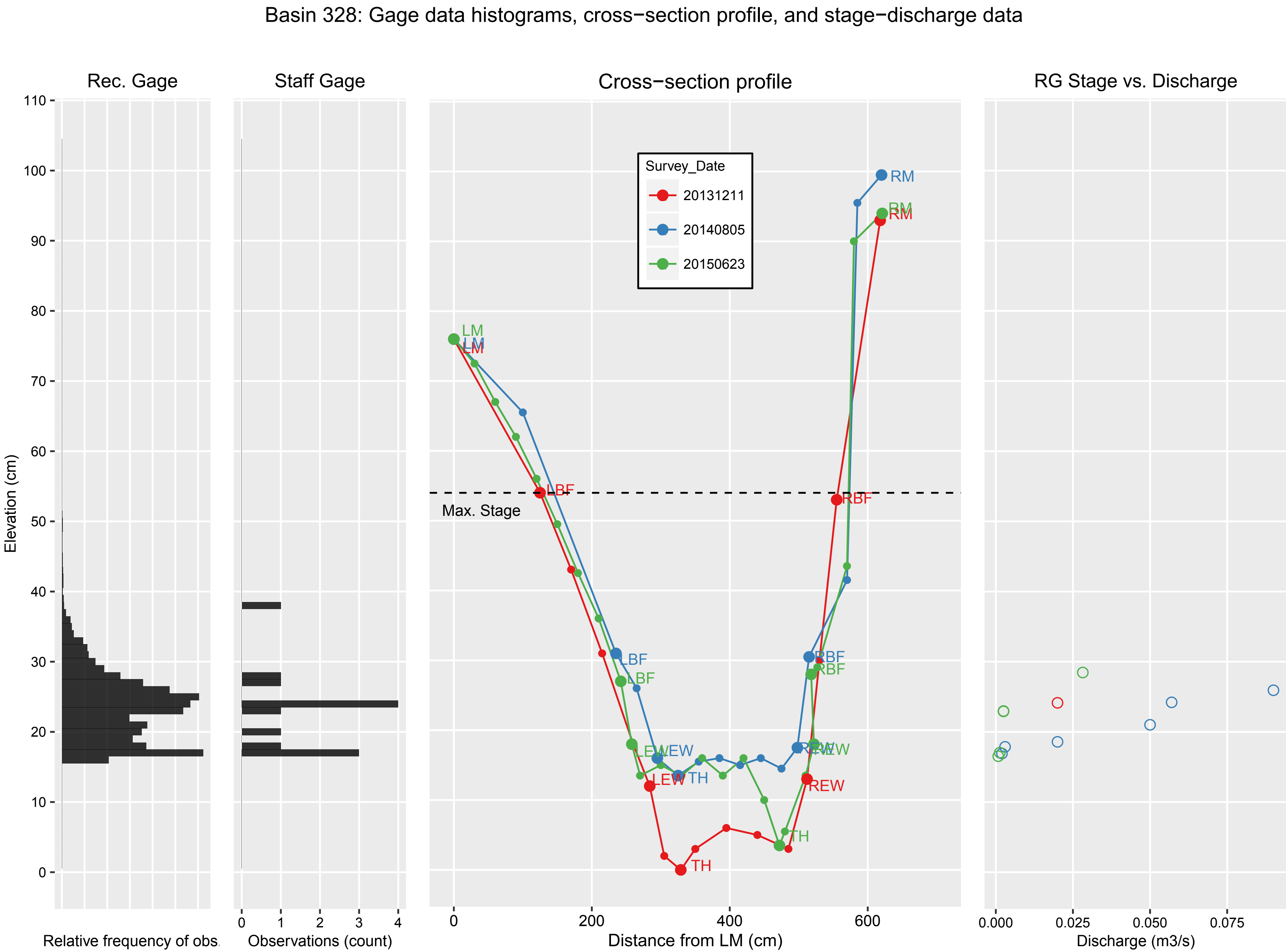
10/22/2014 strays significantly from the necessary 1:1 ratio (blue line on time-series plot).

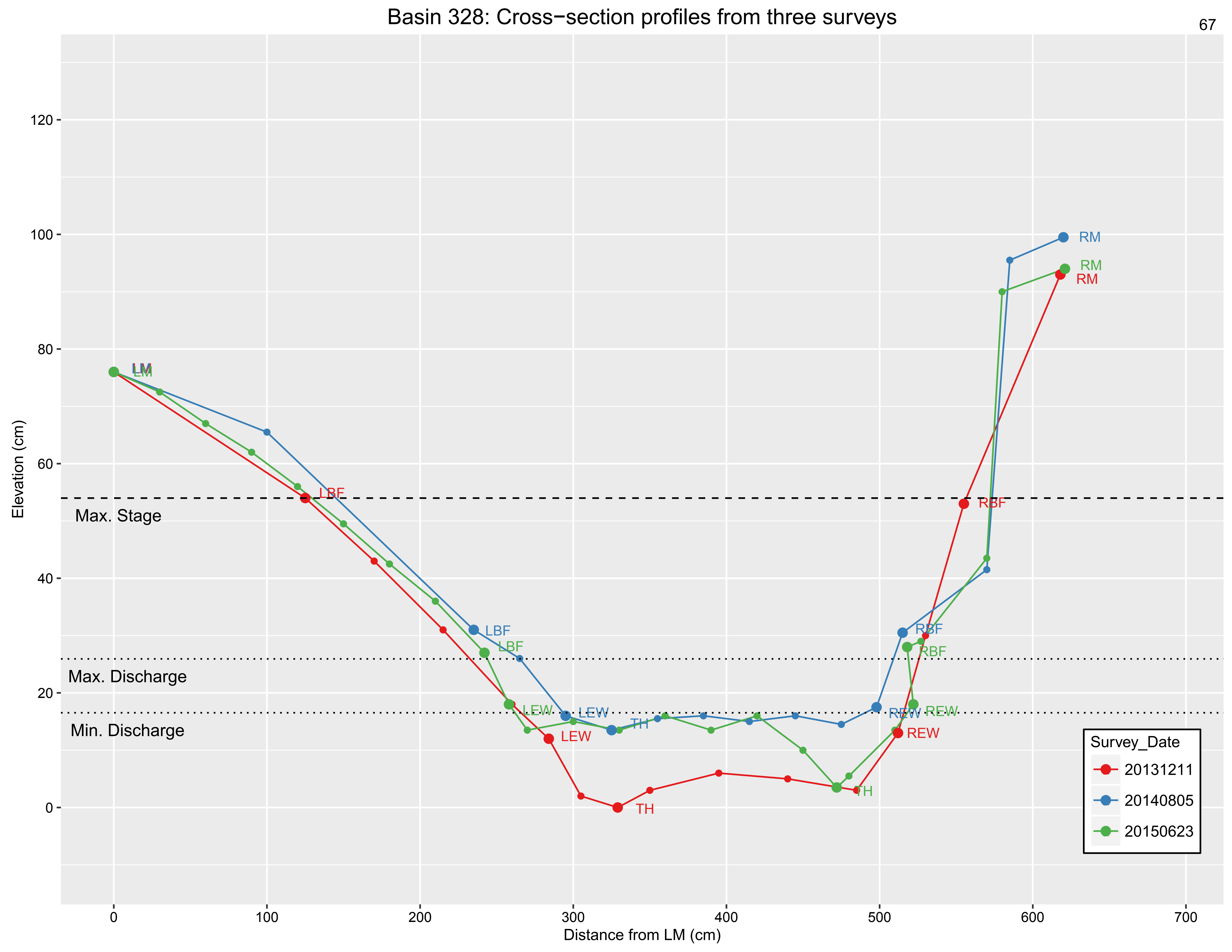
Stage-Discharge Rating Curve

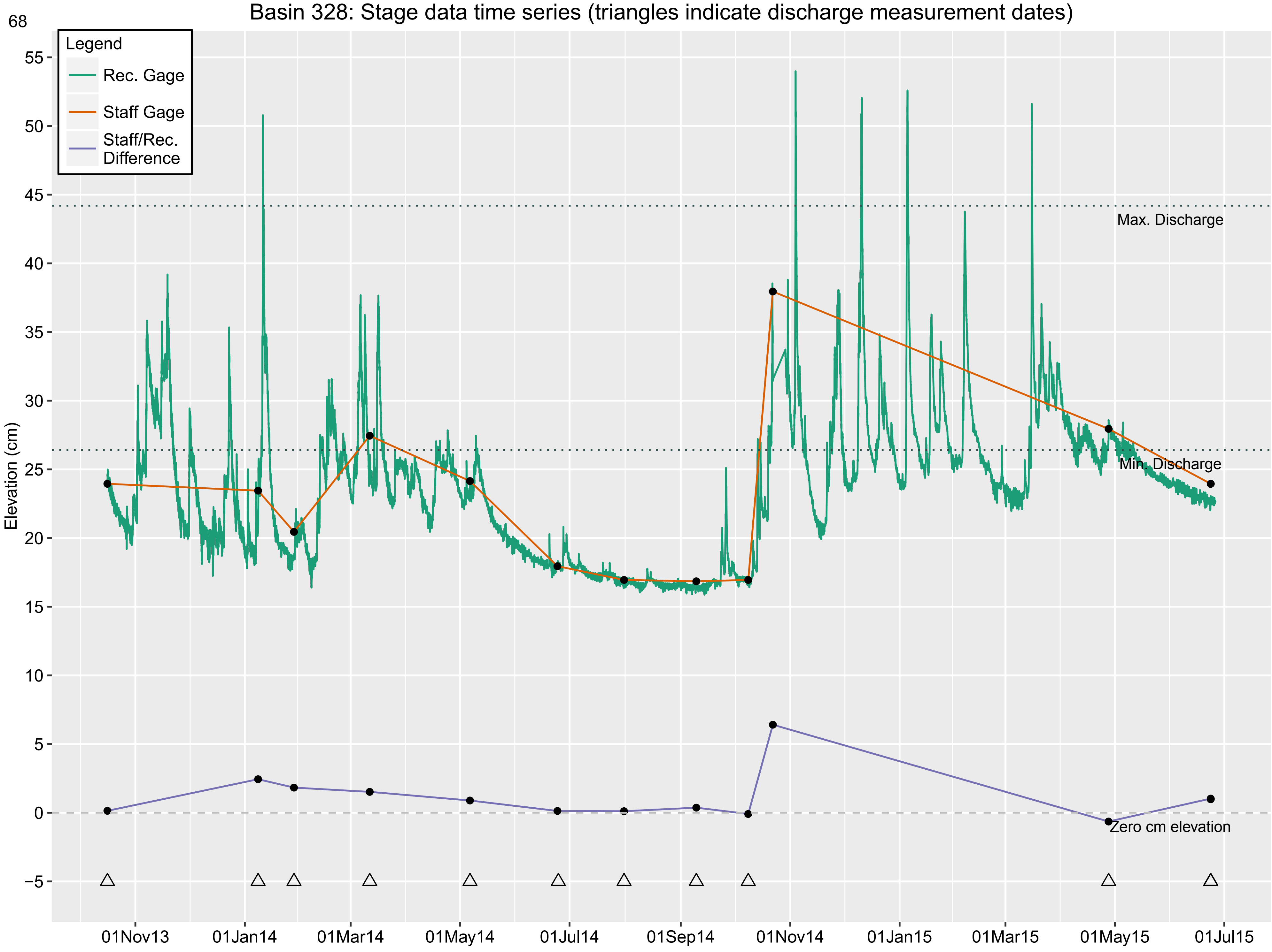
Due to changes in channel geometry over time, the rating curve for this basin must be divided into three sub-sections: Start of monitoring to 01/29/2014; 03/11/2014 to 10/08/20104 and 04/28/2015 to present. At this current point in time, the middle section is the only section where enough data is available to draw a reliable rating curve.

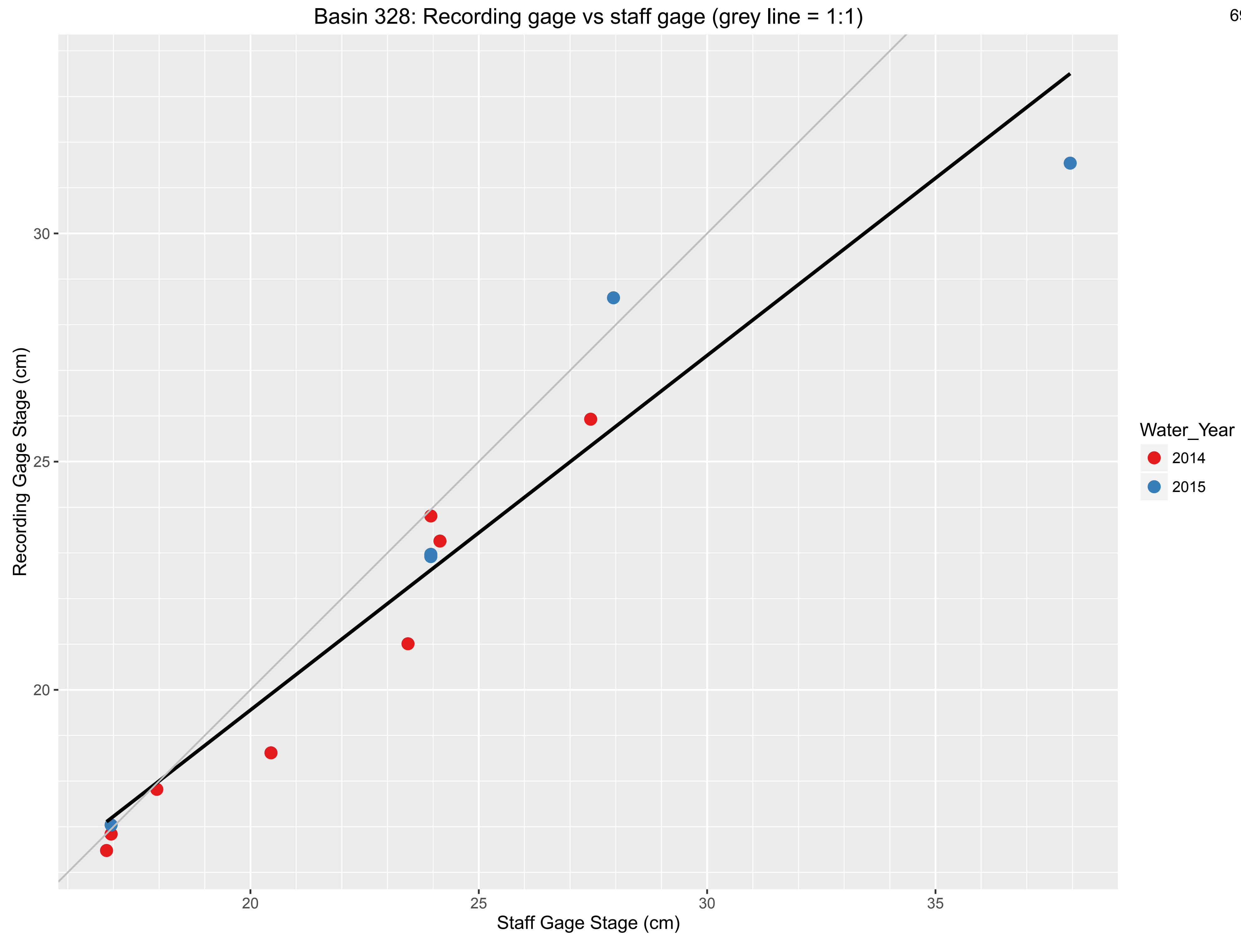
An adjustment factor may be able to be applied after 04/28/2014, however there is still too few data points in this sub-section for it to be appropriate at this time.

Stream gage station in basin 328 at low flow (the removable staff gage is not shown).

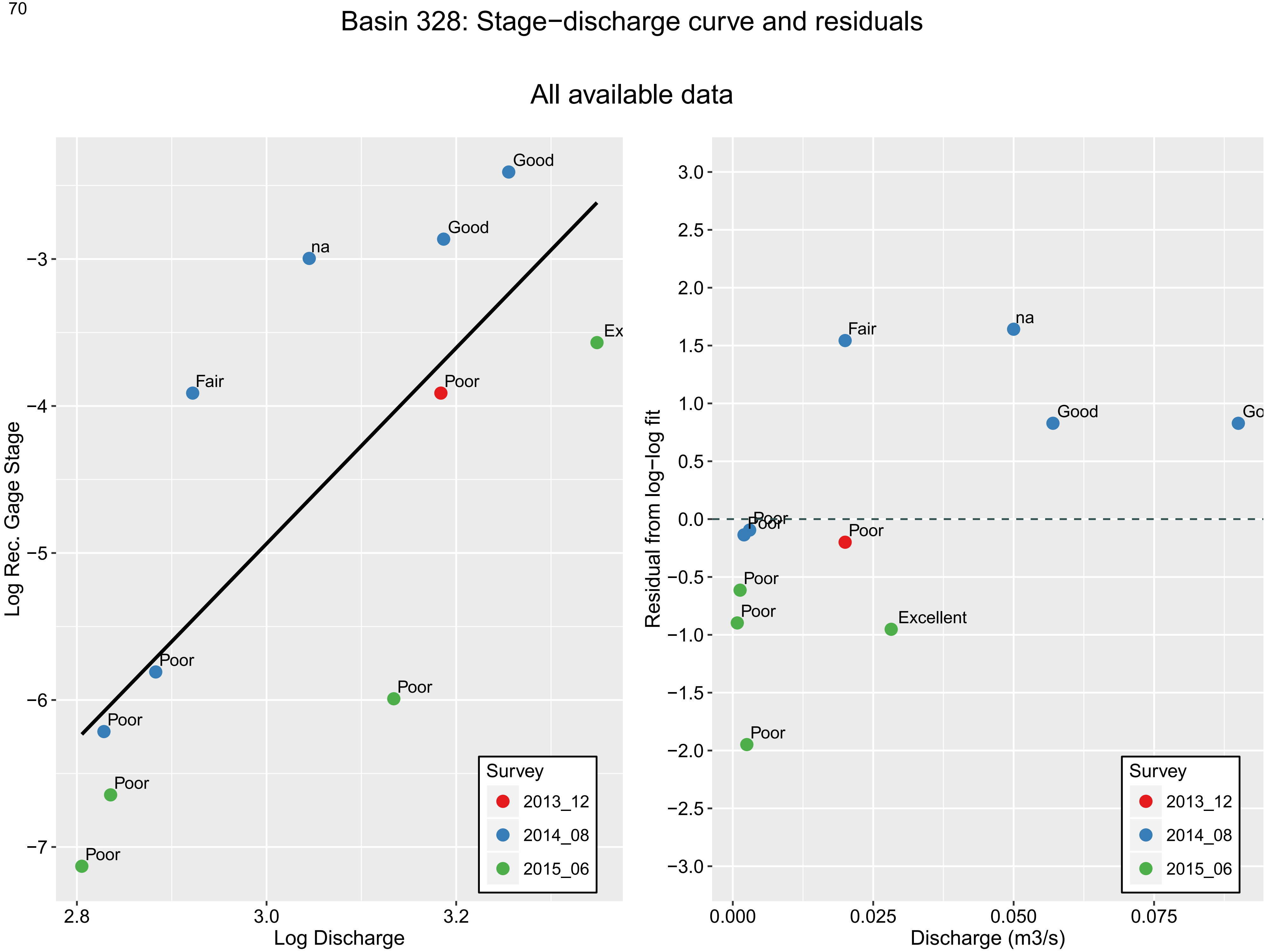

Basin 328: Gage data histograms, cross−section profile, and stage−discharge data
Rec. Gage
Staff Gage
Cross−section profile
RG Stage vs. Discharge
Elevation (cm)
Relative frequency of obs.
Observations (count)
Distance from LM (cm)
Discharge (m3/s)
Survey_Date
20131211
20140805
20150623
Max. Stage
LM
LBF
LEW
TH
REW
RBF
RM

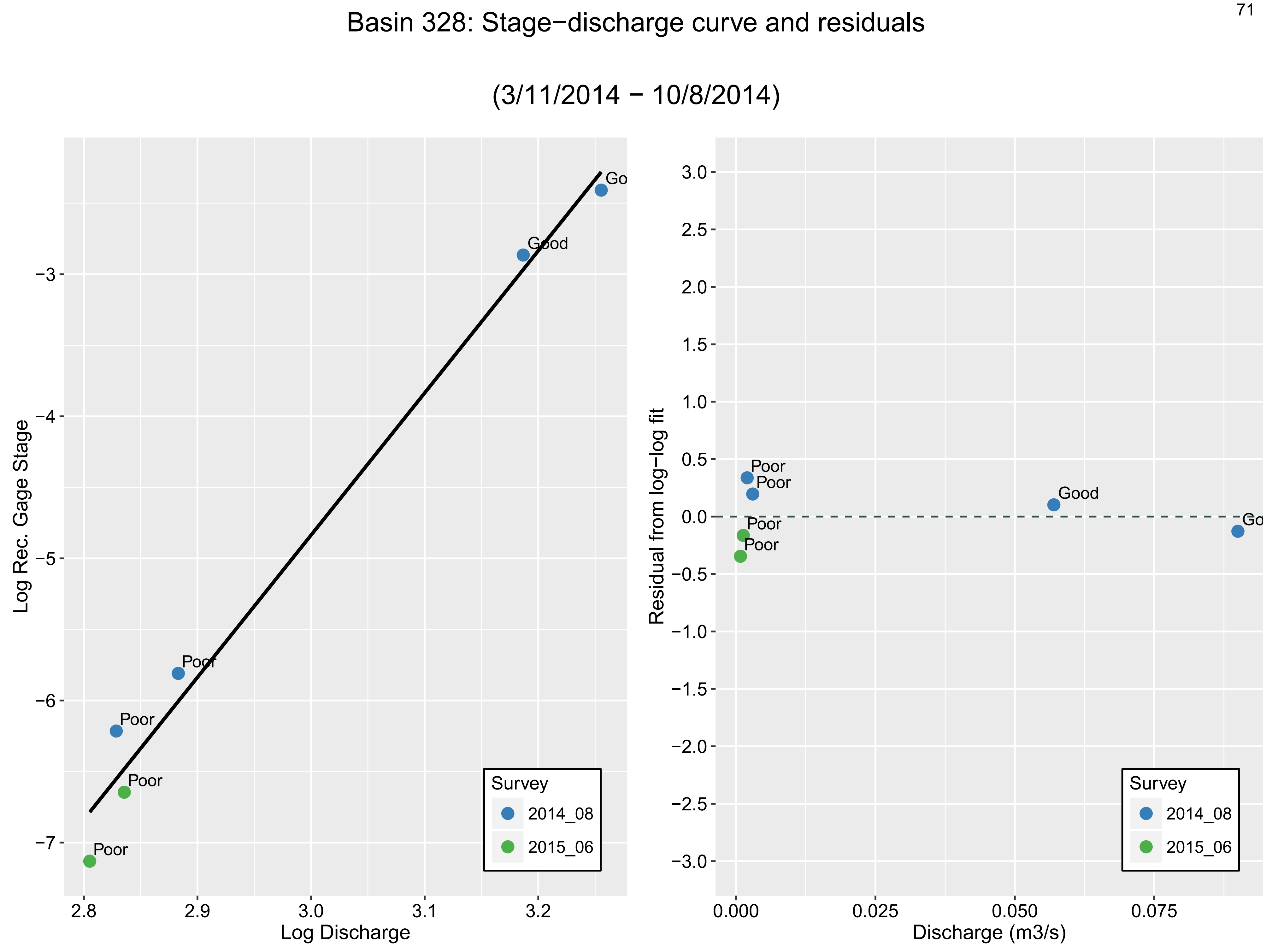

Basin 328: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131211
20140805
20150623
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700


Basin 328: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec. Difference
Max. Discharge
Min. Discharge
Zero cm elevation
Elevation (cm)
55
50
45
40
35
30
25
20
15
10
5
0
−5
01Nov13
01Jan14
01Mar14
01May14
01Jul14
01Sep14
01Nov14
01Jan15
01Mar15
01May15
01Jul15



Basin 328: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
20
25
30
35
Water_Year
2014
2015


Basin 328: Stage−discharge curve and residuals
All available data
Log Rec. Gage Stage
Log Discharge
Good
Good
na
Ex
Fair
Poor
Poor
Poor
Poor
Poor
Poor
−3
−4
−5
−6
−7
2.8
3.0
3.2
Survey
2013_12
2014_08
2015_06
Residual from log−log fit
Discharge (m3/s)
Fair
na
Good
Go
Poor
Poor
Poor
Poor
Poor
Excellent
Poor
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
0.000
0.025
0.050
0.075
Survey
2013_12
2014_08
2015_06


Basin 328: Stage−discharge curve and residuals
(3/11/2014 − 10/8/2014)
Log Rec. Gage Stage
Log Discharge
−3
−4
−5
−6
−7
2.8
2.9
3.0
3.1
3.2
Good
Poor
Survey
2014_08
2015_06
Residual from log−log fit
Discharge (m3/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
0.000
0.025
0.050
0.075

Basin 433

Summary

New side channel and gravel bar located on right bank in 2015. Recording gage intake now buried.

Category:
Not Available

Recommendations for future data collection

Before any additional data can be utilized, gage intake needs to be uncovered and located in main channel.
Discharge during high-flow.
Need at least 4 more points to create rating curve for period after 10/7/2014.

Histograms

This basin shows correlation between range of recording gage readings and range of staff gage measurements, especially near the median flow range. However, there are peaks in recording gage readings that are not observed on staff gage measurements.

Cross-sectional Profiles

Channel is wide with steep banks on each. Maximum stage height occurs just above RM.

Overall channel geometry did not change as significantly from 2013 (red) to 2014 (blue) as it did from 2014 to 2015 (green). Both aggradation near LEW and erosion near REW occurred between 2014 and 2015. Undercutting observed on left bank in 2014 was not observed in 2015. New side channel on right bank that is described in the field notes is apparent from 2015 cross-section.

Staff Gage-Recording Gage Time Series and Regression

It is likely that the high flow in mid-November 2014 affected the recording gage data. Notes from field visits after this date indicate that the recording gage sensor has been buried and that the staff gage is no longer in the main channel. This is represented by the decrease in recording gage baseflow after that time of roughly 10 cm. However, this large shift in baseflow elevation in the recording gage data was not necessarily observed in the staff gage data. Note the consistenlty high values in the staff gage-recording gage difference (blue line) starting on 12/03/2014.

The relationship between staff gage and recording gage has a strong correlation with a slope close to 1 both before and after this shifting event occured. Separate rating curves will need to be made for before and after the channel change.

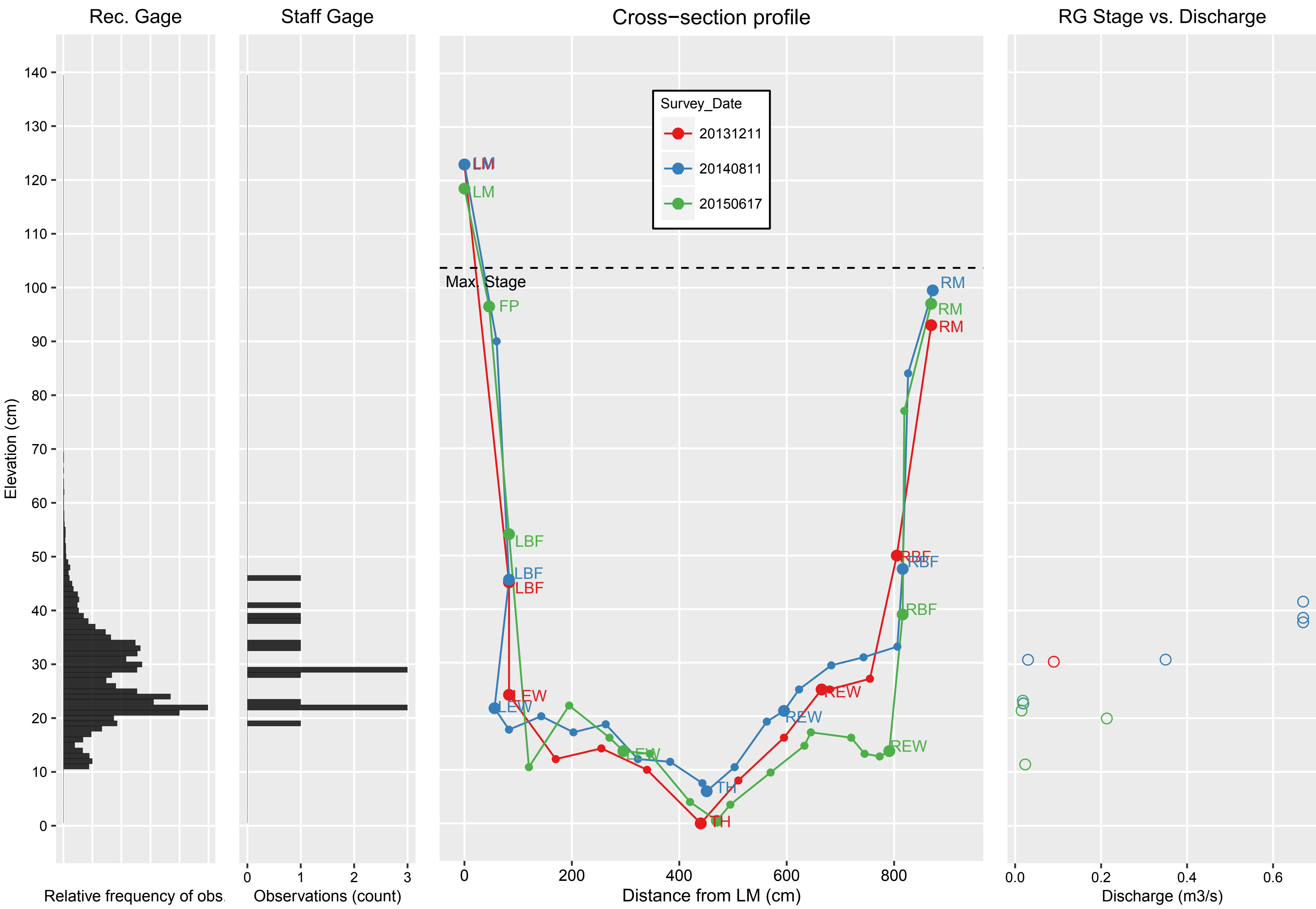
The exact same discharges are recorded on 1/8/2014, 1/30/2014 and 2/19/2014. However, for the same amount of discharge a lower stage height is recorded for each subsequent measurement. This is supported by the cross-section profiles in 2013 and 2014, showing increased undercutting and erosion on the left bank. It is likely that this channel change occurred between 1/8/2014 and 2/19/2014.

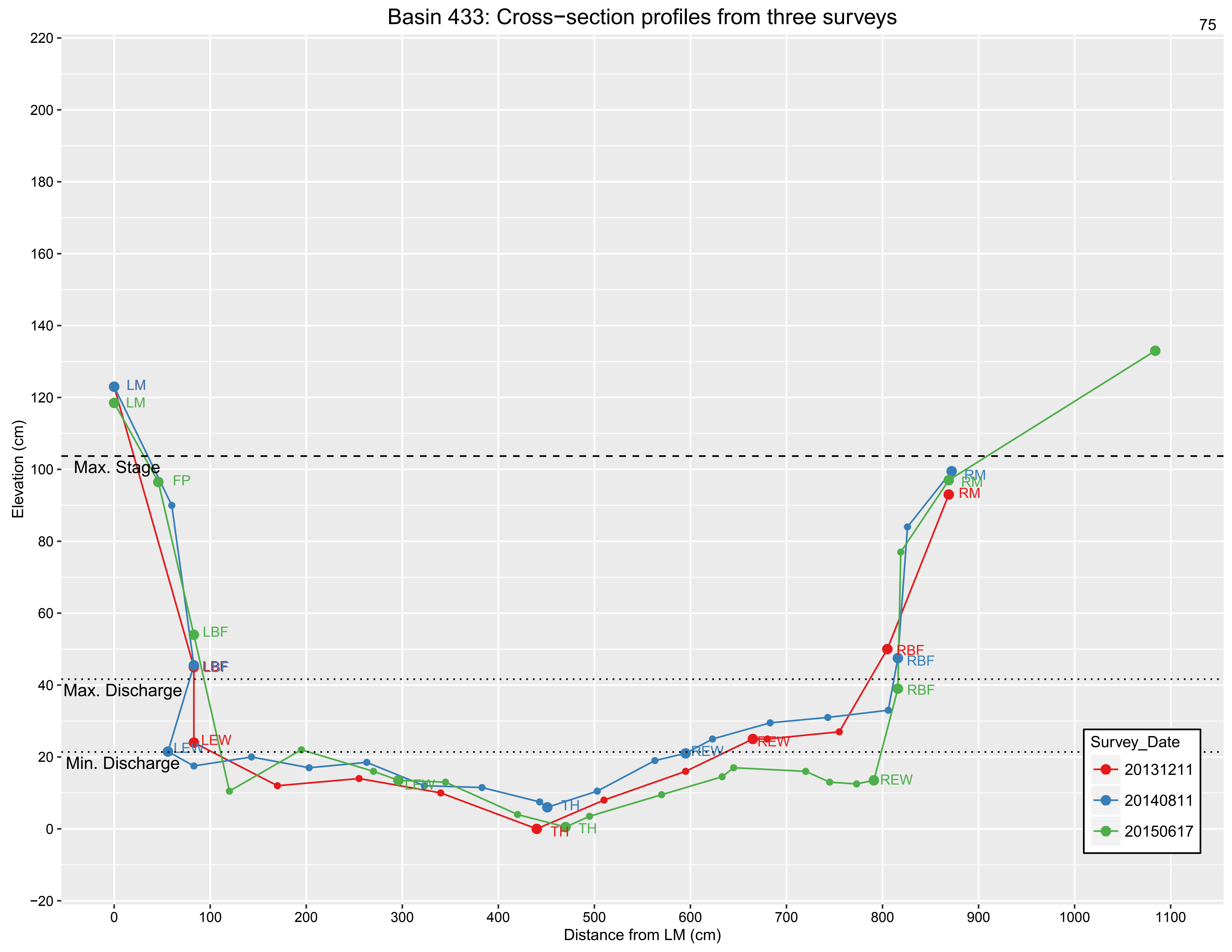
Stage-Discharge Rating Curve

Due to changes in channel geometry over time, the rating curve for this basin is divided into three sub-sections: Start of monitoring to 01/29/2014; 02/19/204 to 10/07/20104 and 04/28/2015 to present. At this current point in time, the middle section is the only section where enough data is available to draw a rating curve, however, this subset only produces a curve with a R2 of 0.8219 indicating a weaker fit of the model predicting discharge from stage height.

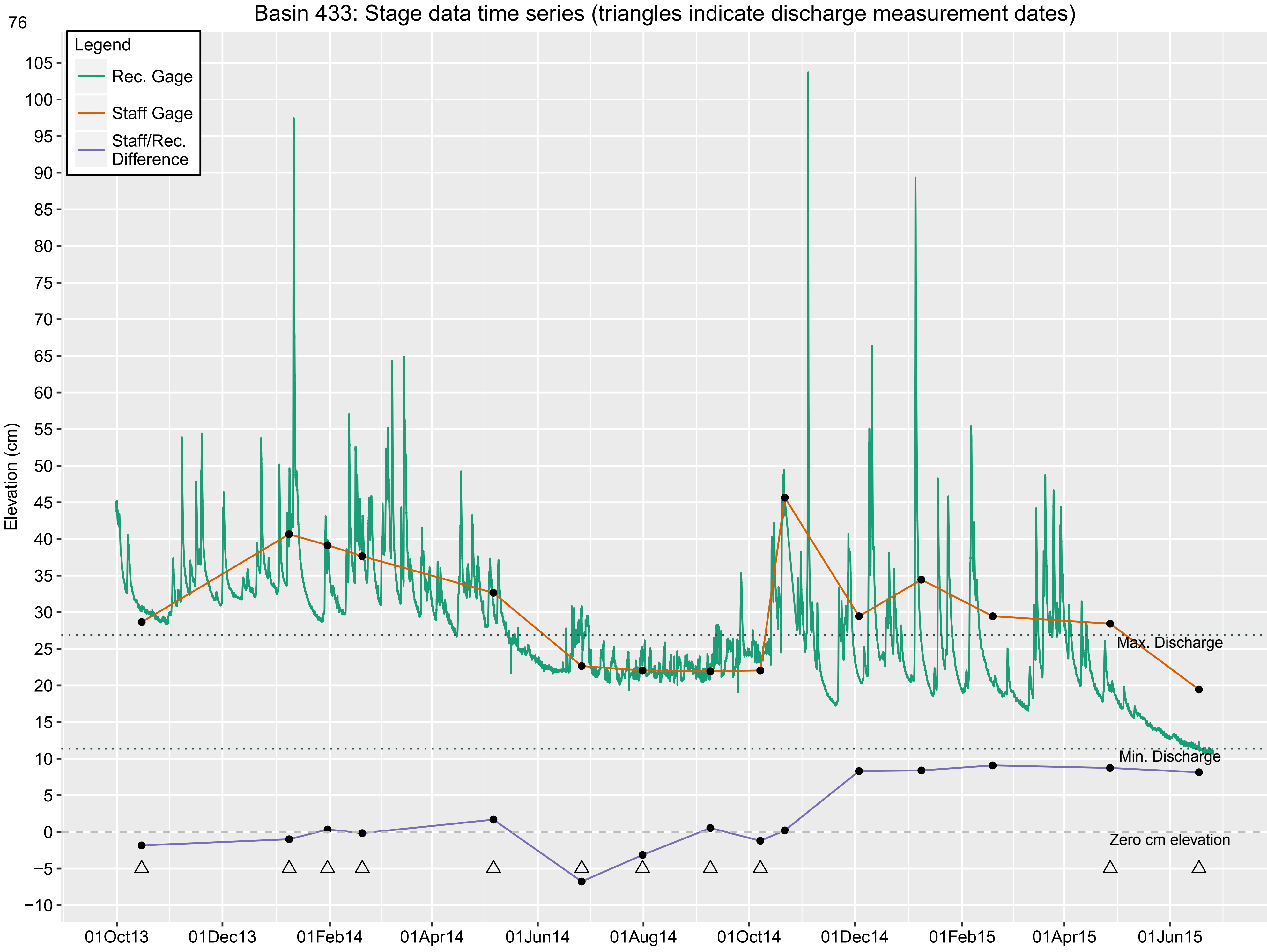
Stream gage station in basin 433 at low flow. Note the gravel bar formed around the gages after November 2014.

