Determining Tidal Corrections for Upper Floridan Aquifer Wells, Beaufort County, South Carolina

Prepared By

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Determining Tidal Corrections for Upper Floridan Aquifer Wells, Beaufort County, South Carolina

SUMMARY

Tidal correction factors were determined for 26 observation wells completed in the Upper Floridan aquifer in Beaufort County, South Carolina. The Upper Floridan aquifer is a confined limestone aquifer that occurs at depths between 50 and 250 feet. Static water levels in the aquifer change in response to the compression and expansion of the aquifer due to rising and falling tides. When preparing potentiometric maps, it is desirable to correct those water-level measurements. Correction factors were determined by calculating tidal efficiency and tidal lag for each of the 26 wells using continuously recorded groundwater-level data and National Oceanic and Atmospheric Administration (NOAA) tide station surface-water level data. The application of these tidal correction factors will improve the accuracy of future potentiometric maps made of the aquifer.

INTRODUCTION

Water levels in wells near tidal water bodies fluctuate in response to the compression and expansion of the aquifer owing to the weight of the incoming and outgoing tide on the confining layer and aquifer (Figure 1). Water levels rise in a well in response to an incoming tide and fall in response to an outgoing tide. Changes to the potentiometric head can range from more than 70 percent of the tide range in wells located a few hundred feet from a tidally-influenced water body to less than 5 percent in wells a mile or more from a tidally-influenced surface-water body.

In South Carolina, static water levels are synoptically collected every three years from several hundred wells completed in the Floridan aquifer system so that a potentiometric map of the aquifer can be produced (Gawne, 1994; Hockensmith et al., 2013; Wachob et al., 2014; Wachob et al., 2017). These maps are used by the State to evaluate changes in aquifer storage and groundwater flow directions. Manual measurements of water levels from coastal wells are typically collected at various times during different tidal cycles. Because water levels change with the tides, a water level measured from a well at high tide cannot be accurately compared to a water level measured from a nearby well at low tide. To make an appropriate comparison, it is necessary to correct the static water-level measurements to account for those changes caused by the tides.

PURPOSE

The purpose of this project is to develop tidal correction factors for 26 wells in coastal Beaufort County, South Carolina. Wells included in the study are completed in the Upper Floridan aquifer, which is a confined, limestone aquifer that occurs at depths between 50 and 250 feet. The methods used in this report follow techniques documented by Gawne (1997) and have been successfully employed in the past to correct water-level measurements used in potentiometric maps of the Floridan aquifer system. The correction factors developed from this study update and add to tidal corrections calculated in the past, and will be used to improve the accuracy of future potentiometric maps made of the aquifer.

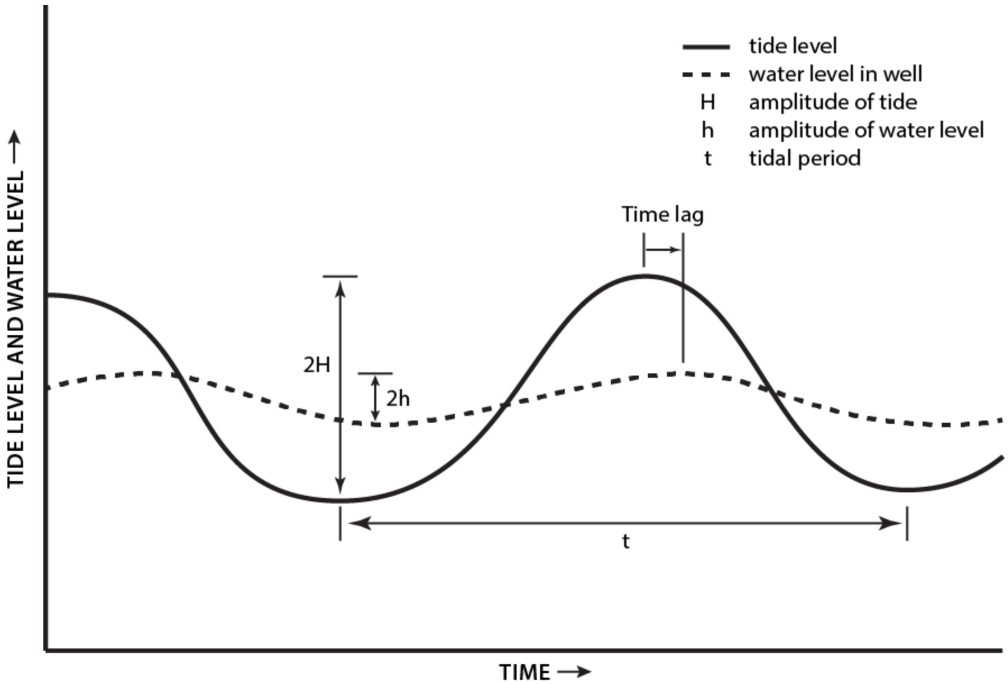

Figure 1. Example of tide level and groundwater level showing tidal lag and relative magnitudes of amplitude over a tidal period (Adapted from Crouch, 1986).

METHODOLOGY

Wells chosen for this study were primarily South Carolina Department of Natural Resources (SCDNR) observation wells having a long-term record of periodic measurements. Attempts were made to develop tidal corrections for 30 wells, as was originally proposed, but four wells had to be omitted due to interferences from pumping or to the absence of a clear tidal signal. Priority was given to Upper Floridan aquifer wells already established within the National Ground-Water Monitoring Network (NGWMN). Of the 26 wells used in the study, only 8 are currently included in NGWMN. Many of the NGWMN wells had pumps in them, which prevented access needed for the installation of the automated data recorders. Where a recorder could not be easily deployed in the well, the established NGWMN wells could not be used and were omitted from this study. The non-NGWMN wells used in this project will be added to the NGWMN in the near future. Figure 2 shows the locations of wells used in this study. Wells that are currently included in the NGWMN are denoted by blue squares; non-NGWMN wells are denoted by red triangles.

Wells were equipped with an automatic data recorder (Solinst Levelogger) programed to log at 12-minute intervals for a period of seven days or more. Manual water-level measurements were collected using an electric water-level tape at the time of logger deployment and retrieval. These measurements were collected to ensure that the logger was correctly functioning, and were later used as points for which to apply tidal corrections. Water levels were corrected for barometric pressure effects using a centrally located pressure logger (Solinst Barologger). Land-surface elevation at well sites was determined using a LiDAR DEM. Water-levels relative to land surface were transformed into water-level elevations referenced to NAVD88. Hydrographs were created to check the data for errors, confirm the accuracy of manual measurements collected in the field, and to determine the mean water level (MWL) for the sample period.

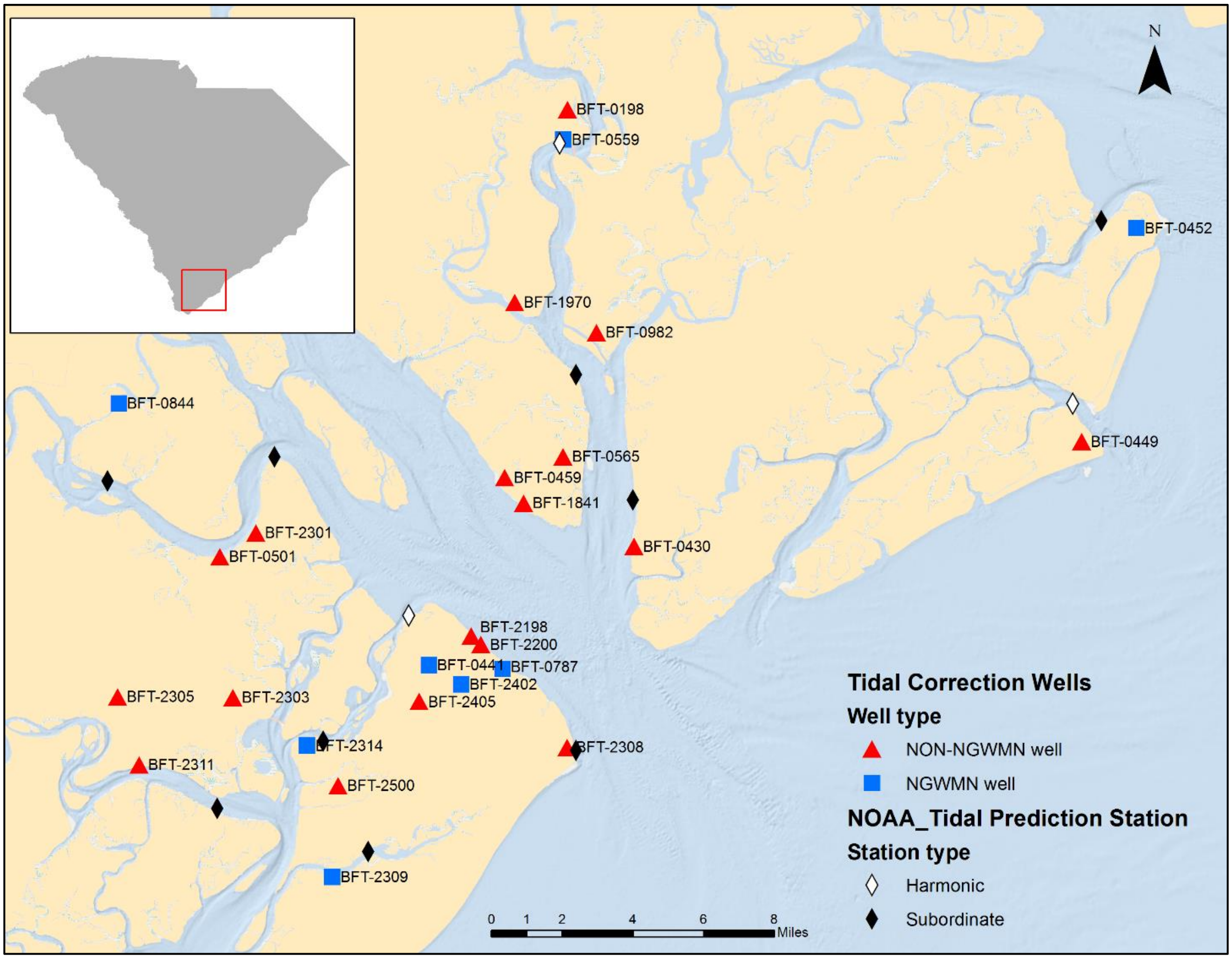

Figure 2. Locations of Upper Floridan aquifer wells and NOAA tidal prediction stations used in this study.

Wells were matched to the nearest local NOAA tide-prediction station referenced to tidal observation station number 8670870 located at the Savannah River entrance, Fort Pulaski, Georgia (NOAA, 2017; available online: http://tidesandcurrents.noaa.gov). Because the analysis required the use of the closest station in proximity to the well site, both harmonic and subordinate tide prediction stations were chosen. Harmonic station predictions are based on harmonic constants derived from water-level observations at that designated reference station, and report predictions on the same time step interval as the reference observation station. Subordinate stations have high- and low-water tide predictions that are based on time and height differences in relation to the designated reference station. In figure 2, harmonic tidal-prediction stations are denoted by white diamonds and subordinate stations by black diamonds.

Tidal corrections were developed by calculating a tidal lag time and a tidal efficiency for each well. Tidal lag (minutes) is the length of time between when high (or low) tide occurs and when the high (or low) water level in the well occurs. In general, the farther the well is from a tidally-influenced water body the greater its lag time. Tidal lag is usually positive, meaning that the peak of the tide in the surface-water body occurs before the peak of water level in the aquifer, but in cases very near to the coast, the lag can be negative. Tidal lag was calculated by comparing the lag time between the high-water level and the high tide, and between the low-water level and the low tide. Differences between high- and low-tide lags were averaged to find an average low/fall lag and high/rise lag for each well. Tidal efficiency (TE) is the ratio of the change (amplitude) in hydraulic head (Δh) to the change in tide stage (ΔH).