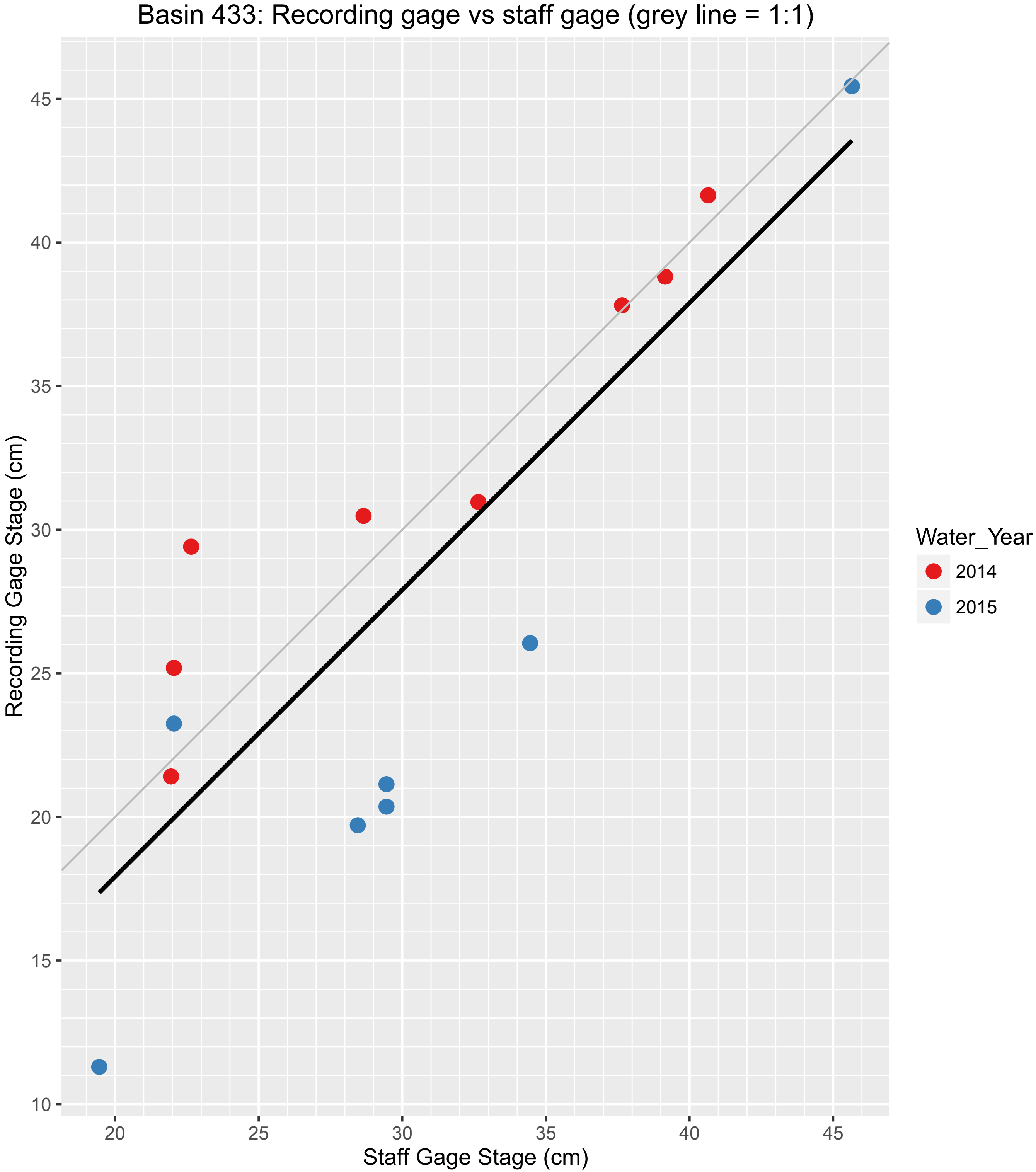
Basin 433: Gage data histograms, cross−section profile, and stage−discharge data





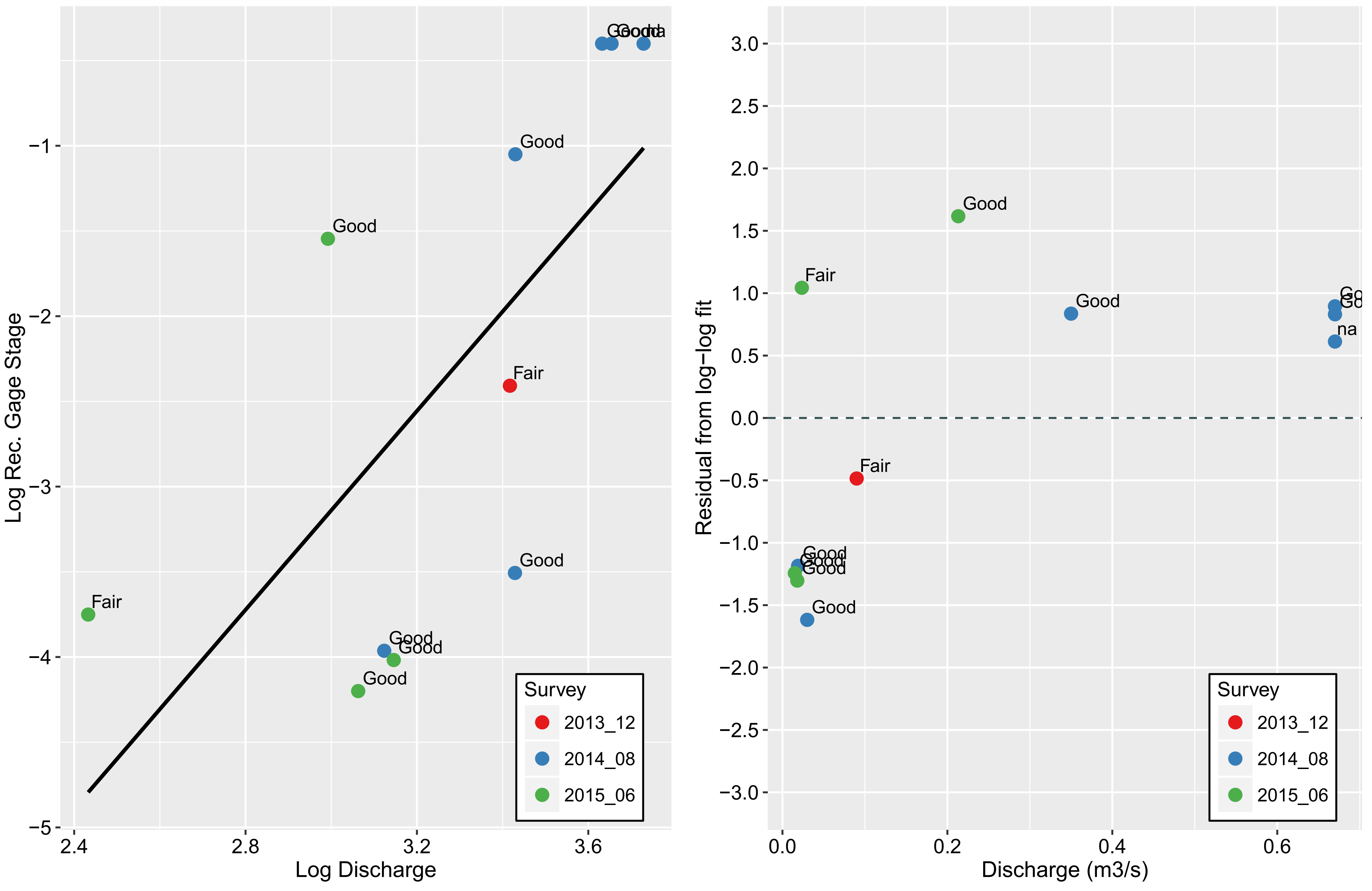
Basin 433: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
FP
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131211
20140811
20150617


Basin 433: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec. Difference
Elevation (cm)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
−10
Max. Discharge
Min. Discharge
Zero cm elevation
01Oct13
01Dec13
01Feb14
01Apr14
01Jun14
01Aug14
01Oct14
01Dec14
01Feb15
01Apr15
01Jun15


Basin 433: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
10
15
20
25
30
35
40
45
20
25
30
35
40
45
Water_Year
2014
2015

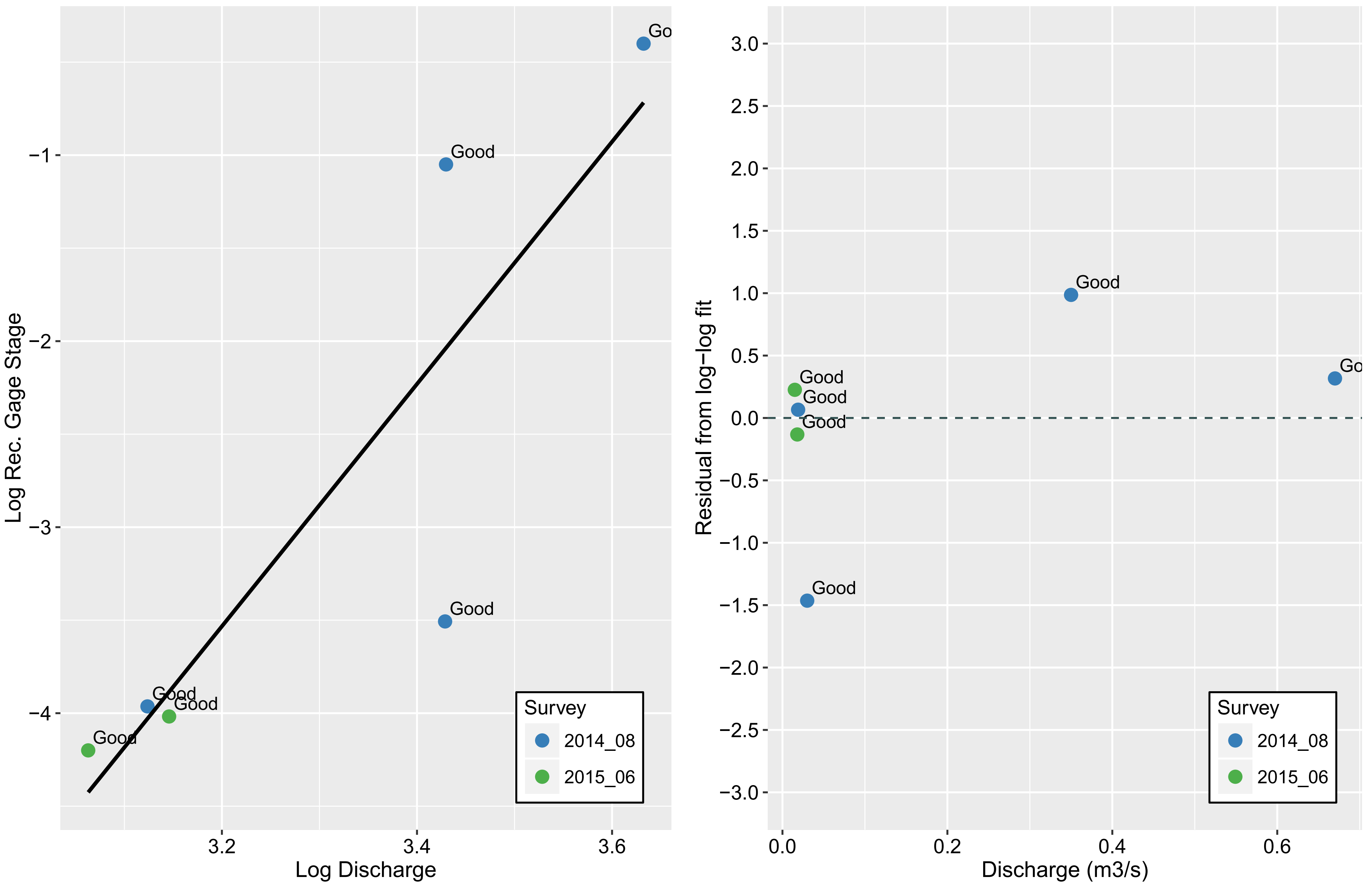
Basin 433: Stage−discharge curve and residuals

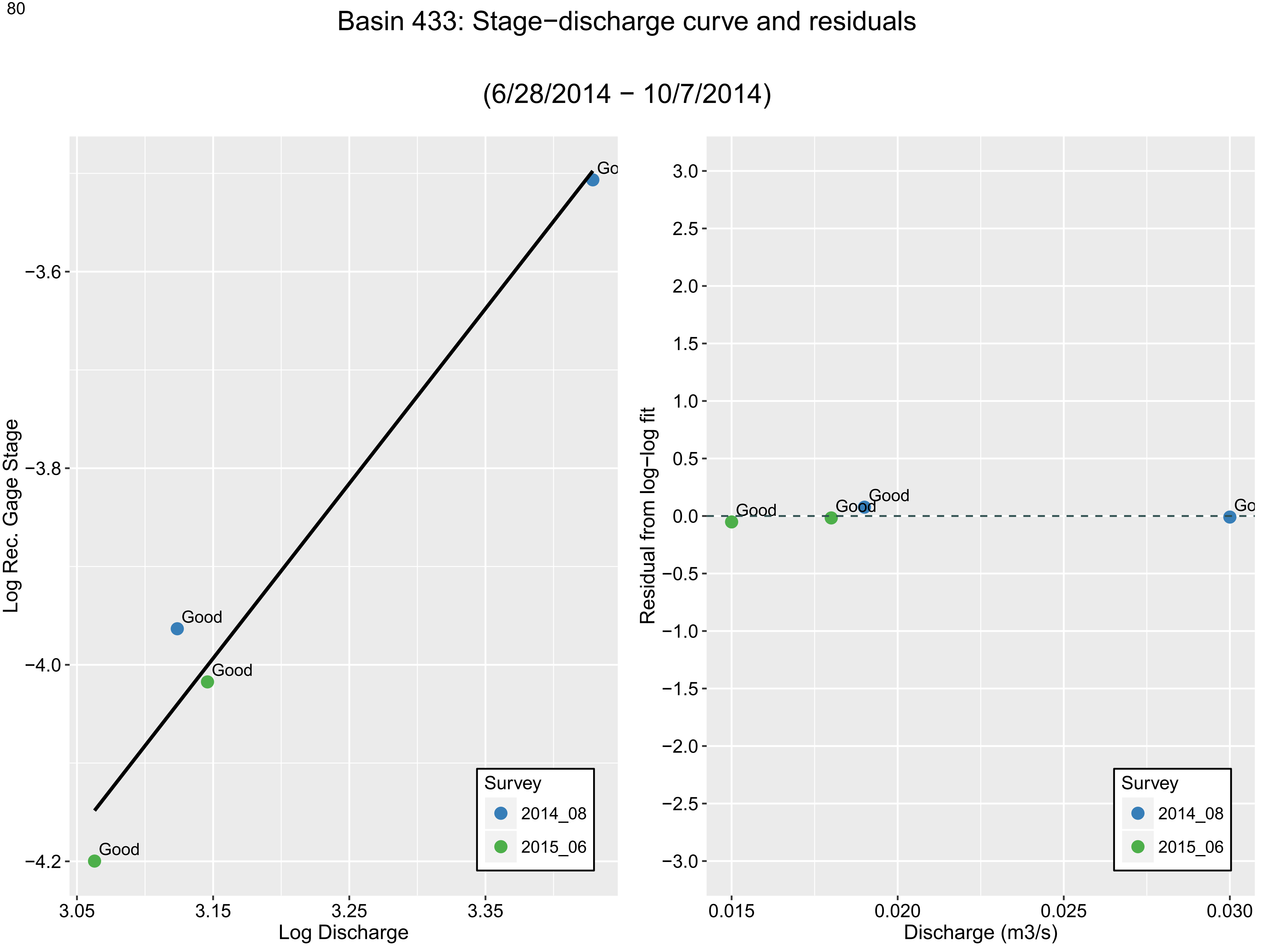
All available data



Basin 433: Stage−discharge curve and residuals

(2/19/2014 − 10/7/2014)





Basin 433: Stage−discharge curve and residuals
(6/28/2014 − 10/7/2014)
Log Rec. Gage Stage
Log Discharge
−3.6
−3.8
−4.0
−4.2
3.05
3.15
3.25
3.35
Good
Survey
2014_08
2015_06
Residual from log−log fit
Discharge (m3/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
0.015
0.020
0.025
0.030

Basin 544

Summary
Rating curve is reliable from 2/19/14 to the date of the last discharge measurement.

Category:
Conditional – Time

Recommendations for future data collection
Discharge during high-flow.
Cross-section stability survey above bankfull.

Histograms

This basin shows correlation between range of recording gage readings and range of staff gage measurements, especially near the median flow range. However, there are peaks in recording gage readings that are not observed on staff gage measurements.

Cross-sectional Profiles

Significant changes in cross-sectional geometry occurred from 2013 (red) to 2014 (blue) surveys including aggradation on the left bank and scour on the right. Changes also occurred between 2014 (blue) to 2015 (green) surveys. Scour near right bank and aggradation near left bank. Potential infill of the floodplain on the right bank between 2014 and 2015 but lack of data points in that area makes this unclear.

2015 TH data point shows that the main channel shifted from left to right. Further investigation into the 2015 baseflow readings on the recording gage may reveal more information about this channel change.

Staff Gage-Recording Gage Time Series and Regression

Baseflow in 2015 is roughly 5 cm lower than in 2014, which could be representative of the change in channel geometry observed on the cross sections. On the other hand, we only have partial data on the 2015 baseflow. Variation in difference between staff gage and recording gage ranges from ~0 to 4 cm.

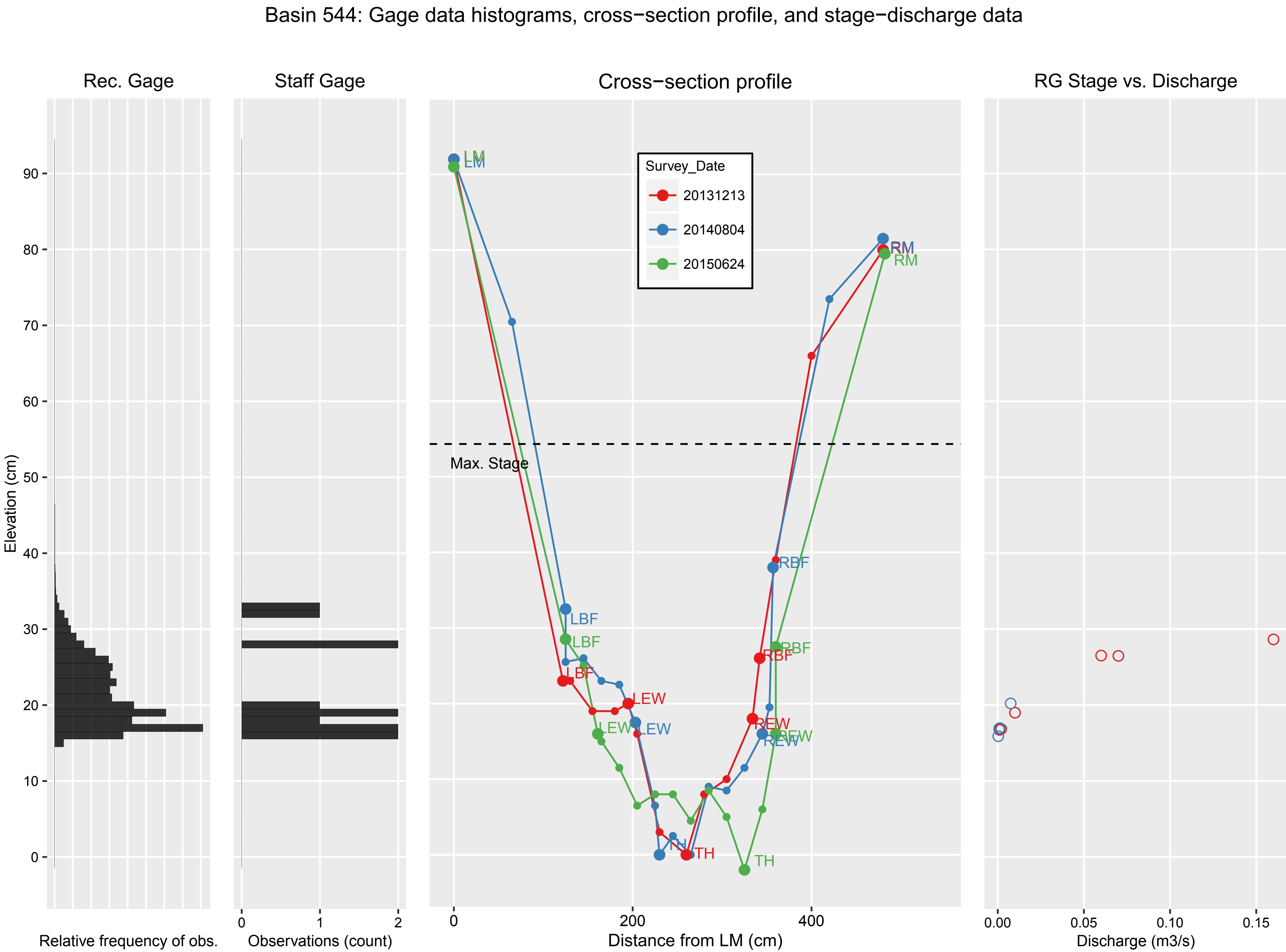
Stage-Discharge Rating Curve

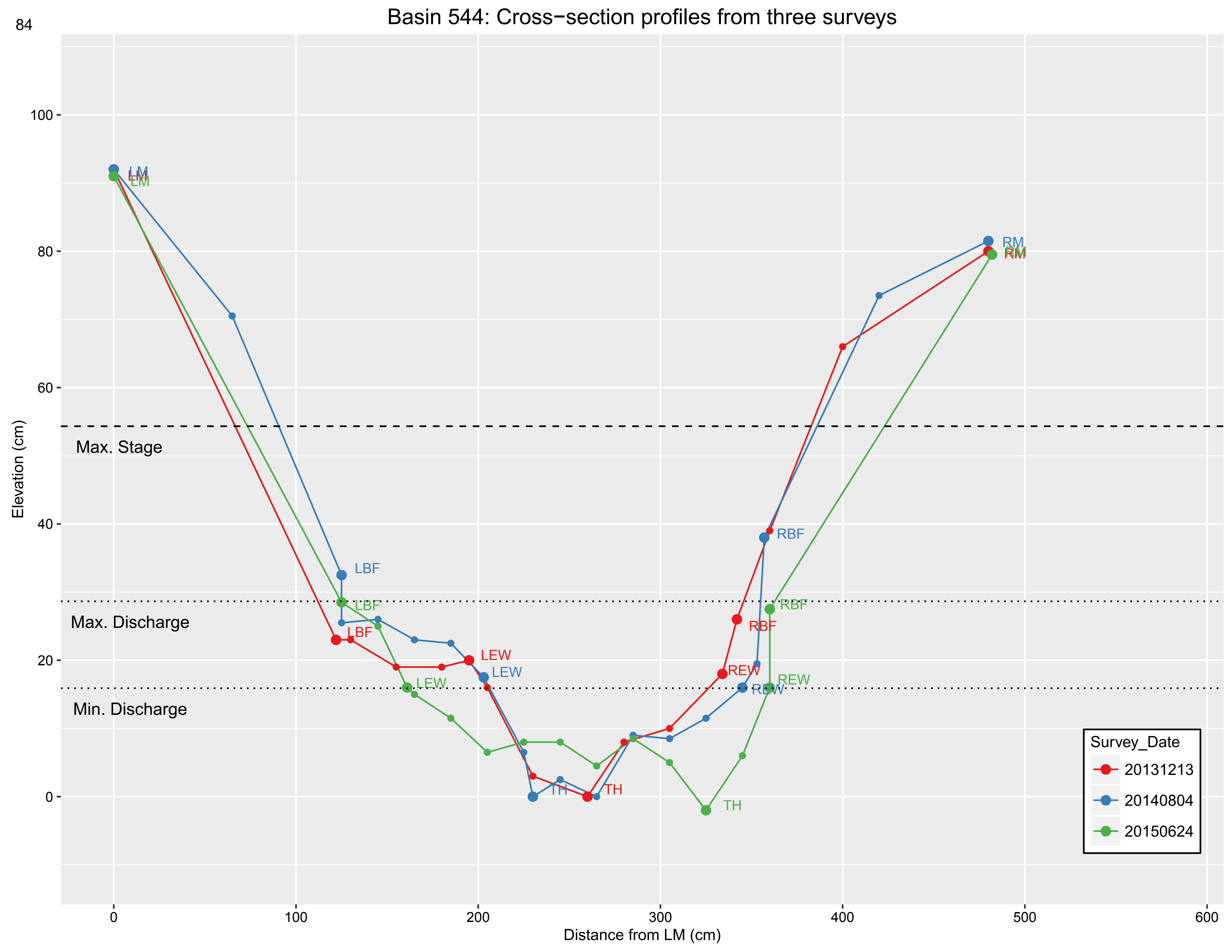
The rating curve for this basin for the entire range of time had an R2 of 0.9456. However, utilizing the just data from 1/29/14 and 2/19/14 to present increases the R2 value to 0.9617. However, this reduces the range of discharges for which the model could be applied from 0.16 to 0.07.

Both of the data points from before 1/29/2014 occur in at a time when a change in channel geometry (steep bank gradient to near flat gradient) occurs at roughly 26 cm in relative elevation. From 2013 to 2014 the channel shape changed, eliminating that sharp change in gradient shift and potentially altering the stage-discharge relationship.

As changes in the channel geometry were even greater from 2014 to 2015, in the future it may be necessary to also create a separate rating curve for 2015. However, at this time the discharge measurements collected in 2015 fit on the same rating curve.

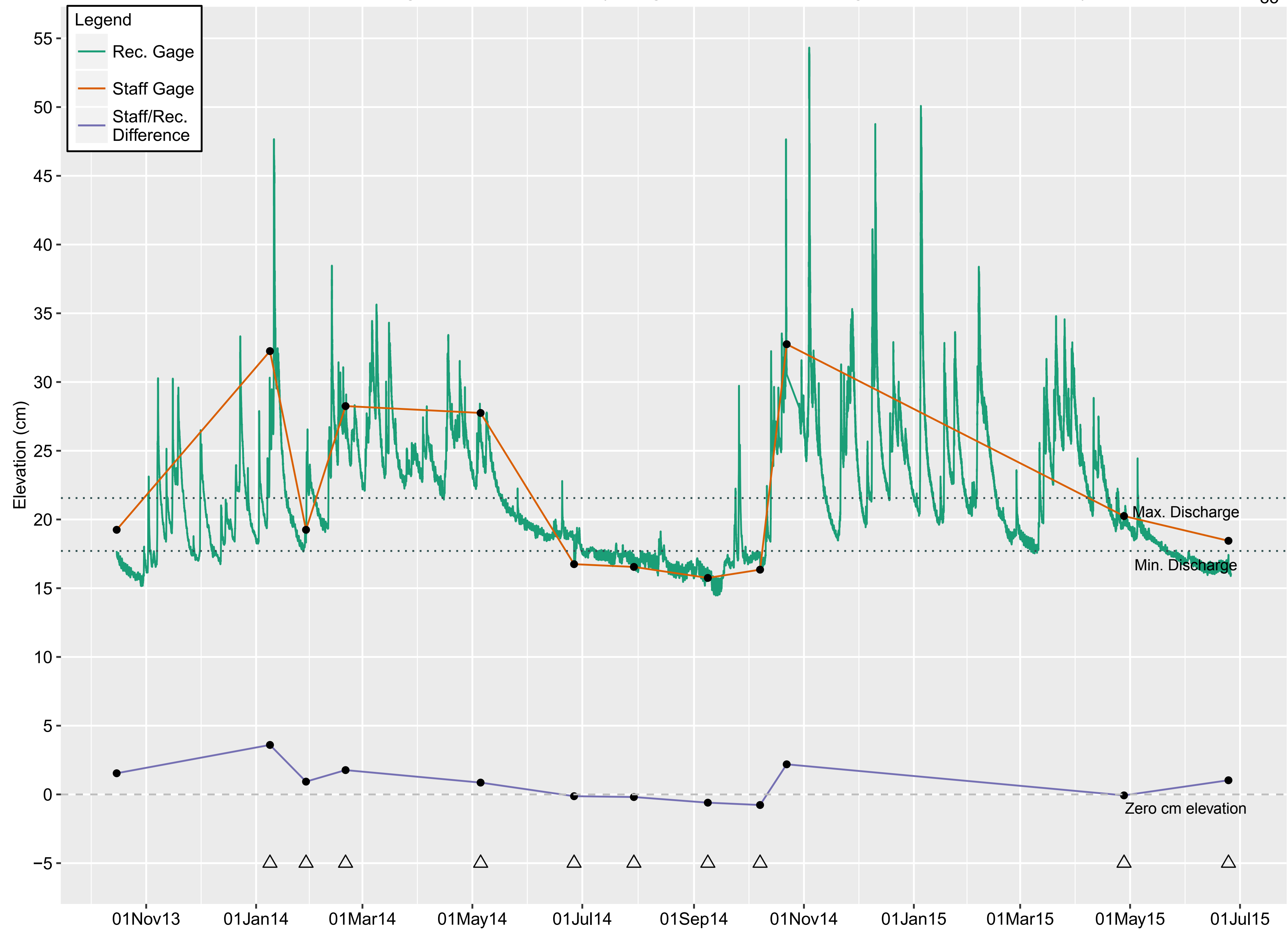
Stream gage station in basin 544 at low flow (removable staff gage not shown).

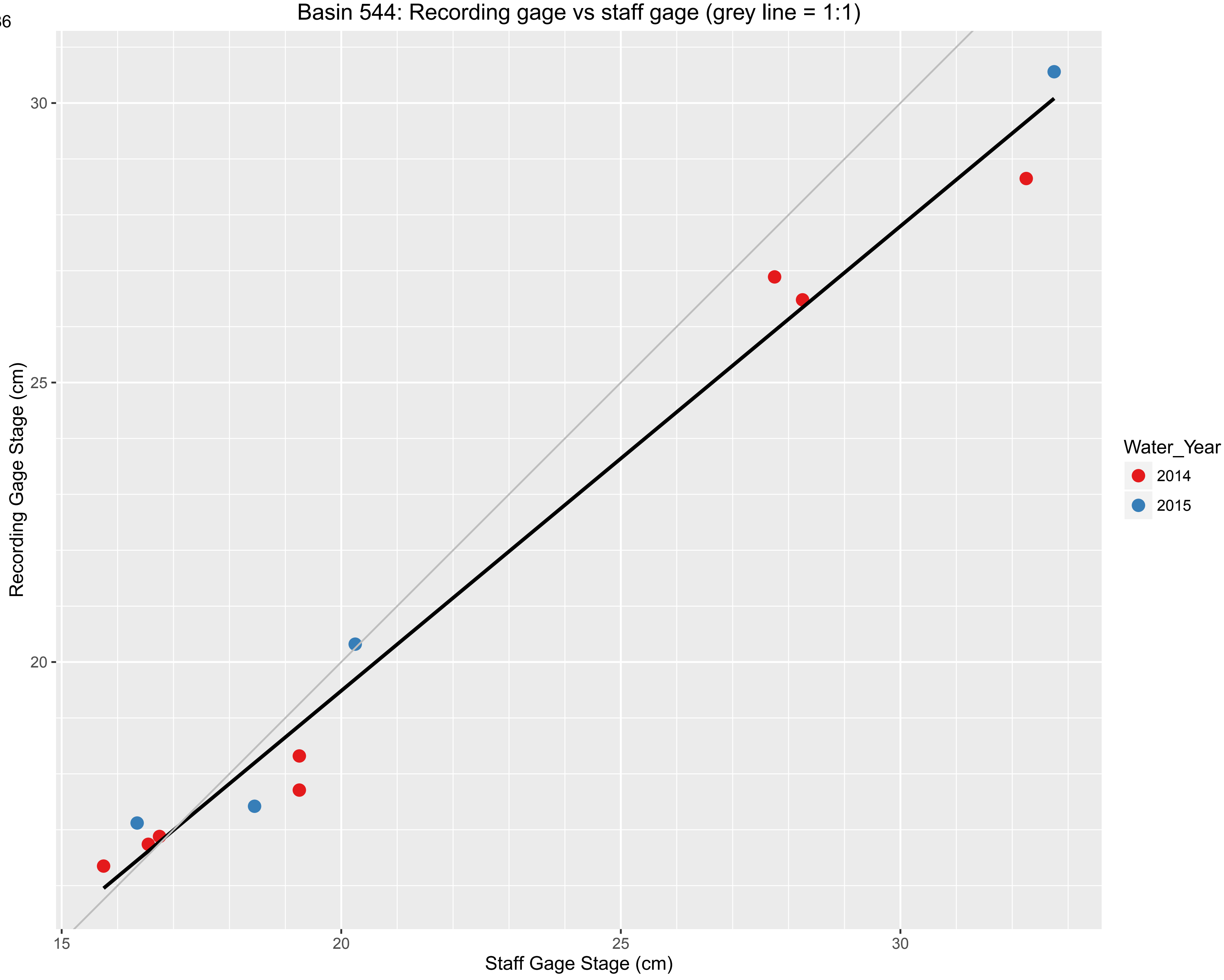

Basin 544: Gage data histograms, cross−section profile, and stage−discharge data
Rec. Gage
Staff Gage
Cross−section profile
RG Stage vs. Discharge
Elevation (cm)
Survey_Date
20131213
20140804
20150624
Max. Stage
LM
RM
LBF
RBF
LEW
REW
TH
Relative frequency of obs.
Observations (count)
Distance from LM (cm)
Discharge (m3/s)

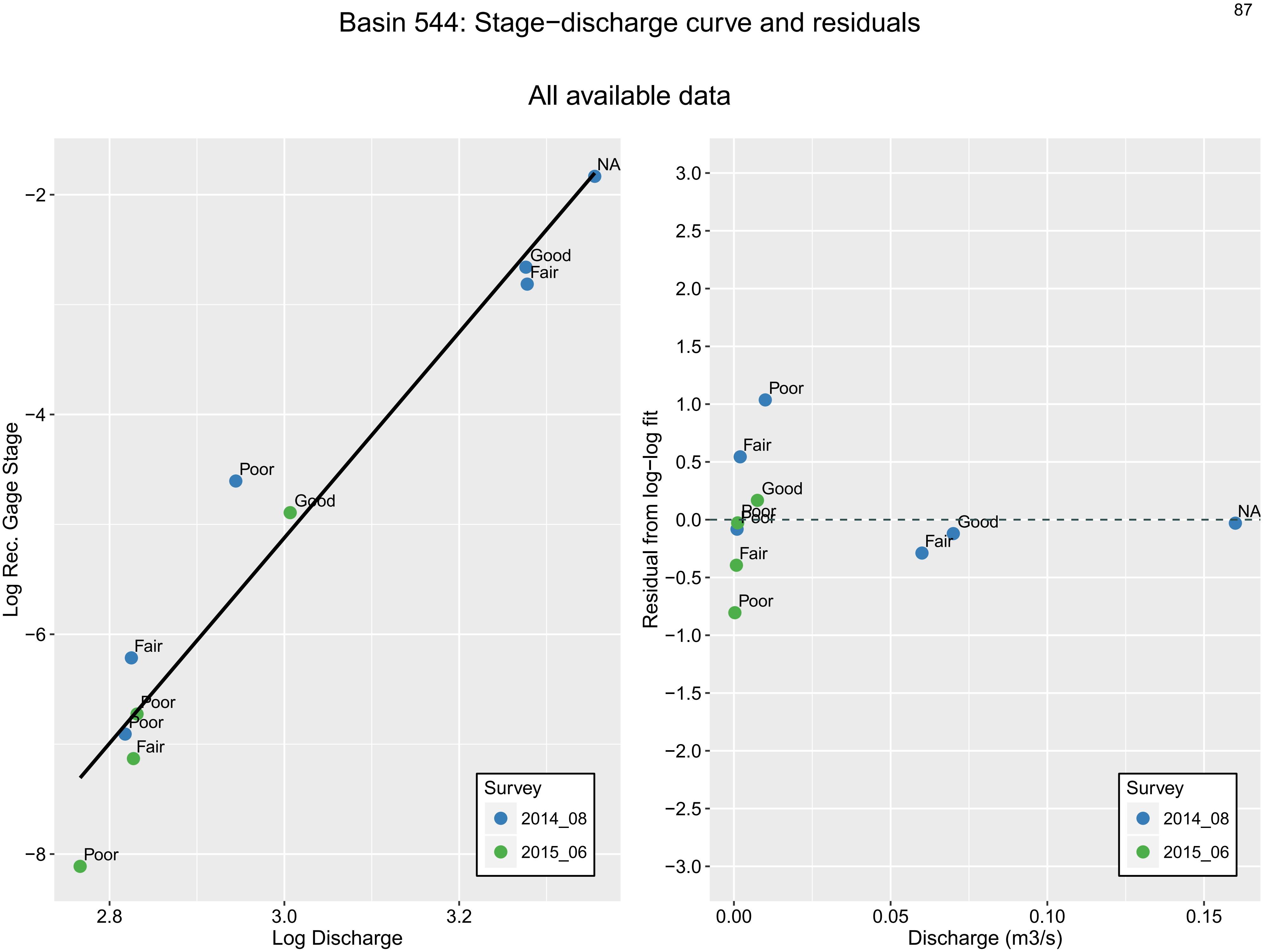


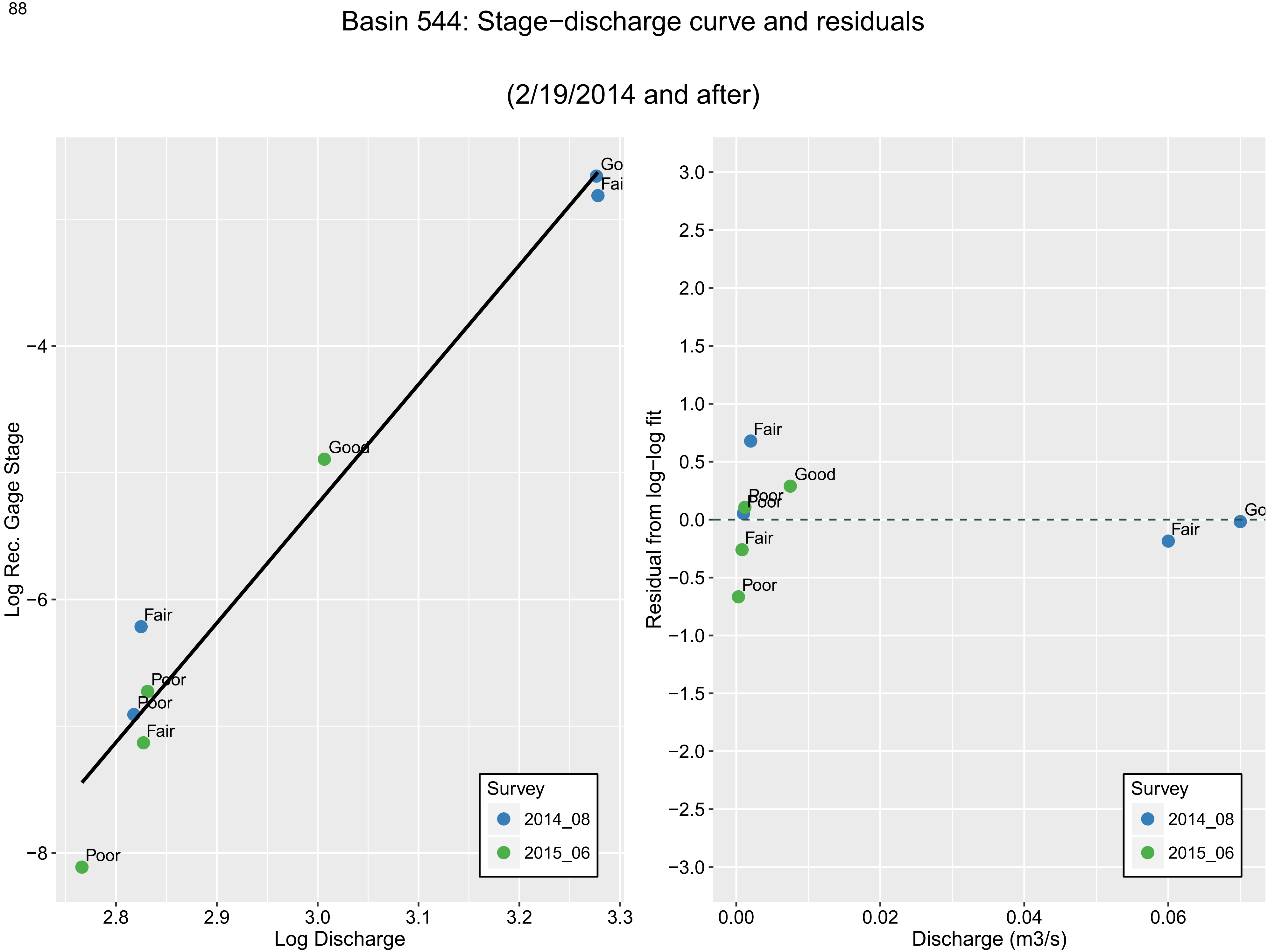
Basin 544: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
RM
LBF
RBF
LEW
REW
TH
Survey_Date
20131213
20140804
20150624

Basin 544: Stage data time series (triangles indicate discharge measurement dates)




Basin 544: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
30
25
20
15
20
25
30
Water_Year
2014
2015


Basin 544: Stage−discharge curve and residuals
All available data
Log Rec. Gage Stage
Log Discharge
−2
−4
−6
−8
2.8
3.0
3.2
NA
Good
Fair
Poor
Good
Fair
Poor
Poor
Fair
Poor
Survey
2014_08
2015_06
Residual from log−log fit
Discharge (m3/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
0.00
0.05
0.10
0.15
Poor
Fair
Good
Poor
Poor
Good
NA
Fair
Fair
Poor
Survey
2014_08
2015_06


Basin 544: Stage−discharge curve and residuals
(2/19/2014 and after)
Log Rec. Gage Stage
Log Discharge
−4
−6
−8
2.8
2.9
3.0
3.1
3.2
3.3
Go
Fai
Good
Fair
Poor
Poor
Fair
Poor
Survey
2014_08
2015_06
Residual from log−log fit
Discharge (m3/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
0.00
0.02
0.04
0.06
Fair
Good
Poor
Poor
Fair
Poor
Fair
Go
Survey
2014_08
2015_06

Basin 584

Summary
Rating curve is reliable for all measurements of discharge between stage heights of 30 and 47 cm.

Category:
Conditional – Stage Height

Recommendations for future data collection
Discharge during high-flow.
Detail in cross-section stability survey at near 47 cm on left bank and 30 cm on both left and right banks to determine elevational inflection points.

Note — Maximum recorded stage height plots at roughly 135 cm in relative elevation, far above bankfull and monuments.

<u>Histograms</u>

This basin only shows correlation between range of recording gage readings and range of staff gage measurements near the median flow range. There are significant peaks in recording gage readings that are not observed on staff gage measurements.

<u>Cross-sectional Profiles</u>

Significant cross-section changes with elevation are observed. Note the undercutting present in 2014 and 2015 near the REW at roughly 25 cm relative elevation. Also note the area of lateral expansion at roughly 50 cm on the left bank.

Slight changes in cross-section geometry from year to year. Most significant changes occurred from 2014 to 2015. Scour/erosion occurred left of TH starting in 2014 and even further in 2015. The left bank near LEW was first eroded in 2014 and then aggraded in 2015.

<u>Staff Gage-Recording Gage Time Series and Regression</u>

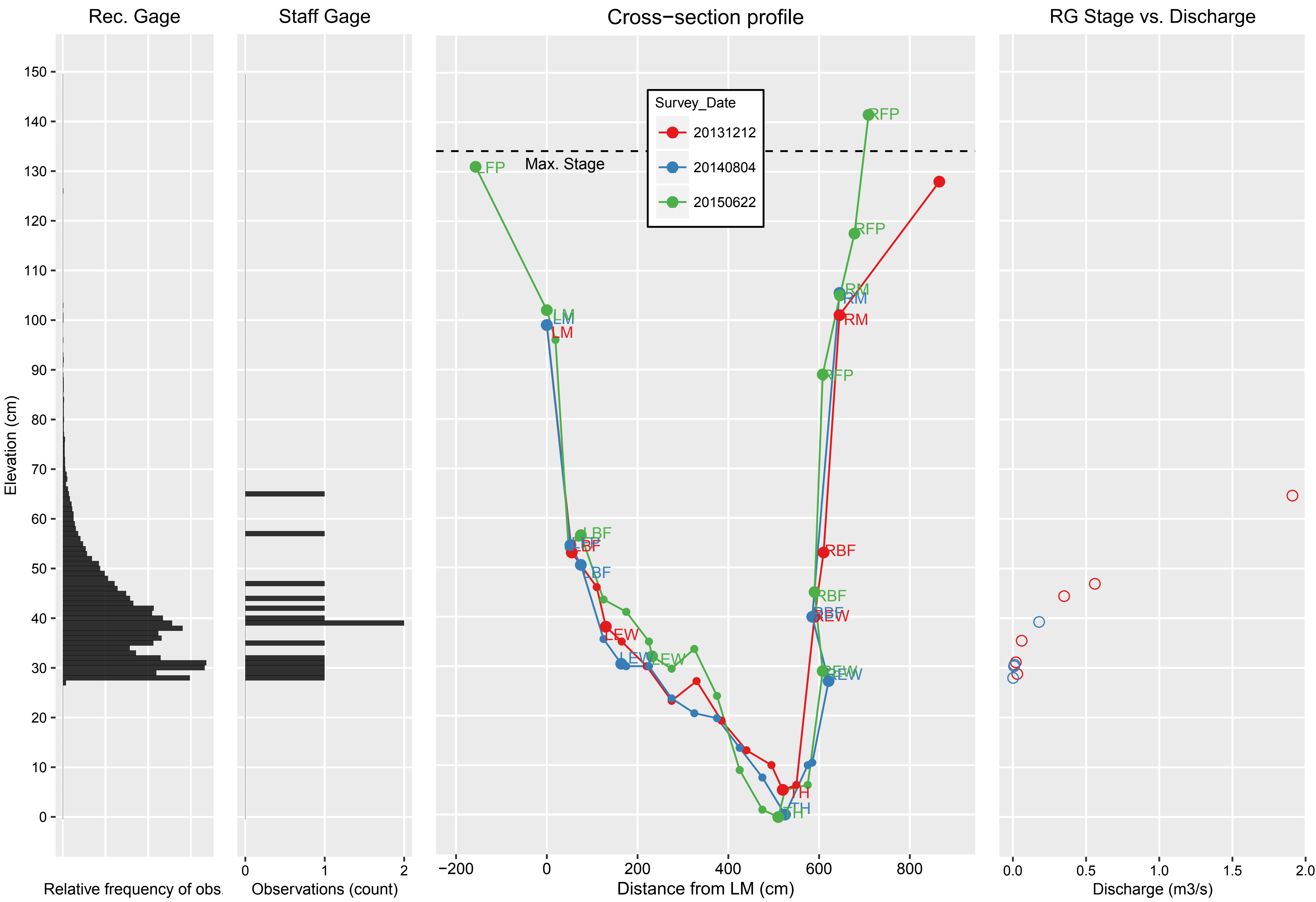
Time Series plot shows stable baseflow from year to year. Note how closely the SG-RG difference (blue line) plots to 0. This basin displays an exemplary relationship between SG and RG. Regression line also shows the staff gage-recording gage relationship very close to 1:1.

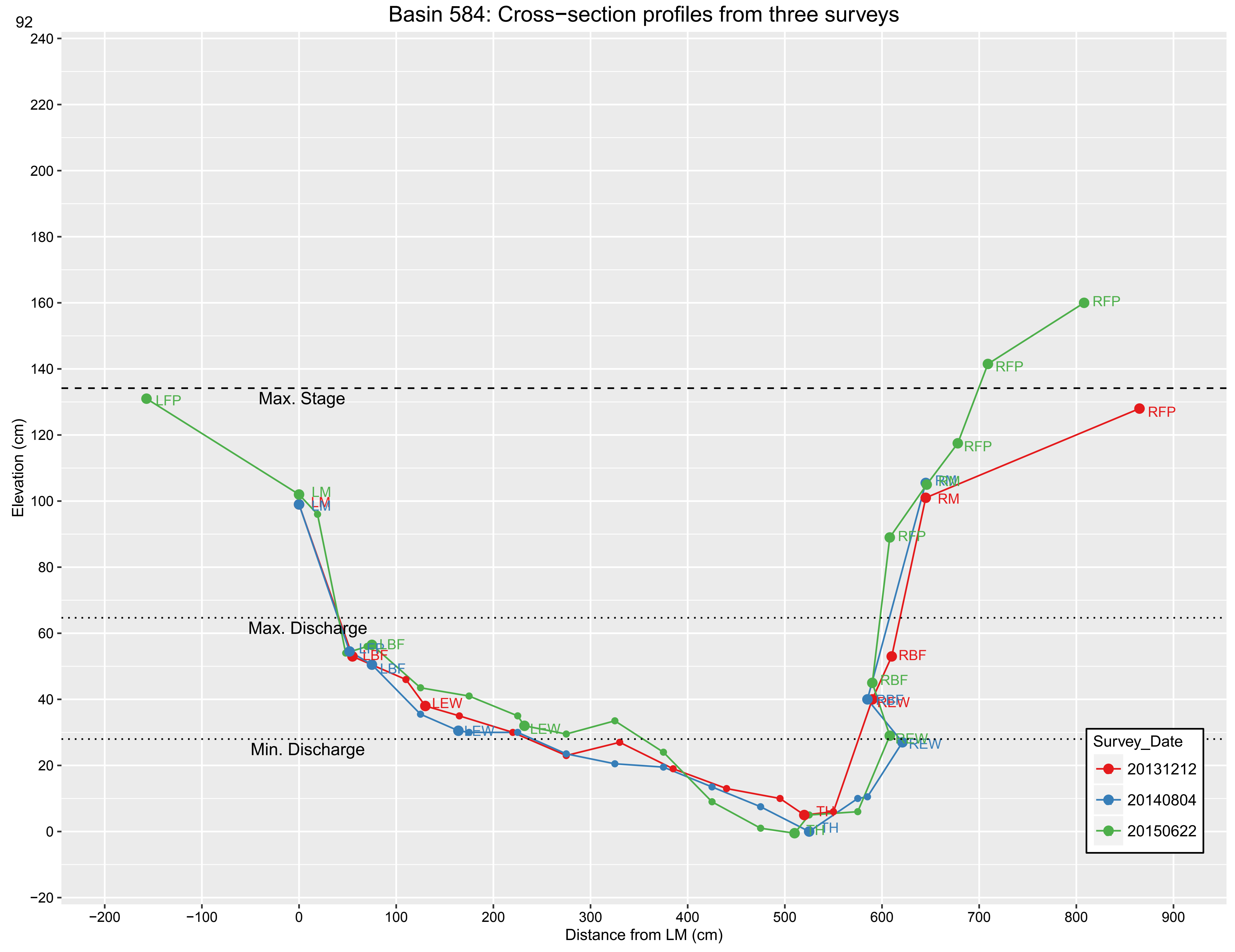
<u>Stage-Discharge Rating Curve</u>

Due to changes in channel geometry with elevation, the rating curve for this basin must be divided into three distinct sections: From stream bottom to 30 cm, 30 cm to 47 cm and 47cm. At this current point in time, the middle section is the only section where enough data are available to draw an accurate rating curve.

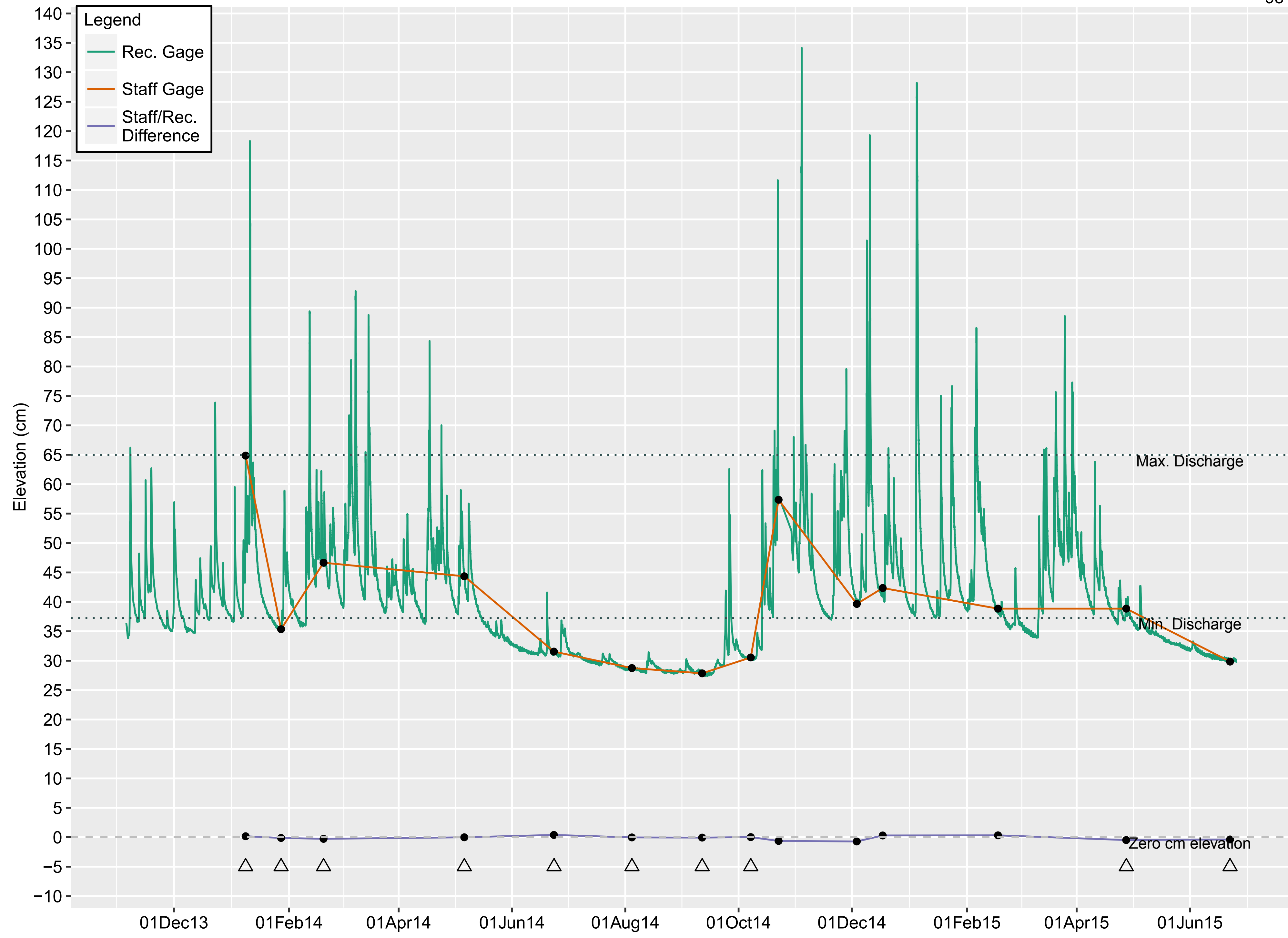
Stream gage station in basin 584 at low flow.

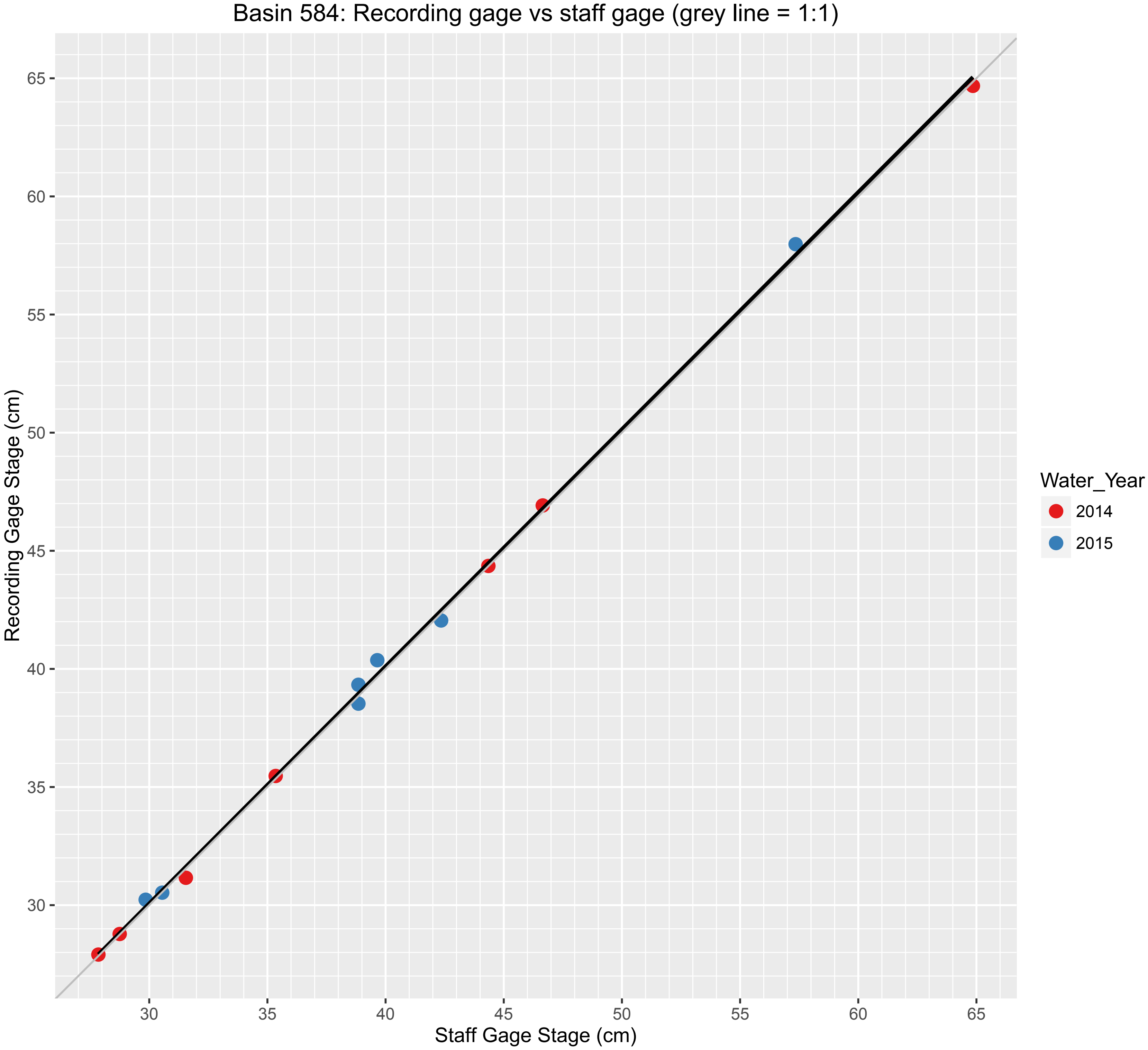
Basin 584: Gage data histograms, cross−section profile, and stage−discharge data




Basin 584: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LFP
LM
LBF
LEW
TH
REW
RBF
RM
RFP
Survey_Date
20131212
20140804
20150622
240
220
200
180
160
140
120
100
80
60
40
20
0
−20
−200
−100
0
100
200
300
400
500
600
700
800
900

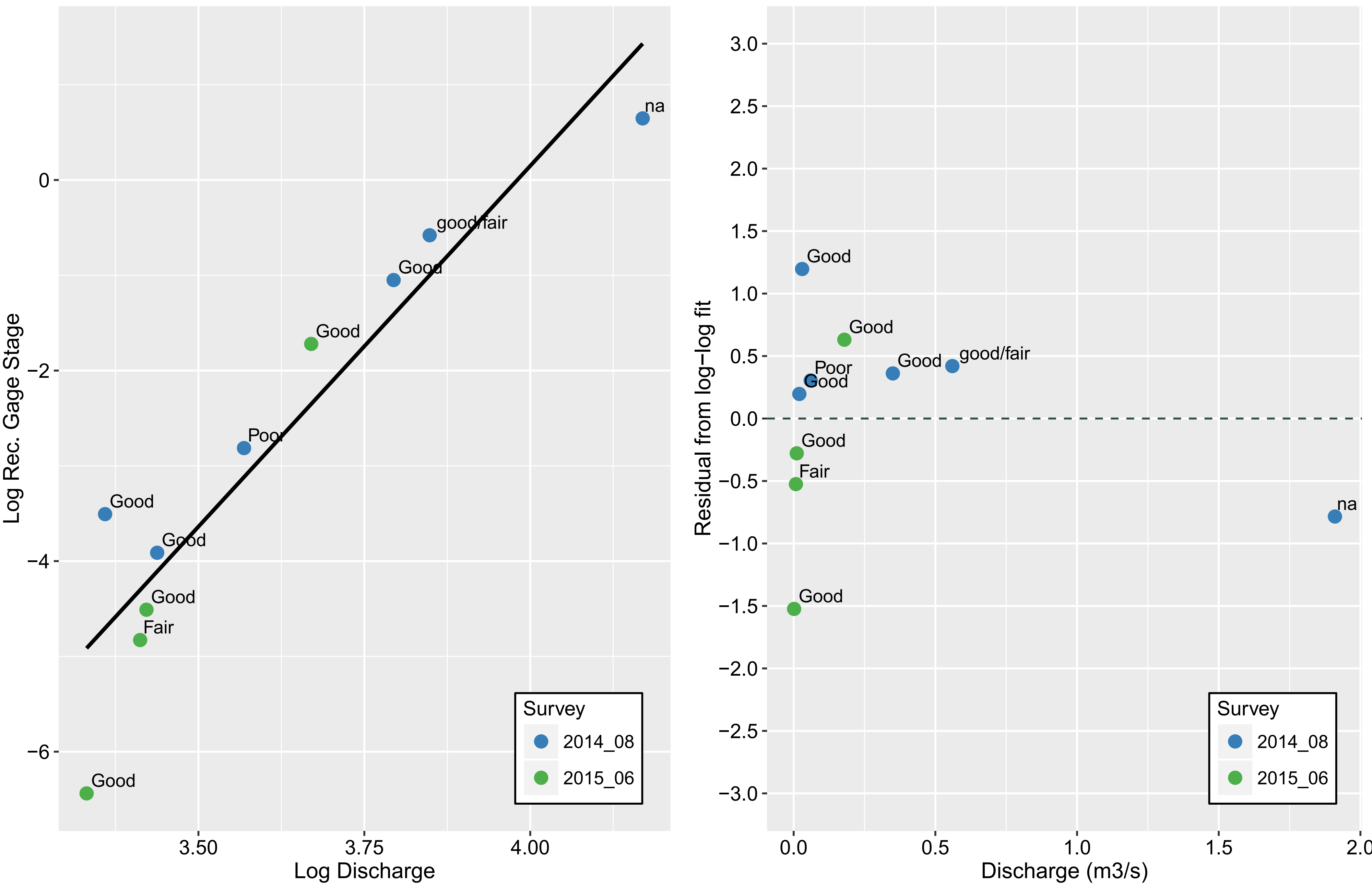
Basin 584: Stage data time series (triangles indicate discharge measurement dates)

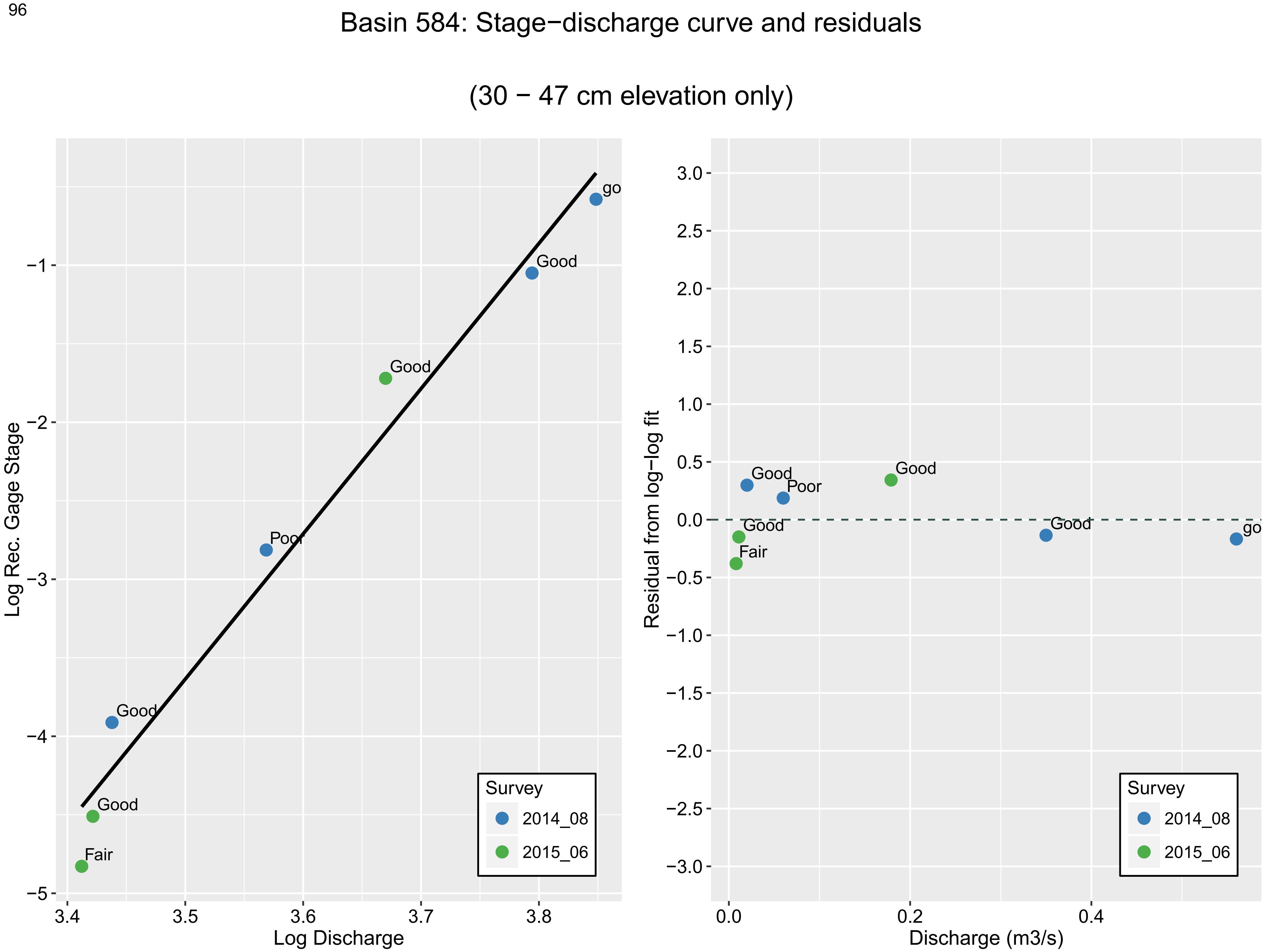



Basin 584: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
30
35
40
45
50
55
60
65
Water_Year
2014
2015

Basin 584: Stage−discharge curve and residuals

All available data




Basin 584: Stage−discharge curve and residuals
(30 − 47 cm elevation only)
Log Rec. Gage Stage
−1
−2
−3
−4
−5
3.4
3.5
3.6
3.7
3.8
Log Discharge
go
Good
Good
Poor
Good
Good
Fair
Survey
2014_08
2015_06
Residual from log−log fit
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
0.0
0.2
0.4
Discharge (m3/s)
Good
Poor
Good
Good
Fair
Good
go
Survey
2014_08
2015_06

Basin 642

Summary
A reliable rating curve cannot be made. Large changes in cross-sectional profile.

Category:
Not Available

Recommendations for future data collection
Continue monitoring as scheduled.
Discharge during at high-flow.

Note — Logging has recently occurred near this monitoring site.

Histograms

Correlation is observed between range of recording gage readings and range of staff gage measurements, especially near the median flow range. However, there are peaks in recording gage readings that are not observed on staff gage measurements.

Cross-sectional Profiles

Cross-section changed slightly from 2013 (red) to 2014 (blue) and dramatically from 2014 to 2015 (green) near center of channel. Likely a 50x20 cm boulder is now in place where one had not been before. From 2014 to 2015 the left bank experienced erosion/scour, leading to significant undercutting. The right bank experienced aggradation from 2013 to 2014 to 2015.

Staff Gage-Recording Gage Time Series and Regression

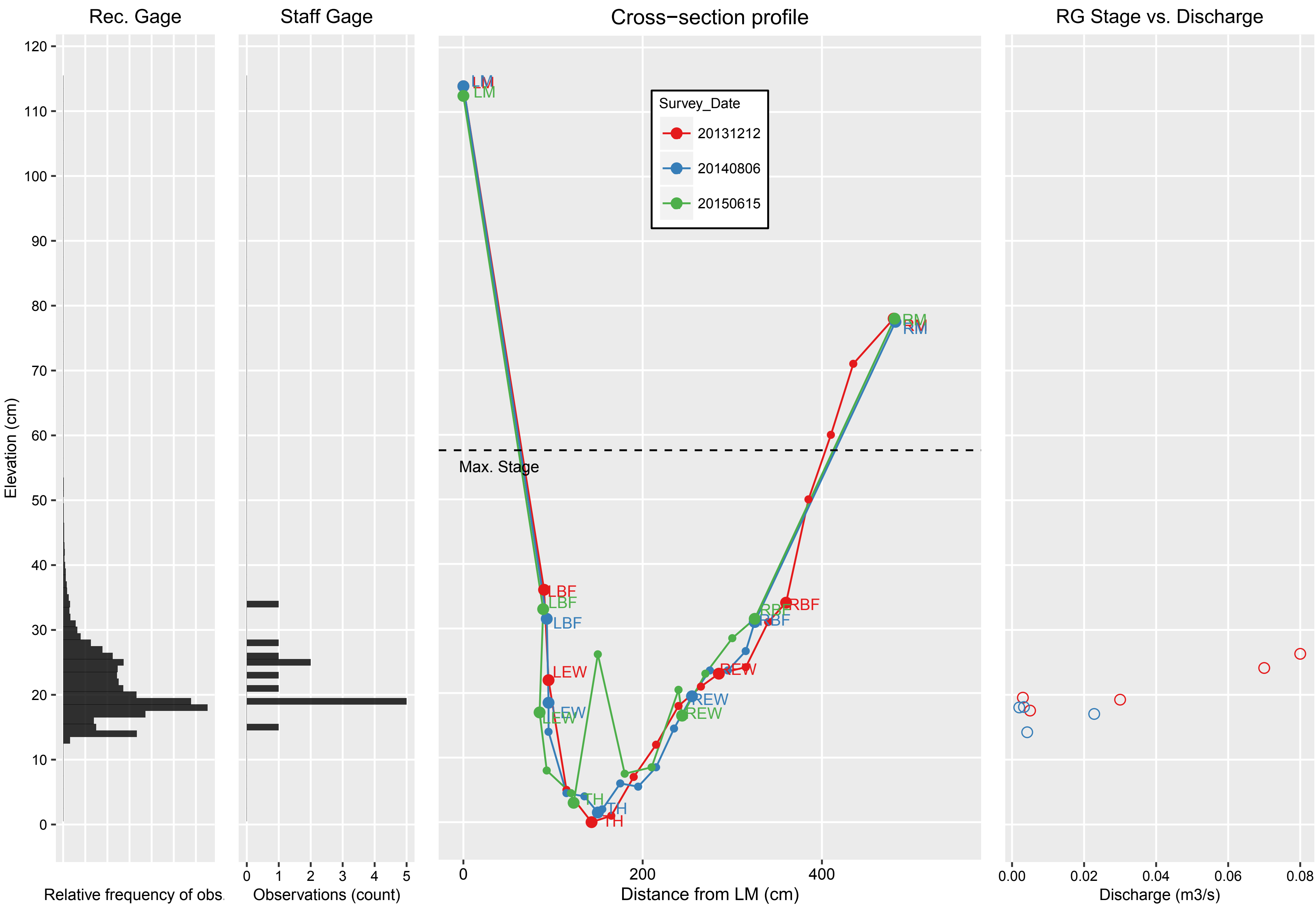
Undercutting on left bank is displayed by the drop in baseflow from 2014 to 2015 low flow data. Further investigation may be conducted once more 2015 low flow data is available. Likely a peak flow during winter 2015 scoured the left bank and mobilized sediments from upstream, depositing them closer to the gages.

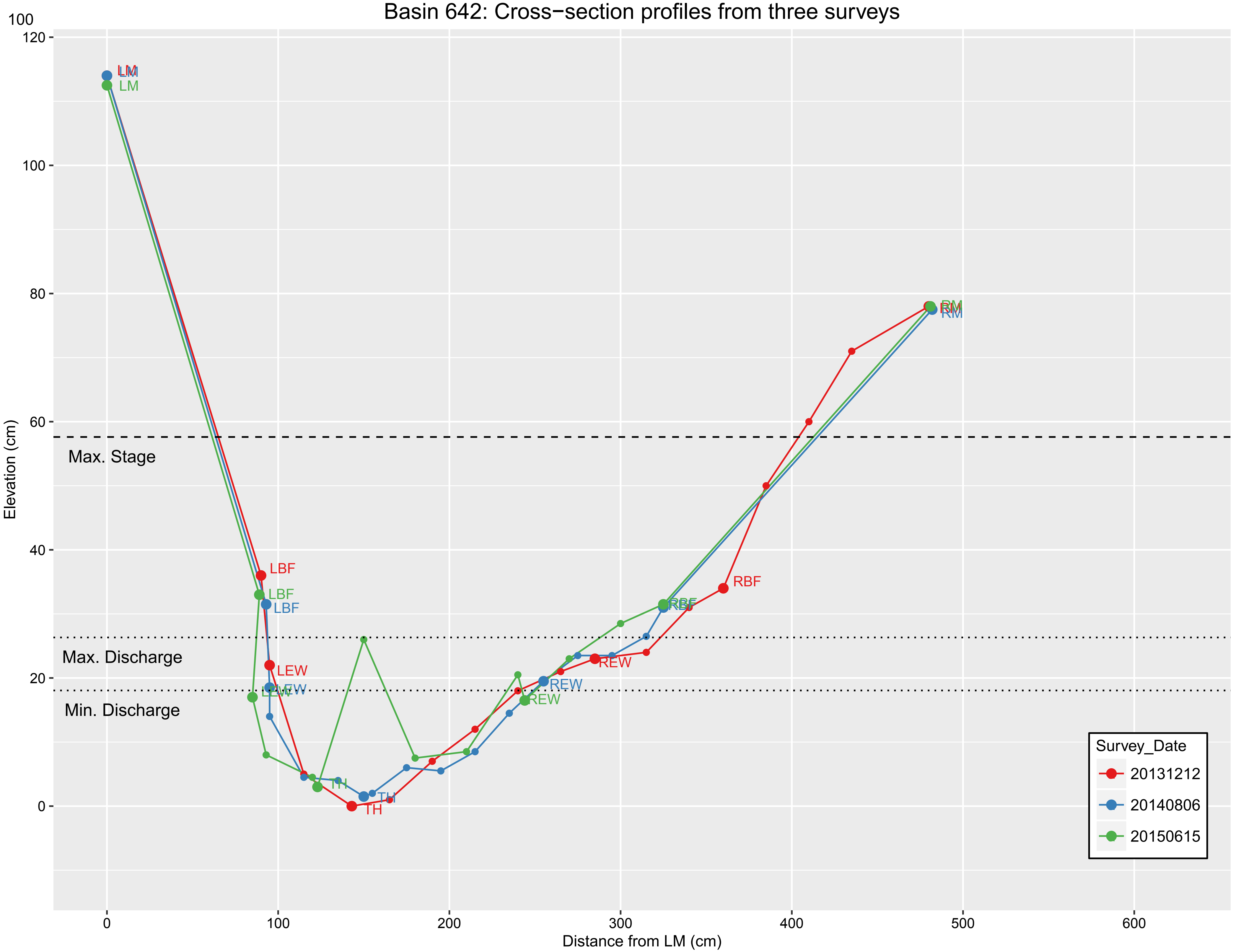
Stage-Discharge Rating Curve

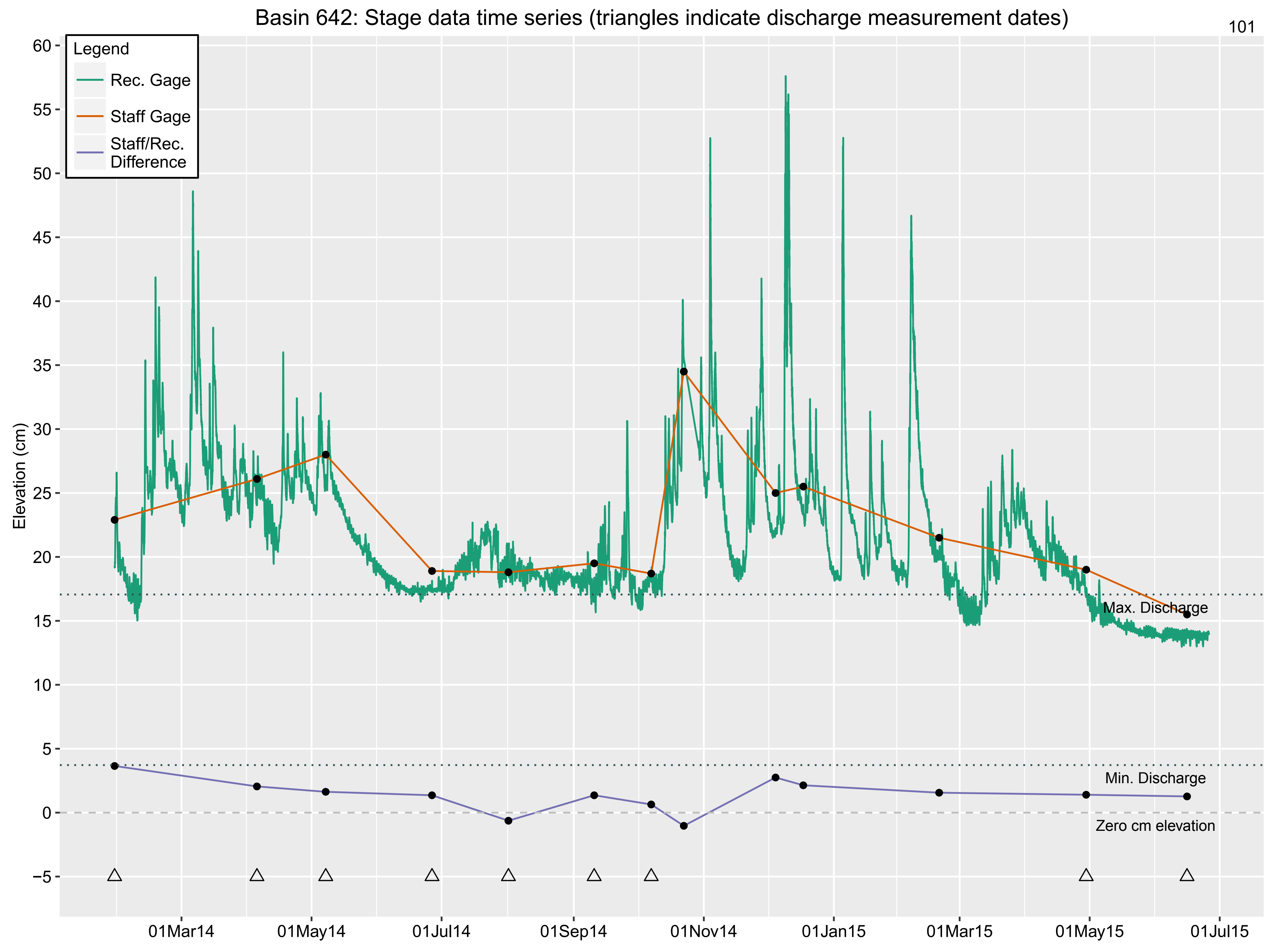
The rating curve relationship presented for the entire range of data has a very weak correlation between discharge and stage height. No subset of either time or elevation has shown to improve that correlation to provide a significant relationship.

Stream gage station in basin 642 at low flow.

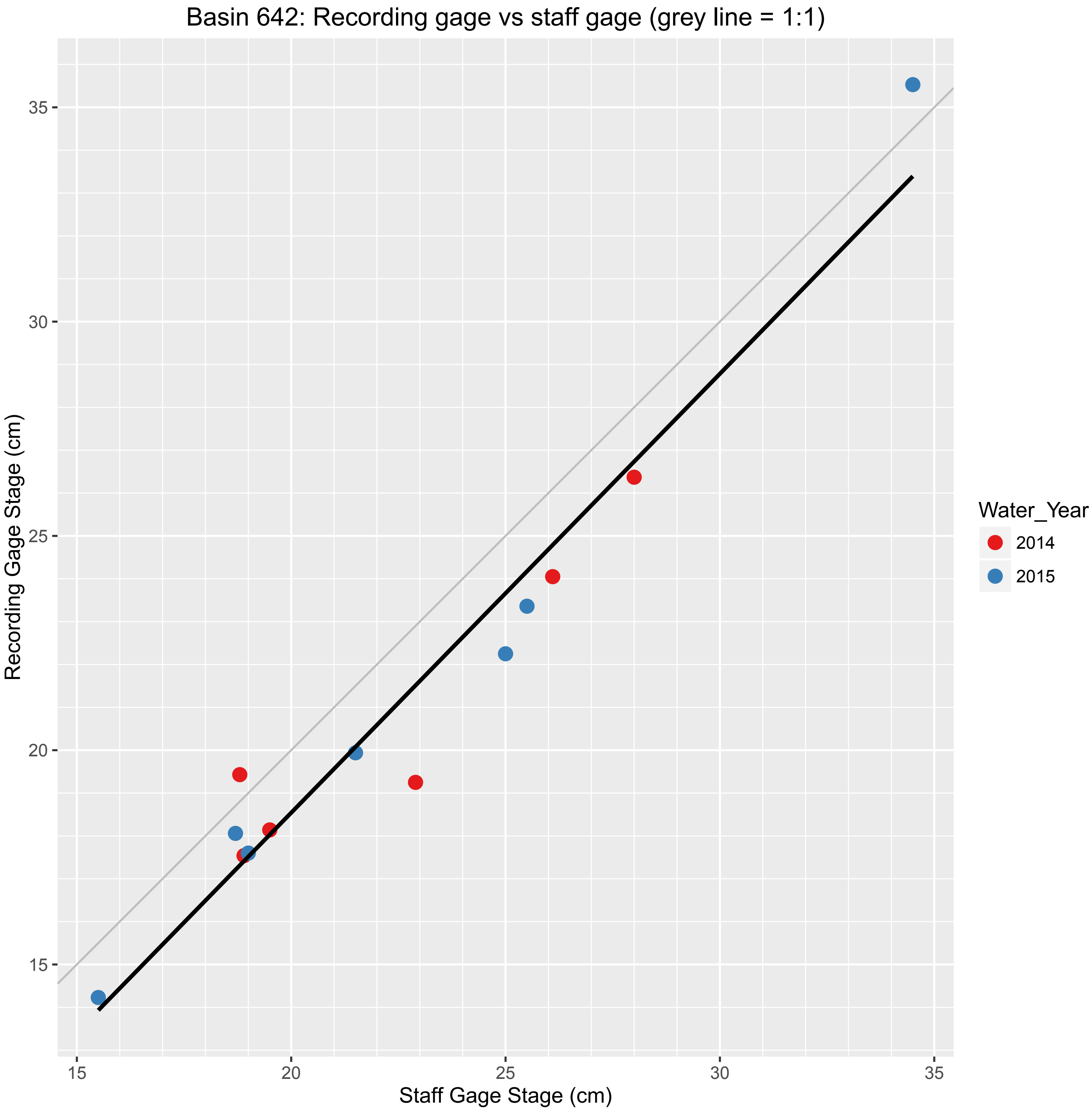
Basin 642: Gage data histograms, cross−section profile, and stage−discharge data




Basin 642: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131212
20140806
20150615
0
20
40
60
80
100
120
0
100
200
300
400
500
600



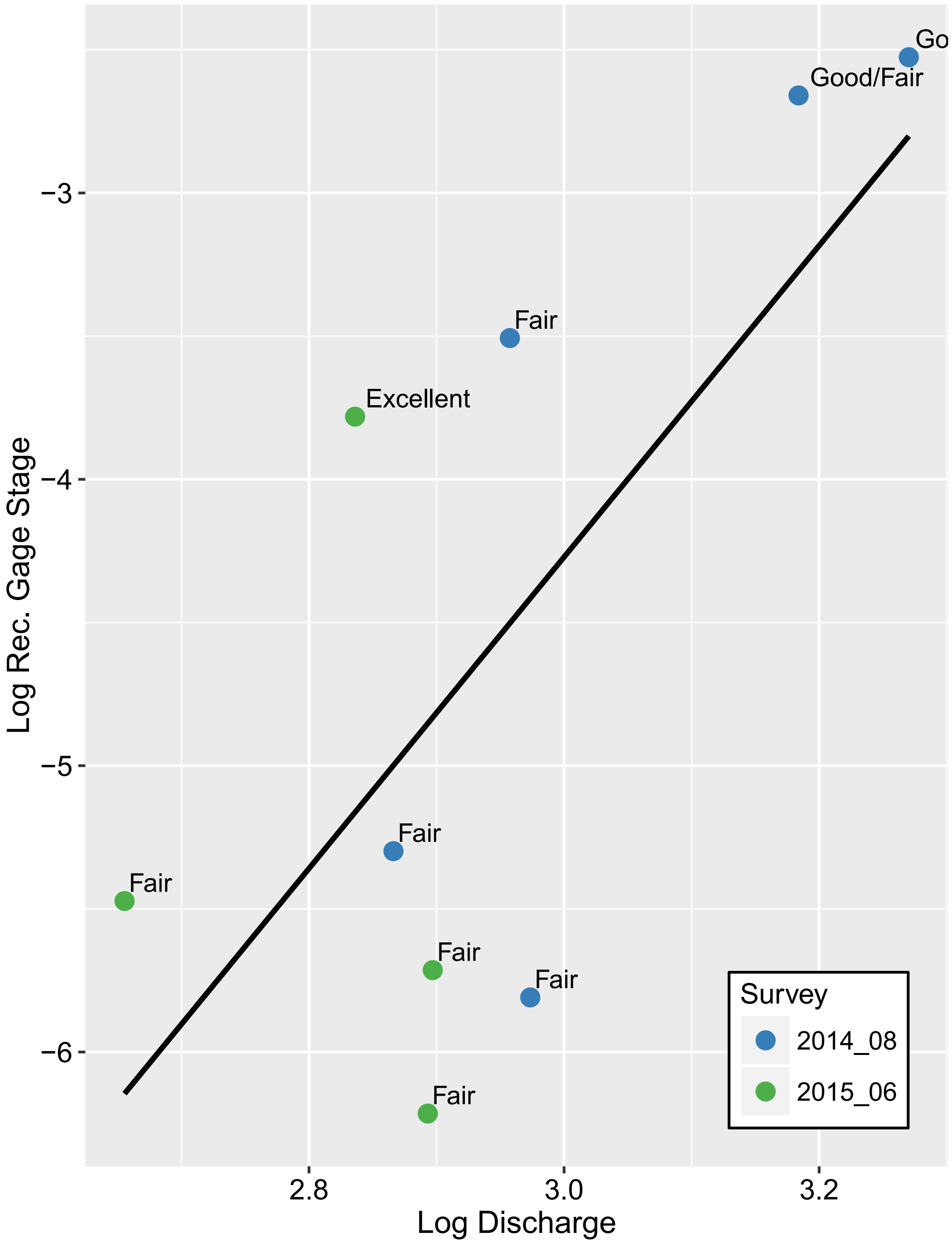
Basin 642: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec. Difference
Elevation (cm)
Max. Discharge
Min. Discharge
Zero cm elevation
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
01Mar14
01May14
01Jul14
01Sep14
01Nov14
01Jan15
01Mar15
01May15
01Jul15

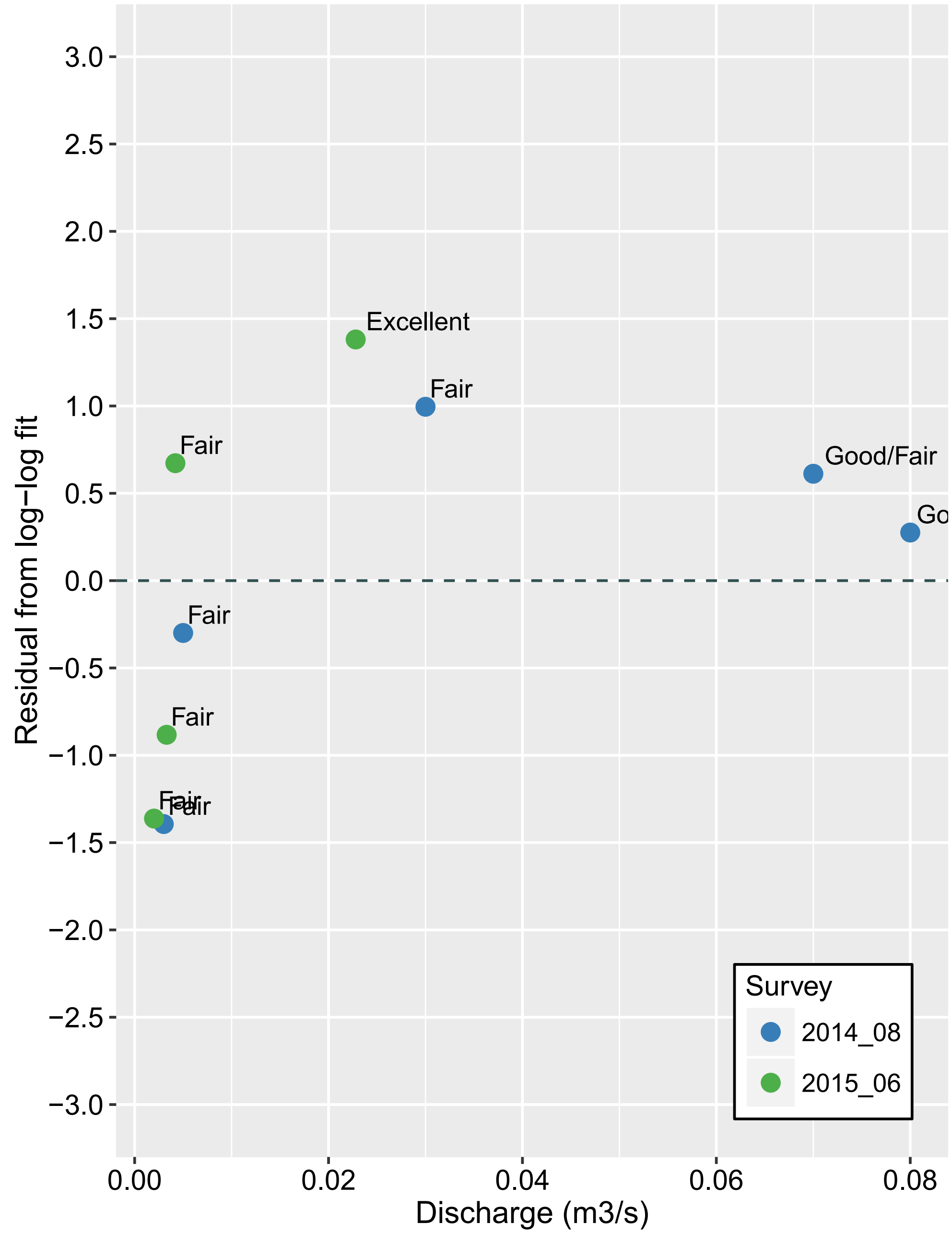


Basin 642: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
15
20
25
30
35
Water_Year
2014
2015

Basin 642: Stage−discharge curve and residuals

All available data





Basin 694

Summary
Reliable rating curve after 2/20/2014.

Category:
Conditional – Time

Recommendations for future data collection
Discharge at stage heights above 30 cm.

Histograms

Staff gage is frequently being read above median recording gage measurements, providing significant data through the entire range of flows.