Once these factors were calculated for each well, NOAA tide-prediction tables were used to correct manual water-level measurements. Because tidal lag and tidal efficiency factors use mean tide level (MTL) in their calculations, it was important to examine hydrographs to ensure that changes from extreme atmospheric or storm-related events (i.e., high wind or storm surge) had not caused large departures from predicted water levels. The inclusion of these events may introduce error by over- or under-estimating amplitude when calculating tidal efficiencies. In cases where this phenomenon was present, the data were clipped to represent normal conditions for analysis.

Twenty-five hour moving averages were calculated based on a full tidal day (24 hours and 50 minutes) to obtain the mean water level based on hourly instrumental measurements. For wells referenced to a harmonic tidal prediction station, tidal corrections of 12-minute, continuous water-level data were calculated. Groundwater level was compared to tidal prediction data referenced to the same 12-minute time-step; tidal lag is subtracted from the groundwater measurement time to shift the water level record to match the tide record. The tide level is then recalculated as above (+) or below (-) the MTL (see Table 2– Tidal Differences and other Constants, NOAA, 2017) with MTL set to zero. Shown in the equation below, the tide level is multiplied by the tidal efficiency (TE) to obtain the correction factor, this value is then subtracted from the uncorrected groundwater level (WL elevation) to calculate the tide corrected water level.

$$\textit{WL elevation} - (\textit{Tide level} * \textit{TE}) = \textit{Corrected water level}$$

Corrections of manual water-level measurements were computed using an Excel spreadsheet modeled after Gawne (1997). To calculate the correction, the half-tidal cycle preceding and following the manual measurement is used to shift the measurement towards the average daily mean. The spreadsheet corrects one measurement at a time, but wells can be grouped according their local NOAA tidal station to expedite the process when several wells are being corrected at once. All uncorrected and corrected hydrographs and a sample spreadsheet can be found at the end of this report.

RESULTS

Tidal correction factors were determined for 26 observation wells completed in the Upper Floridan aquifer in Beaufort County, South Carolina (Table 1). Eight of the wells are current surveillance-type wells in the NGWMN; twelve wells are routinely monitored during SCDNR’s potentiometric effort; and the remaining six wells had not been measured in several years, but will be added to SCDNR’s synoptic (periodic measurement) well network and will be added to the NGWMN in the future. Tidal lags ranged from -37 to 115 minutes and tidal efficiencies ranged from 0.048 to 0.631. The determination and use of these tidal correction techniques has been well documented (Hayes, 1979; Crouch, 1986; Gawne, 1997); in the wells for which corrections had been previously developed, our results show similar ranges in lags and tidal efficiencies to those previously reported.

Table 1. Well identification information, network type, and tidal correction factors

SCDNR Well ID	Latitude	Longitude	Well Elevation (ft)	Well Depth (ft)	Well Network - Type	Local NOAA Tidal Station (number-type)	Tidal Lag (minutes)	Tidal Efficiency
BFT-0198	32.441690	-80.671750	20.9	65	SCDNR synoptic	8667999 Harmonic	85	0.157
BFT-0430	32.290610	-80.644580	5.9	130	New	8668686 Subordinate	6	0.411
BFT-0441	32.249470	-80.728500	10.2	218	NGWMN surveillance	8668918 Harmonic	82	0.148
BFT-0449	32.326889	-80.461306	5.1	209	SCDNR synoptic	8668498 Harmonic	95	0.148
BFT-0452	32.398060	-80.437500	8.7	103	NGWMN surveillance	8668146 Subordinate	62	0.048
BFT-0459	32.314420	-80.697530	5.8	106	New	8668445 Subordinate	12	0.284
BFT-0501	32.287070	-80.813920	17.2	225	SCDNR synoptic	8668619 Subordinate	53	0.244
BFT-0559	32.431190	-80.673500	7.6	62	NGWMN surveillance	8667999 Harmonic	46	0.092
BFT-0565	32.321667	-80.673611	12.0	209	New	8668445 Subordinate	43	0.205
BFT-0787	32.248890	-80.699167	4.7	240	NGWMN surveillance	8668918 Harmonic	21	0.215
BFT-0844	32.340060	-80.55380	9.5	160	NGWMN surveillance	8668655 Subordinate	-37	0.261
BFT-0982	32.364611	-80.659806	10.5	74	SCDNR synoptic	8668445 Subordinate	45	0.339
BFT-1841	32.305560	-80.689722	7.5	190	New	8668445 Subordinate	45	0.324
BFT-1970	32.375000	-80.693333	9.1	90	SCDNR synoptic	8668445 Subordinate	23	0.631
BFT-2198	32.259722	-80.711111	18.4	240	SCDNR synoptic	8667918 Harmonic	15	0.280
BFT-2200	32.256667	-80.707222	17.1	229	SCDNR synoptic	8667918 Harmonic	13	0.259
BFT-2301	32.295278	-80.799167	12.3	162	SCDNR synoptic	8668619 Subordinate	28	0.244
BFT-2303	32.238333	-80.808611	15.5	198	SCDNR synoptic	8669133 Subordinate	30	0.223
BFT-2305	32.238611	-80.855833	21.2	217	SCDNR synoptic	8669262 Subordinate	85	0.058
BFT-2308	32.221111	-80.671944	8.8	216	SCDNR synoptic	8669167 Subordinate	41	0.271
BFT-2309	32.176111	-80.768056	8.5	248	NGWMN surveillance	8669338 Subordinate	27	0.178
BFT-2311	32.215000	-80.846944	4.6	236	New	8669262 Subordinate	-14	0.256
BFT-2314	32.221667	-80.778333	7.6	226	NGWMN surveillance	8669133 Subordinate	0	0.343
BFT-2402	32.242842	-80.715261	15.3	247	NGWMN surveillance	8667918 Harmonic	115	0.101
BFT-2405	32.236980	-80.732411	14.4	230	SCDNR synoptic	8668918 Harmonic	105	0.105
BFT-2500	32.207842	-80.765658	6.6	246	New	8669262 Subordinate	-1	0.247

A comparison of the predicted tide level and the uncorrected water level from well BFT-0441 is shown in Figure 3. The action of the incoming and outgoing tide compress the aquifer with enough force that a clear semi-diurnal tidal signal is present. Note that the y-axis is showing the water level referenced to the mean tide level instead of water elevation; this is to provide a visual reference for identifying the lag and difference in amplitude between the two hydrographs. The tidal lag here (BFT-0441) is 82 minutes and the tidal efficiency is 0.148. A comparison of the corrected to uncorrected water level (Figure 4) shows the corrections have dampened the semi-diurnal tide signal, and the amplitude has been reduced by approximately half (0.68 ft to 0.33 ft). A 25-hour moving average on the hourly uncorrected water level has the most effect by nearly eliminating the tidal signal, showing arithmetic mean from the logged data. The corrected manual measurements were within 1% of the corrected continuous water-level data.

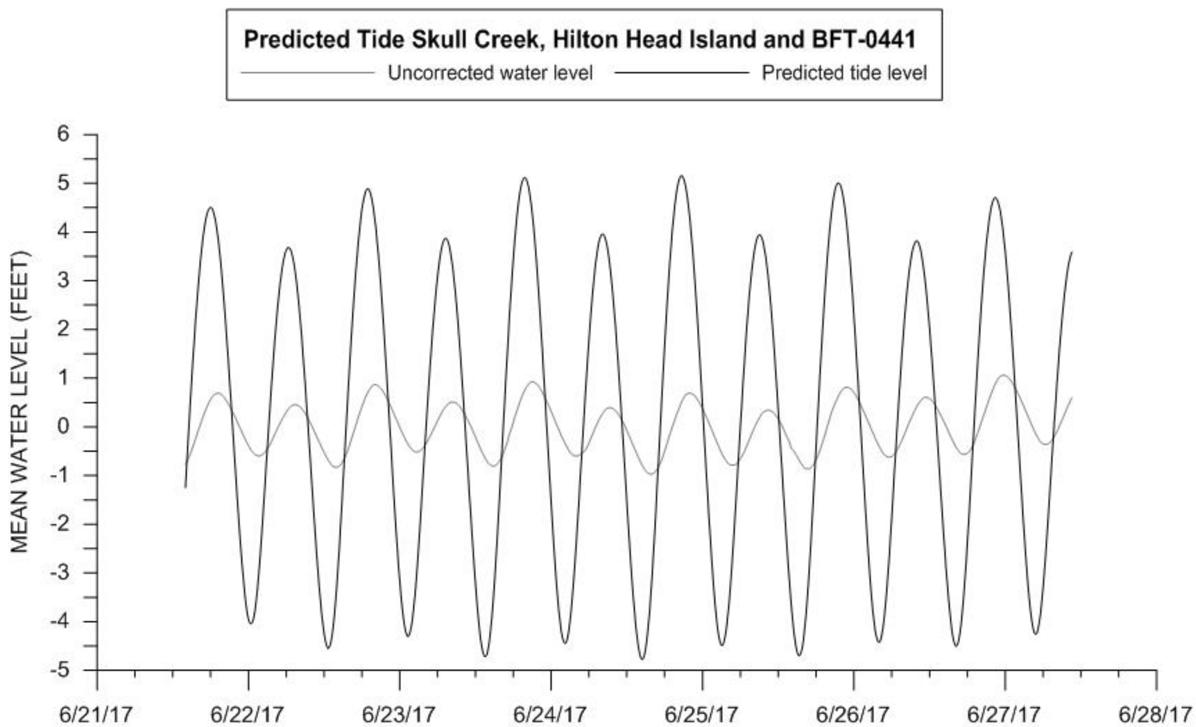

Figure 3. Comparison of predicted tide level at NOAA Tide Prediction Station number 8668918, Skull Creek, North Entrance, Hilton Head Island and water level from BFT-0441. Note the differences in amplitude and the groundwater-level lagging behind the tide.