Cross-sectional Profiles

Wide channel with steep right bank and gradually sloped left bank. Undercutting is present on the right bank in 2015. Note that this gage station is located on the upstream side of a bridge.

Cross-section narrowed and deepened from 2013 (red) to 2014 (blue). Cross-section became wider and shallower from 2014 to 2015 (green), most notably aggradation occurred near TH and LEW. Geometry of channel changes rapidly near LEW in both 2014 and 2015.

Staff Gage-Recording Gage Time Series and Regression

Recording gage time-series shows consistent baseflow over time.

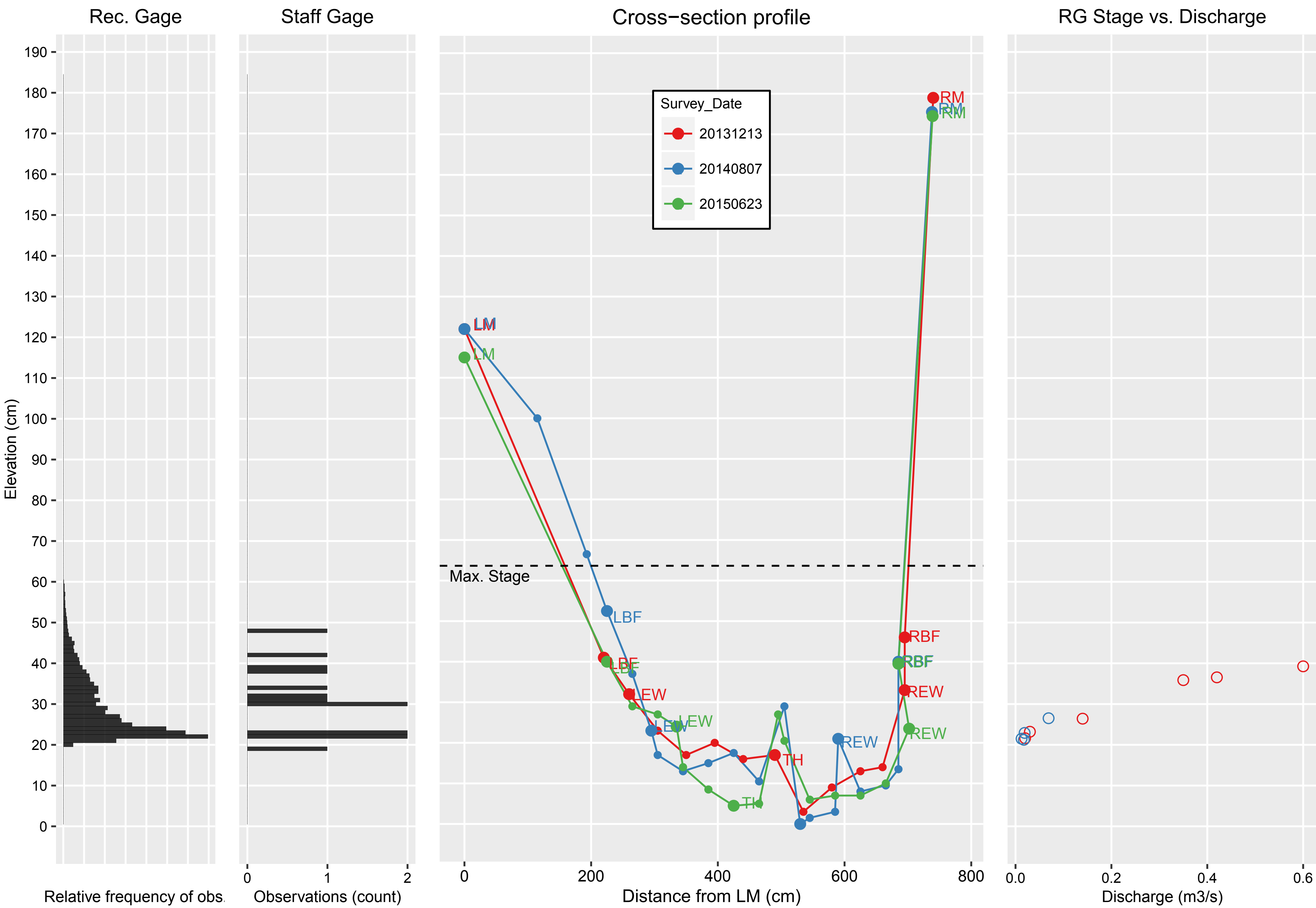
Note that the staff gage/recording gage difference (blue line) dips below zero on only one occasion in early October 2014. Likely this is due to an erroneous staff gage reading as the relationship returns it's previous level (~ 2 cm) later that month.

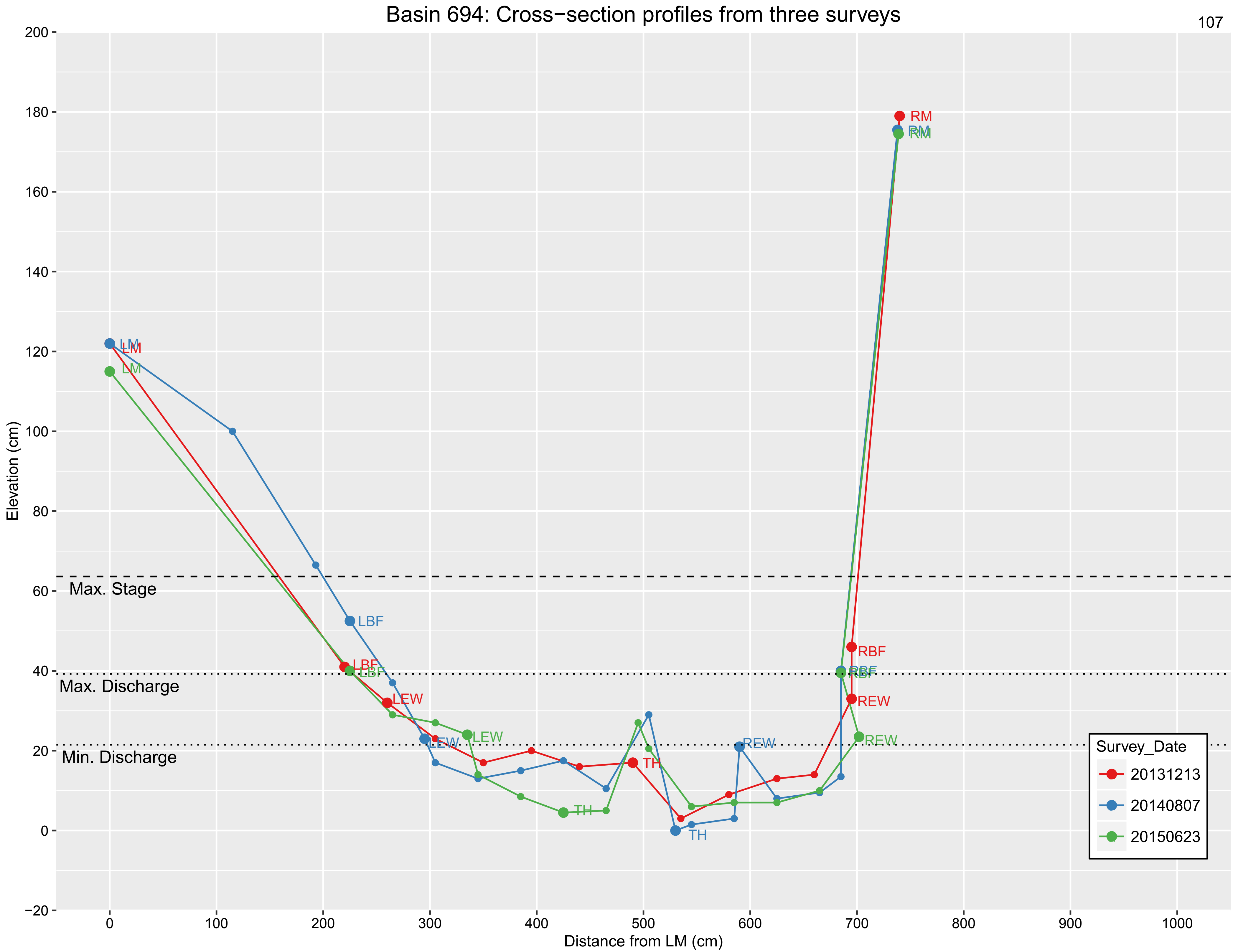
Stage-Discharge Rating Curve

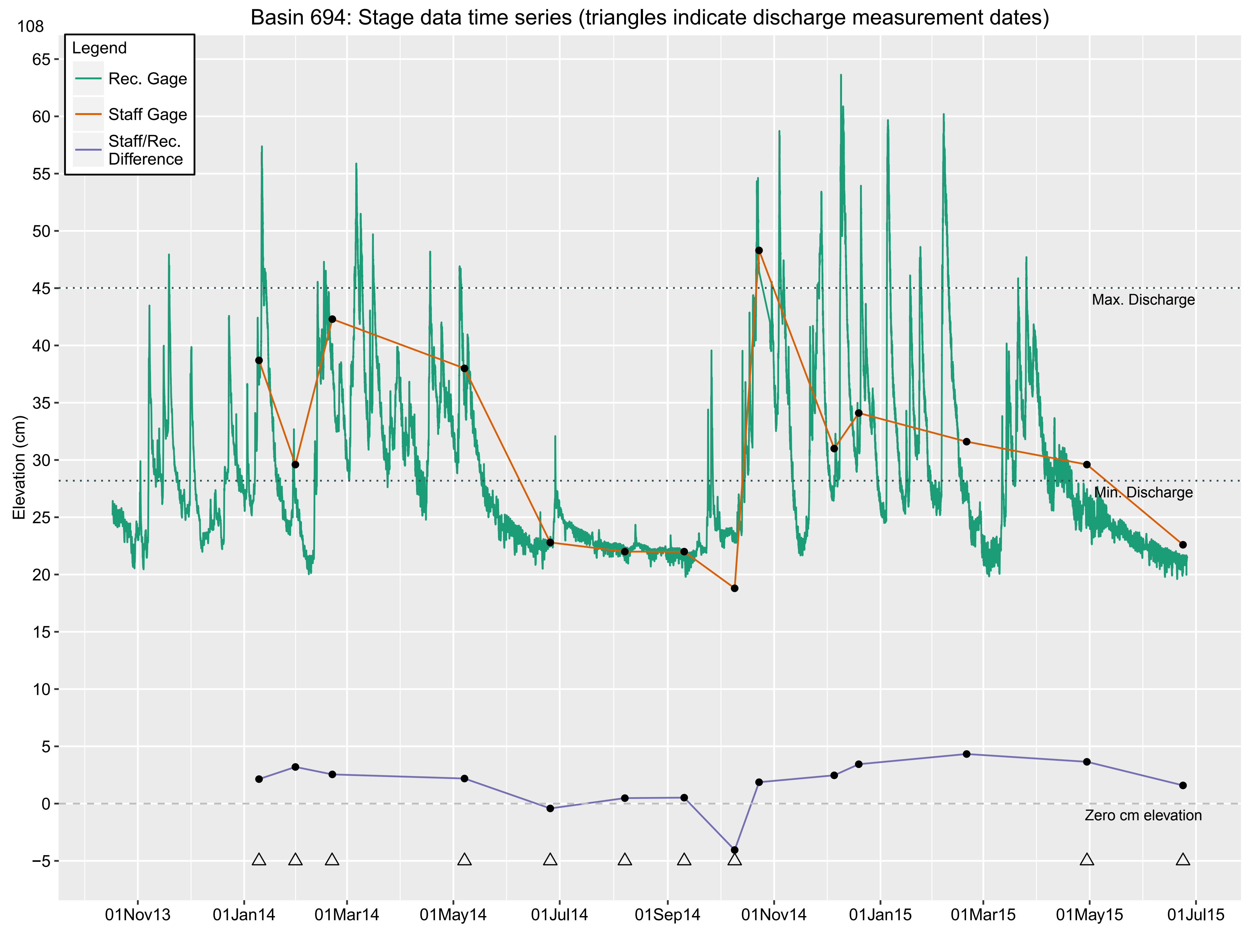
Rating curve shows strong relationship between stage and discharge after 2/20/2014.

Stream gage station in basin 694 at mid flow.

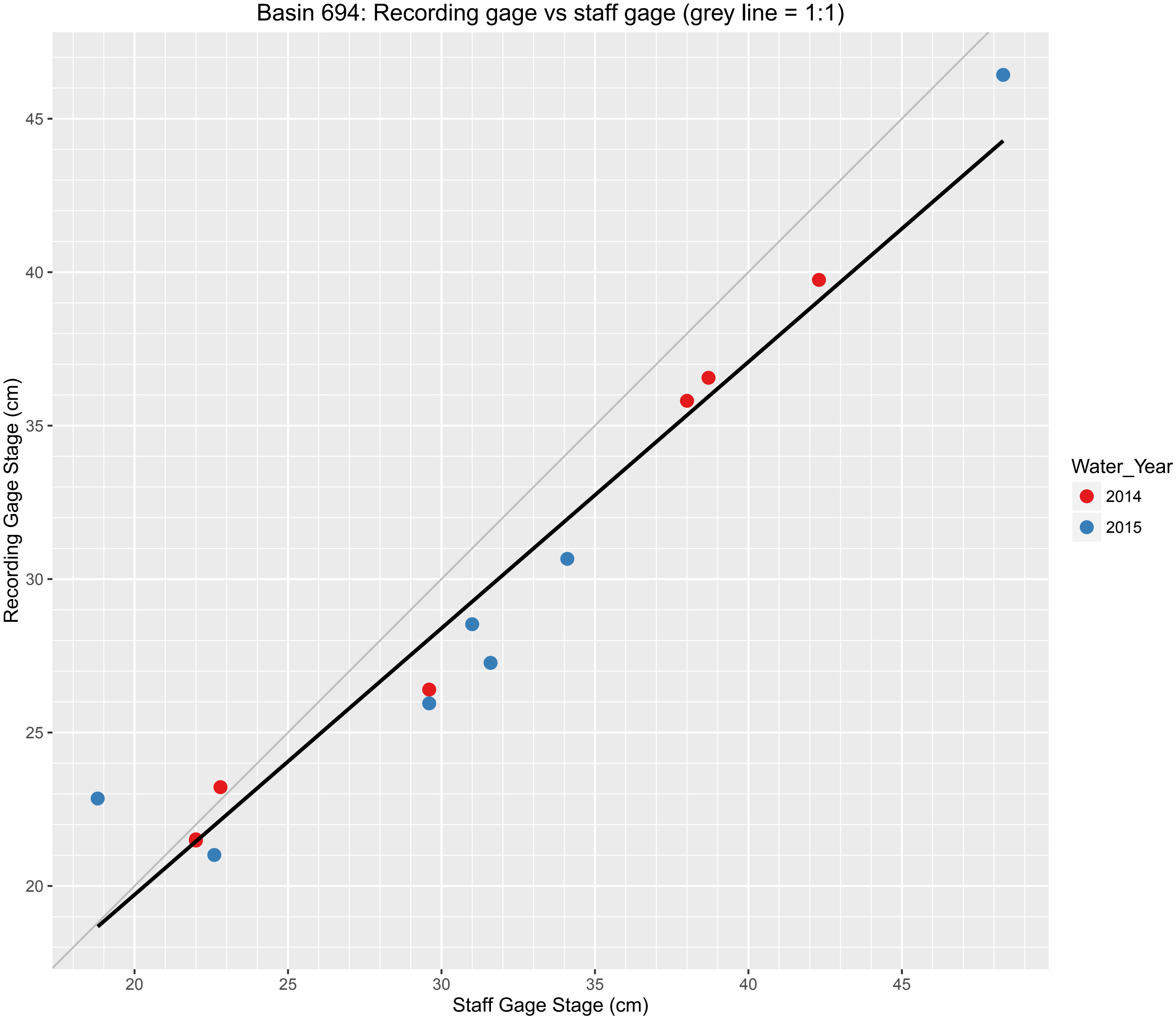
Basin 694: Gage data histograms, cross−section profile, and stage−discharge data

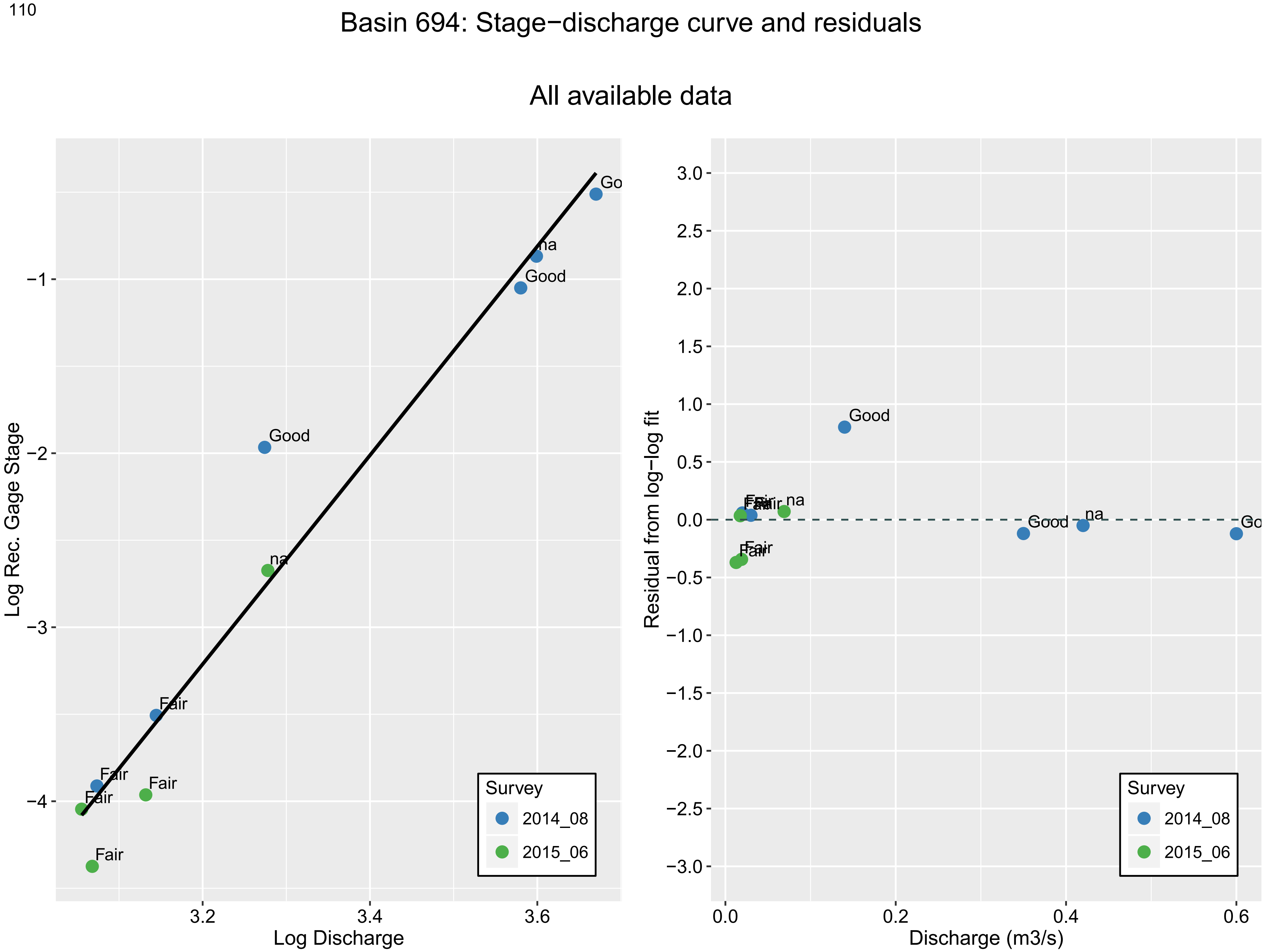



Basin 694: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131213
20140807
20150623
200
180
160
140
120
100
80
60
40
20
0
−20
0
100
200
300
400
500
600
700
800
900
1000



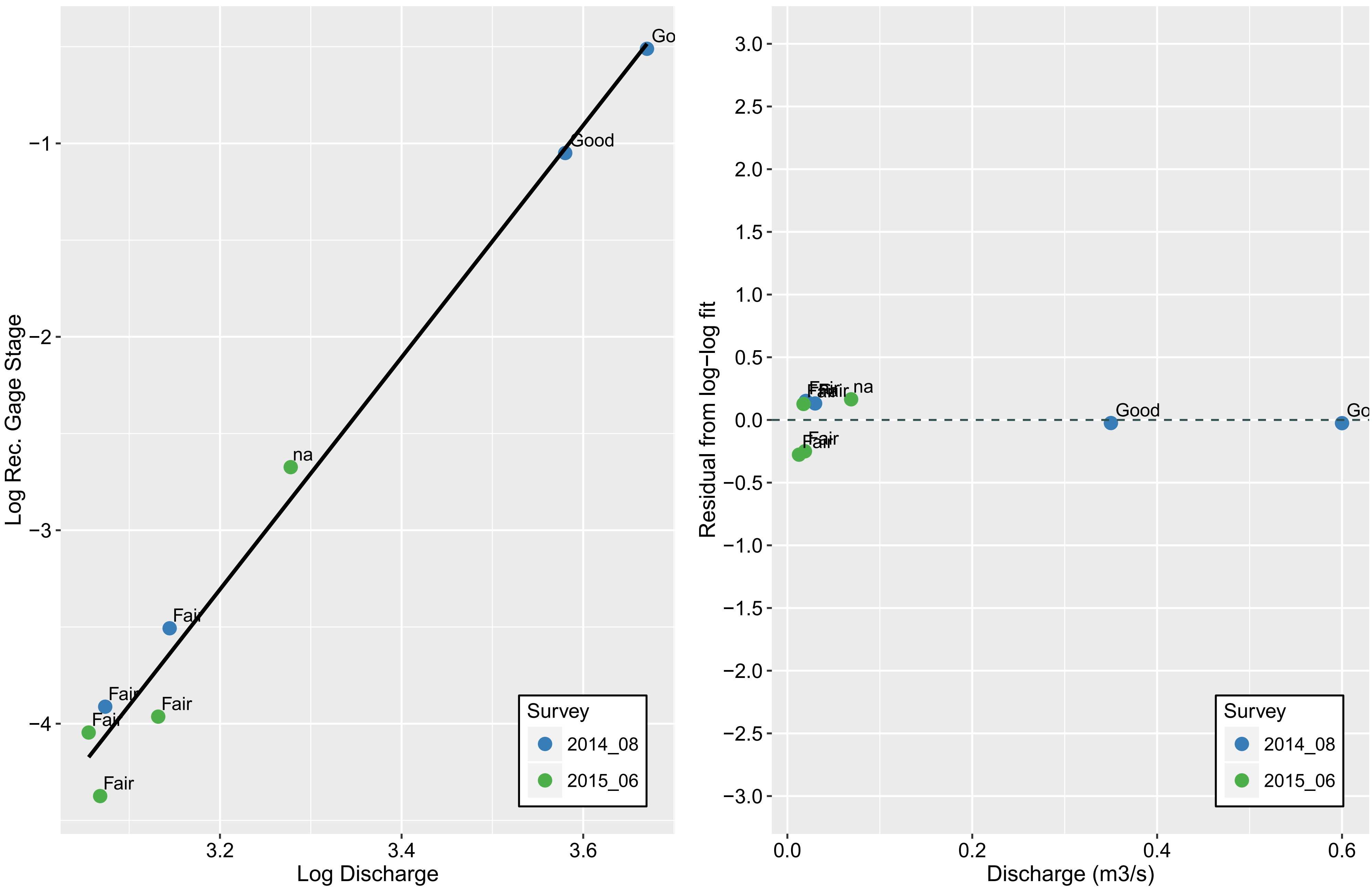
Basin 694: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec. Difference
Max. Discharge
Min. Discharge
Zero cm elevation
Elevation (cm)
65
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
01Nov13
01Jan14
01Mar14
01May14
01Jul14
01Sep14
01Nov14
01Jan15
01Mar15
01May15
01Jul15

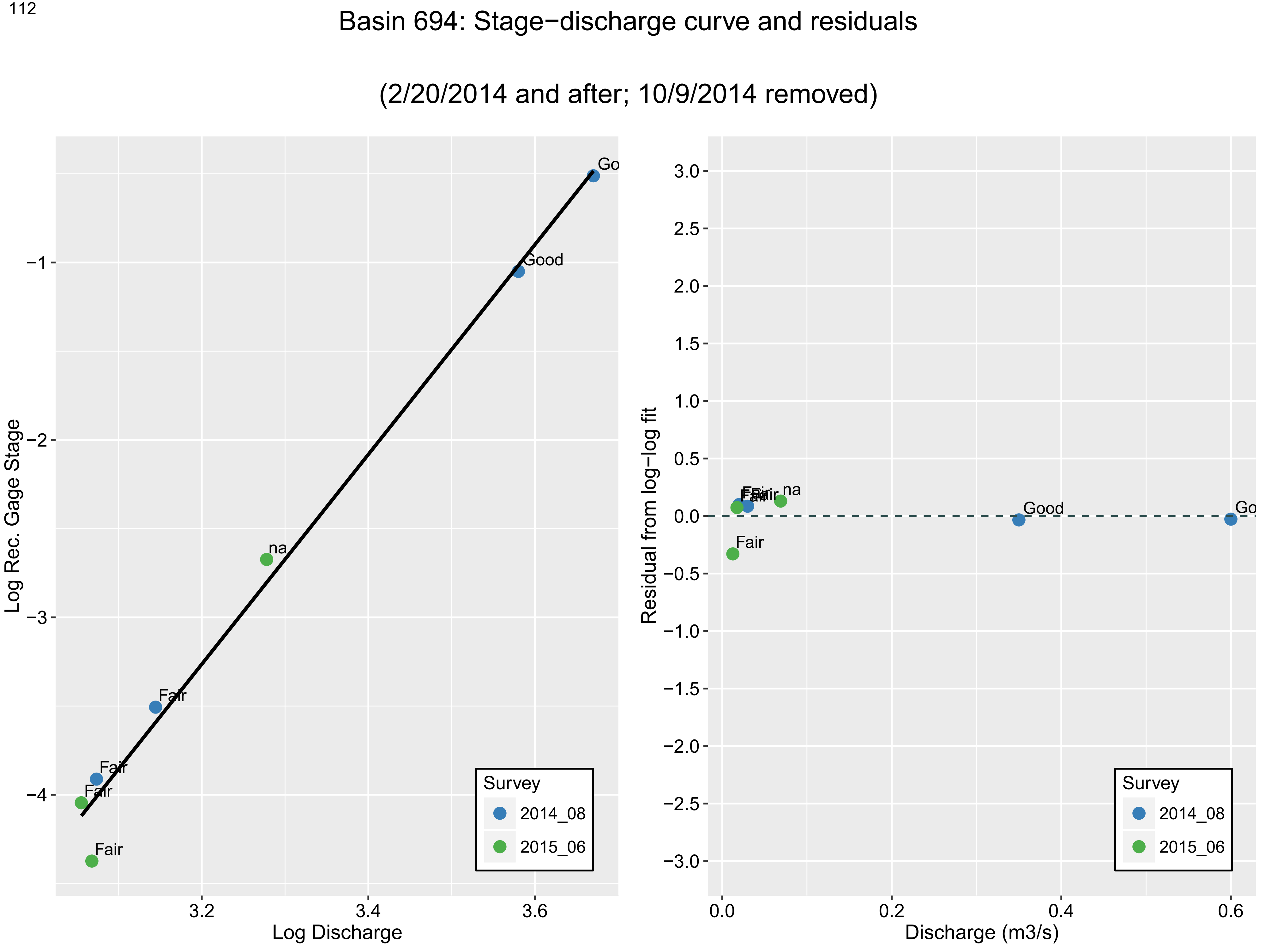

Basin 694: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
20
25
30
35
40
45
Water_Year
2014
2015


Basin 694: Stage−discharge curve and residuals
All available data
Log Rec. Gage Stage
Log Discharge
−1
−2
−3
−4
3.2
3.4
3.6
Good
na
Good
Good
na
Fair
Fair
Fair
Fair
Fair
Survey
2014_08
2015_06
Residual from log−log fit
Discharge (m3/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
0.0
0.2
0.4
0.6
Good
na
Good
na
Good
Fair
Fair
Survey
2014_08
2015_06

Basin 694: Stage−discharge curve and residuals

(2/20/2014 and after)





Basin 694: Stage−discharge curve and residuals
(2/20/2014 and after; 10/9/2014 removed)
Log Rec. Gage Stage
Log Discharge
Residual from log−log fit
Discharge (m3/s)
Go
Good
na
Fair
Fair
Fair
Fair
Survey
2014_08
2015_06

Basin 717

Summary
Large changes in channel geometry from 2014 to 2015.

Category 2c:
Conditional – Time

Recommendations for future data collection
Discharge during high-flow.
Need 4-6 more points to create rating curve for period after 10/6/2014.

Histograms

Histogram plots show two distinct "realms" of stage heights, before and after the channel shift. Otherwise, the median range of recording gage readings is also reflected by the overall range of staff gage measurements. Peaks in the recording gage are roughly 15 cm above the highest staff gage measurement.

Cross-sectional profiles

Channel located in a wide, flat floodplain (near road) with a steep left bank and a gradually sloped right bank.
Erosion/scour is observed from 2013 (red) to 2014 (blue) on right side of channel.
Channel aggradation is observed between 2014 (blue) and 2015 (green) across almost the entire cross-section, significantly altering channel geometry.

Staff Gage-Recording Gage Time Series and Regression

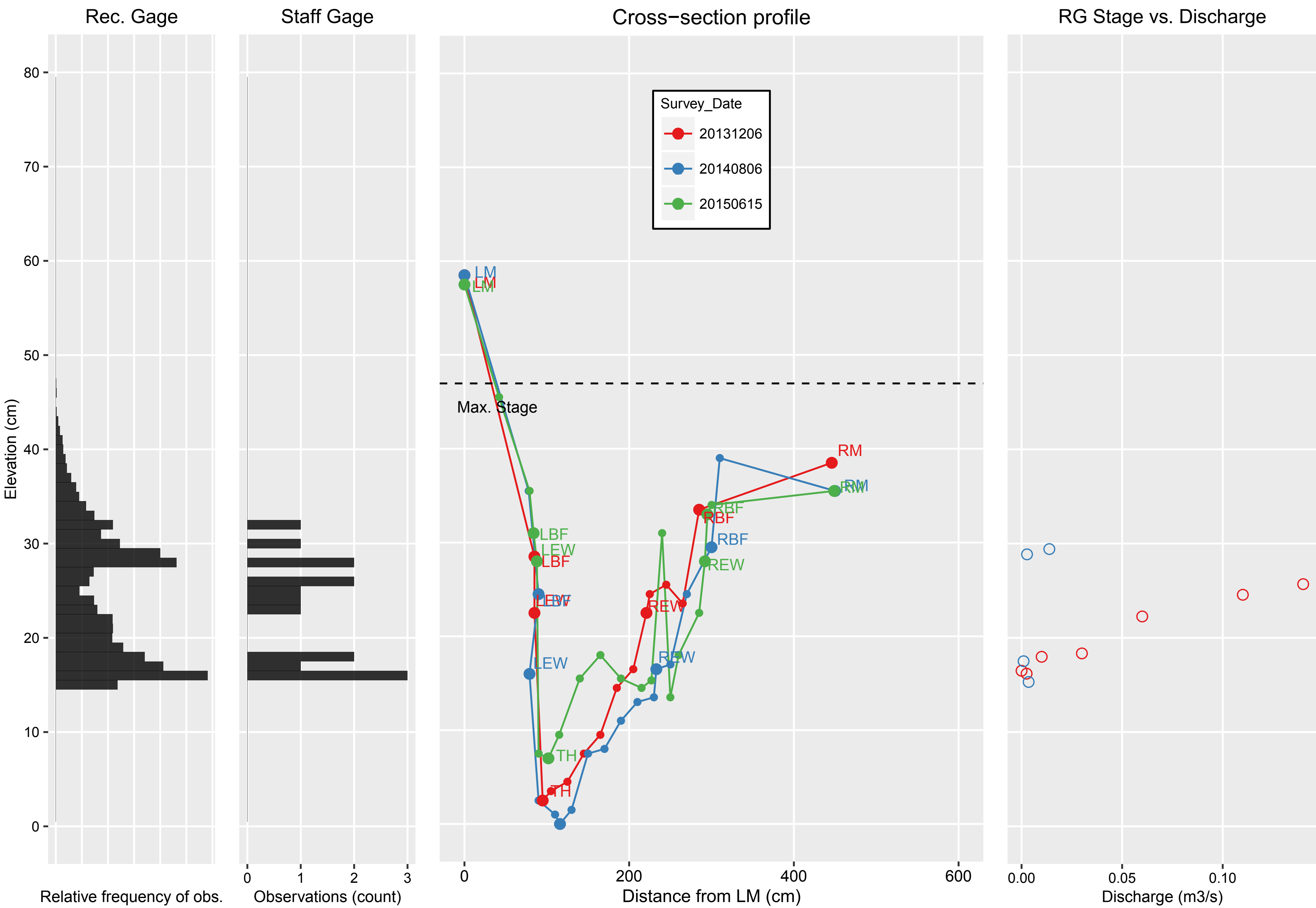
Large increase in baseflow is observed from 2014 to 2015. However, the staff gage-recording gage relationship shows strong correlation, even after large change in channel. This confirms that the channel moved and that the gage intake is not buried.

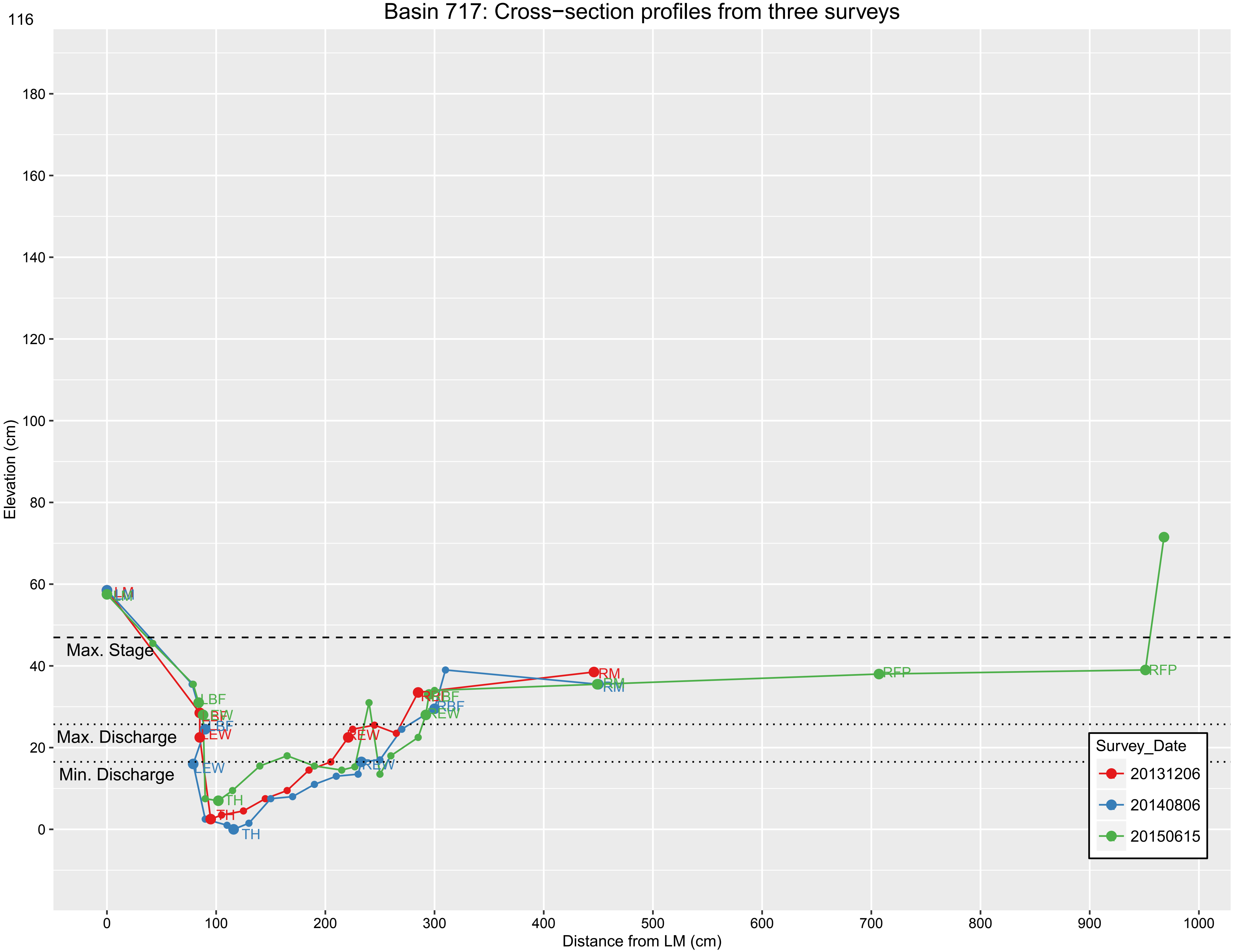
Stage-Discharge Rating Curve

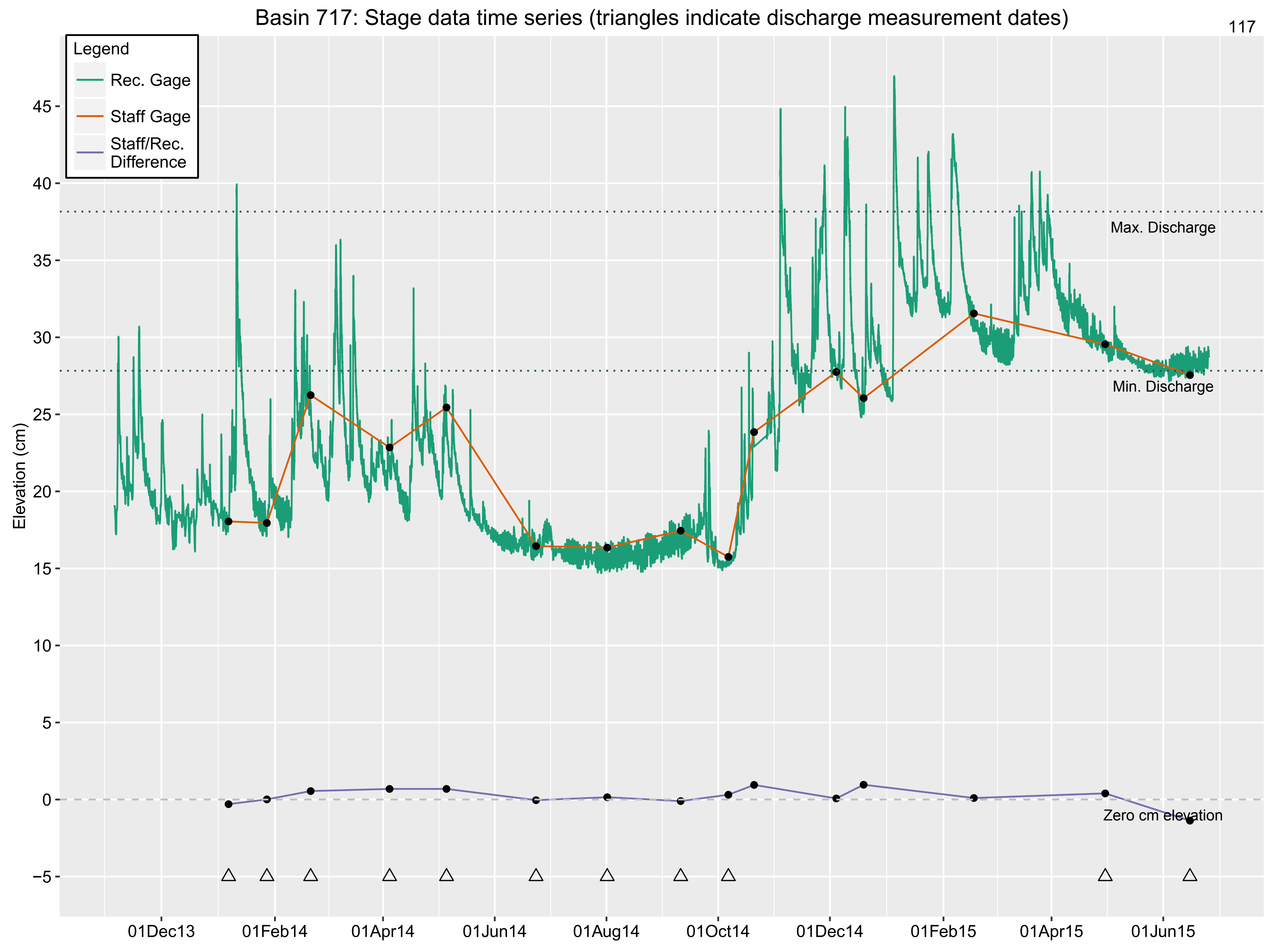
Due to significant changes in channel geometry over time, the rating curve for this basin must be divided into three distinct sections: before 1/27/2014, 1/27/2014 to 10/6/2014 and after 10/6/2014. At this current point in time, the middle section is the only section where enough data is available to draw an accurate rating curve. Note that all three points in the low-flow season of 2014 occur at or very close to 0 discharge and that the point with 0 m^3/second discharge is excluded from the rating curve.

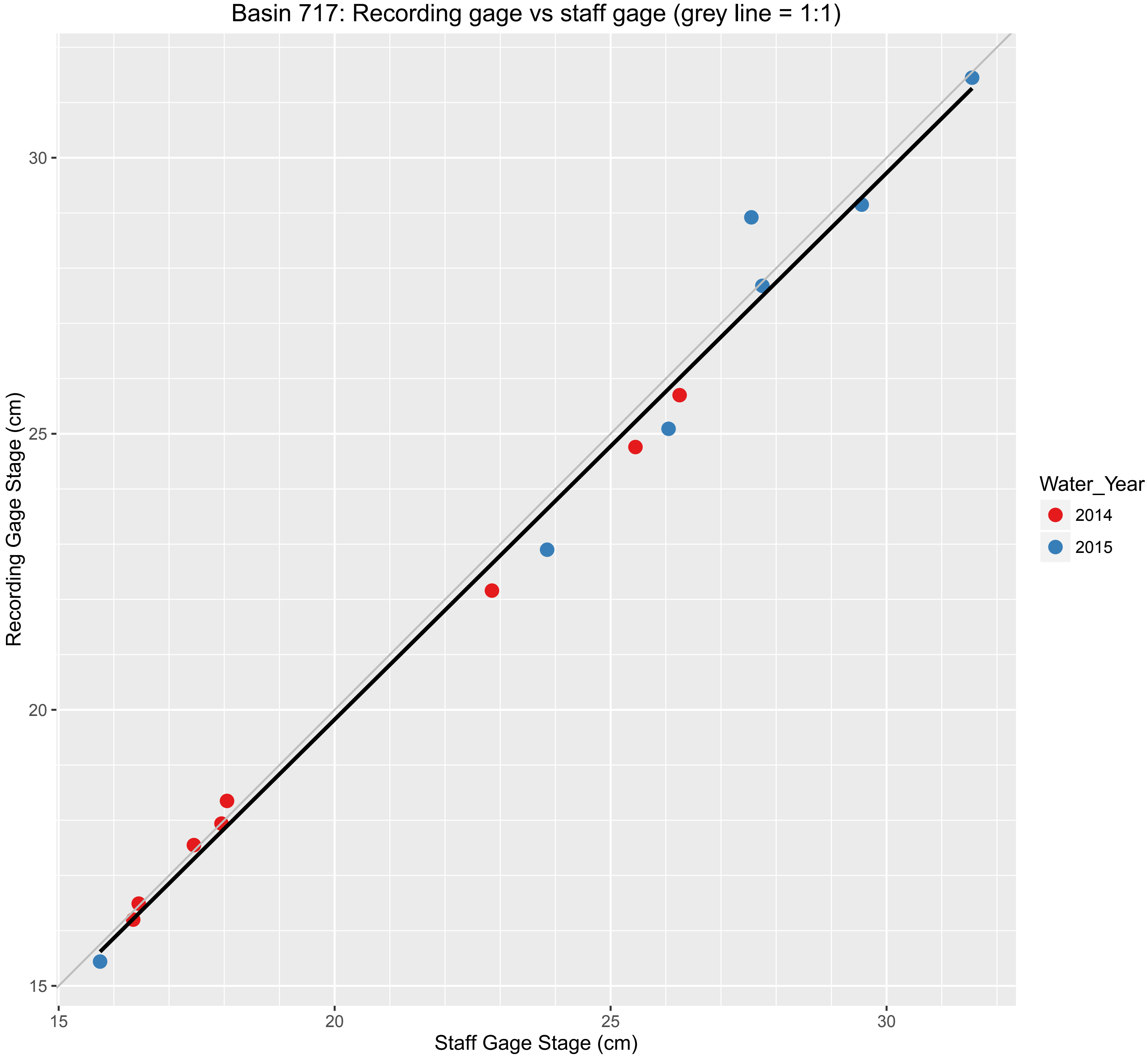
Stream gage station in basin 717 at mid flow.

Basin 717: Gage data histograms, cross−section profile, and stage−discharge data



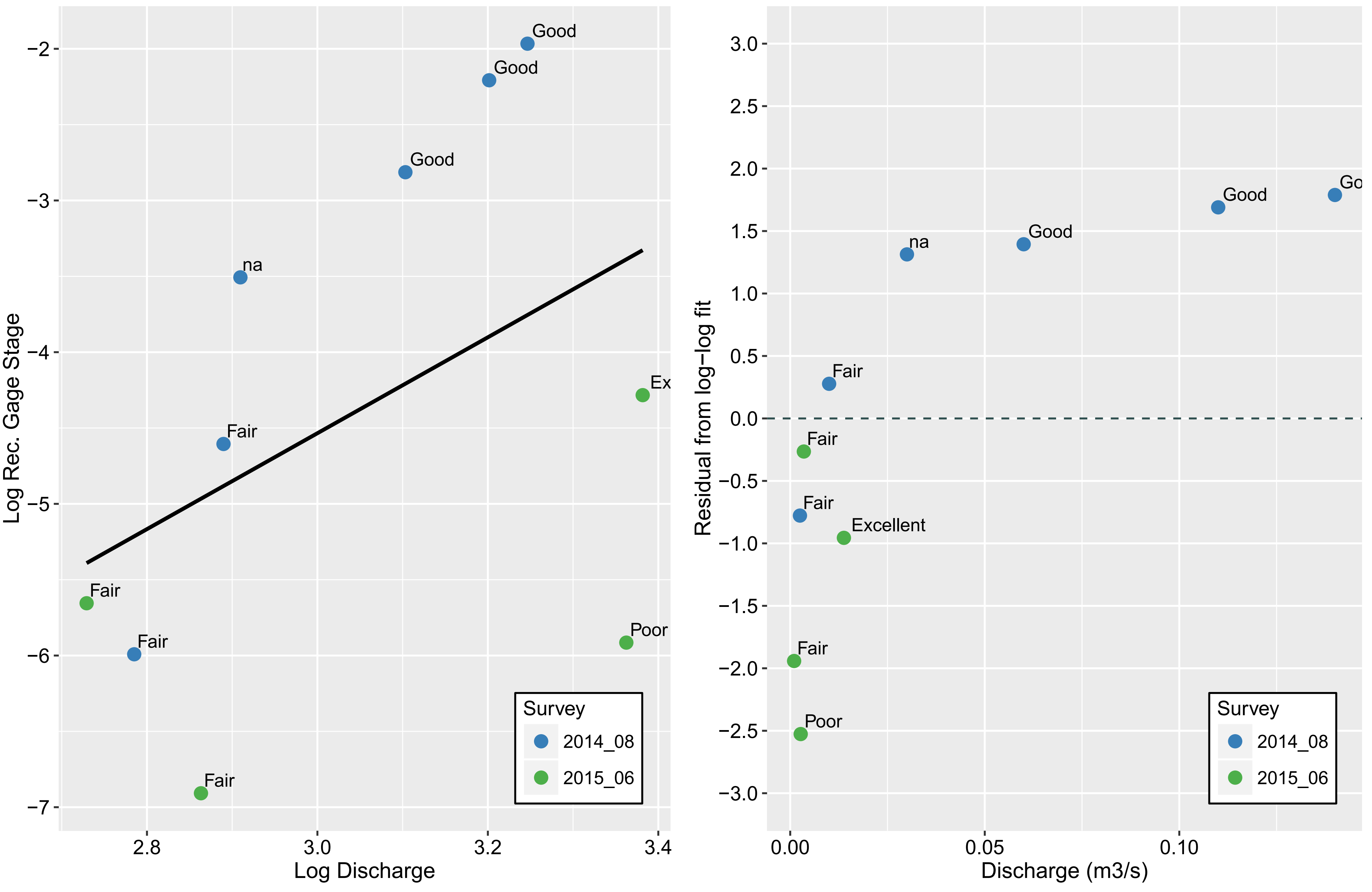

Basin 717: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
Survey_Date
20131206
20140806
20150615
LM
LBF
LEW
TH
REW
RBF
RM
RFP
0
20
40
60
80
100
120
140
160
180
0
100
200
300
400
500
600
700
800
900
1000


Basin 717: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec. Difference
Max. Discharge
Min. Discharge
Zero cm elevation
Elevation (cm)
45
40
35
30
25
20
15
10
5
0
−5
01Dec13
01Feb14
01Apr14
01Jun14
01Aug14
01Oct14
01Dec14
01Feb15
01Apr15
01Jun15


Basin 717: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
15
20
25
30
Water_Year
2014
2015

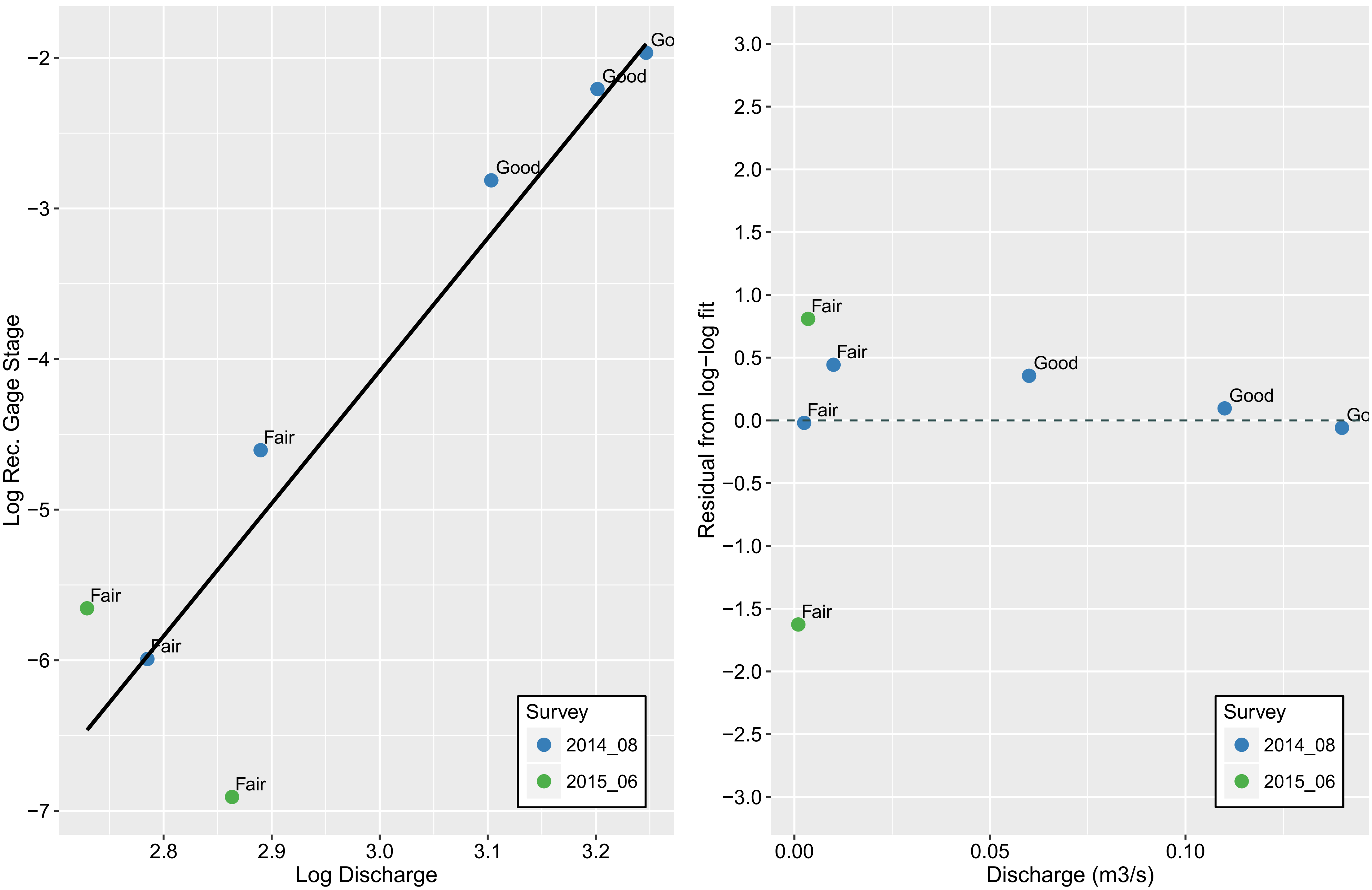
Basin 717: Stage−discharge curve and residuals

All available data



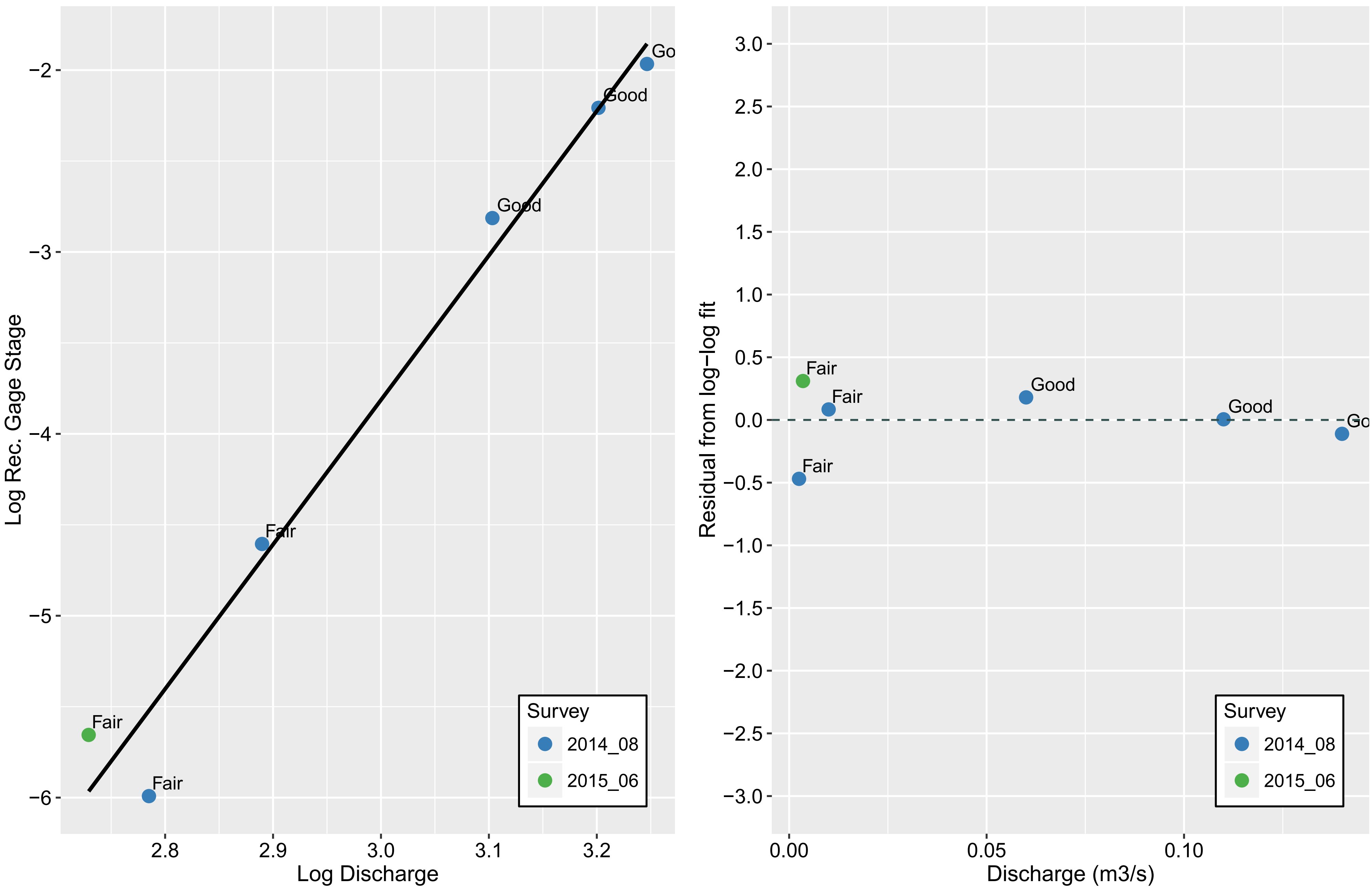
Basin 717: Stage−discharge curve and residuals

(1/27/2014 − 10/6/2014)



Basin 717: Stage−discharge curve and residuals

(1/27/2014 − 10/6/2014; two zero discharge readings removed)



Basin 724

Summary
Large changes in channel geometry from 2014 to 2015. Gages now out of water.

Category:
Conditional – Time

Recommendations for future data collection
Before any additional data can be utilized, gage intake needs to be uncovered and located within the main channel of flow.
Need 4-6 more points to create rating curve for period after 10/6/2014.

Histograms

Histogram plots show two distinct "realms" of stage heights, before and after the channel shift. Otherwise, the median range of recording gage readings is also reflected by the overall range of staff gage measurements. Peaks in the recording gage are roughly 15 cm above the highest staff gage measurement.

Cross-sectional Profile

Scour is observed on the left side of the channel and deposition on the right between 2013 (red) and 2014 (blue) surveys.

Substantial change in channel geometry from 2014 to 2015 (green). A large amount of scour occurred, on the left side of the channel. This is very well reflected in the RG time series graph.

2014 survey notes: "Huge amount of erosion, x-section control destroyed. Gage dry, obvious channel migration and elevation drop. Gaging station out of service! No SG reading because it is DRY! RGB elevation measured at top of end cap. SGB elevation measured at top of end cap. No Manning's coefficients measured."

Staff Gage-Recording Gage Time Series and Regression

A very obvious decrease in baseflow is observed on 1/4/2015. It is likely that the rating curve for the current "realm" will be applied after this date.

Recording gage and staff gage responded the bed scour in similar (1:1) relationship (blue line). This signifies that the gages have not moved but rather the bed. Strong correlation in staff gage-recording gage relationship. Slope very close to 1, 1:1 ratio between staff gage-recording gage maintained, even after large erosion even in channel.

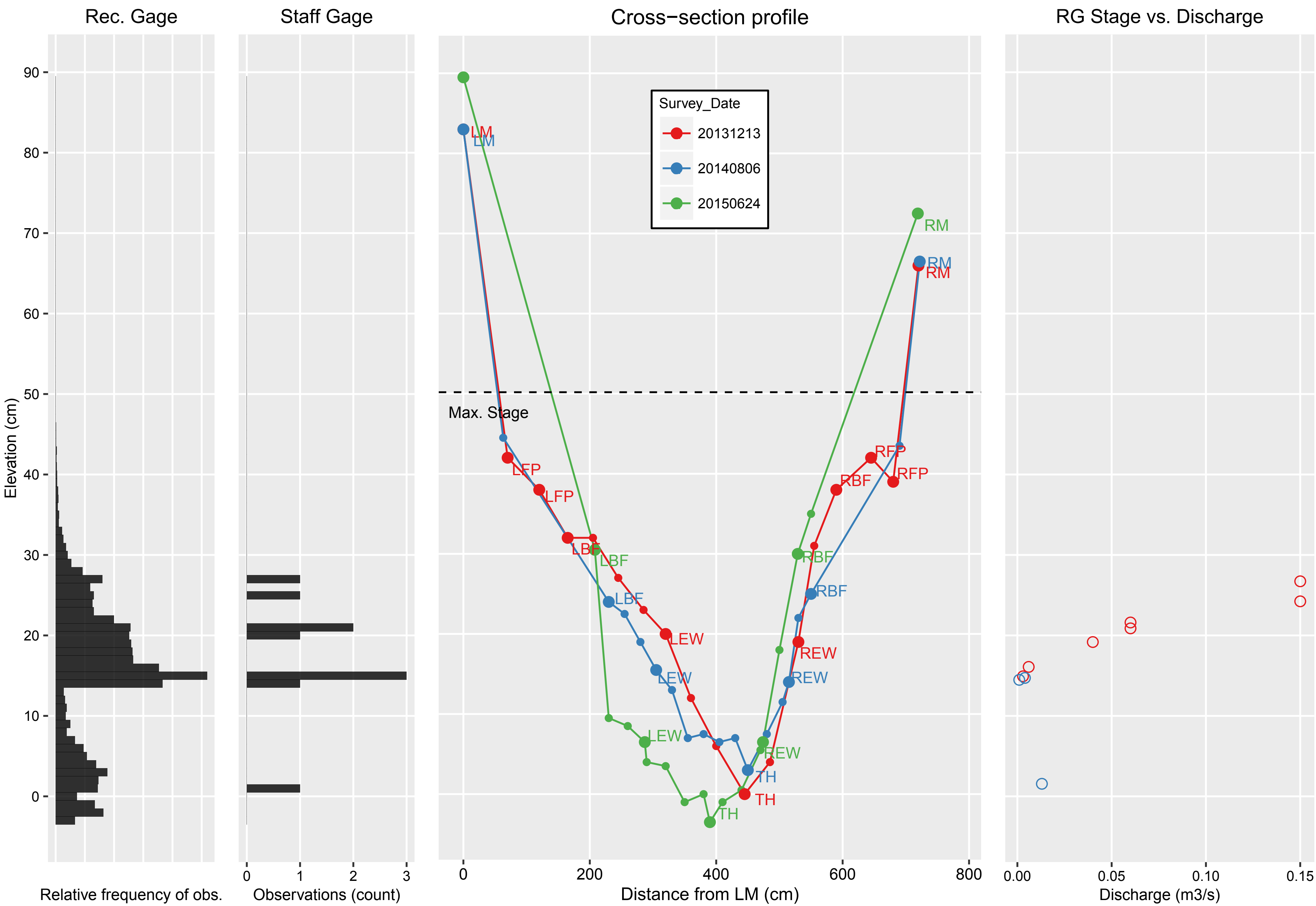
Another potential scour event may have occurred in late January 2014, however there is limited discharge data for this time period and it may be difficult to determine the exact date/time of this event.

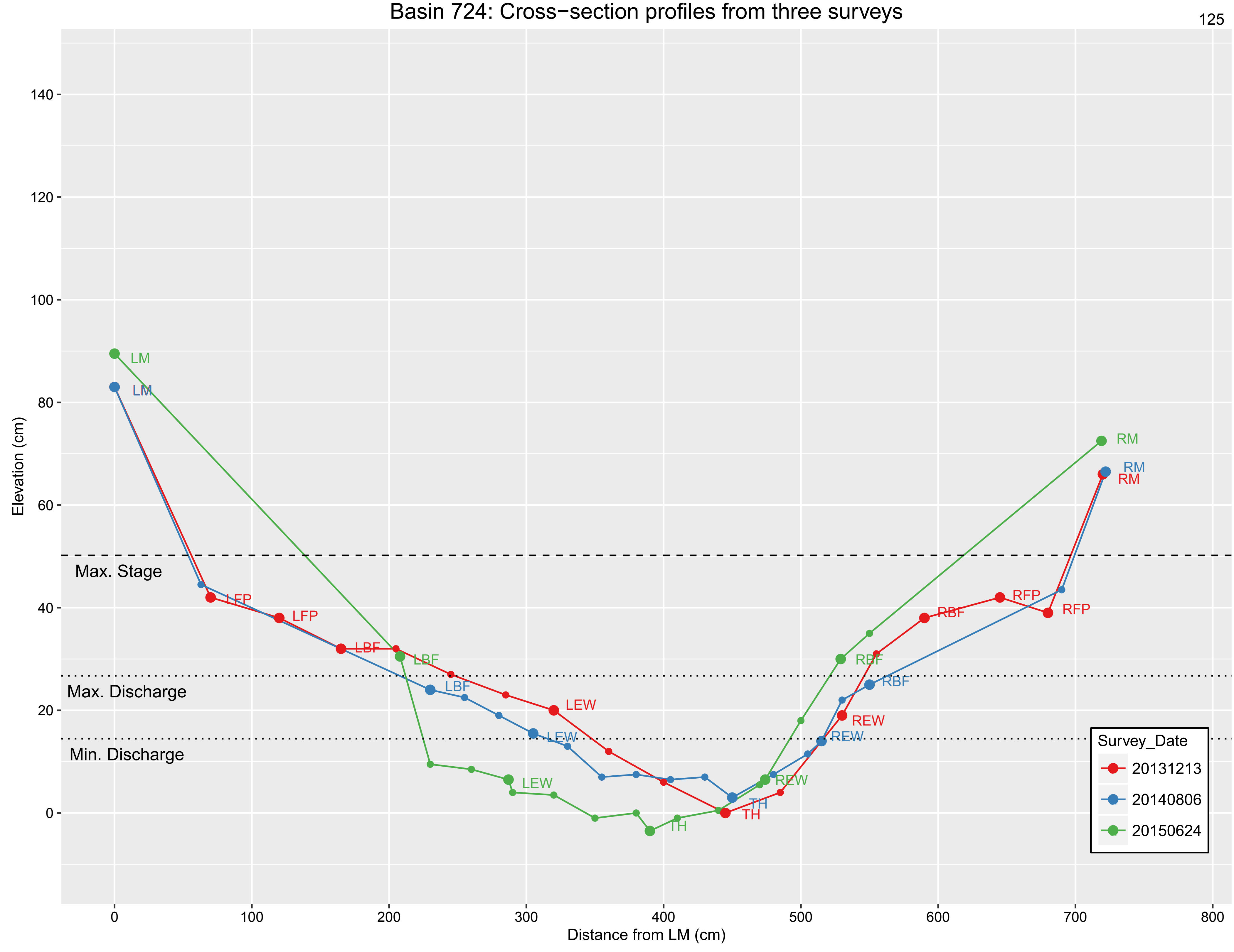
Stage-Discharge Rating Curve

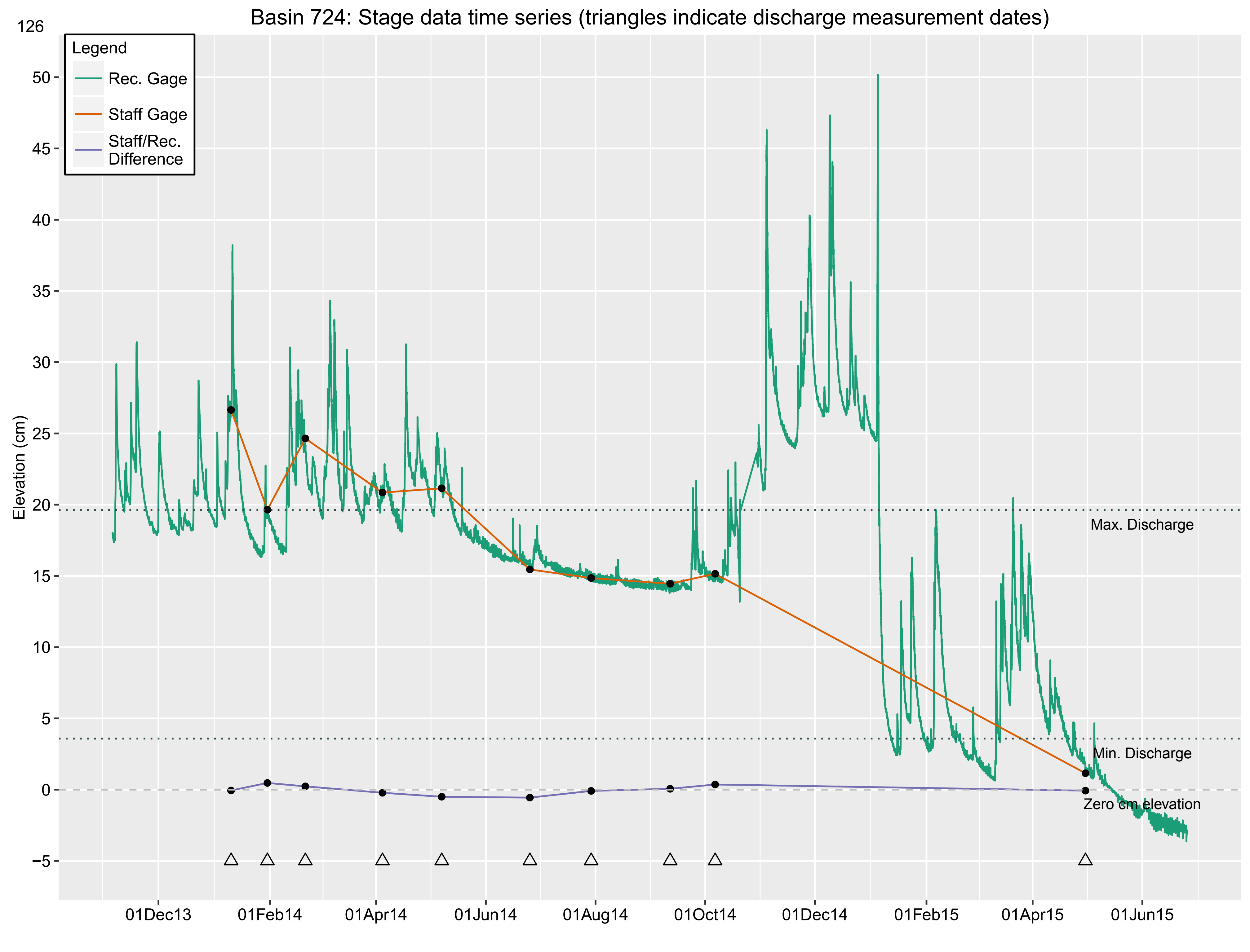
Due to two significant changes in channel geometry over time, the rating curve for this basin must be divided into three distinct sections: Start of monitoring to 2/20/2014; 2/20/2014 to 10/06/20104 and 10/6/2014 to present. At this current point in time, the middle section is the only section where enough data is available to draw an accurate rating curve.

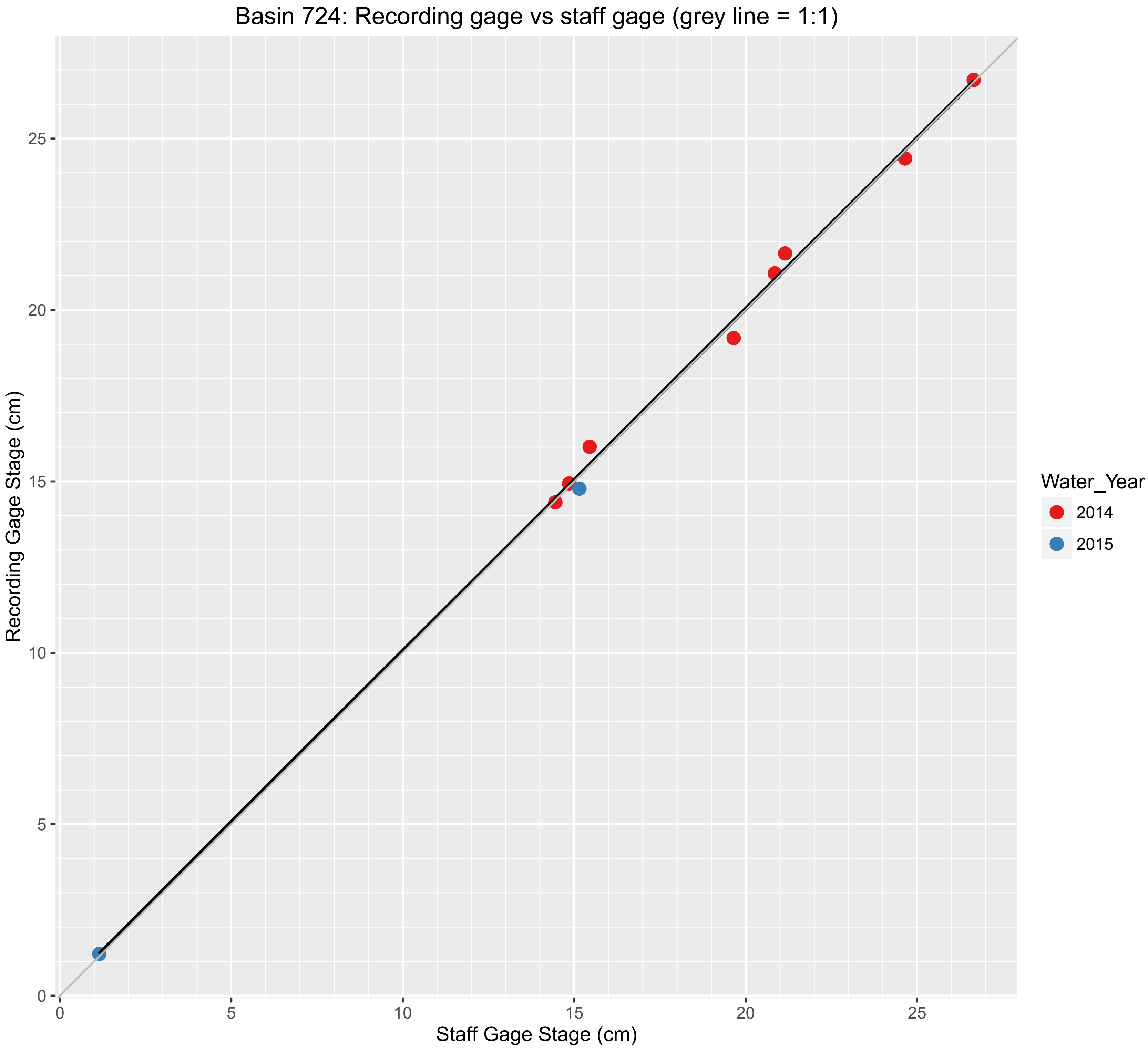
Stream gage station in basin 724 at low flow (the removable staff gage is not shown). Note the large tree which felt above the gage station in the winter of 2014/2015 and altered the channel flow.

Basin 724: Gage data histograms, cross−section profile, and stage−discharge data



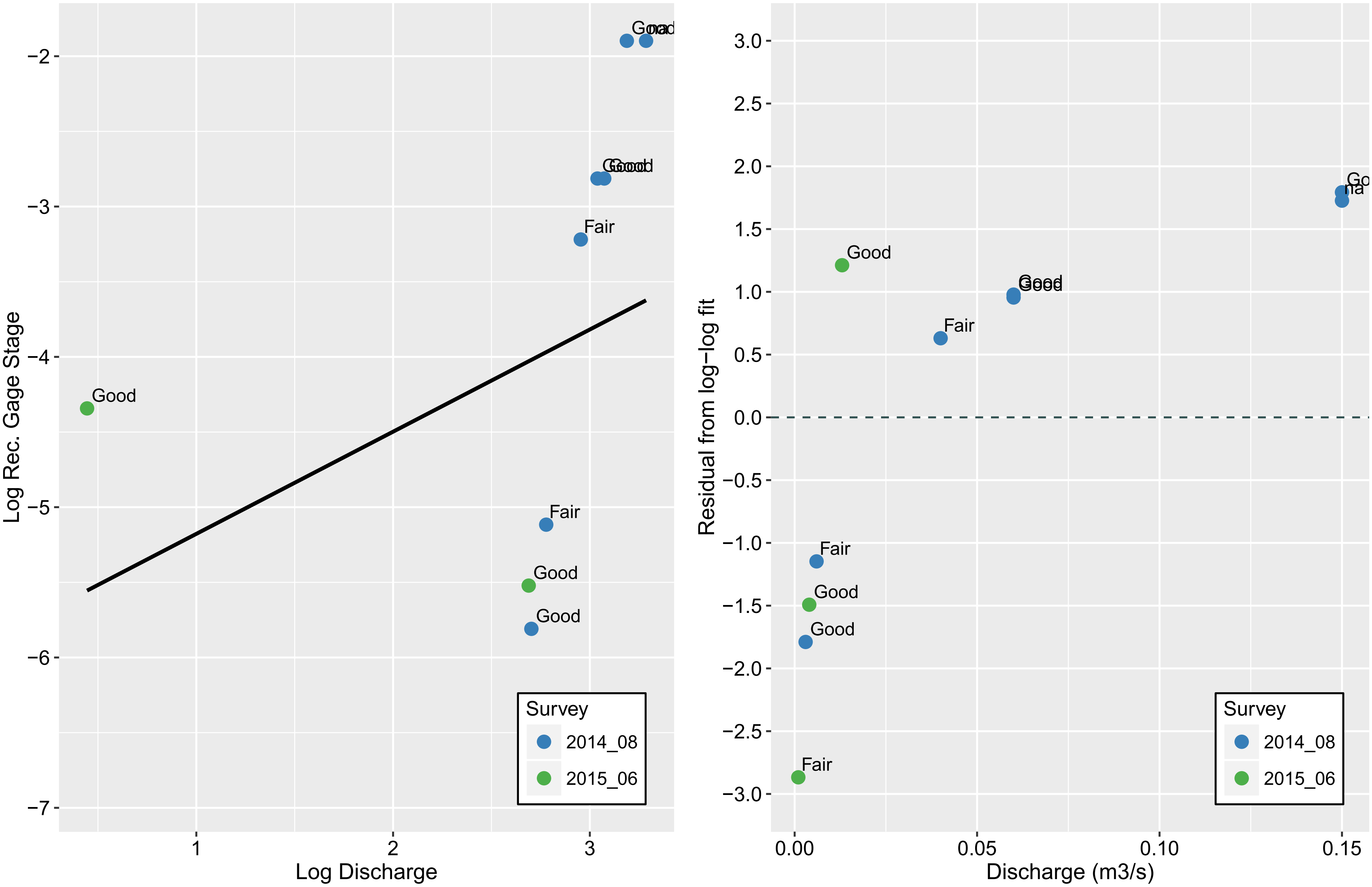

Basin 724: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LFP
LBF
LEW
TH
REW
RBF
RFP
RM
Survey_Date
20131213
20140806
20150624


Basin 724: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec. Difference
Elevation (cm)
50
45
40
35
30
25
20
15
10
5
0
−5
Max. Discharge
Min. Discharge
Zero cm elevation
01Dec13
01Feb14
01Apr14
01Jun14
01Aug14
01Oct14
01Dec14
01Feb15
01Apr15
01Jun15


Basin 724: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
0
5
10
15
20
25
Water_Year
2014
2015

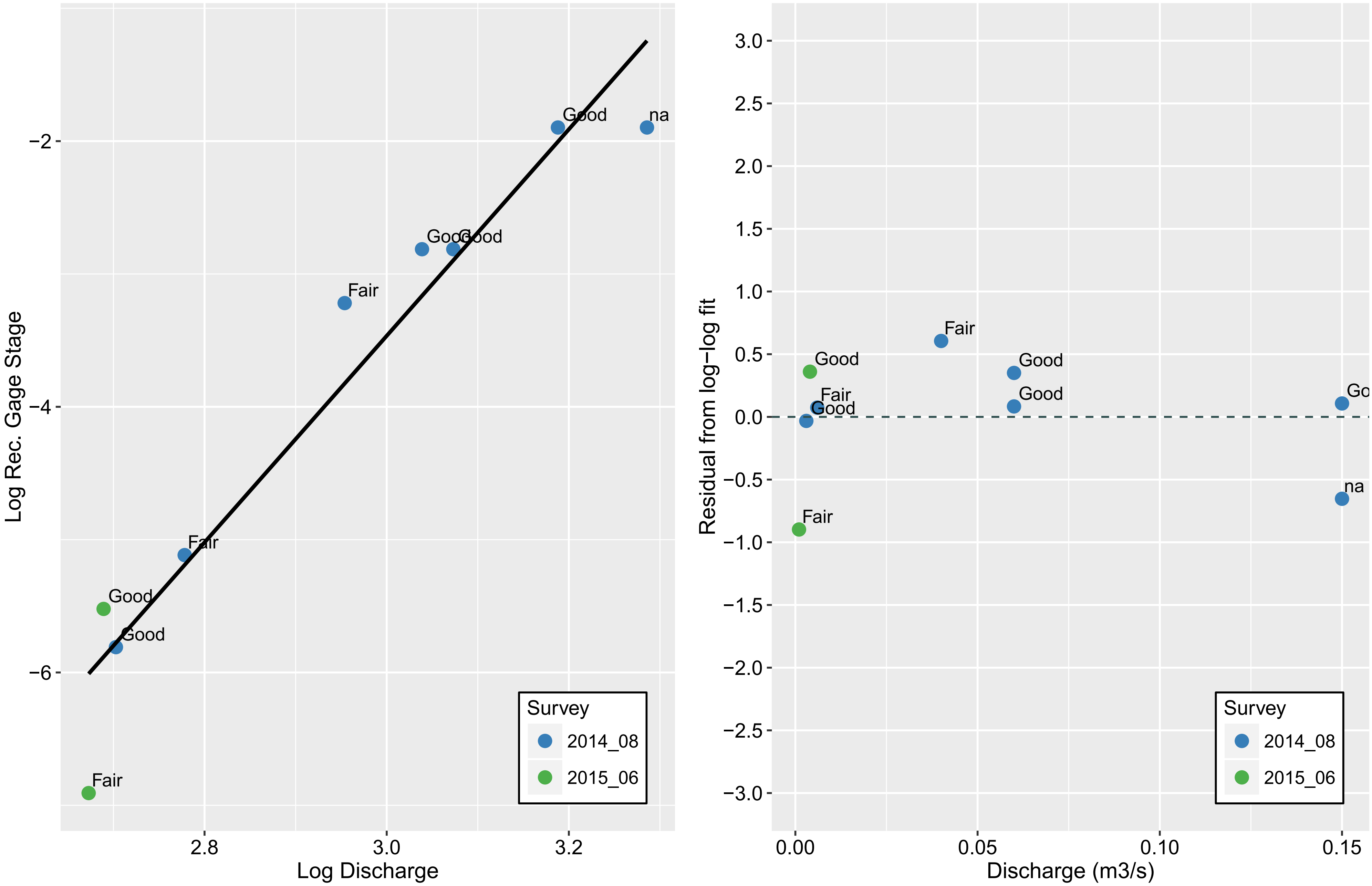
Basin 724: Stage−discharge curve and residuals

All available data



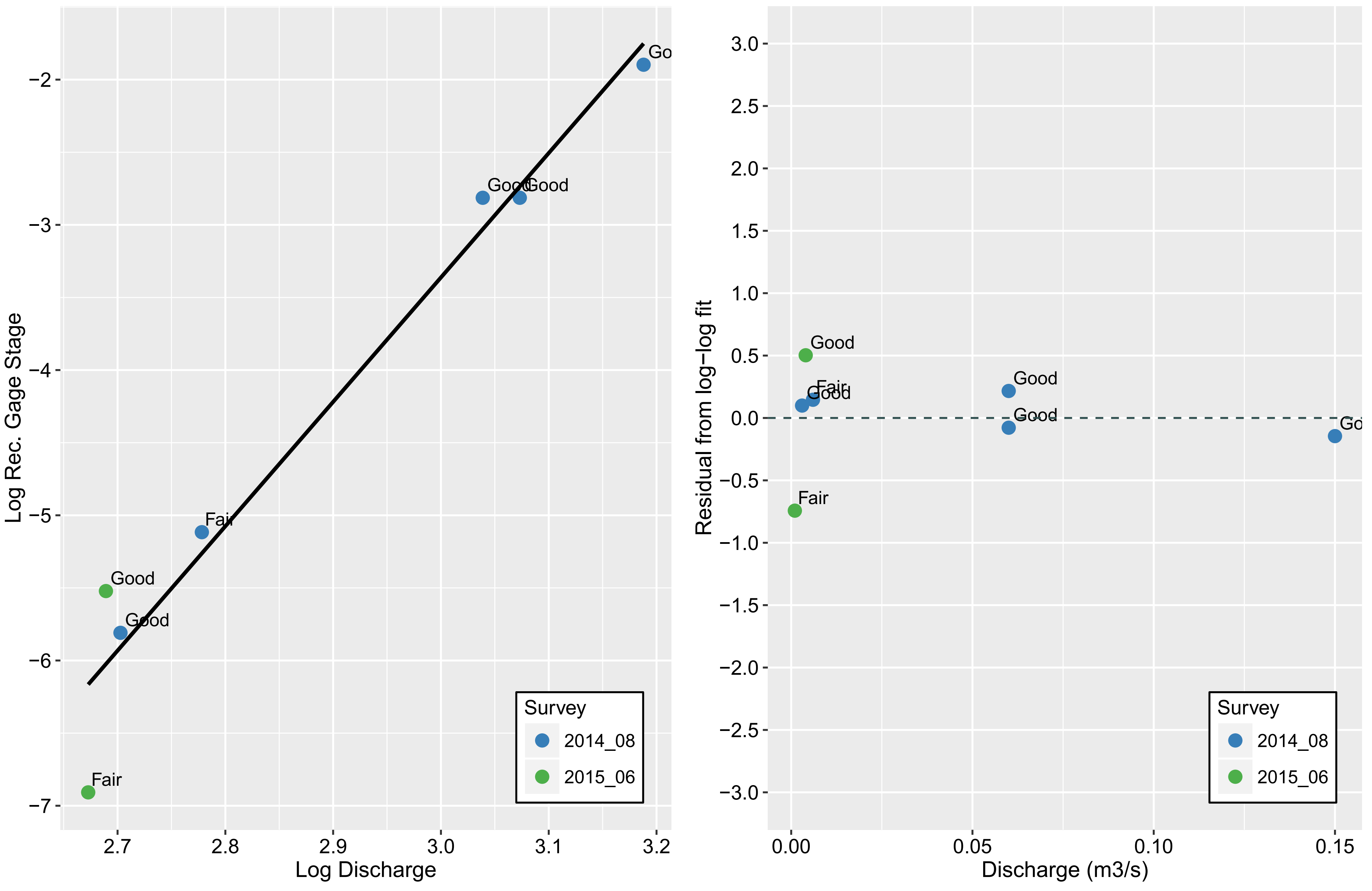
Basin 724: Stage−discharge curve and residuals

(prior to 10/6/2014)



Basin 724: Stage−discharge curve and residuals

(2/20/2014 − 10/6/2014)



Basin 737

Summary
Rating curve is reliable for all measurements of discharge within observation period.

Category:
Accepted

Recommendations for future data collection
Discharge during high-flow.
Cross-section stability survey above bankfull.

Histograms

Correlation is observed between range of recording gage readings and range of staff gage measurements, especially near the median flow range. However, there are peaks in recording gage readings that are not observed on staff gage measurements.