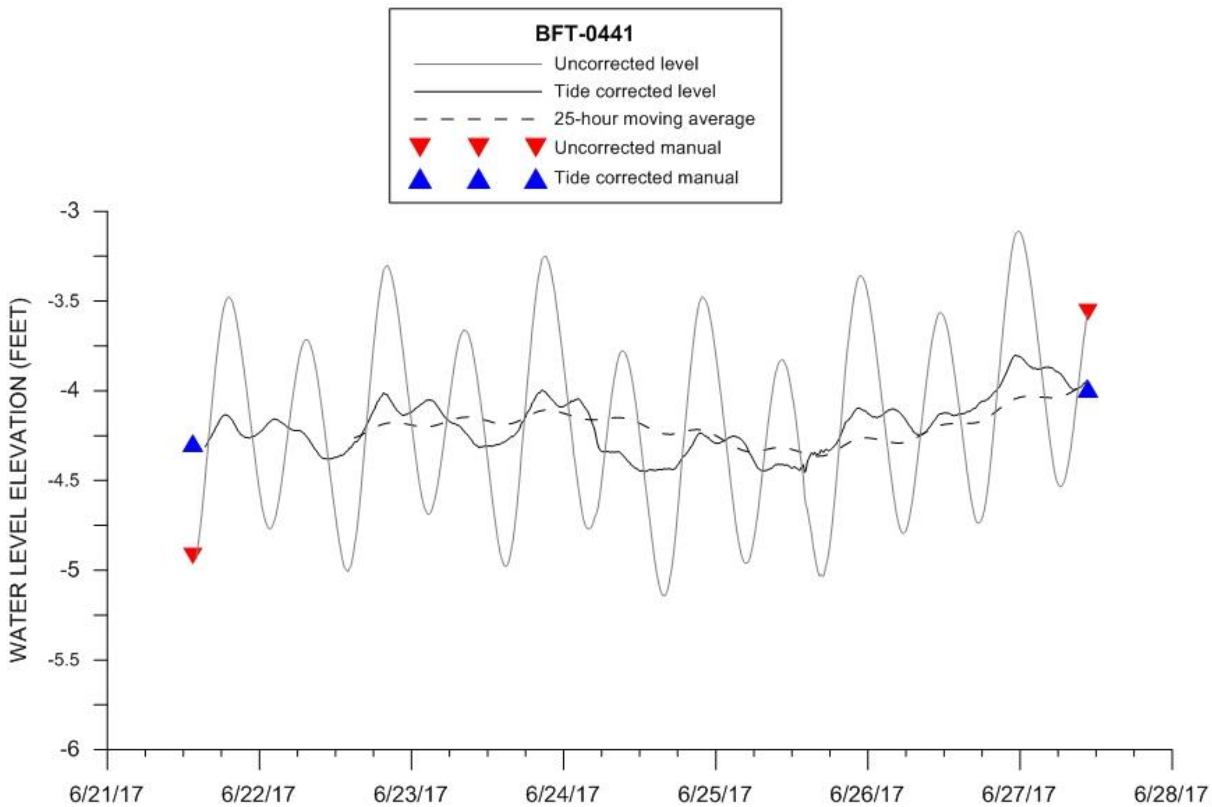

Figure 4. Comparison of uncorrected and corrected water level data at well BFT-0411. Continuous water levels are corrected to tidal predictions made at 12-minute intervals, a 25-hour moving average is based on hourly water level measurements, and manual measurements are corrected to the half-cycle preceding and following high or low tide at NOAA station number 8668918, Skull Creek, North Entrance.

DISCUSSION

We achieved good results employing tidal correction methods to correct for tidally influenced water-level fluctuations in the Upper Floridan aquifer. Although it is not practical to collect surface water tide level data at multiple locations in an estuary system, nor to collect continuous water-level data from every well, the careful use of tidal prediction data can significantly improve the accuracy of manually and continuously measured water levels. Because the water level corrections use the predicted mean tide level in their calculations, they are susceptible to systematic errors due to weather disturbances (high wind, storm surge). To achieve the best results, tidal prediction charts should be consulted and all measurements should be collected under normal weather conditions, if possible.

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National Oceanic Atmospheric Administration (NOAA), 2017, Table 2 – Tidal differences and other constants, In: Tide Tables 2017 - High and low water predictions, East Coast of North and South America including Greenland. Accessed online:
https://tidesandcurrents.noaa.gov/tidetables/2017/ectt2017book.pdf

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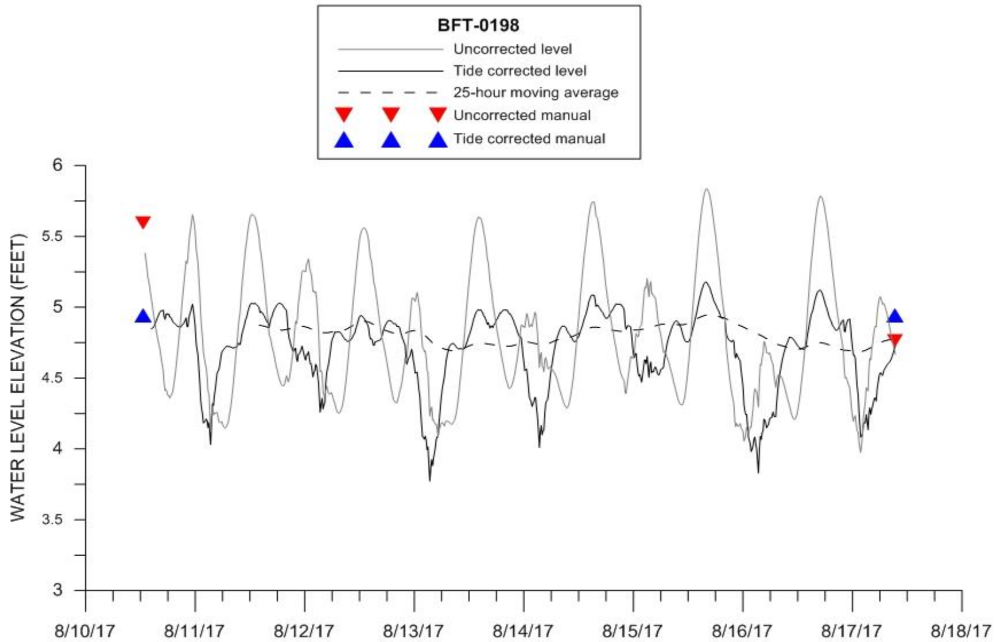
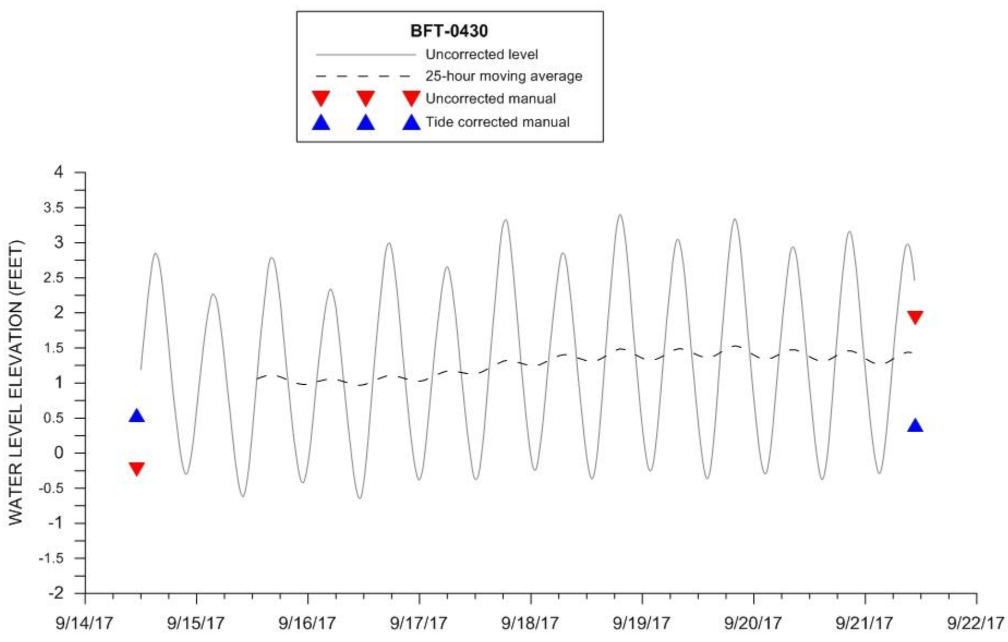
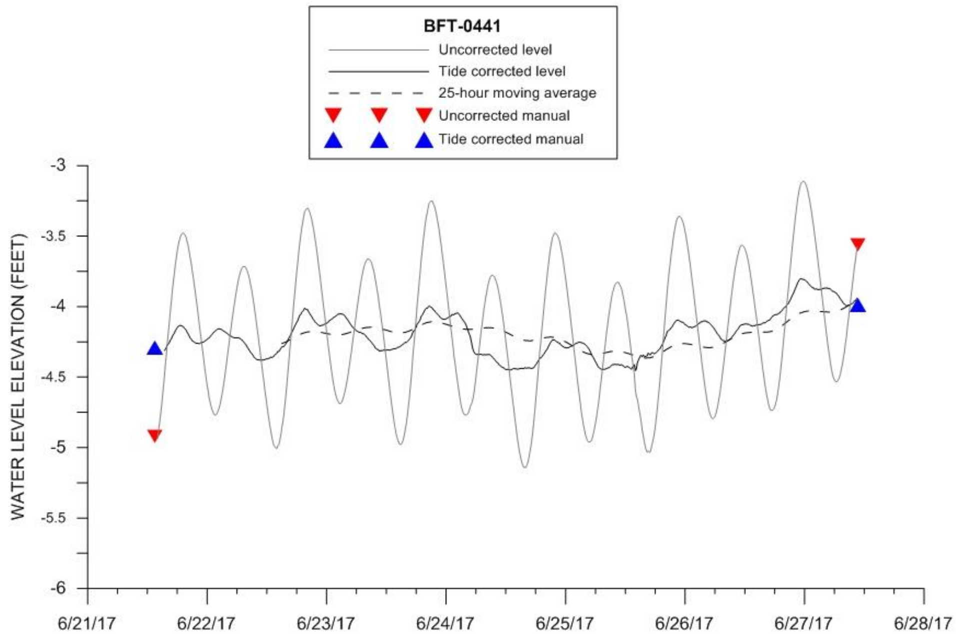
APPENDIX A. WELL HYDROGRAPHS