Cross-sectional Profiles

Narrow channel with near vertical banks on both sides.

Minor changes in cross section are observed from year-to-year. Not sure if floodplain is actually changing or if we just don't have enough data there. Change in TH from 2014 to 2015 may be offset overall by aggradation to the right of TH, and may not affect the cross-sectional area or stage-discharge relationship significantly.

Staff Gage-Recording Gage Time Series and Regression

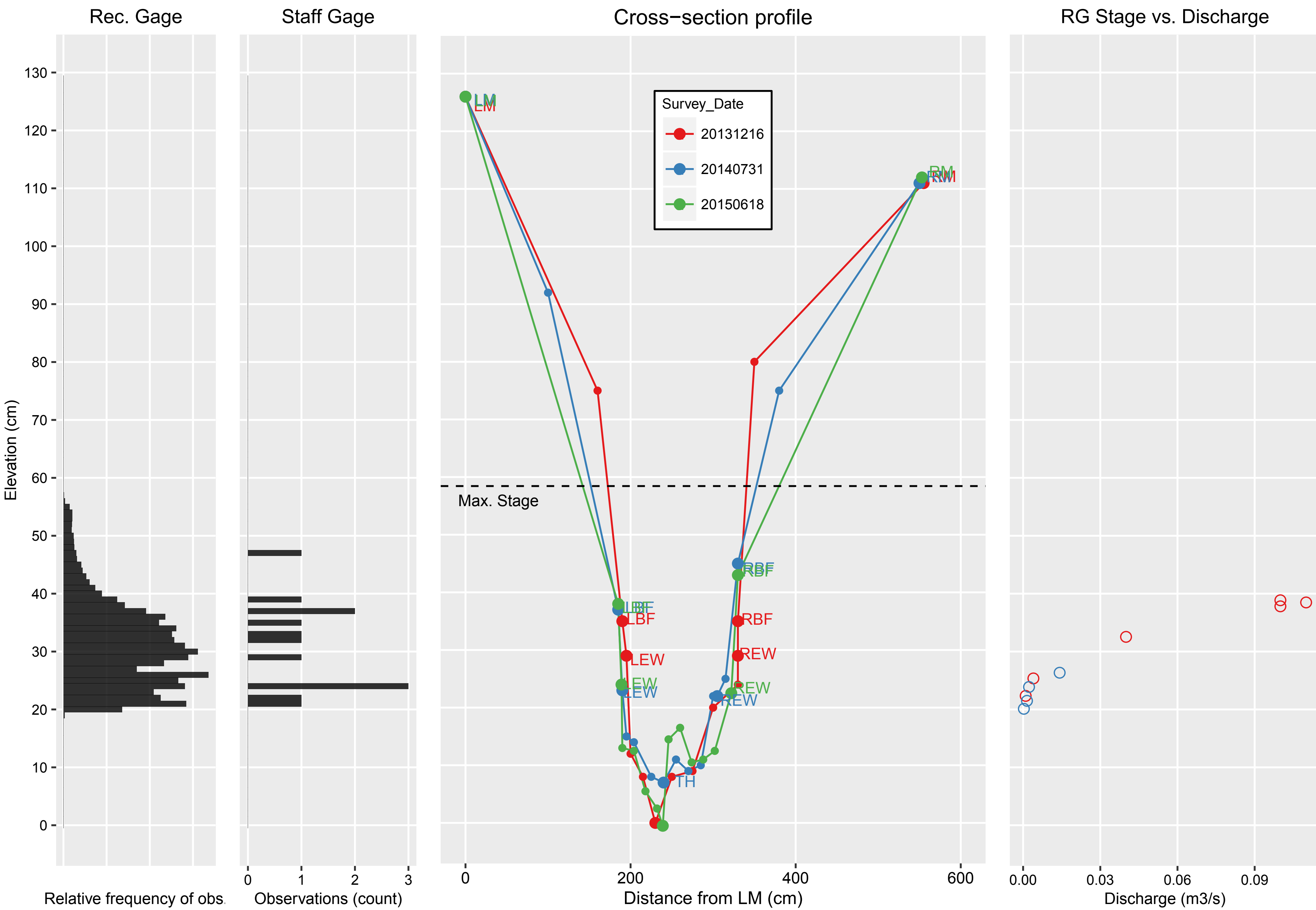
Baseflow appears to be consistent from year to year. Variation in staff gage/recording gage difference ranges from -0.1 to 0.2 cm. Strong correlation in staff gage-recording gage relationship. Slope very close to 1. 1:1 in staff gage-recording gage relationship appears to be well-established.

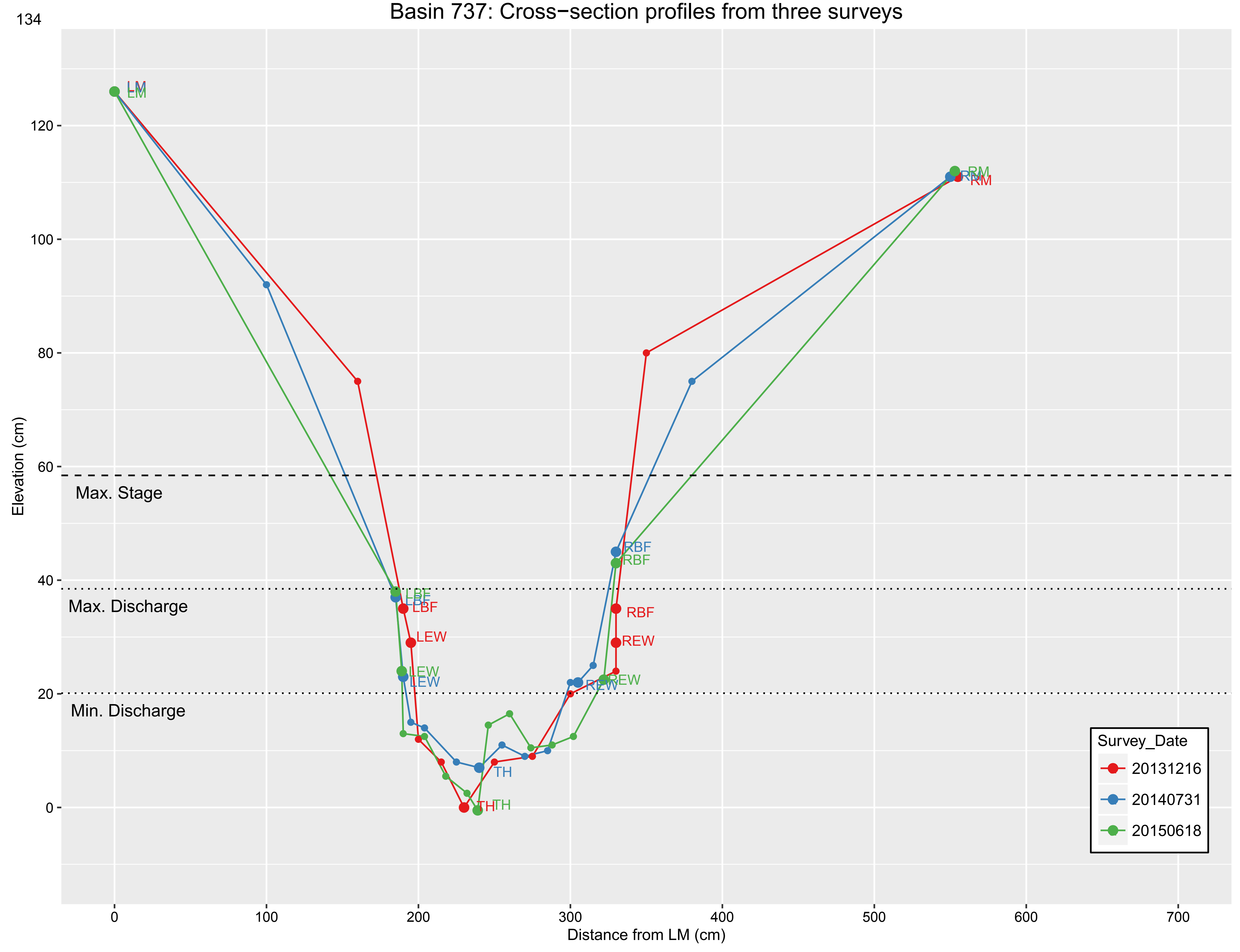
Stage-Discharge Rating Curve

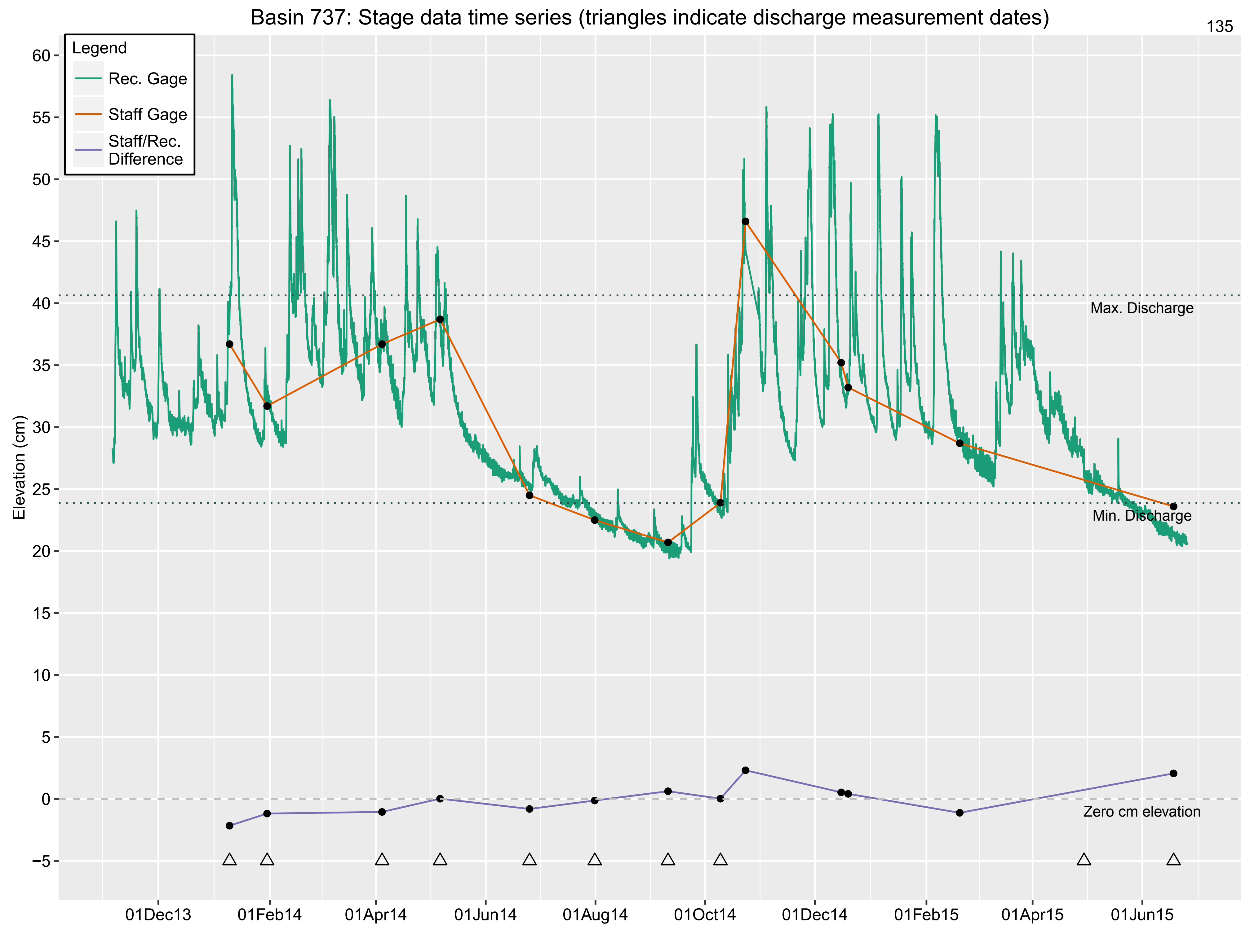
Rating curve model fits well for the entire range of time. At this point there are no sub-sections that have been created for the rating curve equation.

Stream gage station in basin 737 at high flow.

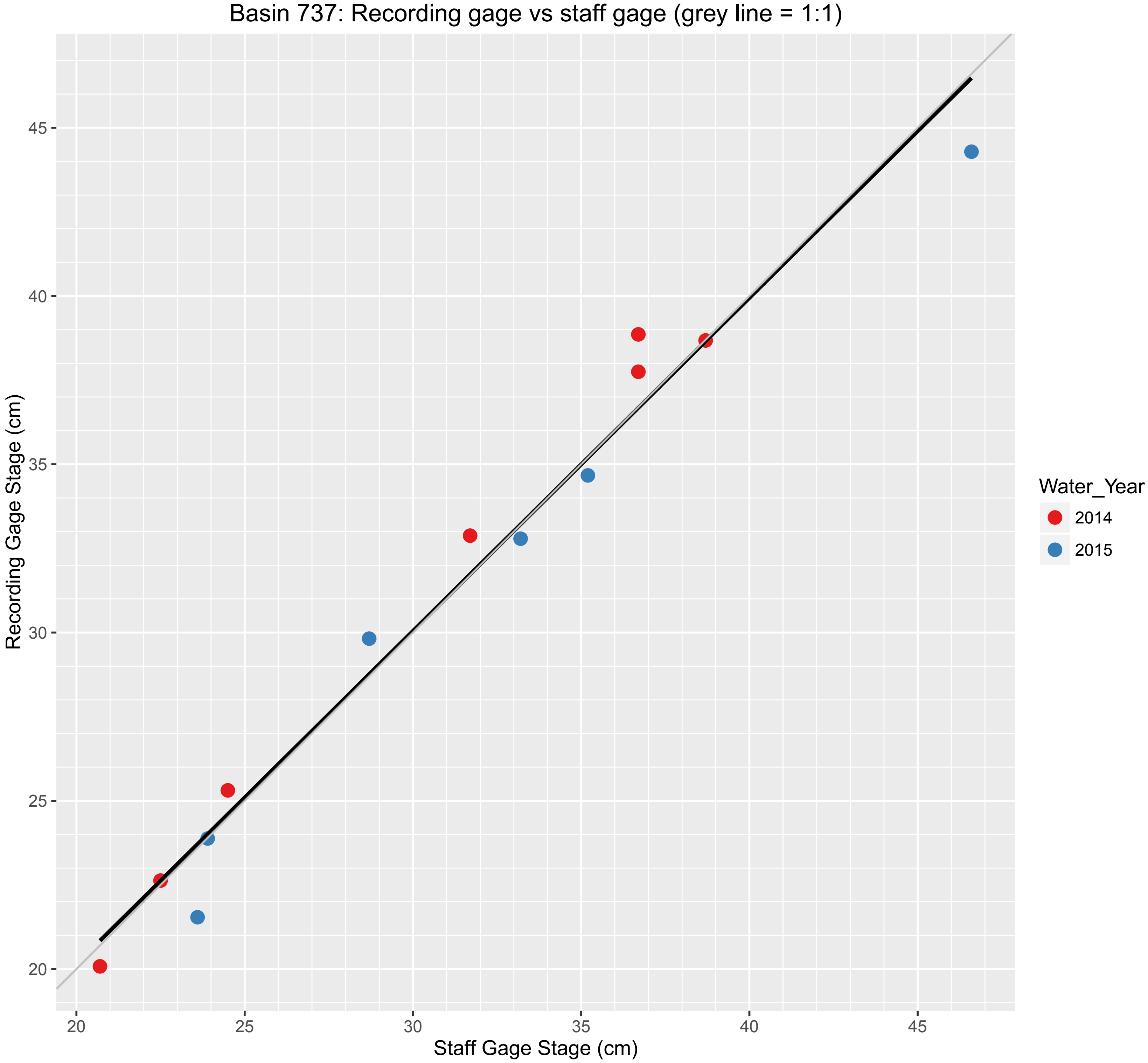
Basin 737: Gage data histograms, cross−section profile, and stage−discharge data




Basin 737: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131216
20140731
20150618
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700

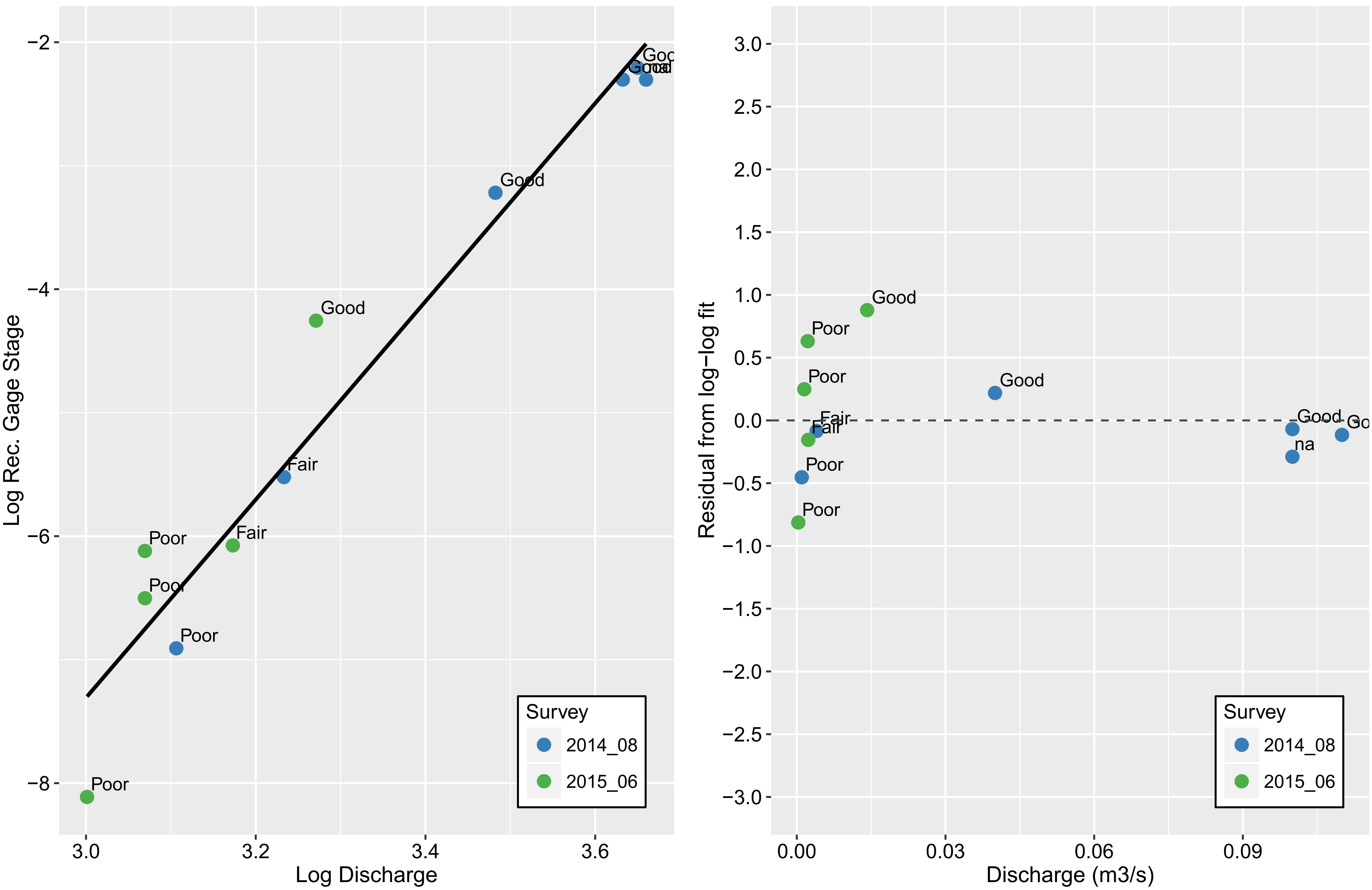


Basin 737: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec. Difference
Max. Discharge
Min. Discharge
Zero cm elevation
Elevation (cm)
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
01Dec13
01Feb14
01Apr14
01Jun14
01Aug14
01Oct14
01Dec14
01Feb15
01Apr15
01Jun15


Basin 737: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
20
25
30
35
40
45
Water_Year
2014
2015

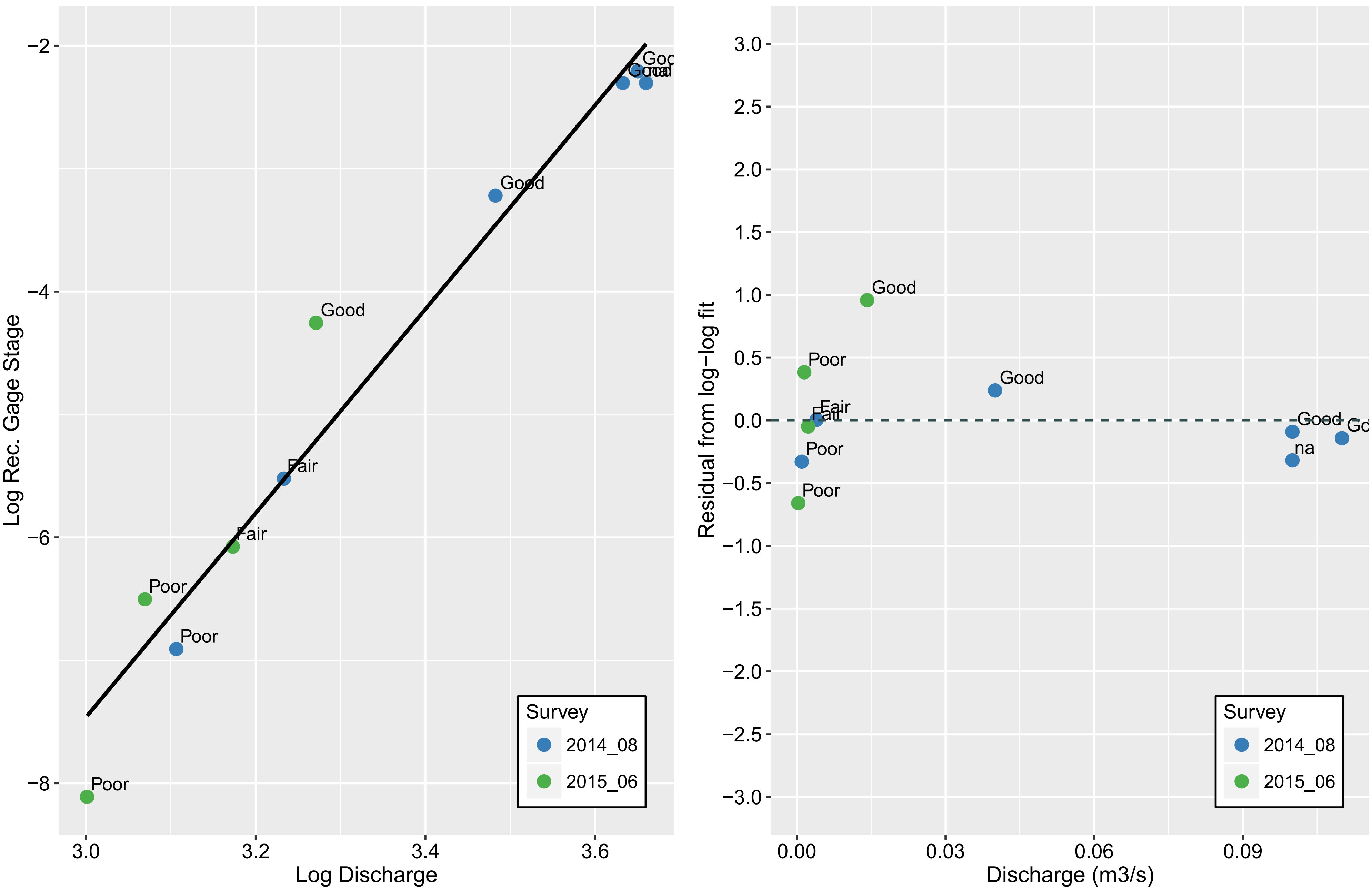
Basin 737: Stage−discharge curve and residuals

All available data



Basin 737: Stage−discharge curve and residuals

(removed one point from 6/18/2014)



Basin 769

Summary
Large changes in channel geometry from 2014 to 2015.
Reliable rating curve is available from April to October 2014.

Category:
Conditional – Time

Recommendations for future data collection
NBO method is ineffective.
Discharge at stage heights above 7 cm.

Histograms

RG and SG histograms show correlation between range of recording gage readings and range of staff gage measurements, especially near the median flow range. However, there are peaks in recording gage readings that are not observed on staff gage measurements.

Cross-sectional Profiles

Steep left bank with gradually sloped right bank. Undercutting present on left bank and deep channel.

Significant aggradation is observed from 2013 (red) to 2014 (blue) surveys. Change in cross-section geometry from 2014 to 2015 (green) as a result of scour near LEW and aggradation near REW.

Staff Gage-Recording Gage Time Series and Regression

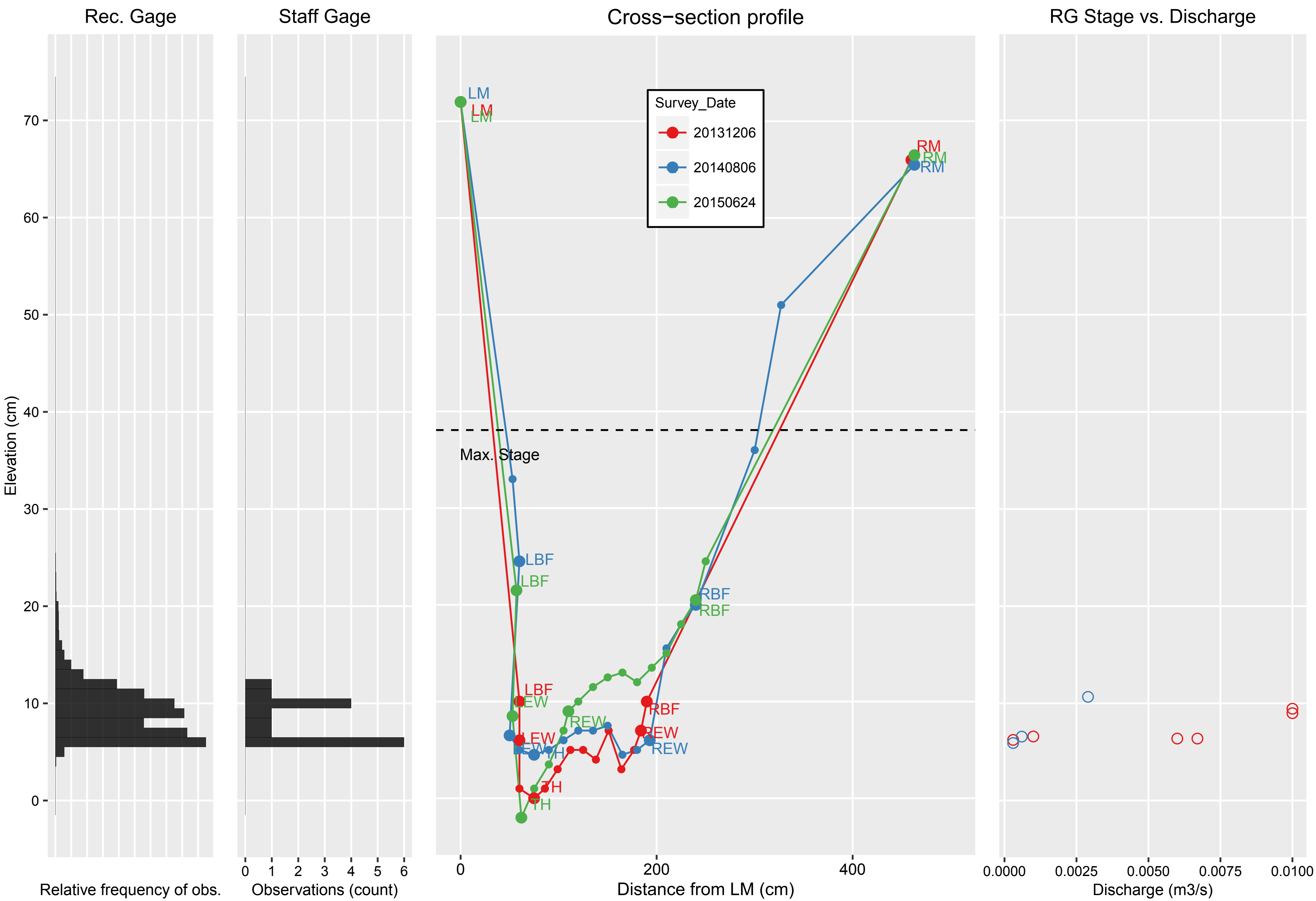
Time-series of recording gage shows that baseflow is roughly 2 cm higher in 2015 low flows than in 2014. This is likely the result of the channel change that occurred between these two years.
However, the staff gage-recording gage relationship shows strong correlation both before and after this decrease in baseflow.

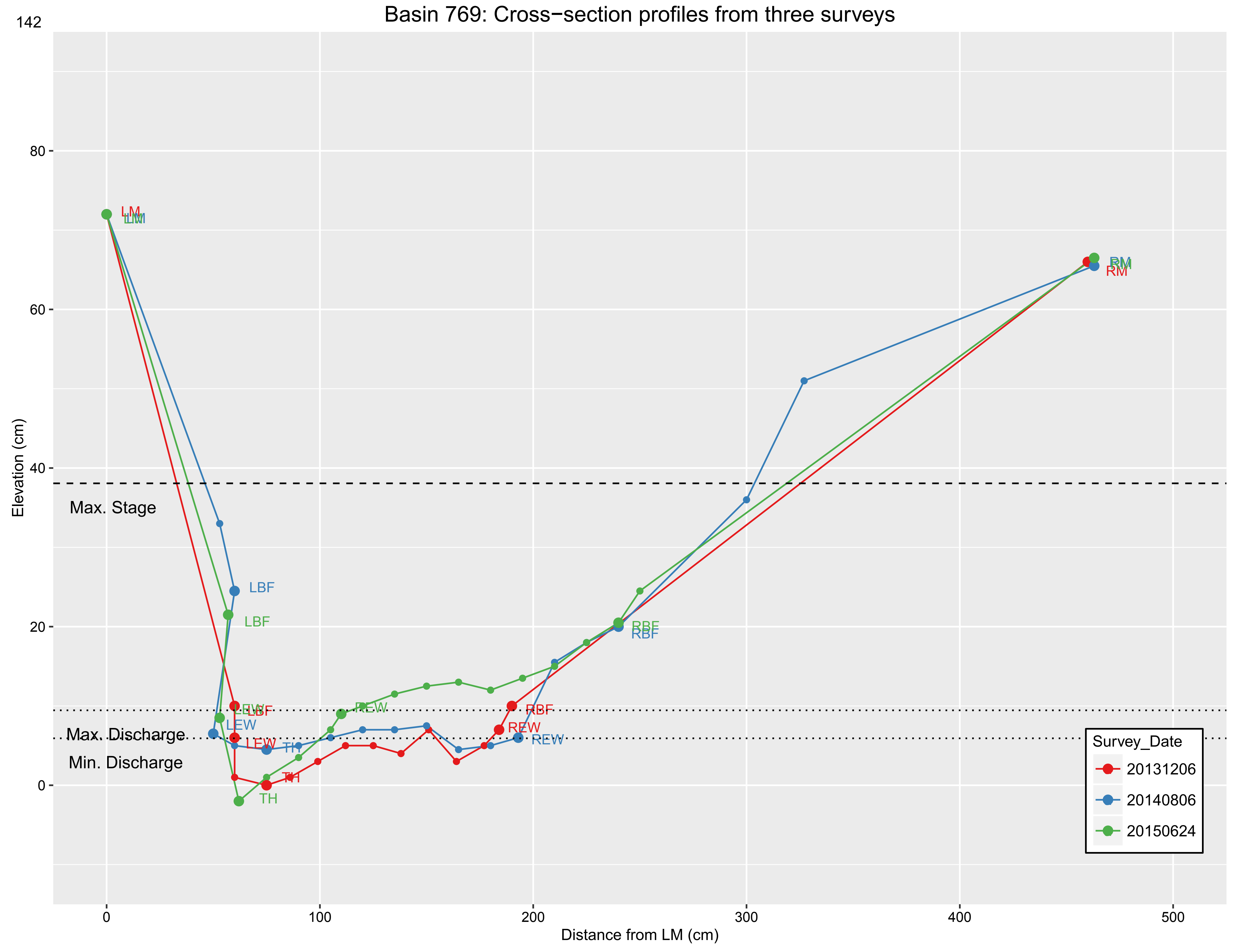
Stage-Discharge Rating Curve

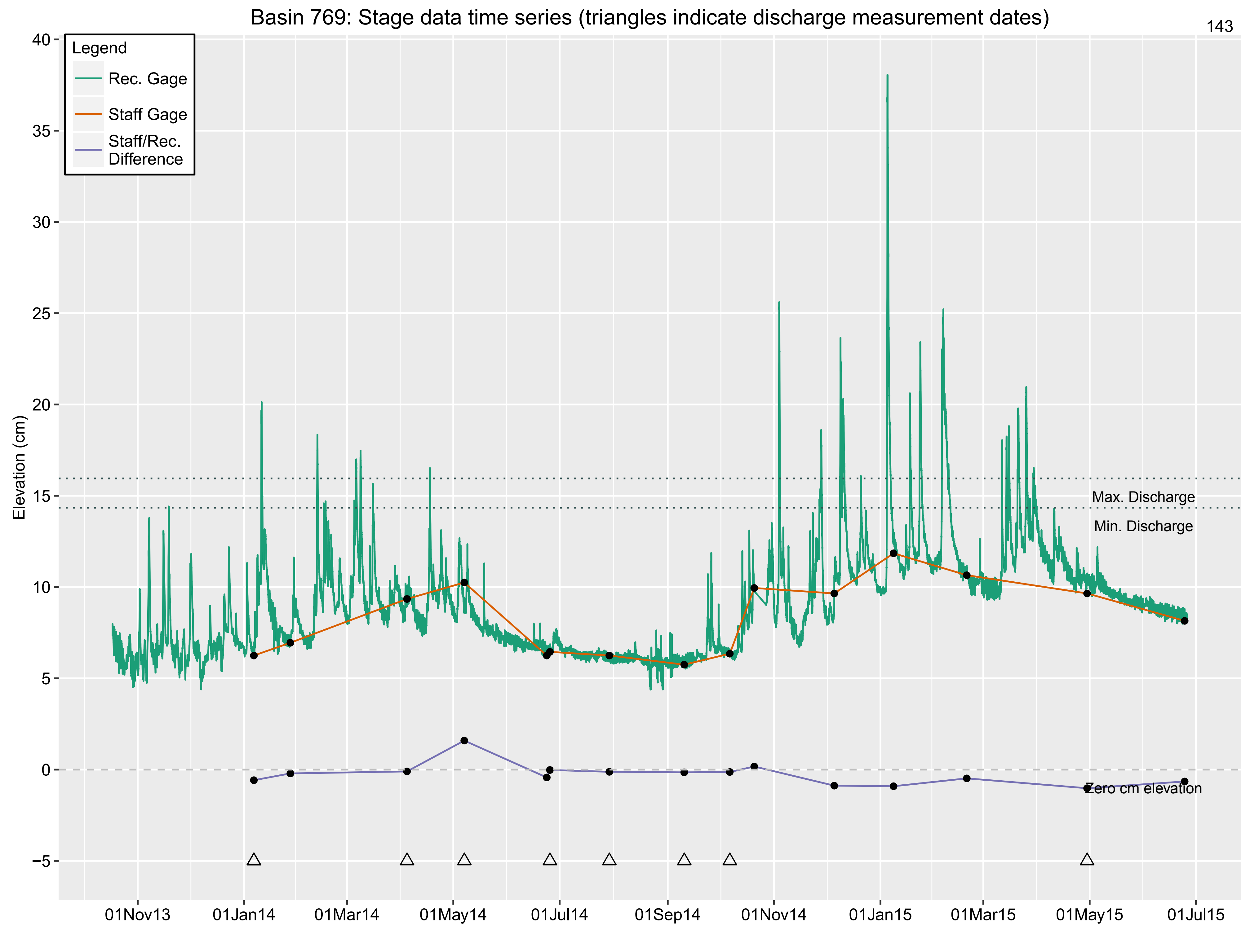
Rating curve model including all data points explains very little of the variability in the relationship between discharge and stage. When the discharge measurement taken using the NBO method (near 10.5 cm elevation) is excluded, the model improves and more accurately represents the high flow data point near 0.01 cms. Investigation should be conducted in the validity of the NBO method.
Due to changes in the channel cross-section, the rating curve will need to be divided into two sub-sections: before 4/4/2014 and after 4/4/2015.

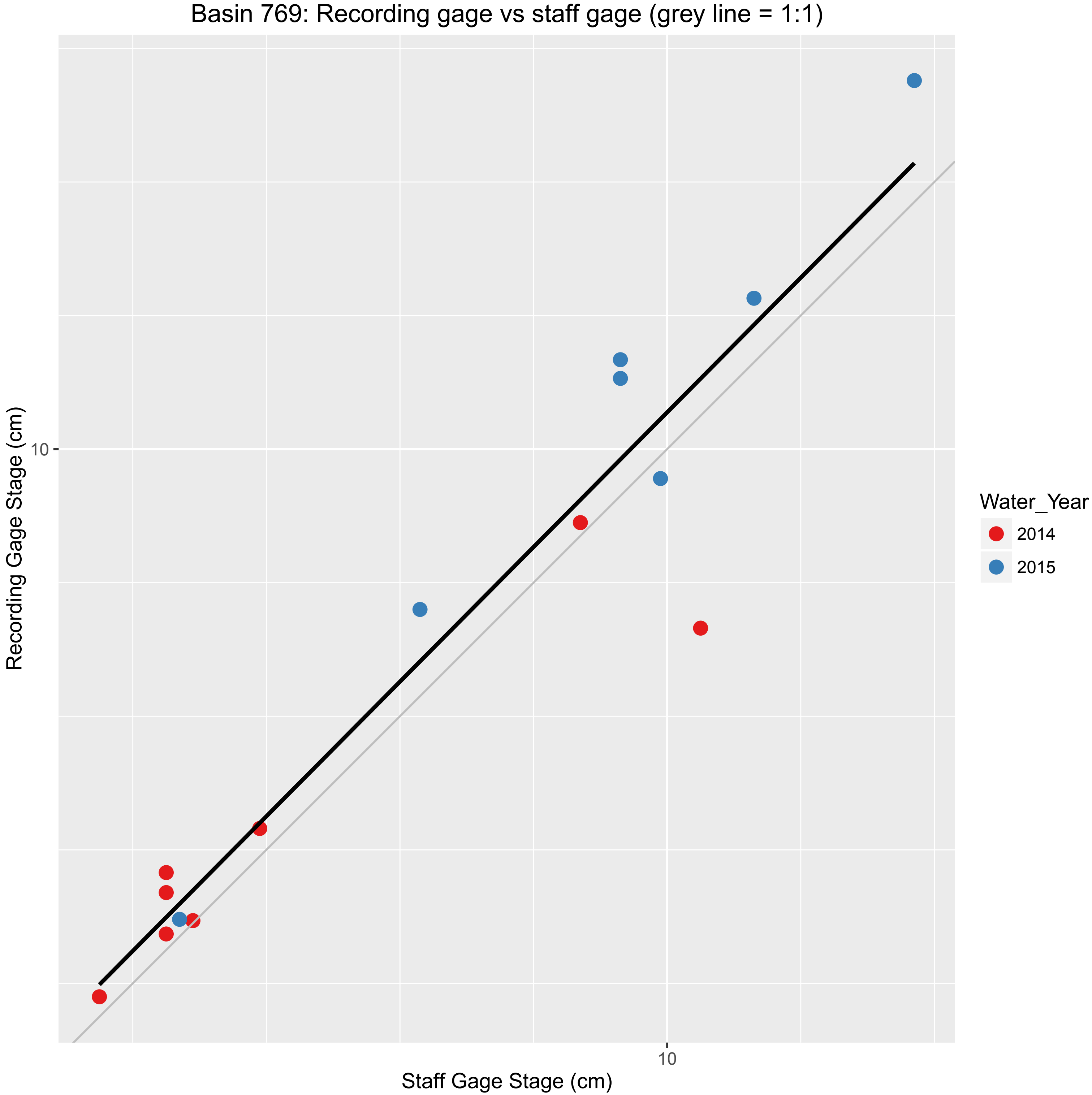
Stream gage station in basin 769 at low flow (the removable staff gage is not shown).

Basin 769: Gage data histograms, cross−section profile, and stage−discharge data

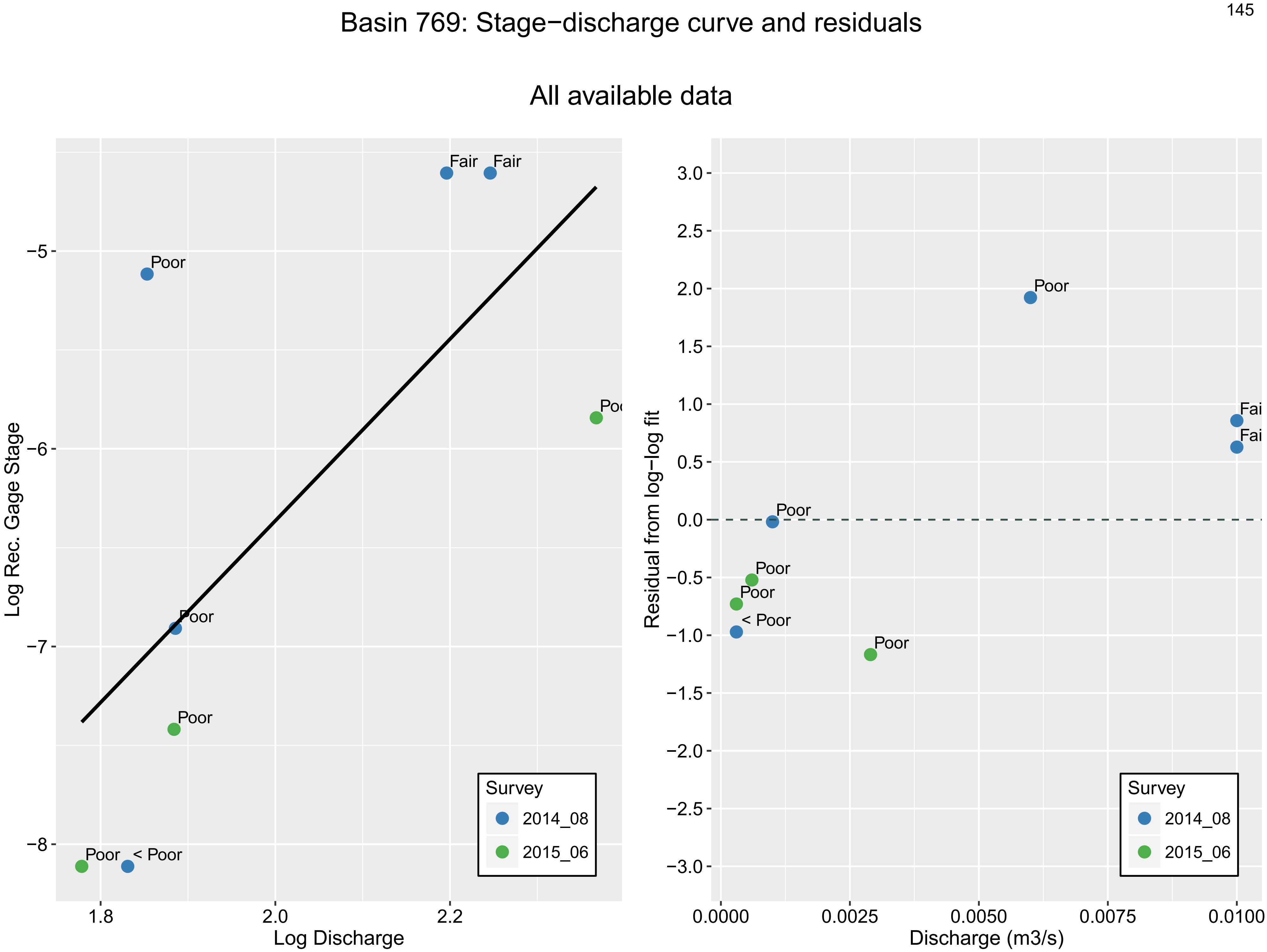



Basin 769: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131206
20140806
20150624
0
20
40
60
80
0
100
200
300
400
500


Basin 769: Stage data time series (triangles indicate discharge measurement dates)
Legend
Rec. Gage
Staff Gage
Staff/Rec.
Difference
Elevation (cm)
Max. Discharge
Min. Discharge
Zero cm elevation
40
35
30
25
20
15
10
5
0
−5
01Nov13
01Jan14
01Mar14
01May14
01Jul14
01Sep14
01Nov14
01Jan15
01Mar15
01May15
01Jul15

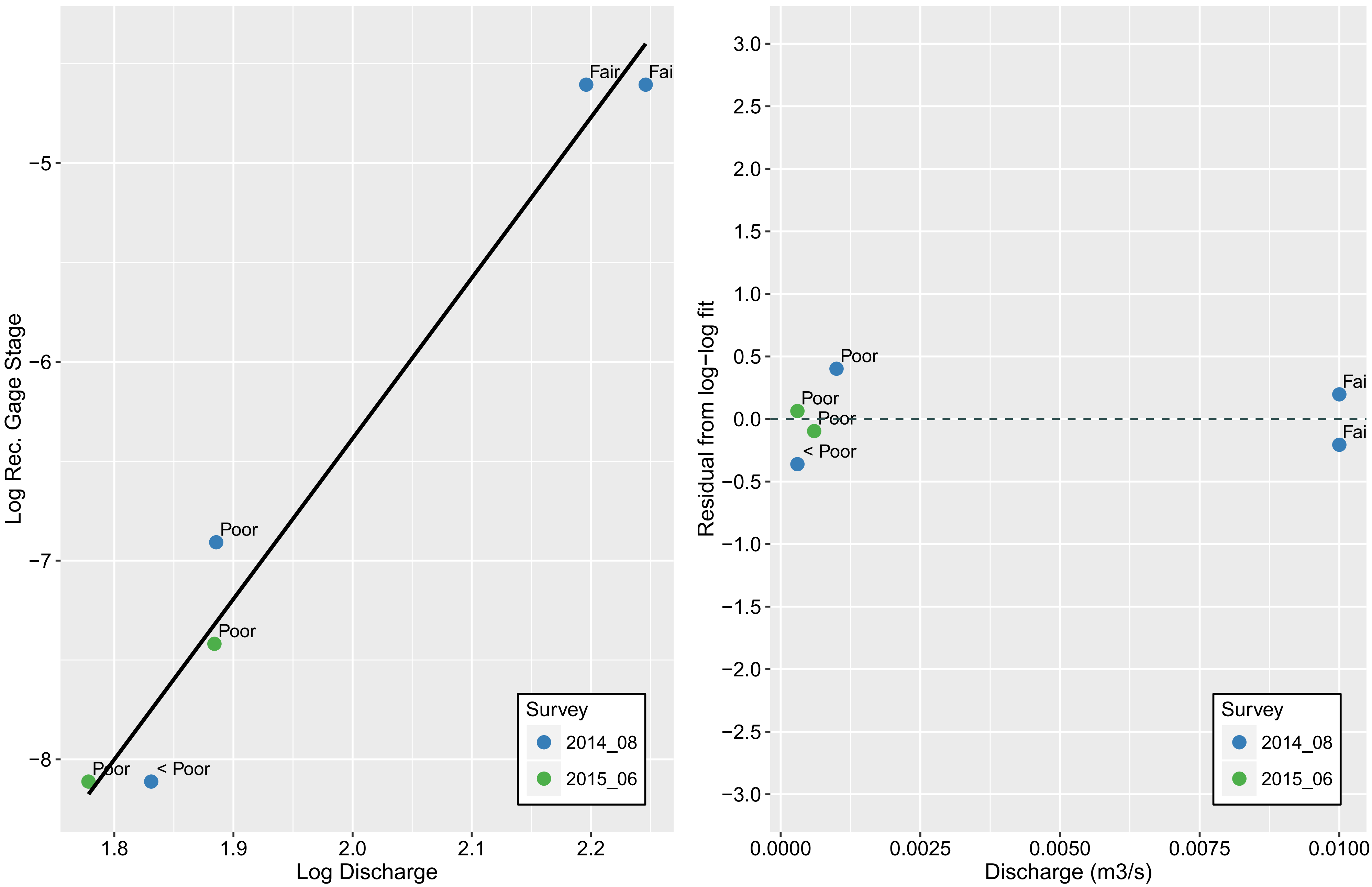


Basin 769: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
10
Staff Gage Stage (cm)
10
Water_Year
2014
2015


Basin 769: Stage−discharge curve and residuals
All available data
Log Rec. Gage Stage
Log Discharge
Residual from log−log fit
Discharge (m3/s)
Survey
2014_08
2015_06
Fair
Poor
< Poor

Basin 769: Stage−discharge curve and residuals

(4/4/2014 − 10/6/2014)



Basin 790

Category:
Conditional – Time

Summary
Large changes in channel geometry from 2014 to 2015.
High flows in late 2014 buried recording gage intake and shifted main channel towards the right bank.
Rating curve available for low flows of 2014.

Recommendations for future data collection
Before any additional data can be utilized, gage intake needs to be uncovered and located in main channel.

Histograms

Histograms show correlation between range of recording gage readings and range of staff gage measurements, especially near the median flow range. However, there are peaks in recording gage readings that are not observed on staff gage measurements.

Cross-sectional Profiles

Steep right bank with gradually sloping left bank. Variation in elevation across channel, no obvious deep/main channel. Side channel possible on right bank.

Shifting as a result of alternating eriosion and aggradation within the channel near TH occurred between 2014 (blue) and 2015 (green) surveys, however this may not affect the overall stage-discharge relationship as the cross-sectional area may not have changed significantly.

> *2015 survey notes: 'Gages have been covered in sediment due to large boulders just upstream. Dug out sediment in front of staff gage to obtain reading. RB monument bent, most likely by a falling log located on new elk trail. RGB and SGB both measured on streambed on thalweg side of gage."*

Staff Gage-Recording Gage Time Series and Regression

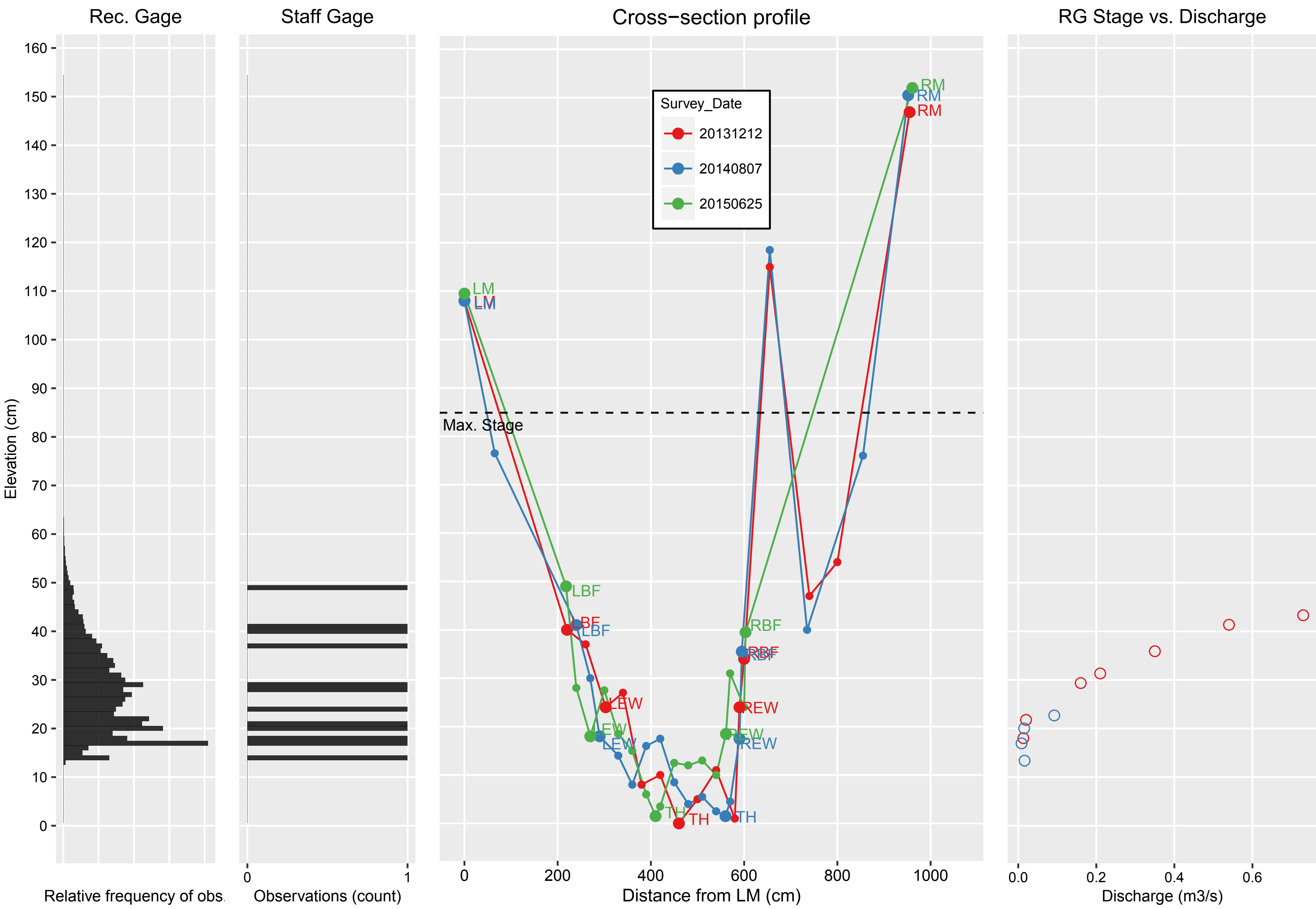
Rating curve time series shows 2015 baseflow much lower than 2014 baseflow. This should be investigated further as new data is collected. Overall, however, the relationship between SG and RG shows a strong correlation, note the SG/RG difference is a relatively flat line (blue) that is very close to zero. The data point on 04/24/2014 shows a 8cm difference in recording gage and staff gage readings, and may be either due to a data collection/entry error or is indicating that recording gage and staff gage do not match up as easily during rapidly changing flows (as explained in discussion section in Part 1 of this report)

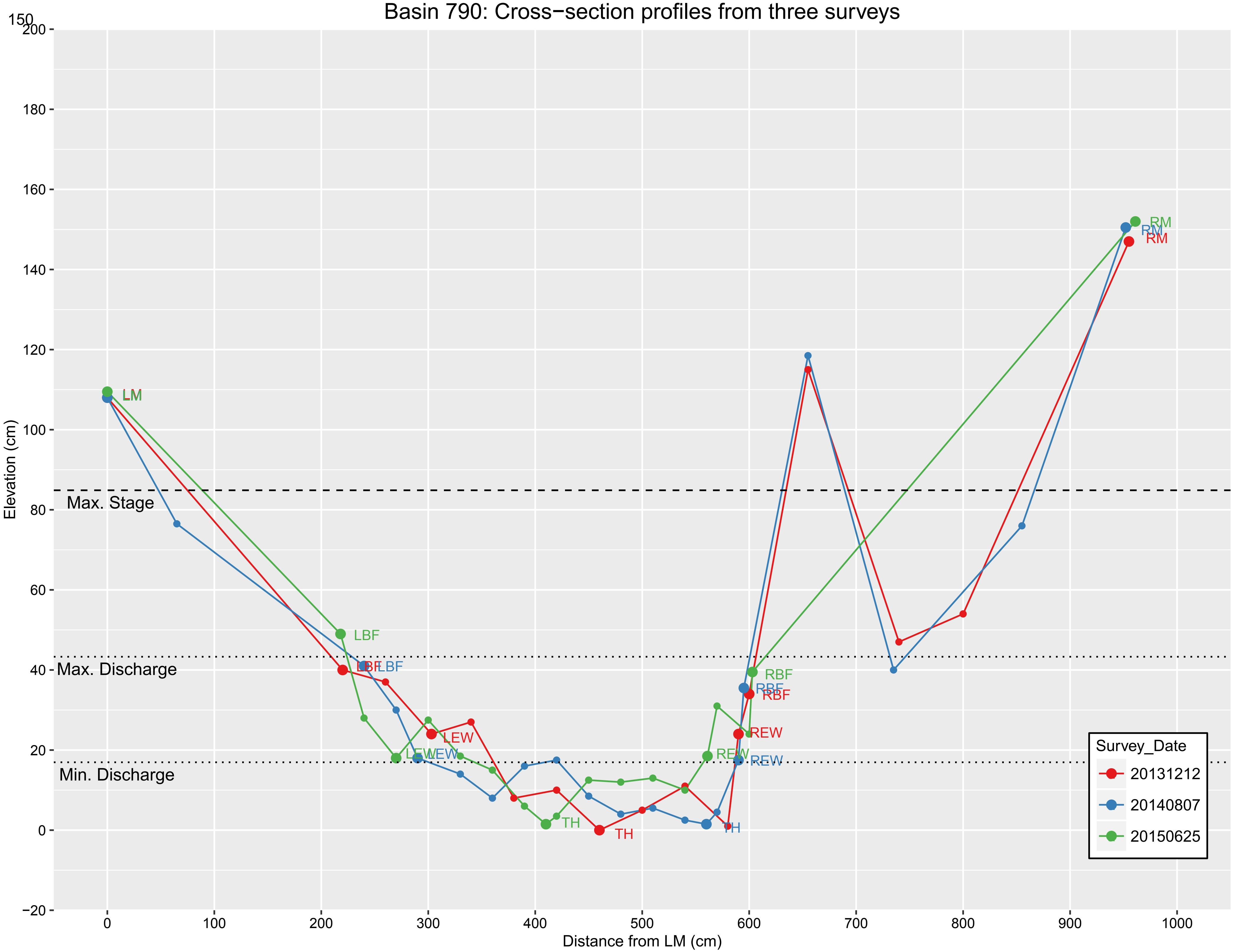
Stage-Discharge Rating Curve

Due to changes in channel geometry over time, the rating curve for this basin must be divided into two sub-sections: Start of monitoring to 10/9/2014, and 10/9/2014 to present. At this current point in time, the first section is the only section where enough data are available to draw an accurate rating curve.

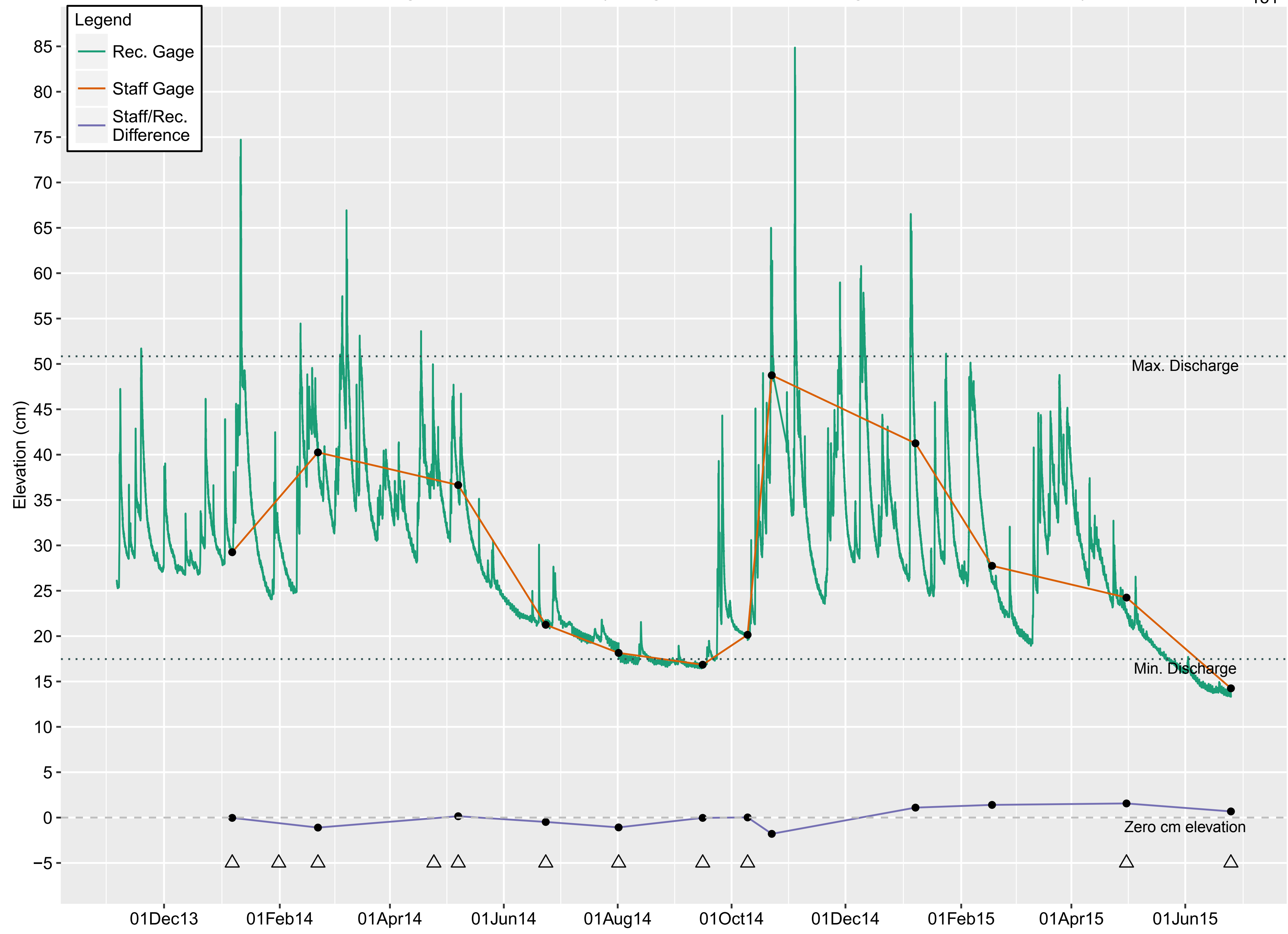
Stream gage station in basin 790 (measurement tape marks the location of the discharge measurements).

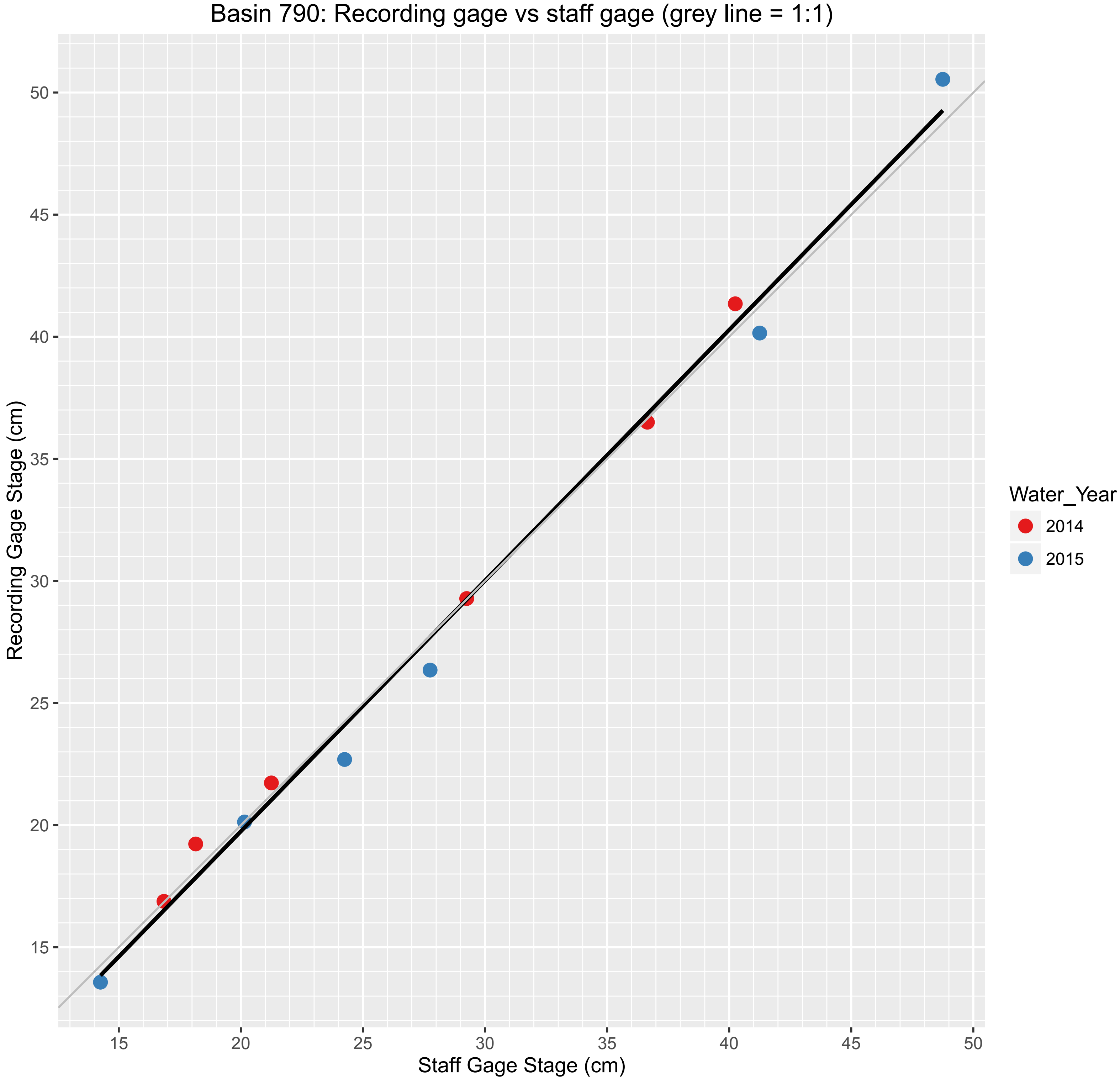
Basin 790: Gage data histograms, cross−section profile, and stage−discharge data




Basin 790: Cross−section profiles from three surveys
Elevation (cm)
Distance from LM (cm)
Max. Stage
Max. Discharge
Min. Discharge
LM
LBF
LEW
TH
REW
RBF
RM
Survey_Date
20131212
20140807
20150625
200
180
160
140
120
100
80
60
40
20
0
−20
0
100
200
300
400
500
600
700
800
900
1000

Basin 790: Stage data time series (triangles indicate discharge measurement dates)

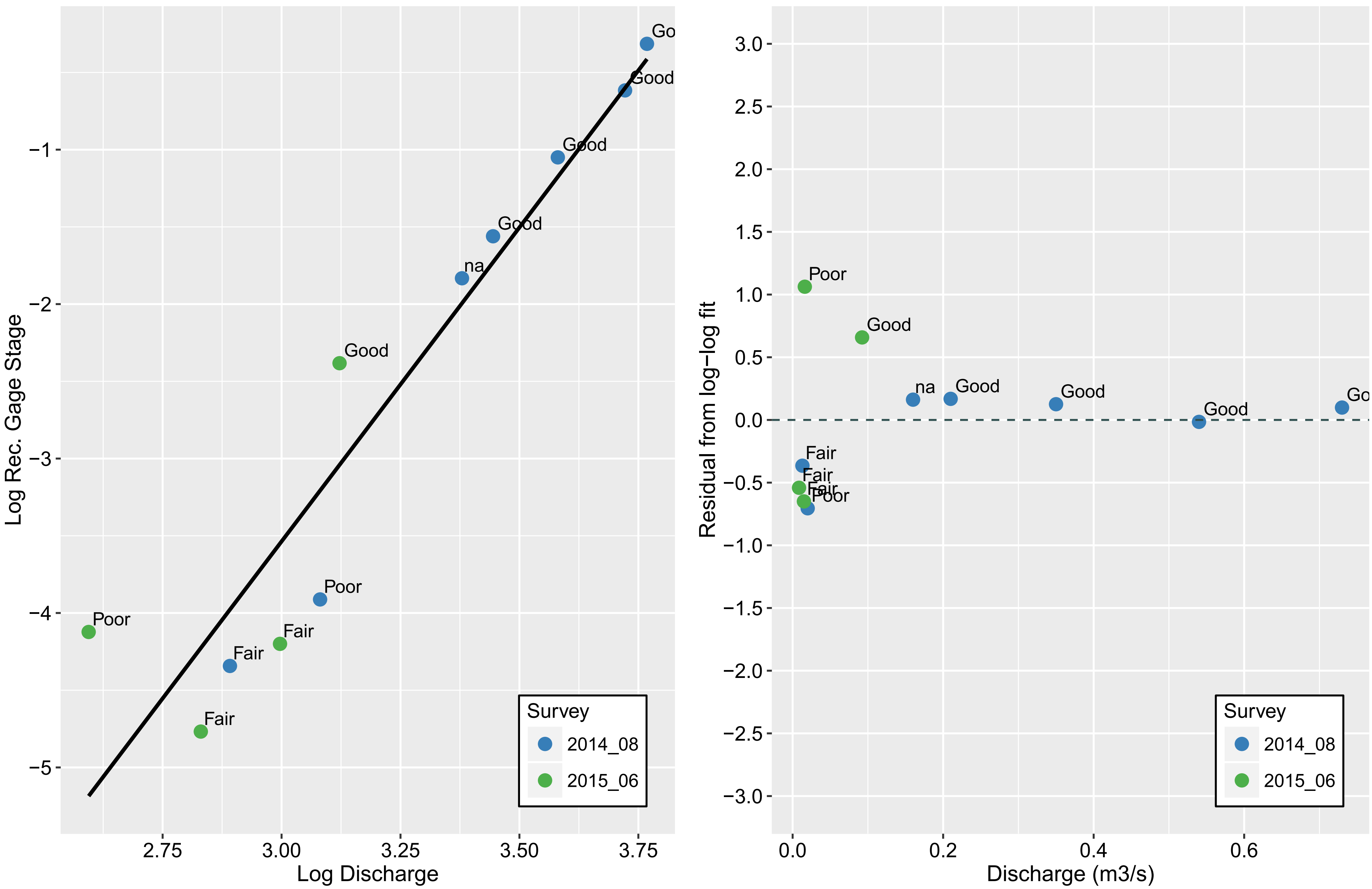




Basin 790: Recording gage vs staff gage (grey line = 1:1)
Recording Gage Stage (cm)
Staff Gage Stage (cm)
15
20
25
30
35
40
45
50
Water_Year
2014
2015

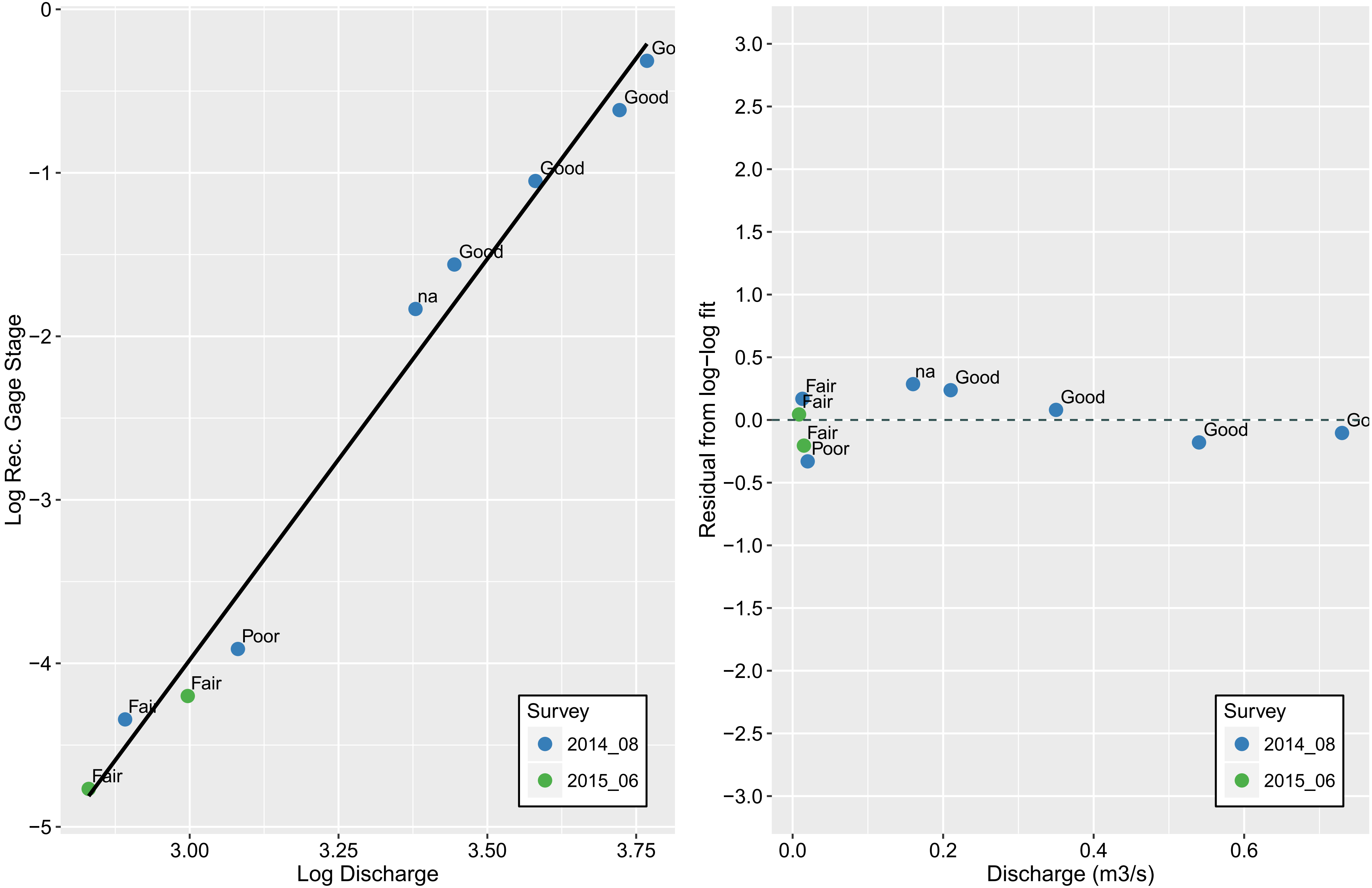
Basin 790: Stage−discharge curve and residuals

All available data



Basin 790: Stage−discharge curve and residuals

(all data through 10/9/2014)



REFERENCES

Boiten, Wubbo, 1987. *Hydrometry*. 2nd ed. Brookfield, VT: Rotterdam. Print.

Braca, Giovanni 2008. Stage–discharge relationships in open channels: Practices and problems. FORALPS Technical Report, 11. Università degli Studi di Trento, Dipartimento di Ingegneria Civile e Ambientale, Trento, Italy, 24 pp.

Devine W. and R. LovellFord, In Prep. Riparian Status and Trends Monitoring for the Olympic Experimental State Forest. Stream Discharge Data Management and Analysis. DNR Forest Resources Division, Olympia, WA.

Gore, James A. "Discharge Measurements and Streamflow Analysis." *Methods in Stream Ecology.* By F. Richard Hauer and Gary A. Lamberti. San Diego: Academic, 1996. Print.

Langbein, W. B. and K. T. Iseri, 1972. Manual of Hydrology: Part 1. General Surface-Water Techniques, Geological Survey Water-Supply Paper 1541-A, Methods and practices of the Geological Survey

LovellFord, R. Cropper, E. and J. Ricklefs, In Prep. Riparian Status and Trends Monitoring for the Olympic Experimental State Forest. Stream Discharge Field Procedures. DNR Forest Resources Division, Olympia, WA.

Minkova, T., J. Ricklefs, S. Horton and R. Bigley, 2012. Riparian Status and Trends Monitoring for the Olympic Experimental State Forest. Draft Study Plan. DNR Forest Resources Division, Olympia, WA.

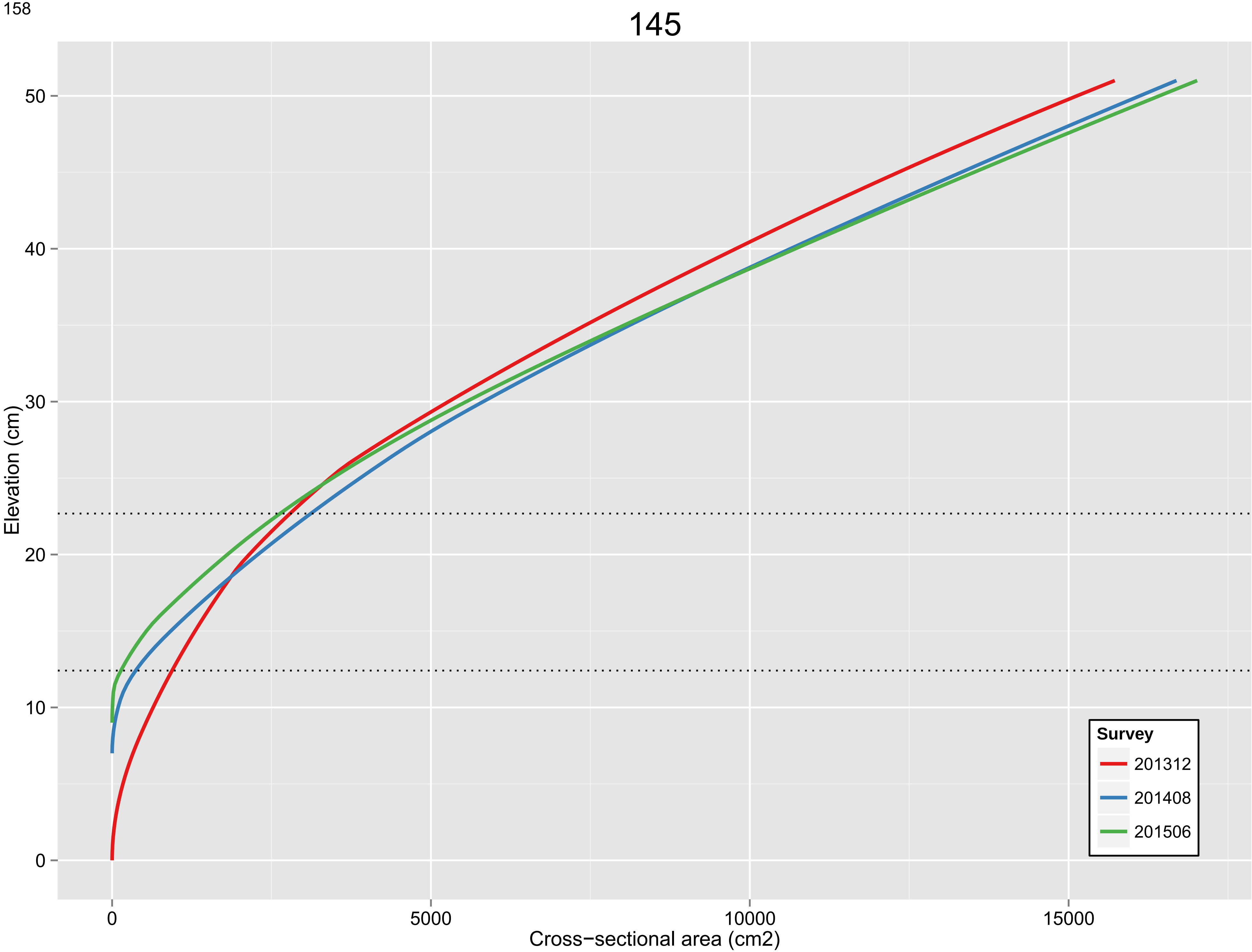
Minkova, T. and M. Vorwerk, 2013. Riparian Status and Trends Monitoring for the Olympic Experimental State Forest. 2012 Establishment report: field reconnaissance and delineation of sample sites. DNR Forest Resources Division, Olympia, WA

Minkova, T. and M. Vorwerk. 2014. Status and Trends Monitoring of Riparian and Aquatic Habitat in the Olympic Experimental State Forest. 2013 Establishment Report: Field Installations and Development of Monitoring Protocols. Washington State Department of Natural Resources, Forest Resources Division, Olympia, WA.

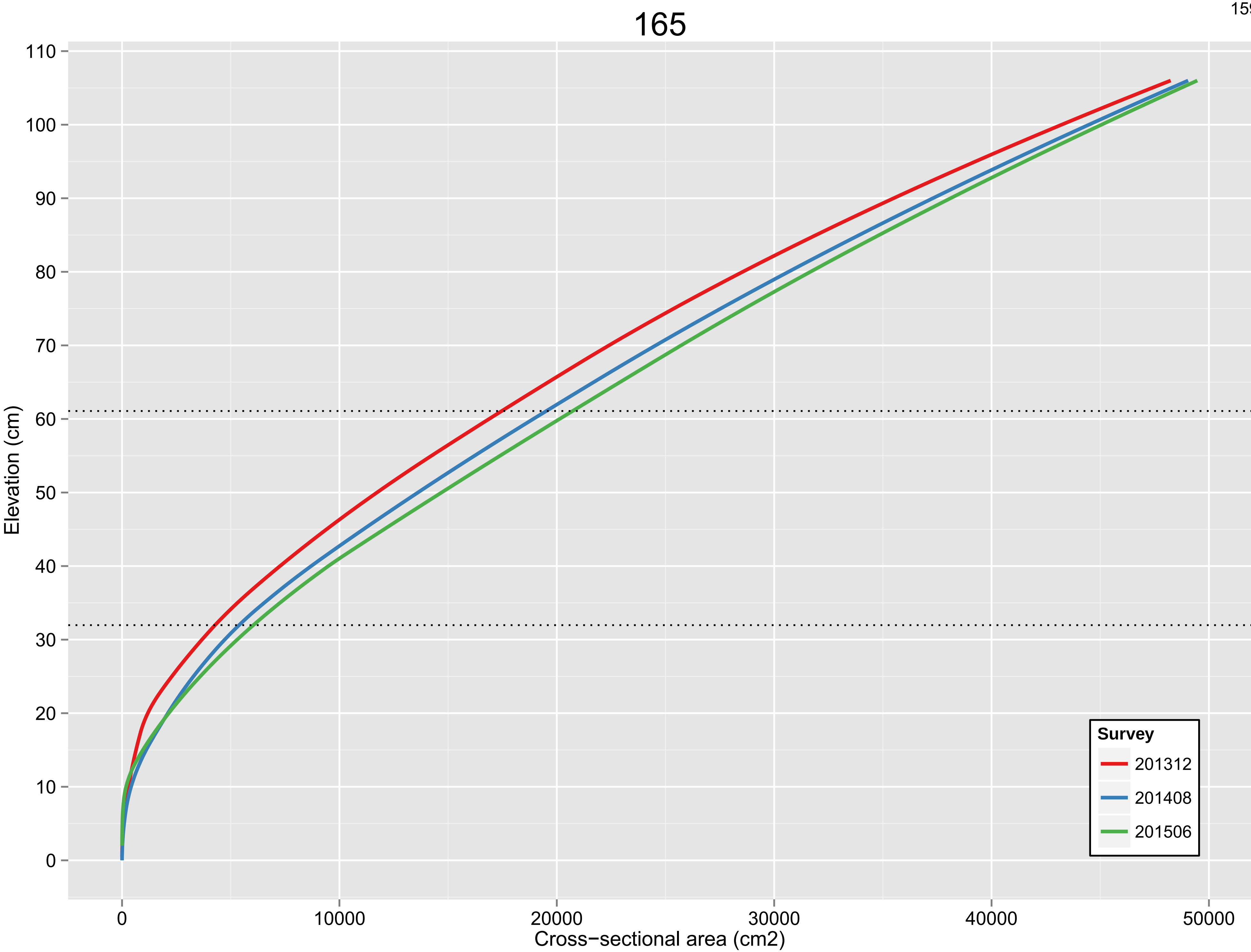
Rantz, S. E., 1982. Measurement and Computation of Streamflow, U.S. Geological Survey, Water Supply Paper 2175

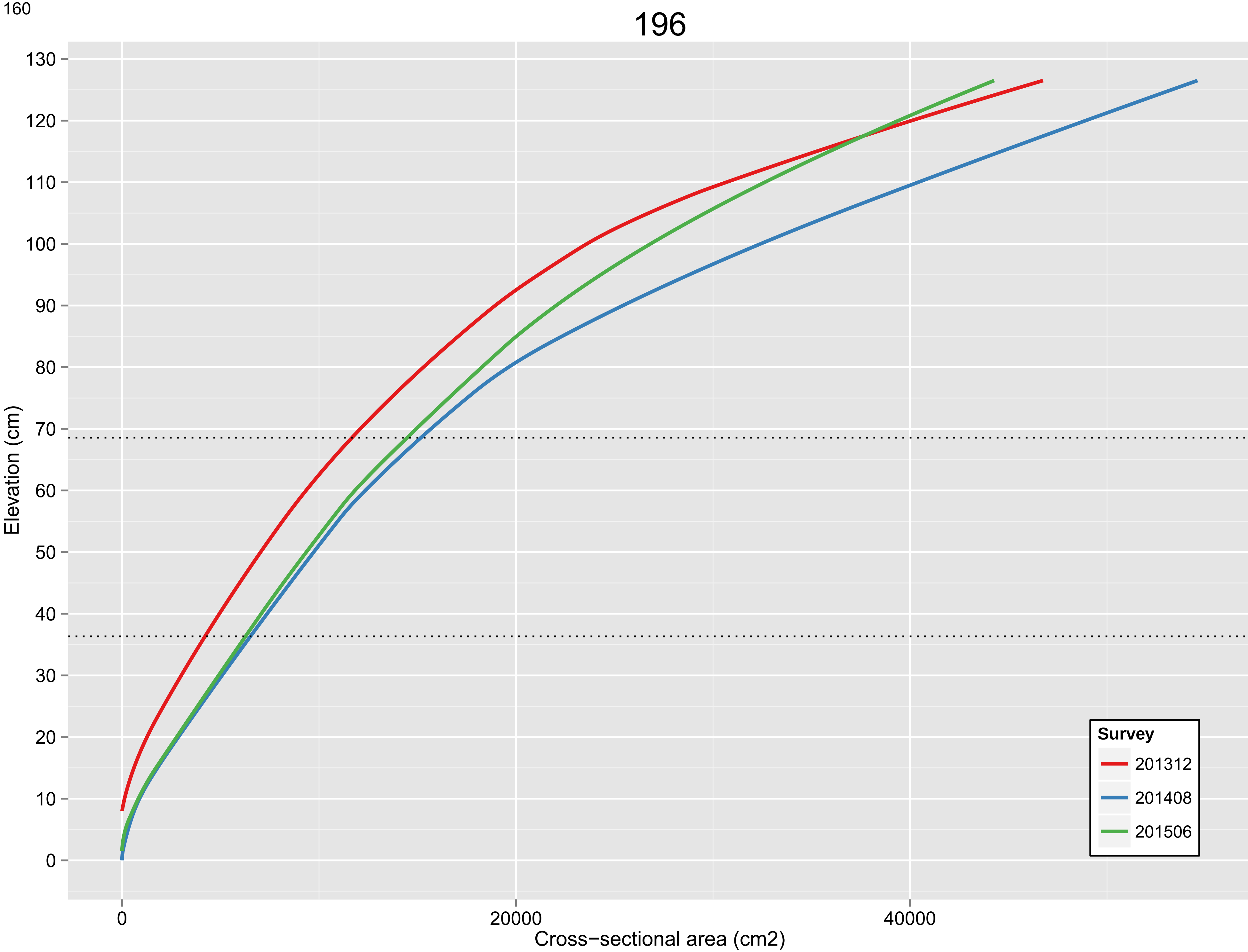
APPENDIX:

Stage-Area Curves

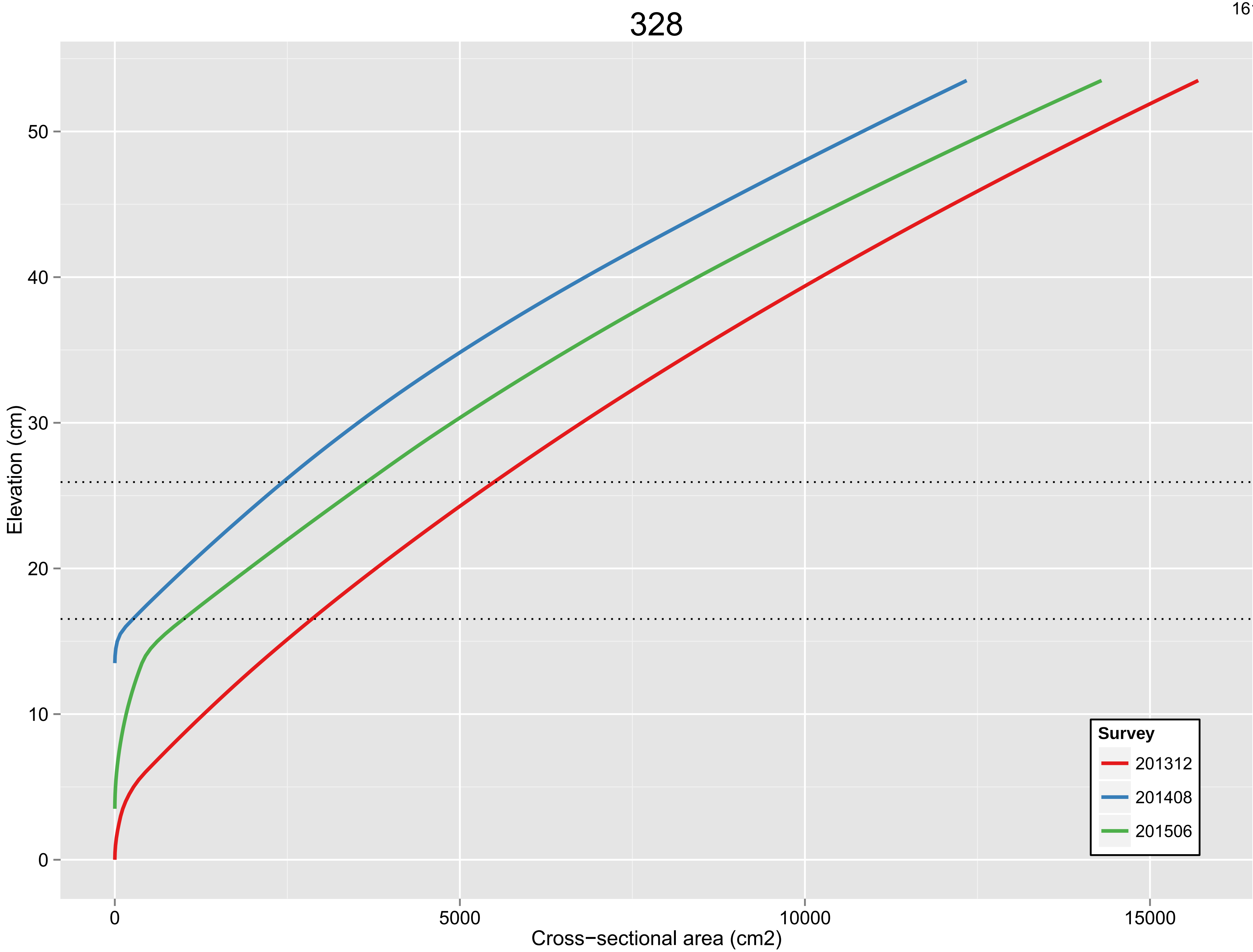


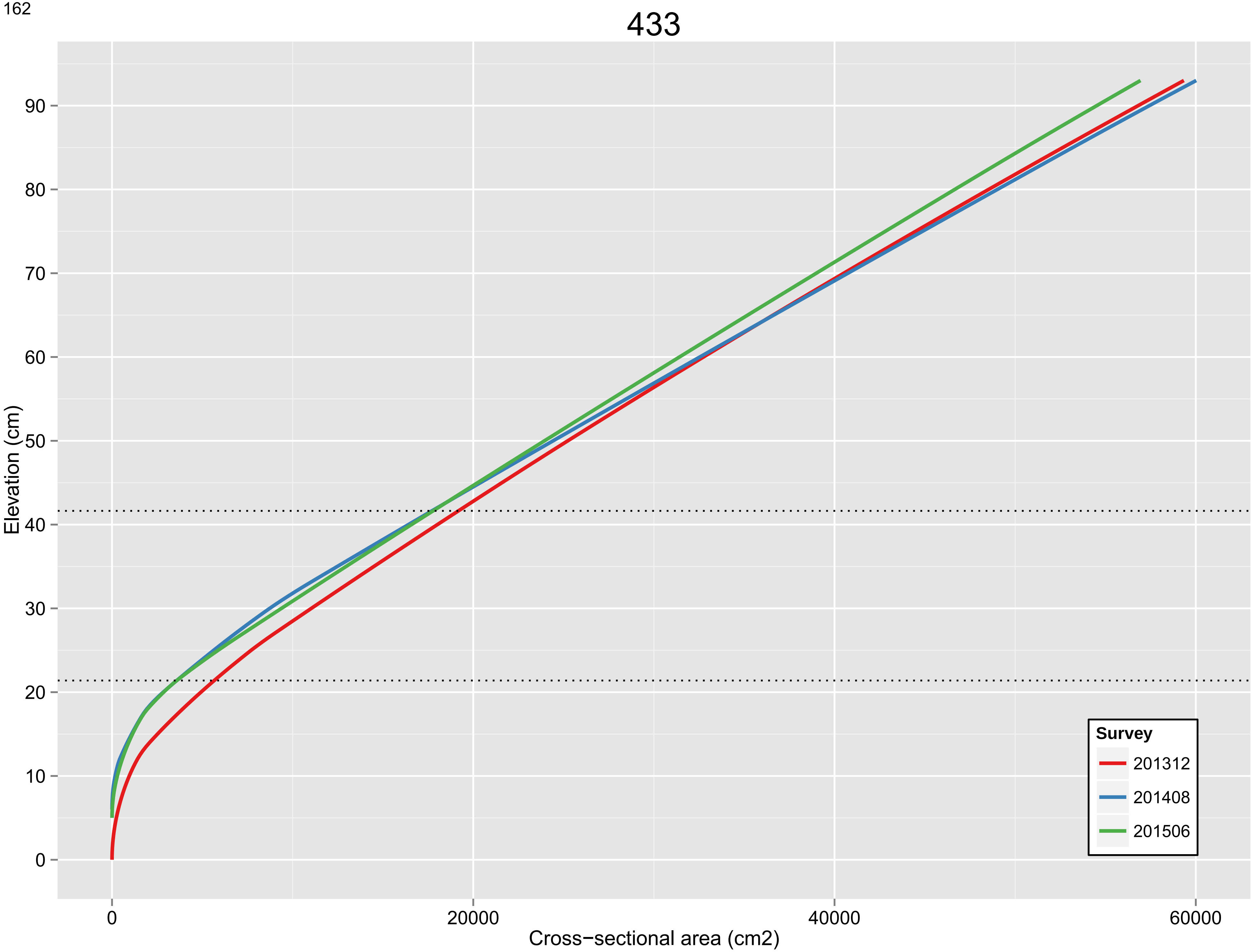
145
Elevation (cm)
0
10
20
30
40
50
Cross−sectional area (cm2)
0
5000
10000
15000
Survey
201312
201408
201506

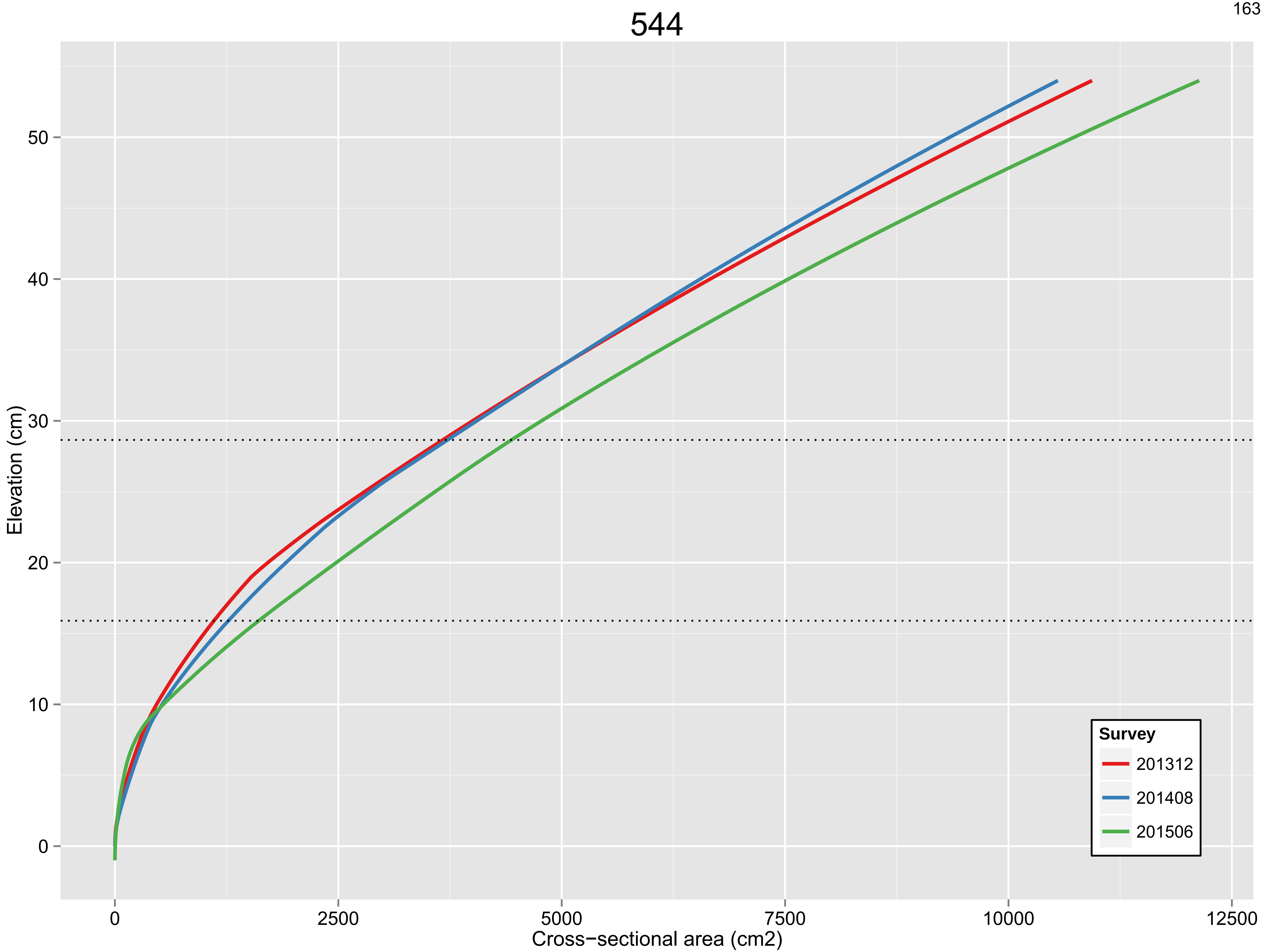

165
Elevation (cm)
Cross−sectional area (cm2)
Survey
201312
201408
201506
0
10
20
30
40
50
60
70
80
90
100
110
0
10000
20000
30000
40000
50000



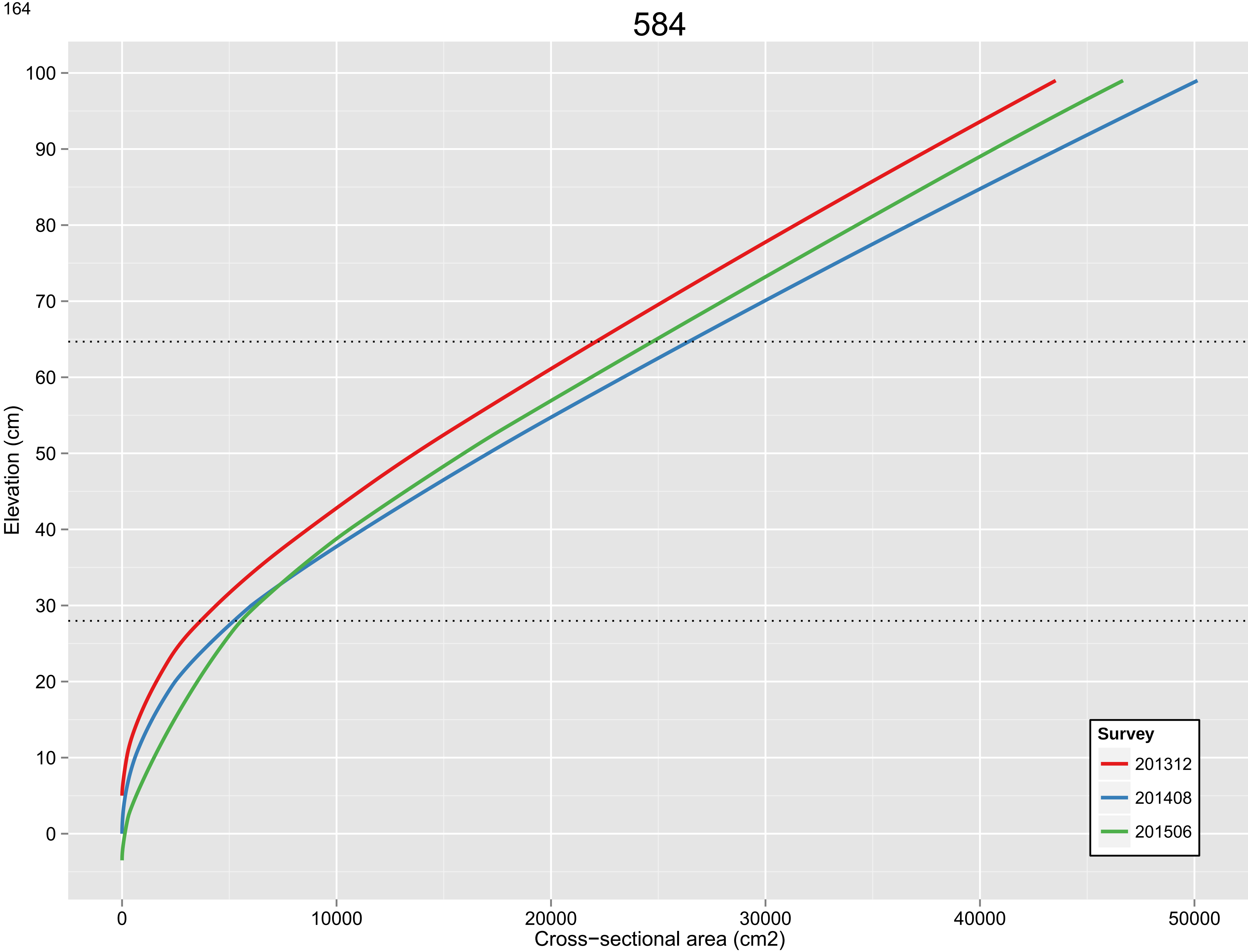
196
Elevation (cm)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20000
40000
Cross−sectional area (cm2)
Survey
201312
201408
201506

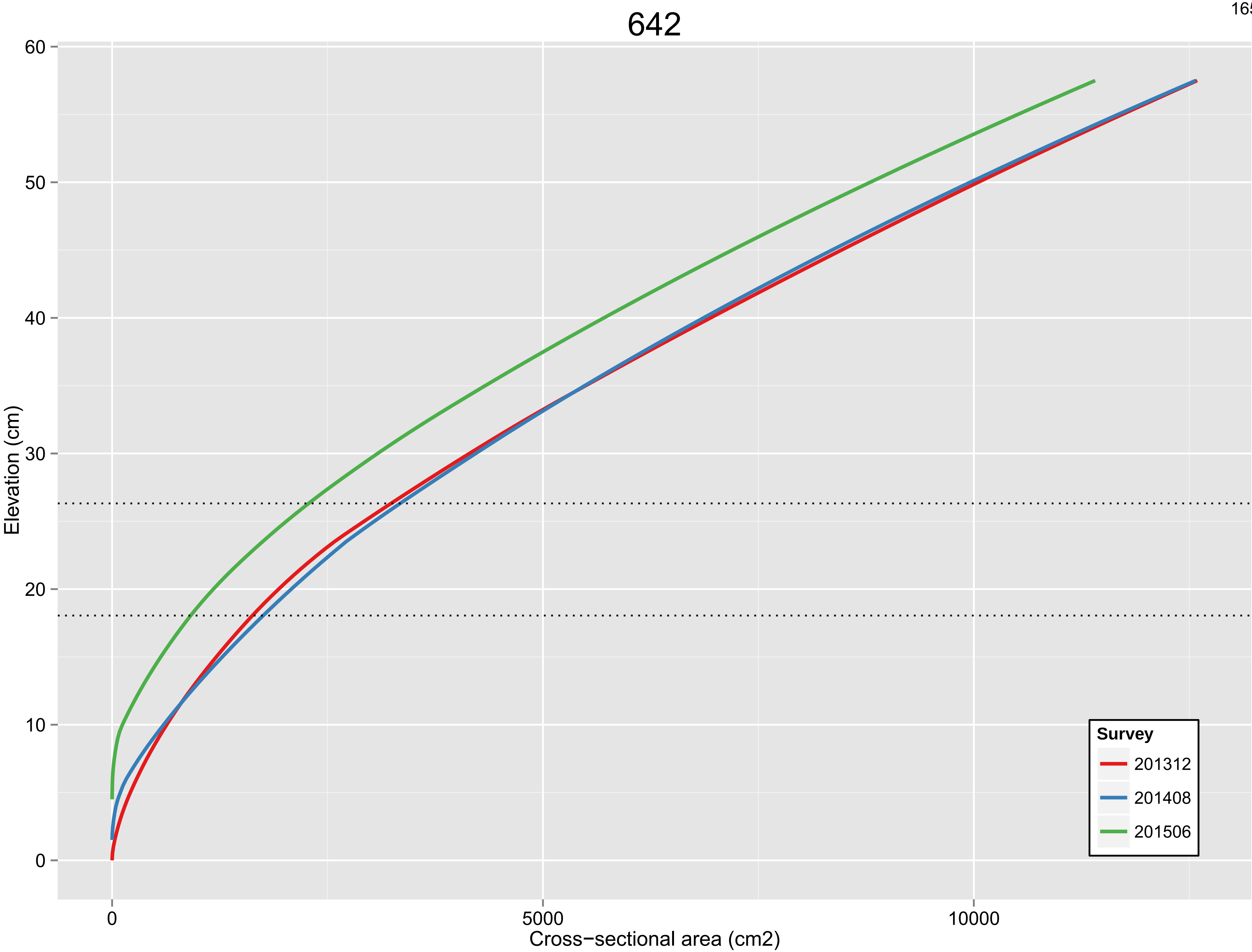

328
Elevation (cm)
0
10
20
30
40
50
Cross−sectional area (cm2)
0
5000
10000
15000
Survey
201312
201408
201506

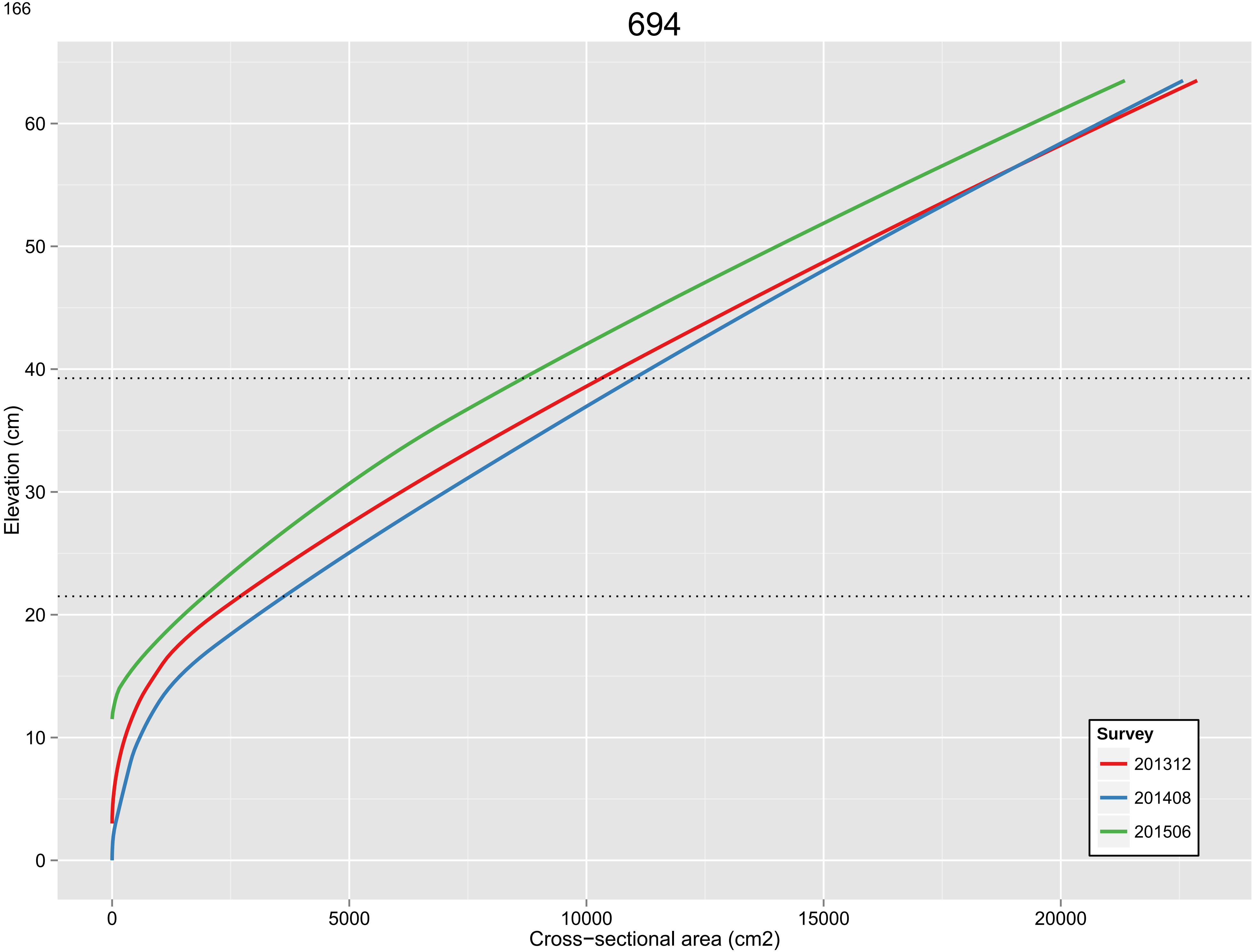

433
Elevation (cm)
0
10
20
30
40
50
60
70
80
90
Cross−sectional area (cm2)
0
20000
40000
60000
Survey
201312
201408
201506



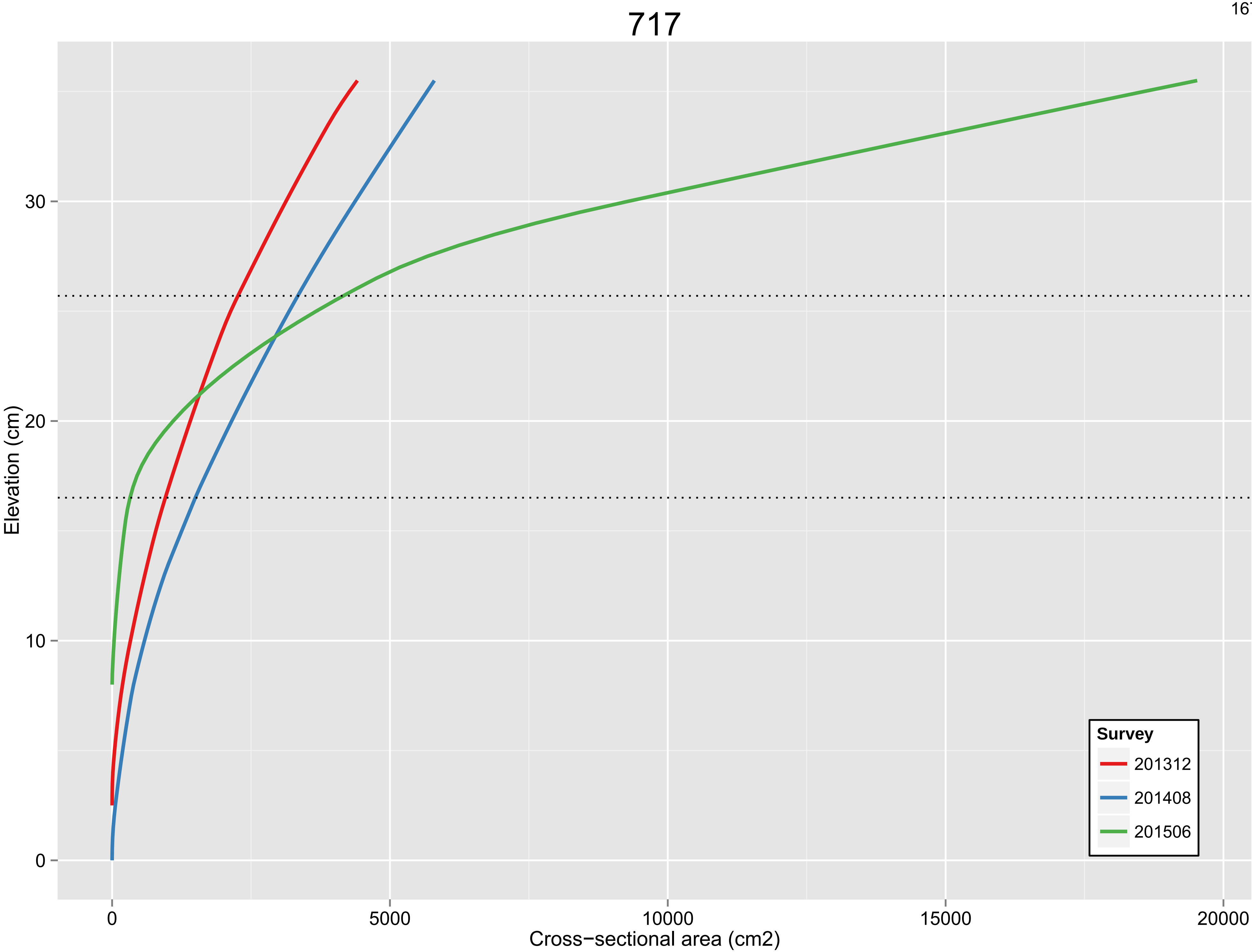
544
Elevation (cm)
0
10
20
30
40
50
0
2500
5000
7500
10000
12500
Cross−sectional area (cm2)
Survey
201312
201408
201506


584
Elevation (cm)
100
90
80
70
60
50
40
30
20
10
0
0
10000
20000
30000
40000
50000
Cross−sectional area (cm2)
Survey
201312
201408
201506

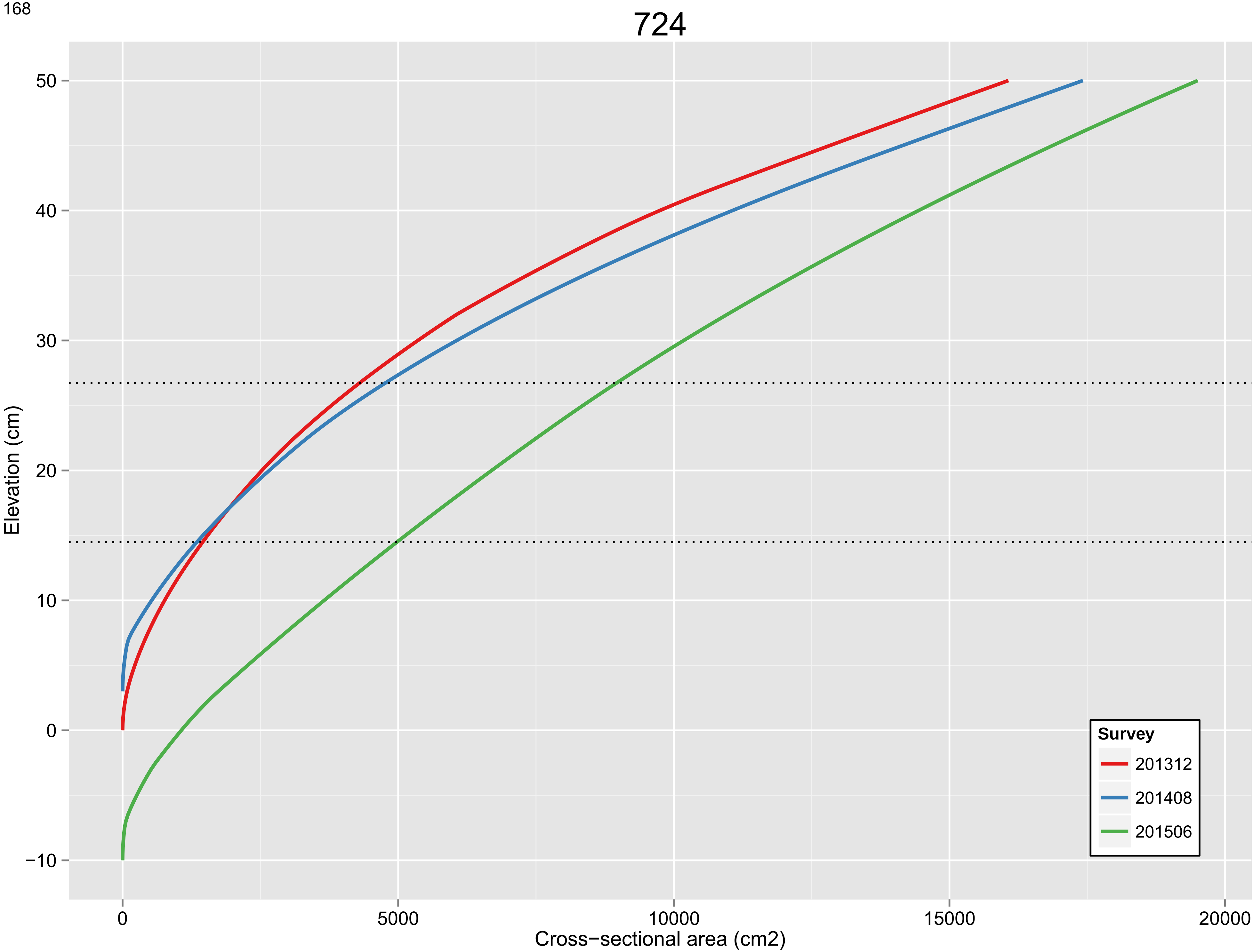

642
Elevation (cm)
0
10
20
30
40
50
60
0
5000
10000
Cross−sectional area (cm2)
Survey
201312
201408
201506



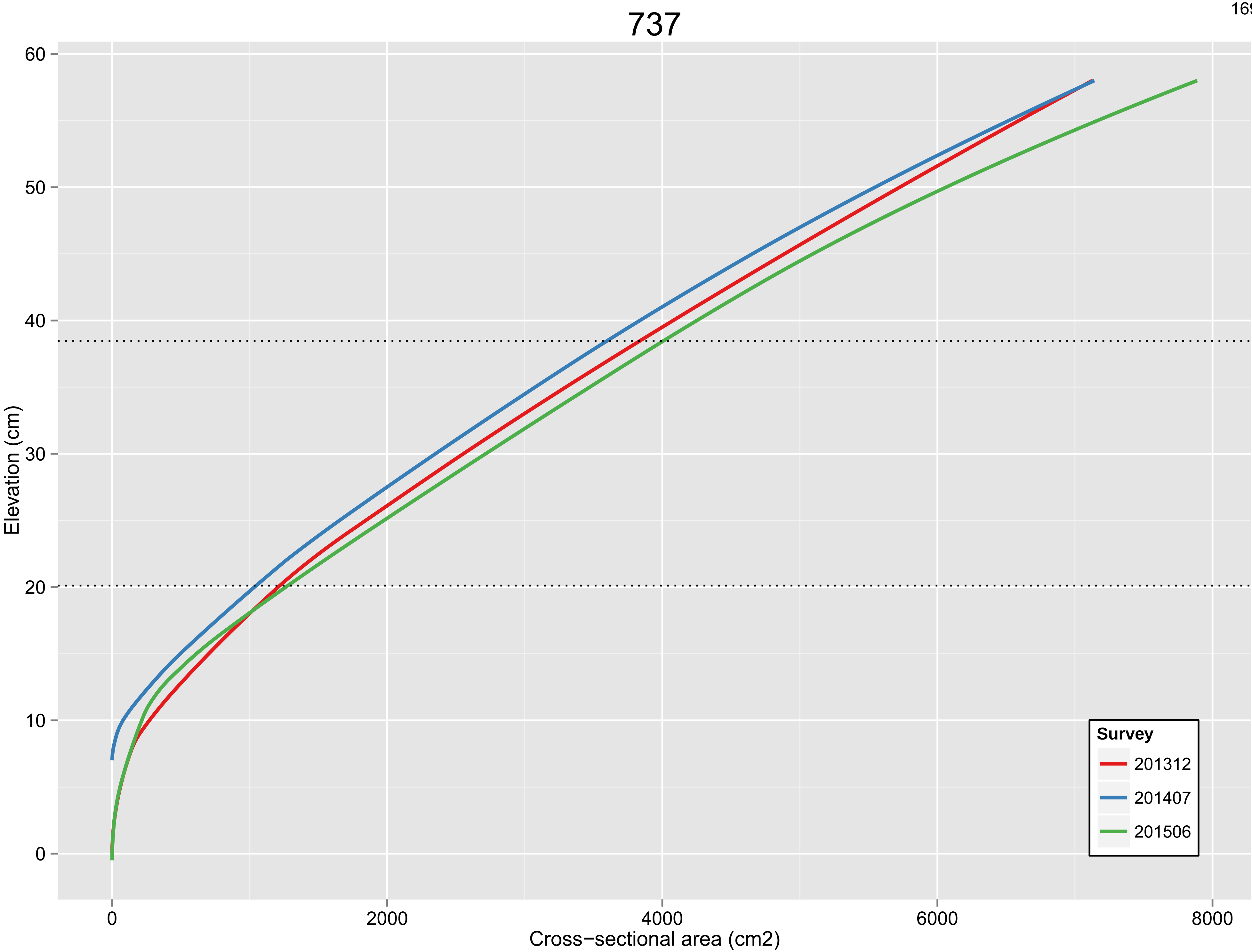
694
Elevation (cm)
0
10
20
30
40
50
60
0
5000
10000
15000
20000
Cross−sectional area (cm2)
Survey
201312
201408
201506

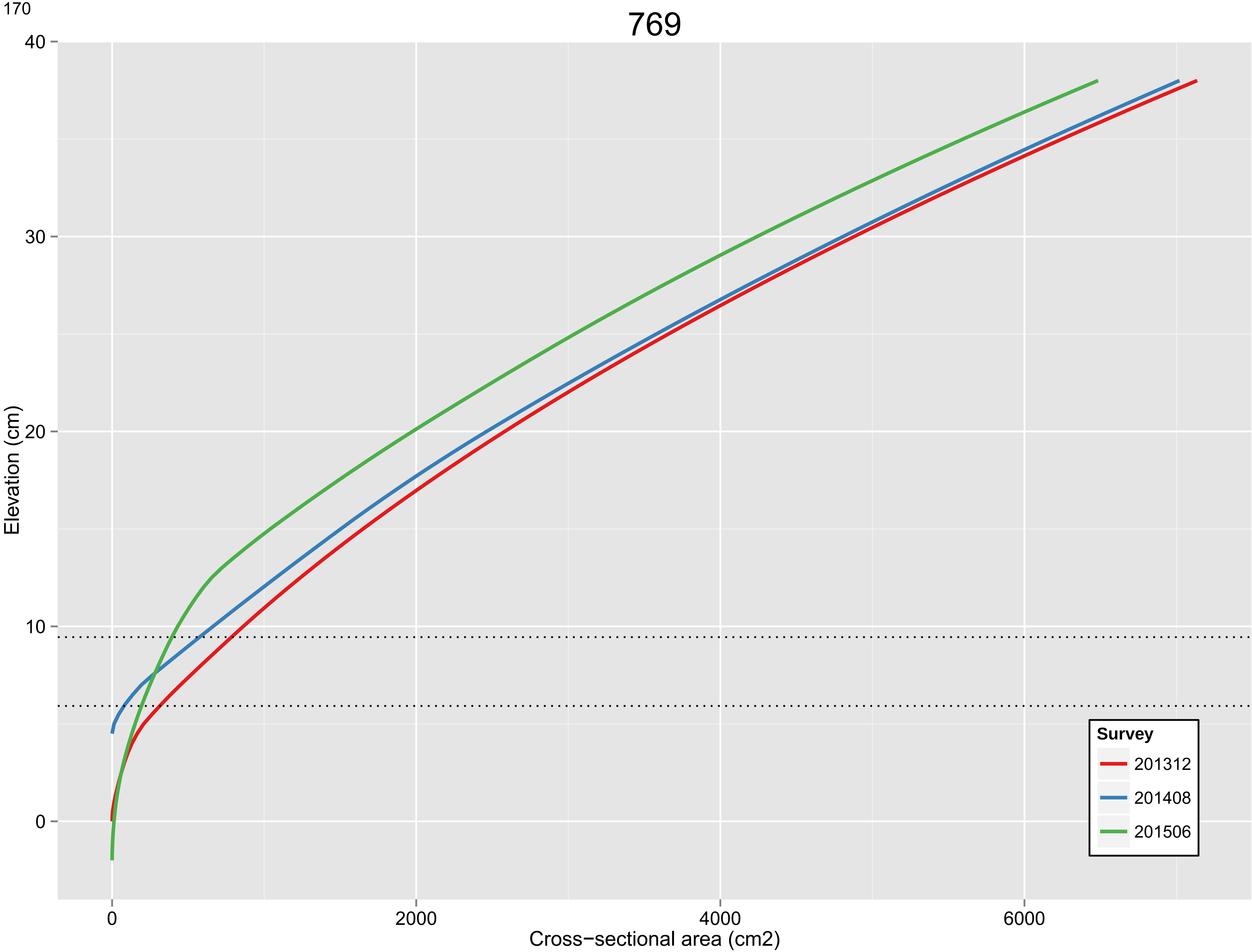


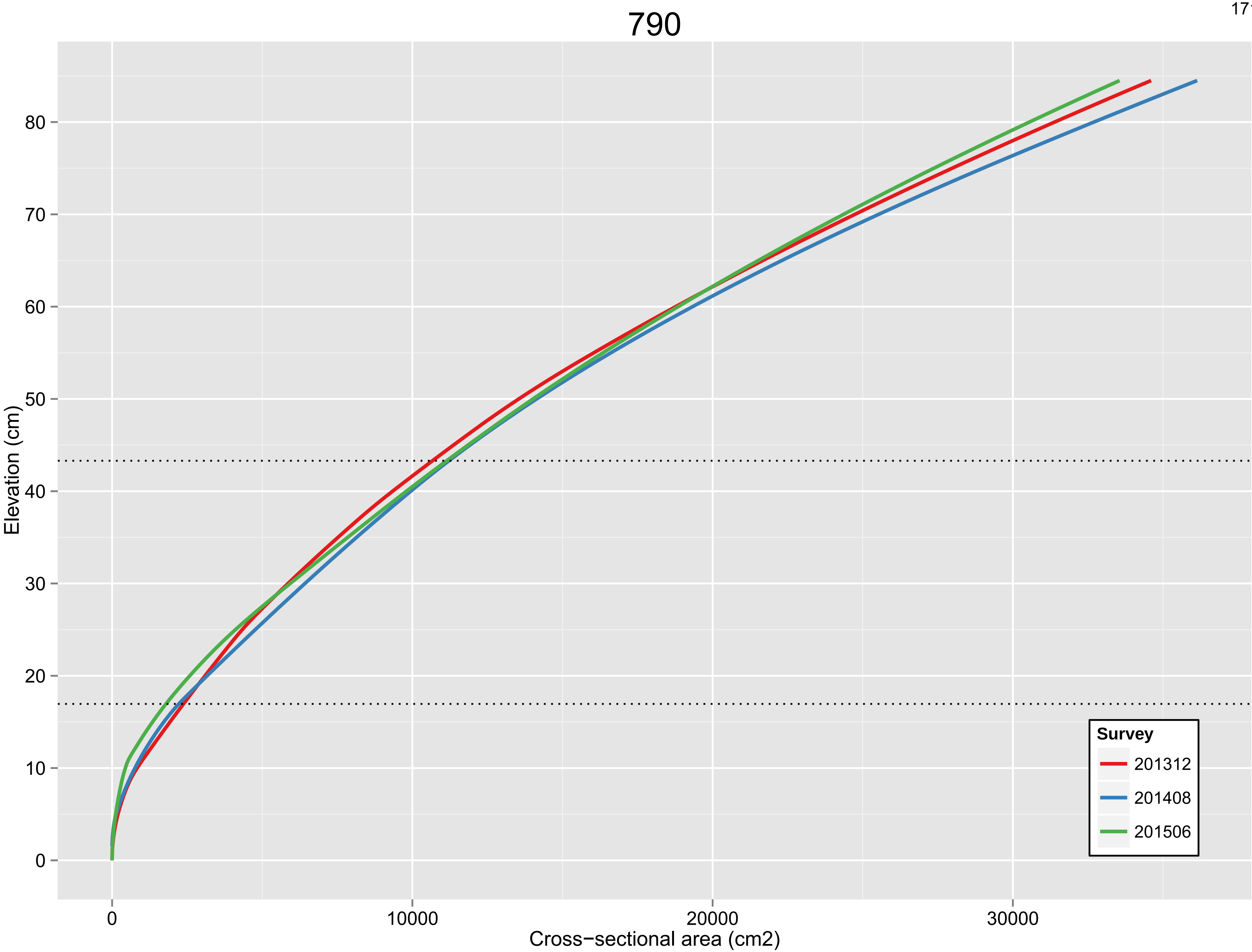
717
Elevation (cm)
30
20
10
0
0
5000
10000
15000
20000
Cross−sectional area (cm2)
Survey
201312
201408
201506



724
50
40
30
20
10
0
−10
Elevation (cm)
0
5000
10000
15000
20000
Cross−sectional area (cm2)
Survey
201312
201408
201506


737
Elevation (cm)
60
50
40
30
20
10
0
0
2000
4000
6000
8000
Cross−sectional area (cm2)
Survey
201312
201407
201506


769
40
30
20
10
0
Elevation (cm)
0
2000
4000
6000
Cross−sectional area (cm2)
Survey
201312
201408
201506


790
Elevation (cm)
Cross−sectional area (cm2)
0
10
20
30
40
50
60
70
80
0
10000
20000
30000
Survey
201312
201408
201506