BFT-0441
Uncorrected level
Tide corrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-3
-3.5
-4
-4.5
-5
-5.5
-6
6/21/17
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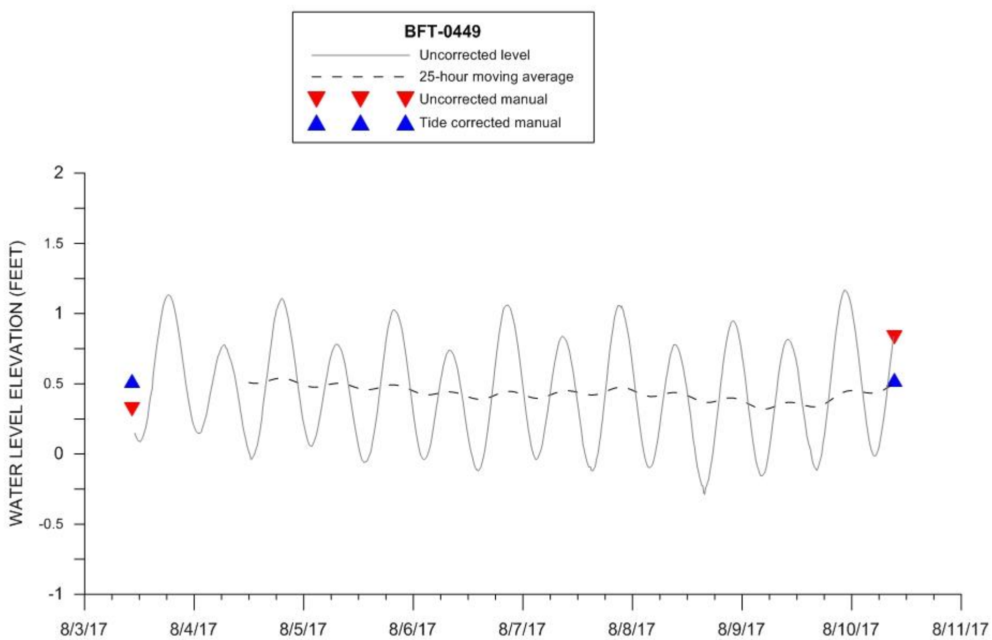
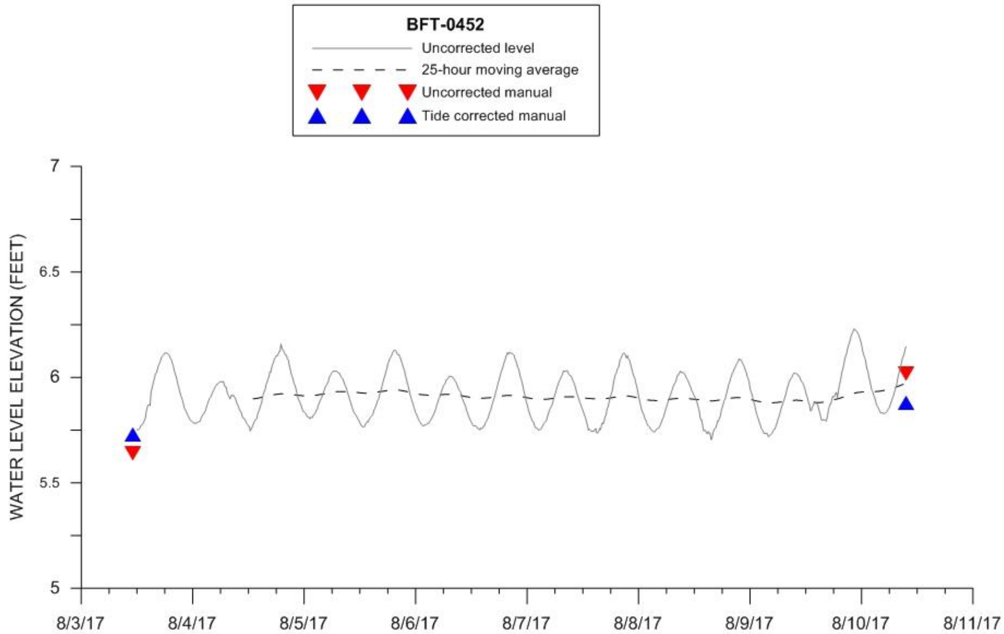
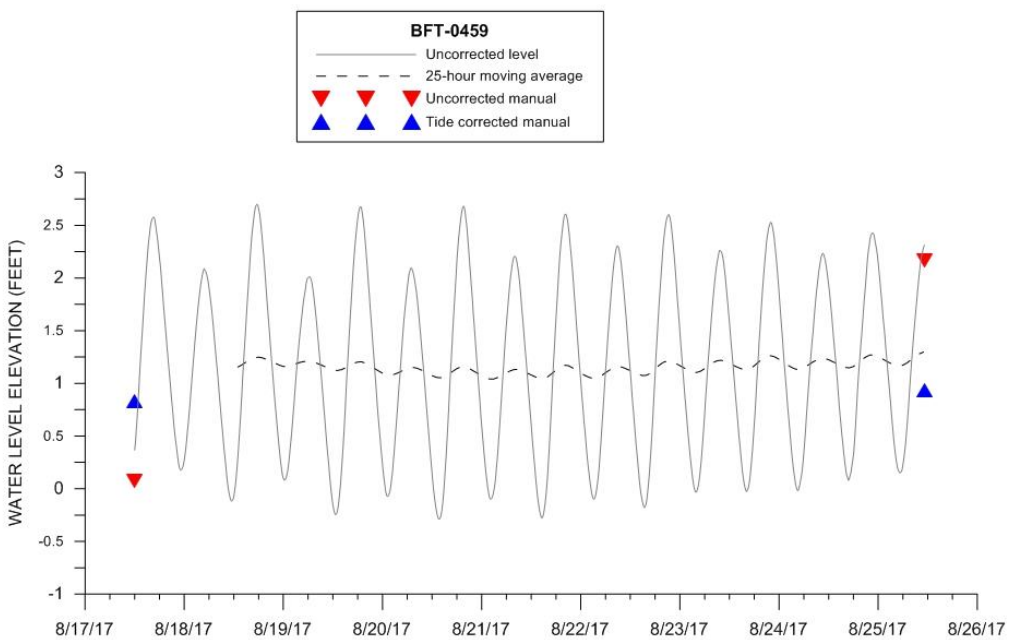
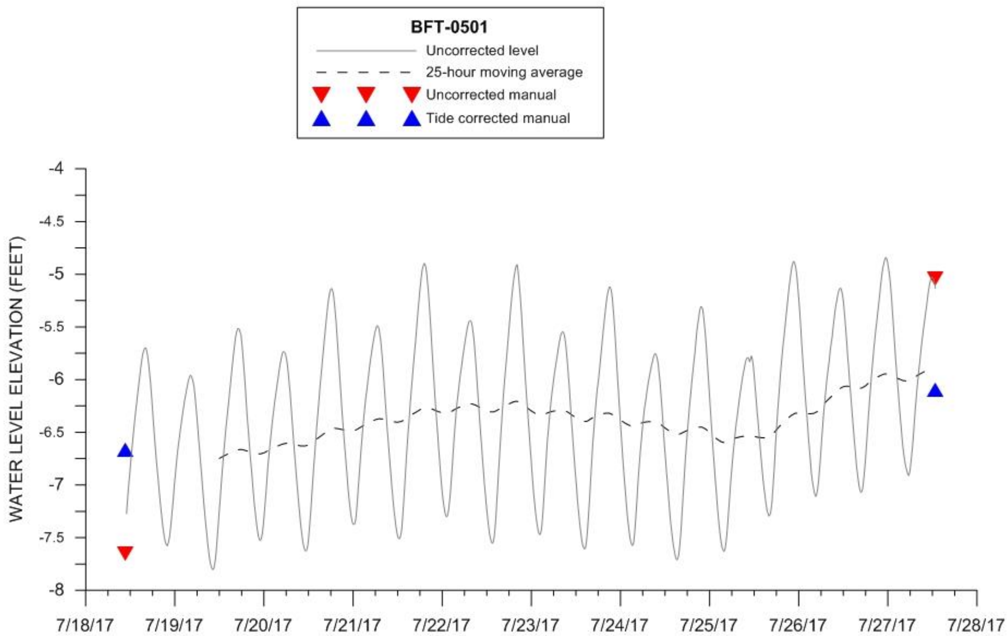
6/25/17
6/26/17
6/27/17
6/28/17


BFT-0449
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
2
1.5
1
0.5
0
-0.5
-1
8/3/17
8/4/17
8/5/17
8/6/17
8/7/17
8/8/17
8/9/17
8/10/17
8/11/17


BFT-0452
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
7
6.5
6
5.5
5
8/3/17
8/4/17
8/5/17
8/6/17
8/7/17
8/8/17
8/9/17
8/10/17
8/11/17


BFT-0459
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
8/17/17
8/18/17
8/19/17
8/20/17
8/21/17
8/22/17
8/23/17
8/24/17
8/25/17
8/26/17


BFT-0501
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-4
-4.5
-5
-5.5
-6
-6.5
-7
-7.5
-8
7/18/17
7/19/17
7/20/17
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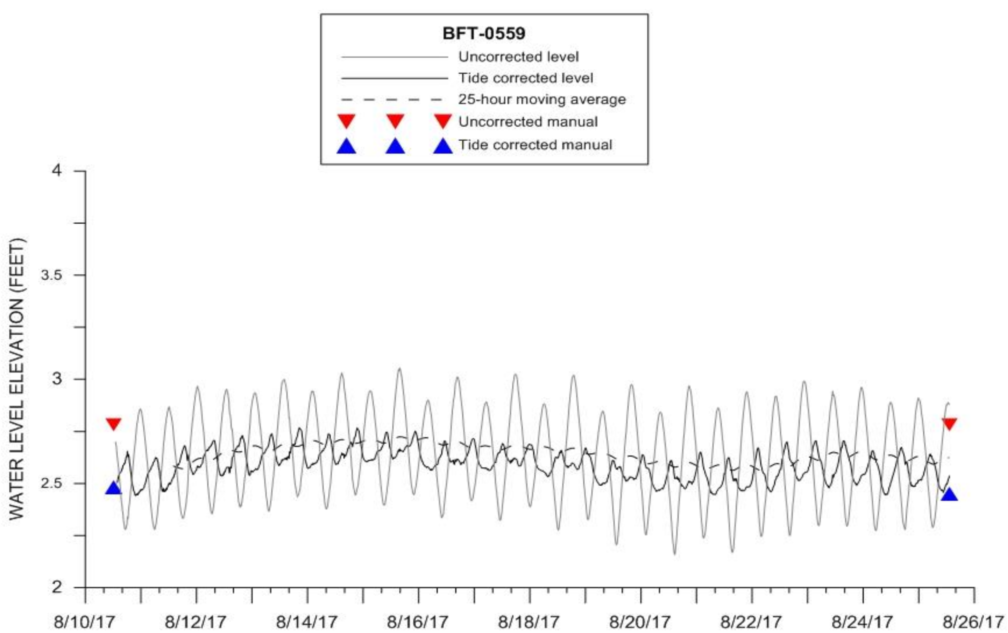
7/27/17
7/28/17


BFT-0559
Uncorrected level
Tide corrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
4
3.5
3
2.5
2
8/10/17
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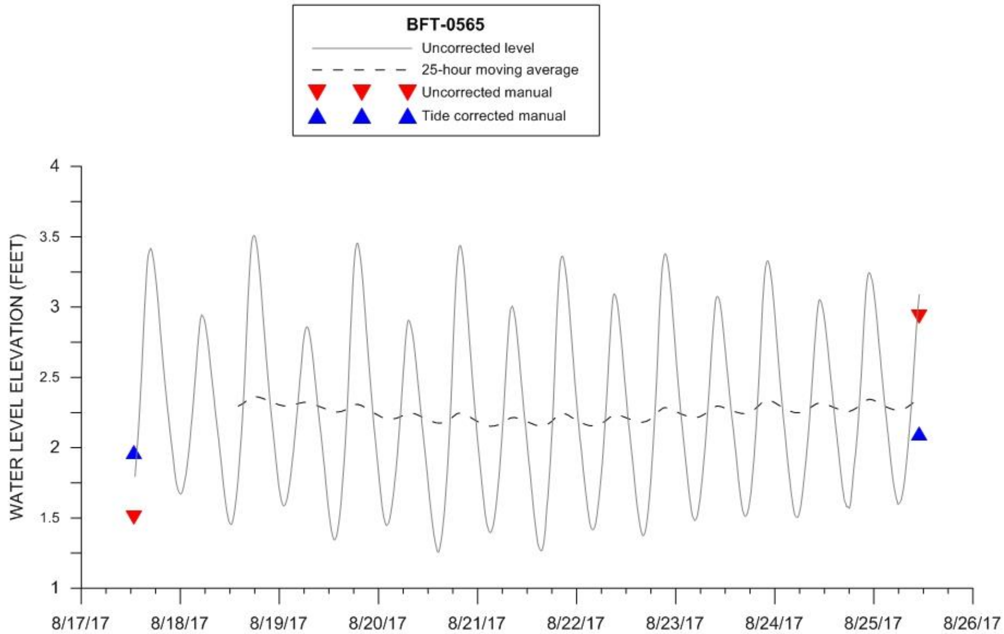
8/24/17
8/26/17



BFT-0565
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
4
3.5
3
2.5
2
1.5
1
8/17/17
8/18/17
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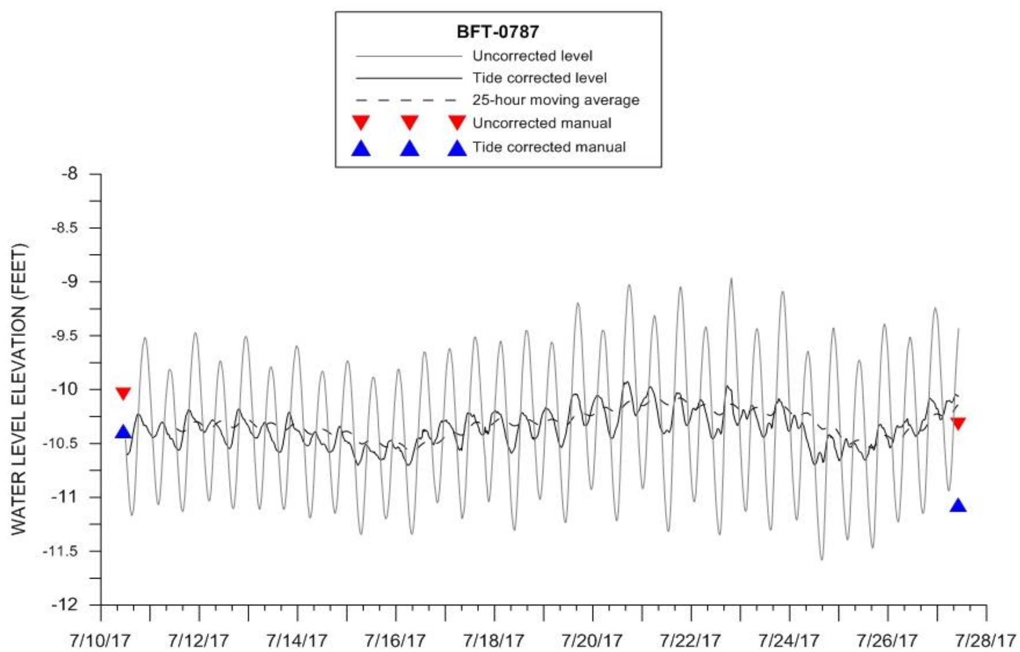
8/25/17
8/26/17



BFT-0787
Uncorrected level
Tide corrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-8
-8.5
-9
-9.5
-10
-10.5
-11
-11.5
-12
7/10/17
7/12/17
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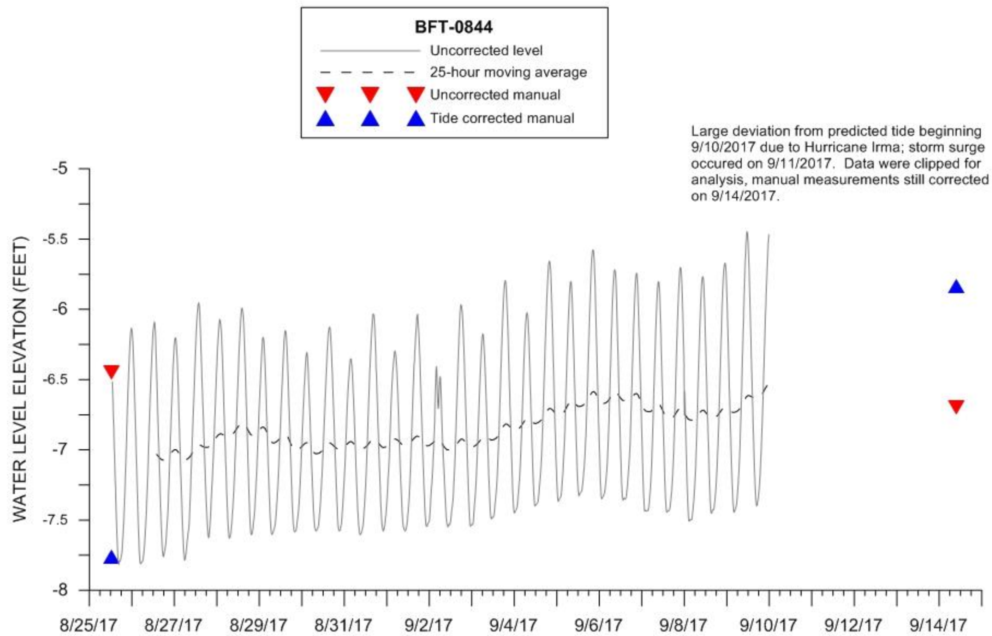
7/26/17
7/28/17


BFT-0844
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
Large deviation from predicted tide beginning 9/10/2017 due to Hurricane Irma; storm surge occured on 9/11/2017. Data were clipped for analysis, manual measurements still corrected on 9/14/2017.
WATER LEVEL ELEVATION (FEET)
-5
-5.5
-6
-6.5
-7
-7.5
-8
8/25/17
8/27/17
8/29/17
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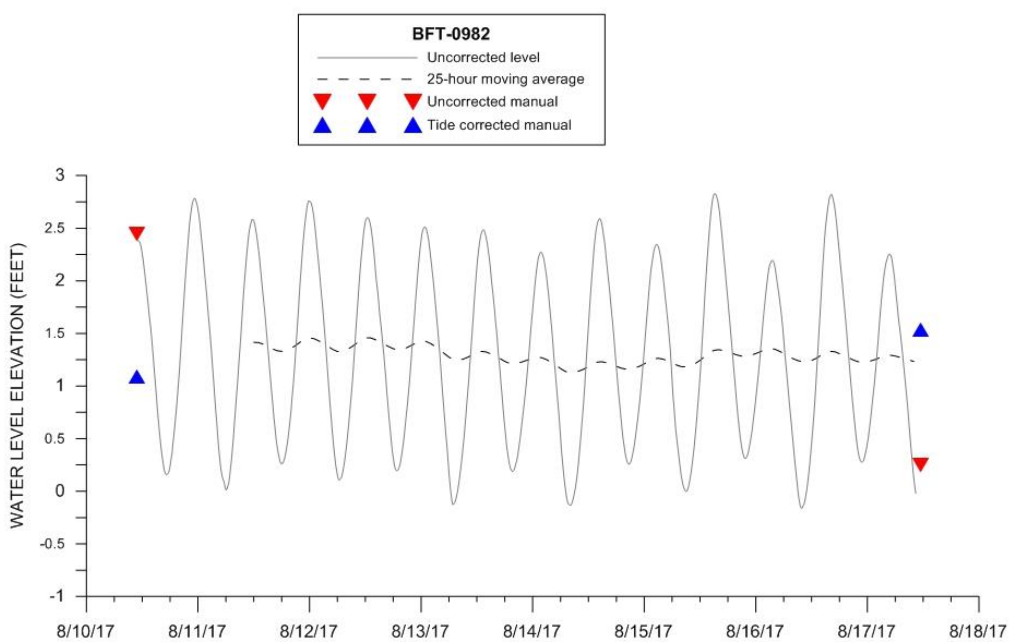
9/12/17
9/14/17


BFT-0982
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
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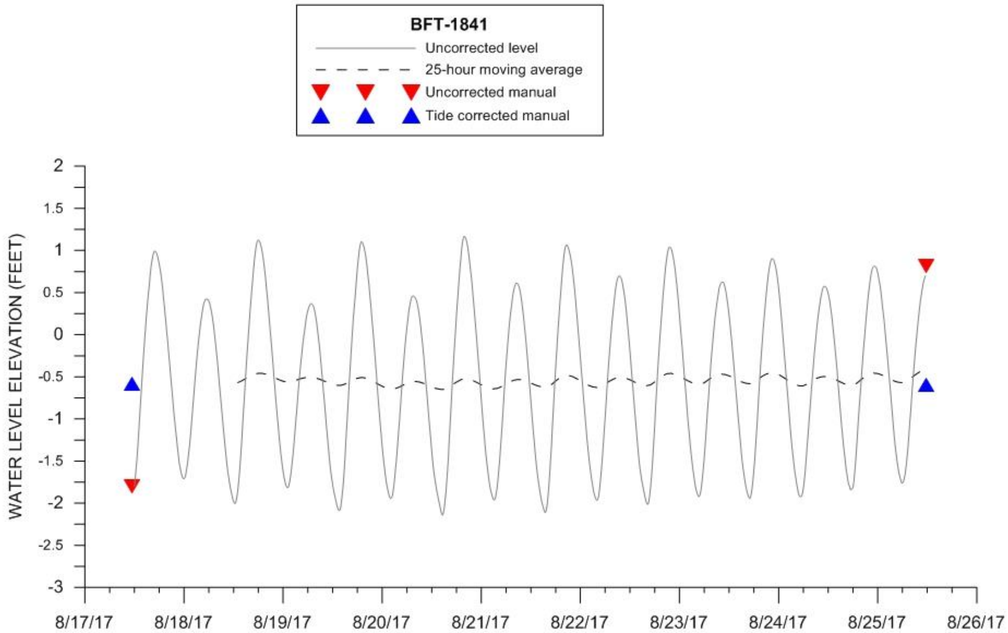
2.5
2
1.5
1
0.5
0
-0.5
-1
8/10/17
8/11/17
8/12/17
8/13/17
8/14/17
8/15/17
8/16/17
8/17/17
8/18/17


BFT-1841
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
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1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
8/17/17
8/18/17
8/19/17
8/20/17
8/21/17
8/22/17
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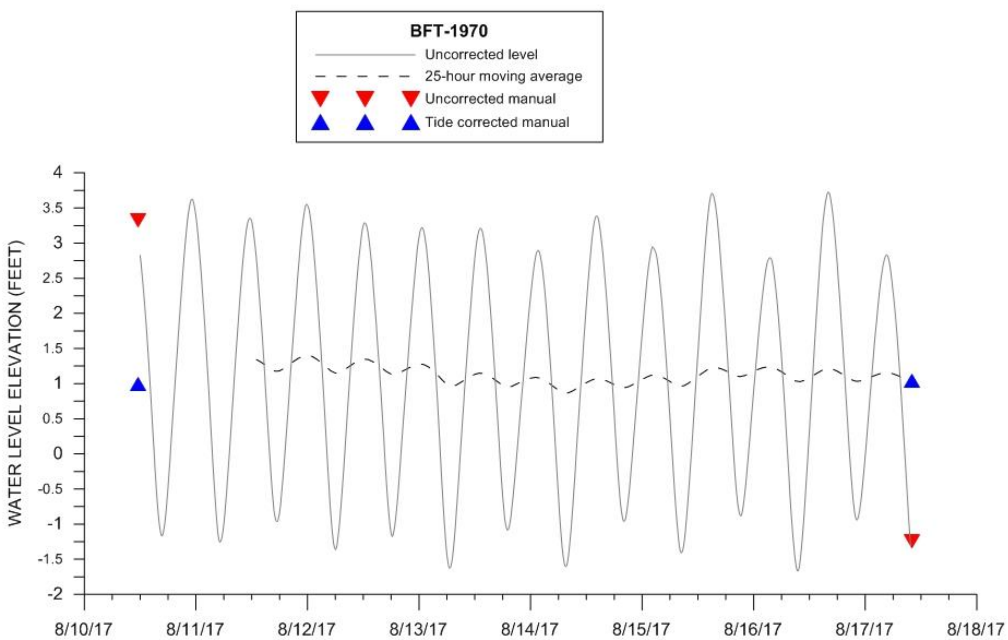
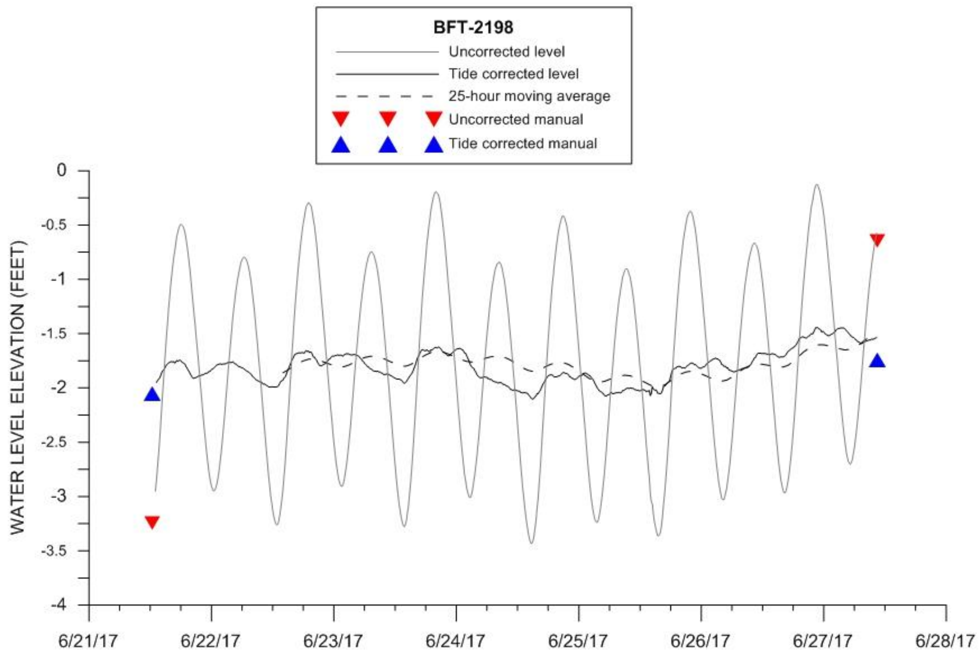
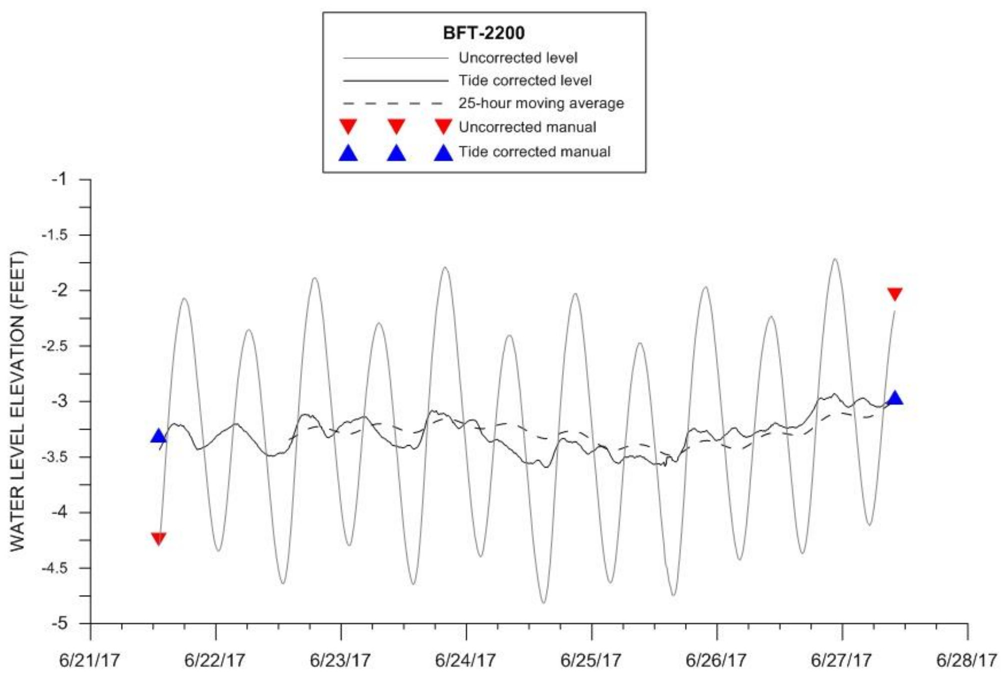
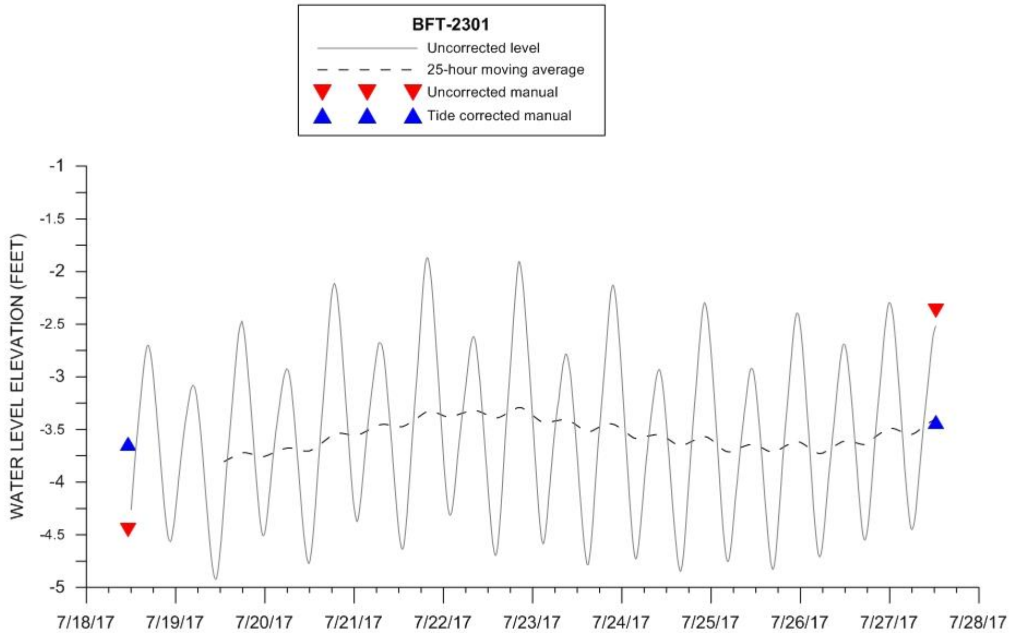
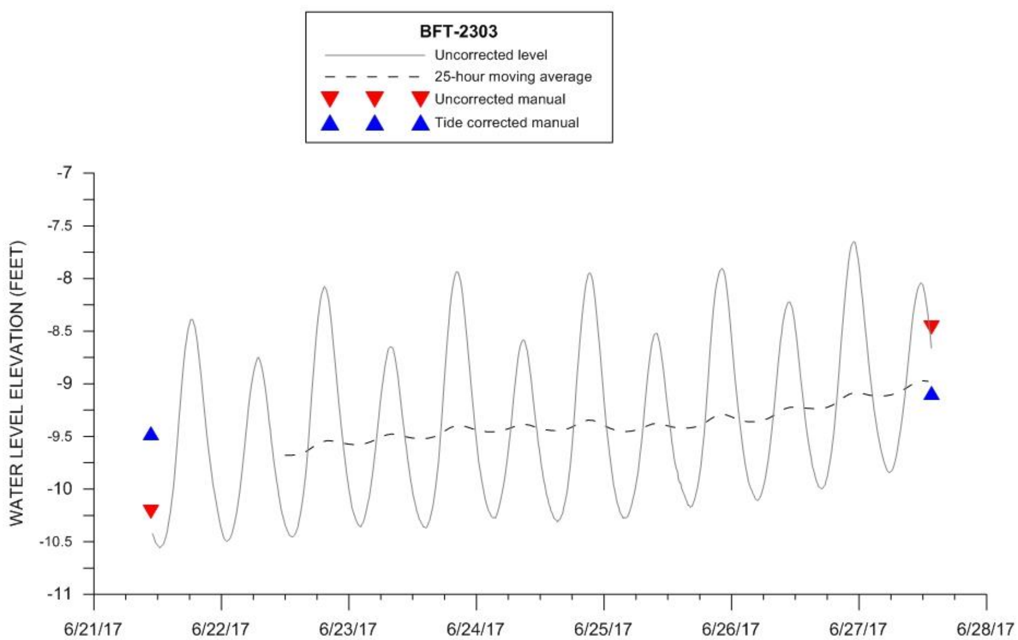
8/25/17
8/26/17

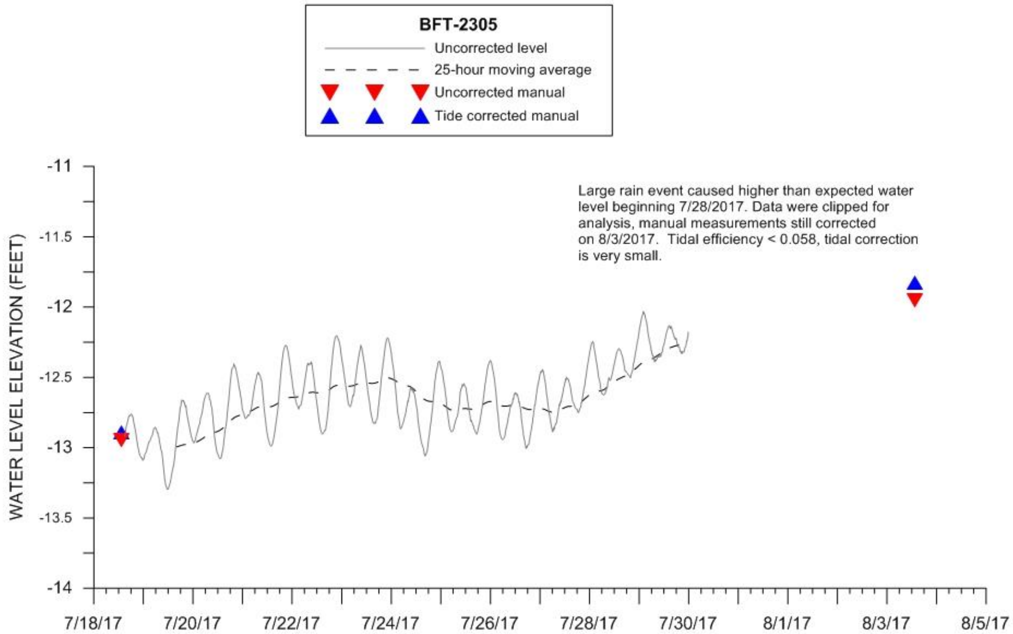

BFT-1970
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
8/10/17
8/11/17
8/12/17
8/13/17
8/14/17
8/15/17
8/16/17
8/17/17
8/18/17

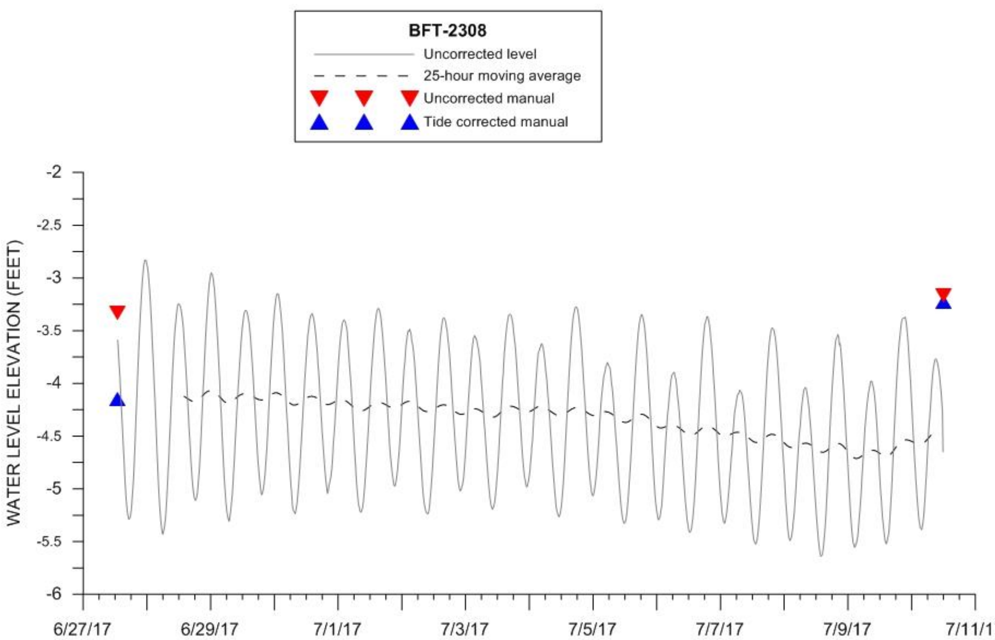

BFT-2198
Uncorrected level
Tide corrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
6/21/17
6/22/17
6/23/17
6/24/17
6/25/17
6/26/17
6/27/17
6/28/17

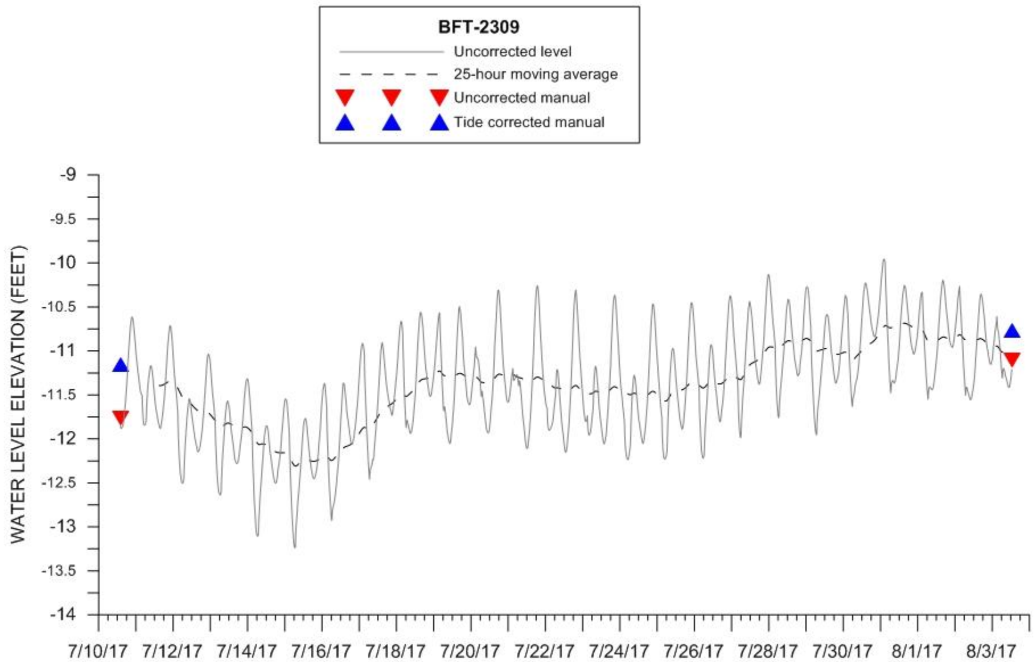

BFT-2200
Uncorrected level
Tide corrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
6/21/17
6/22/17
6/23/17
6/24/17
6/25/17
6/26/17
6/27/17
6/28/17

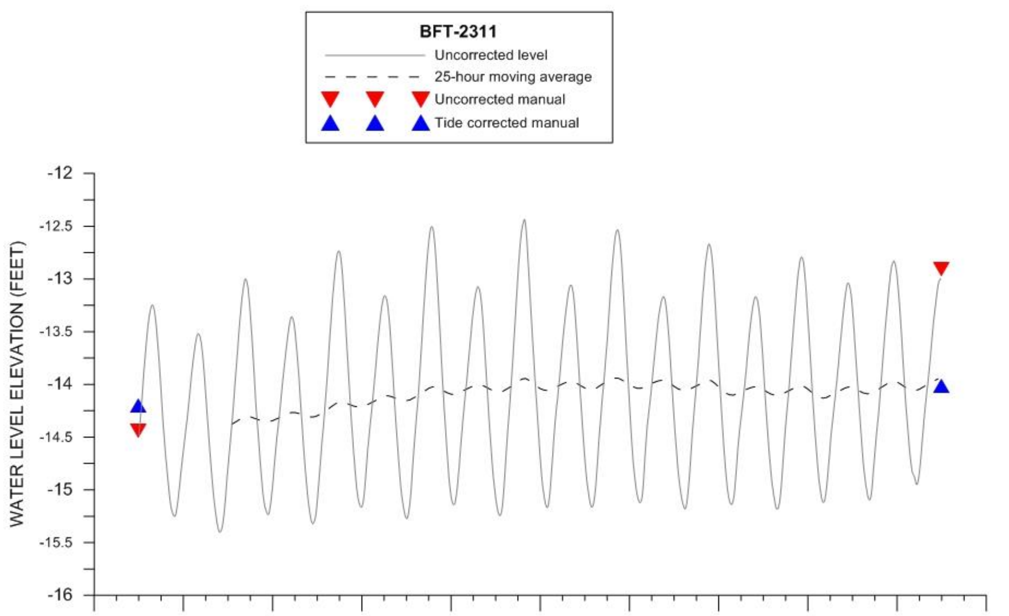

BFT-2301
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
7/18/17
7/19/17
7/20/17
7/21/17
7/22/17
7/23/17
7/24/17
7/25/17
7/26/17
7/27/17
7/28/17

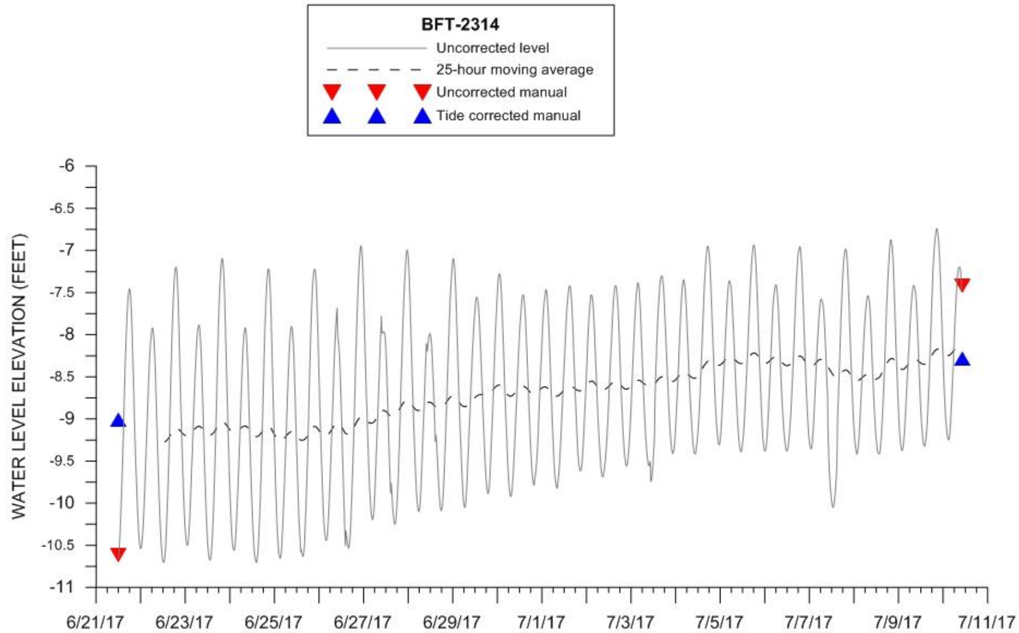

BFT-2303
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-7
-7.5
-8
-8.5
-9
-9.5
-10
-10.5
-11
6/21/17
6/22/17
6/23/17
6/24/17
6/25/17
6/26/17
6/27/17
6/28/17

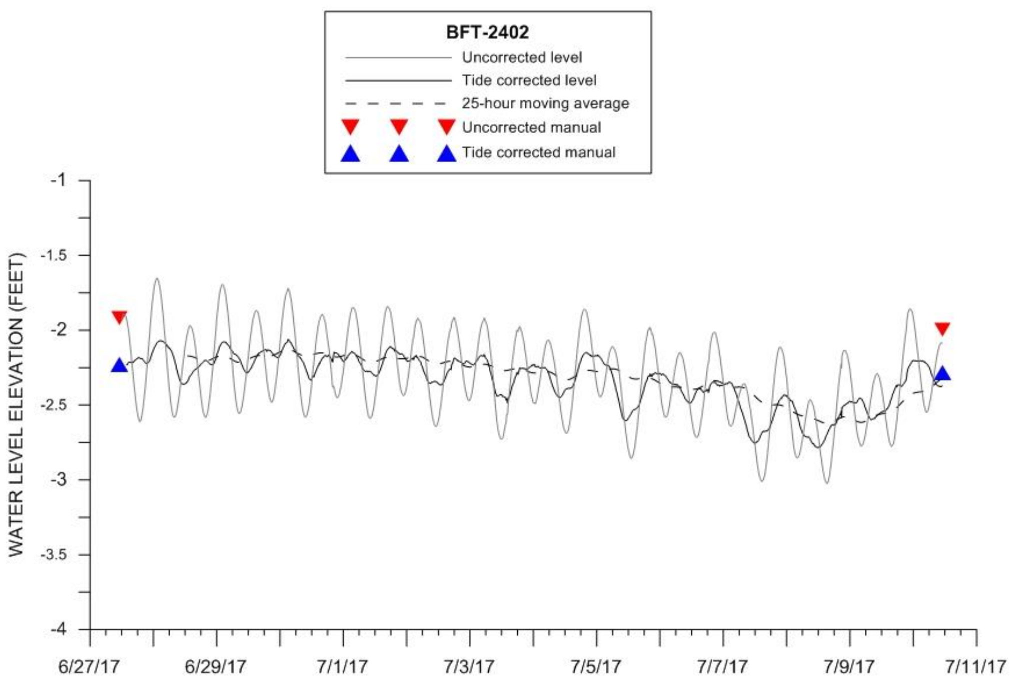

BFT-2305
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-11
-11.5
-12
-12.5
-13
-13.5
-14
7/18/17
7/20/17
7/22/17
7/24/17
7/26/17
7/28/17
7/30/17
8/1/17
8/3/17
8/5/17
Large rain event caused higher than expected water level beginning 7/28/2017. Data were clipped for analysis, manual measurements still corrected on 8/3/2017. Tidal efficiency < 0.058, tidal correction is very small.

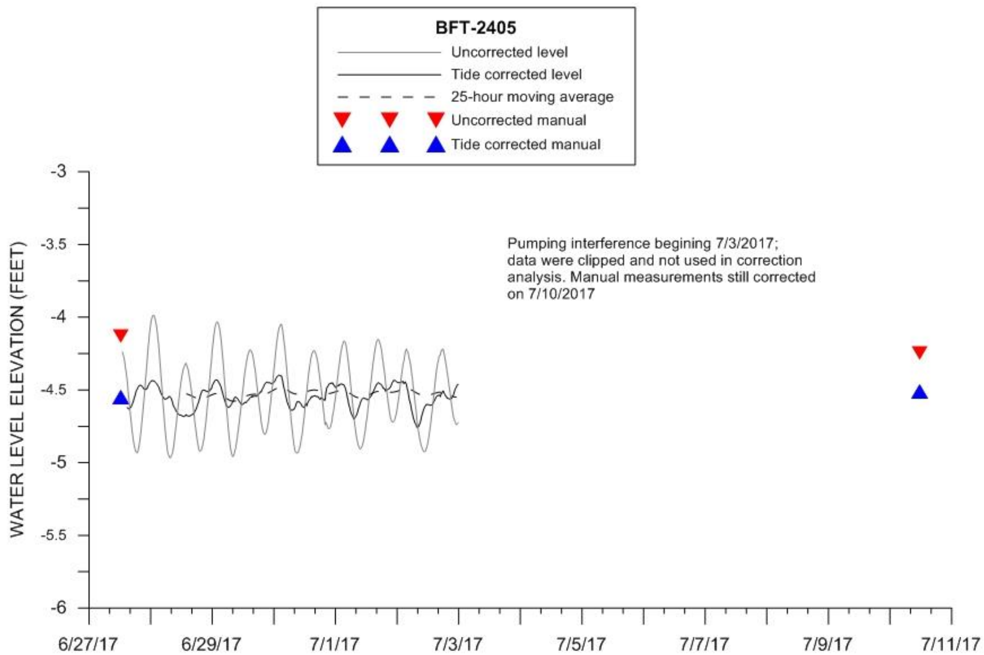

BFT-2308
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
6/27/17
6/29/17
7/1/17
7/3/17
7/5/17
7/7/17
7/9/17
7/11/17

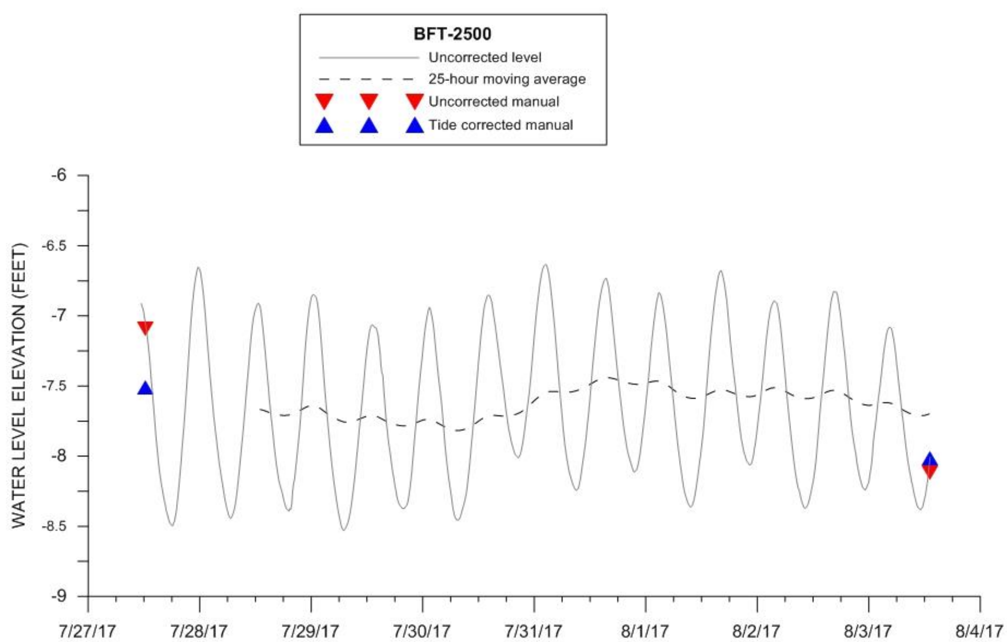

BFT-2309
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-9
-9.5
-10
-10.5
-11
-11.5
-12
-12.5
-13
-13.5
-14
7/10/17
7/12/17
7/14/17
7/16/17
7/18/17
7/20/17
7/22/17
7/24/17
7/26/17
7/28/17
7/30/17
8/1/17
8/3/17


BFT-2311
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-12
-12.5
-13
-13.5
-14
-14.5
-15
-15.5
-16
7/18/17
7/19/17
7/20/17
7/21/17
7/22/17
7/23/17
7/24/17
7/25/17
7/26/17
7/27/17
7/28/17


BFT-2314
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-6
-6.5
-7
-7.5
-8
-8.5
-9
-9.5
-10
-10.5
-11
6/21/17
6/23/17
6/25/17
6/27/17
6/29/17
7/1/17
7/3/17
7/5/17
7/7/17
7/9/17
7/11/17


BFT-2402
Uncorrected level
Tide corrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-1
-1.5
-2
-2.5
-3
-3.5
-4
6/27/17
6/29/17
7/1/17
7/3/17
7/5/17
7/7/17
7/9/17
7/11/17


BFT-2405
Uncorrected level
Tide corrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
Pumping interference begining 7/3/2017; data were clipped and not used in correction analysis. Manual measurements still corrected on 7/10/2017
WATER LEVEL ELEVATION (FEET)
-3
-3.5
-4
-4.5
-5
-5.5
-6
6/27/17
6/29/17
7/1/17
7/3/17
7/5/17
7/7/17
7/9/17
7/11/17


BFT-2500
Uncorrected level
25-hour moving average
Uncorrected manual
Tide corrected manual
WATER LEVEL ELEVATION (FEET)
-6
-6.5
-7
-7.5
-8
-8.5
-9
7/27/17
7/28/17
7/29/17
7/30/17
7/31/17
8/1/17
8/2/17
8/3/17
8/4/17

APPENDIX B. SAMPLE OF TIDAL CORRECTION SPREADSHEET

WATER-LEVEL MEASUREMENT IN WELL									REF STATION: SAVANNAH RIV. ENT.							
CONSTANTS	DST CORR	0	PI	3.1416					PRECEEDING TIDE, FOLLOWING TIDE							
WELL ID	DATE	HOUR	MIN	WL ELEV	LAG	TIDAL EFF	COMP TIME	PRECEED	HOUR	MIN	PT HGT	P TIDE MIN	HOUR	MIN	FT HGT	F TIDE MINS
BFT-0430	9/14/2017	11	13	0.23	6	0.411	667	L	8	36	0.696	516	14	36	8.364	876
BFT-0430	9/21/2017	10	41	1.93	6	0.411	635	H	8	48	8.613	528	15	6	0.513	906
BFT-0844	8/25/2017	12	42	-6.45	21	0.261	741	H	10	30	7.921	630	16	48	1.185	1008
BFT-0844	9/14/2017	9	40	-6.7	21	0.261	559	L	8	36	0.696	516	14	36	8.364	876
BFT-2405	6/27/2017	12	11	-4.13	105	0.105	626	H	10	48	8.009	648	16	54	0.221	1014
BFT-2405	7/10/2017	11	25	-4.25	105	0.105	580	H	8	30	6.625	510	14	30	0.303	870
BFT-0787	7/10/2017	10	55	-10.04	21	0.215	634	H	8	30	6.625	510	14	30	0.303	870
BFT-0787	7/27/2017	10	27	-10.32	21	0.215	606	L	5	6	0.306	306	10	54	7.78	654
BFT-2198	6/21/2017	12	27	-3.25	15	0.28	732	L	11	30	-0.836	690	17	24	8.603	1044
BFT-2198	6/27/2017	10	26	-0.65	15	0.28	611	L	4	42	-0.016	282	10	48	8.009	648
BFT-2200	6/21/2017	13	2	-4.25	13	0.259	769	L	11	30	-0.836	690	17	24	8.603	1044
BFT-2200	6/27/2017	10	3	-2.04	13	0.259	590	L	4	42	-0.016	282	10	48	8.009	648
BFT-2402	6/27/2017	11	22	-1.92	115	0.101	567	H	10	48	8.009	648	16	54	0.211	1014
BFT-2402	7/10/2017	11	7	-2	115	0.101	552	H	8	30	6.625	510	14	30	0.303	870
BFT-2405	6/27/2017	12	11	-4.13	105	0.105	626	H	10	48	8.009	648	16	54	0.221	1014
BFT-2405	7/10/2017	11	25	-4.25	105	0.105	580	H	8	30	6.625	510	14	30	0.303	870

	LOCAL SATION												TIDE CORRECTION FOR WATER-LEVEL MEASUREMENT IN WELL								
		PRECEEDING TIDE, FOLLOWING TIDE; TIME DIFFERENCES						FROM TABLE 2			FT ABOVE MLLW						MTR-MTL				
LOCAL ST. N(	LOCAL ST. N	HOUR (DIF	MIN (DIF)	P TIDE MIN	HOUR (DIF	MIN (DIF)	F TIDE MINS	MTL	PT RATIO	FT RATIO	PT HGT	FT HGT	MTR	DURATION	ELAPSED T	ANGLE	[MTC]	AMP	TIDE H	TIDE CORR	COR ELEV
8668686	Ft. Fremont	0	17	533	0	19	895	3.45	0.64	0.95	0.44544	7.9458	4.19562	362	134	1.162913	0.74562	-3.75018	-1.48757	-0.30494	0.53
8668686	Ft. Fremont	0	19	547	0	17	923	3.45	0.95	0.64	8.18235	0.32832	4.255335	376	88	0.735268	0.805335	3.927015	2.912474	1.52802	0.40
8668655	Callawassie	1	9	699	0	40	1048	4.1	1.19	1.11	9.42599	1.31535	5.37067	349	42	0.378072	1.27067	4.05532	3.768925	1.315334	-7.77
8668655	Callawassie	0	40	556	1	9	945	4.1	1.11	1.19	0.77256	9.95316	5.36286	389	3	0.024228	1.26286	-4.5903	-4.58895	-0.86811	-5.83
8668918	Skull Cr, N E	0	15	663	0	16	1030	3.62	0.99	0.91	7.92891	0.20111	4.06501	367	-37	-0.31673	0.44501	3.8639	3.671708	0.432255	-4.56
8668918	Skull Cr, N E	0	15	525	0	16	886	3.62	0.99	0.91	6.55875	0.27573	3.41724	361	55	0.478637	-0.20276	3.14151	2.788478	0.2715	-4.52
8668918	Skull Cr, N E	0	15	525	0	16	886	3.62	0.99	0.91	6.55875	0.27573	3.41724	361	109	0.948572	-0.20276	3.14151	1.831011	0.350074	-10.39
8668918	Skull Cr, N E	0	16	322	0	15	669	3.62	0.91	0.99	0.27846	7.7022	3.99033	347	284	2.571223	0.37033	-3.71187	3.124286	0.751343	-11.07
8668918	Skull Cr, N E	0	16	706	0	15	1059	3.62	0.91	0.99	-0.76076	8.51697	3.878105	353	26	0.231393	0.258105	-4.63887	-4.51523	-1.19199	-2.06
8668918	Skull Cr, N E	0	16	298	0	15	663	3.62	0.91	0.99	-0.01456	7.92891	3.957175	365	313	2.69403	0.337175	-3.97174	3.580537	1.096959	-1.75
8668918	Skull Cr, N E	0	16	706	0	15	1059	3.62	0.91	0.99	-0.76076	8.51697	3.878105	353	63	0.560682	0.258105	-4.63887	-3.92862	-0.95066	-3.30
8668918	Skull Cr, N E	0	16	298	0	15	663	3.62	0.91	0.99	-0.01456	7.92891	3.957175	365	292	2.51328	0.337175	-3.97174	3.213215	0.919551	-2.96
8668918	Skull Cr, N E	0	15	663	0	16	1030	3.62	0.99	0.91	7.92891	0.19201	4.06046	367	-96	-0.82178	0.44046	3.86845	2.634097	0.31053	-2.23
8668918	Skull Cr, N E	0	15	525	0	16	886	3.62	0.99	0.91	6.55875	0.27573	3.41724	361	27	0.234967	-0.20276	3.14151	3.055187	0.288095	-2.29
8668918	Skull Cr, N E	0	15	663	0	16	1030	3.62	0.99	0.91	7.92891	0.20111	4.06501	367	-37	-0.31673	0.44501	3.8639	3.671708	0.432255	-4.56
8668918	Skull Cr, N E	0	15	525	0	16	886	3.62	0.99	0.91	6.55875	0.27573	3.41724	361	55	0.478637	-0.20276	3.14151	2.788478	0.2715	-4.52