

Radar Rainfall Analysis

August 2019 Summary Report



Prepared for 3 Rivers Wet Weather

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Glossary

Average Difference (AD) – Average of the absolute percentage differences between the rain gauge data and uncalibrated radar data sampled over the gauges.

Bias Correction Factor – Bias is a systematic error that can be corrected through calibration. The correction factor is the sum of the gauges divided by the sum of the sampled radar values over the gauges.

Calibrated Average Difference (CAD) – Average of the absolute percentage differences between the rain gauges and local bias calibrated radar data sampled over the gauges.

Cumulative Distribution Plot (CDP) – A graph depicting the accumulation of a rain gauge and the unadjusted/adjusted radar over that gauge.

Decibels of Reflectance (dBZ) – The logarithmic scale for measuring radar reflectivity factor or a measure of reflectivity of a radar signal off a remote object.

Gauge Adjusted Radar Rainfall (GARR) – Bias corrected radar rainfall through comparison with rain gauges.

KCCX – Federal Communications Commission (FCC) call sign for the NEXRAD near State College, PA.

KPBZ – Federal Communications Commission (FCC) call sign for the NEXRAD near Pittsburgh, PA.

Level II – The Level II radar products are the highest resolution, and consist of the base data that includes reflectivity measured in decibels of reflectance (dBZ) among Doppler velocity and spectrum width.

Level III – The Level III radar products are derivative products from Level II, and consist of horizontal and vertical reflectivity among other products.

Local Bias (LB) – An approach to adjusting radar rainfall that uses the ratio of gauge to radar accumulations from surrounding gauges, with the closest gauge having the most weight.

Minimum Storm Total Threshold (MSTT) – A check used to remove radar/gauge pairs whose cumulative radar and/or gauge values for a given event period were below 0.05 inches.

Next Generation RADAR (NEXRAD) – A network of S-band (10.5-cm wavelength) radars operated by the National Weather Service.

Radio Detection and Ranging (RADAR) – An electronic instrument used for the detection and ranging of distant objects of such composition that they scatter or reflect radio energy.

Radar-Gauge (RG) – A pair of rainfall accumulations measured by the rain gauge and the radar rainfall accumulation sampled above the gauge.

Z-R relationship – An empirical relationship between radar reflectivity factor Z ($\text{mm}^6 \text{m}^{-3}$) and rain rate R (mm hr^{-1}). Radar reflectivity factor is dependent on the rain drop size distribution. [$Z = aR^b$, where a and b are empirically derived constants]

- **Convective** – generally used for convective (i.e. thunderstorms) rainfall [$Z = 300R^{1.4}$]
- **Eastern U.S. Cool Stratiform** – generally used for cool season, non-convective rainfall that occurs east of the Continental Divide [$Z = 130R^{2.0}$]

Overview

Vieux & Associates, Inc. (Vieux) processes radar and rain gauge data for 3 Rivers Wet Weather (3RWW). During each month, radar and rain gauge data are segmented into qualified storm event periods and then Quality Controlled (QC). To produce QC gauge-adjusted radar rainfall (GARR), both radar and rain gauge data are reviewed manually to remove inconsistent data. While only qualified rainfall events are included in this report, the RainVieux online database contains continuous data where QC rain gauge and radar data are available during the inter-event periods. QC is performed to remove anomalous radar data and inconsistent rain gauges during both the qualified and inter-event periods.

Radar data used in production of GARR is produced by the National Weather Service (NWS) Next Generation Radar (NEXRAD) system. NEXRAD Level II radar data are often referred to as Base Data and contain the full spatial/temporal/data resolution data from the radar. Level II radar data measures reflectivity in decibels of reflectance (dBZ), and at a spatial resolution of 0.5-degree by 0.25-km every 4 – 10 minutes with a data resolution of 0.5 dBZ amounting to 256 data levels of data. Level III reflectivity radar data have the same data and temporal resolution, but a reduced spatial resolution of 1-degree by 1-km.

The primary radar data source used to process this period was Level II NEXRAD data from KPBZ located near Pittsburgh, PA. The succession of data used gives priority to Level II followed by Level III products. If KPBZ Level II NEXRAD data are unavailable, then KPBZ Level III Q1 is substituted. If no radar data are available from KPBZ, then Level III Q0 NEXRAD data from KCCX (State College, PA) are used. In the event that all radar sources are unavailable or if the radar provides insufficient rainfall information, then a gauge-only product that spatially distributes point rainfall estimates is used. All radar data were processed into five-minute increments.

Because the radar measures reflectivity in polar coordinates centered on the radar installation, the 1-degree azimuth increases in width as range increases from the radar. Range resolution of the Level II radar data is 1-km and is measured out to 230 km from the radar. Due to the proximity of KPBZ to the study area, the polar coordinates defining horizontal resolution over Allegheny County range from 0.1 – 0.9 km, whereas KCCX ranges from 2.5 – 3.6 km. The radar data represented in these polar coordinates are sampled through spatial averaging into a Cartesian grid of uniform resolution, i.e. 1x1 km. An advantage of the Cartesian grid is that one radar can be substituted for the other without changing the grid resolution, as would be necessary if polar coordinates were used for output of rainfall information at 1x1 km spatial resolution. The Cartesian grid used was defined by a 1-km² grid domain shapefile containing 2313 1-km² pixels covering the study area. CDM Smith provided two basin shapefiles consisting of 440 RFM basins and 871 RFM sheds that are located within the 1-km² pixel domain.

Rain gauge data from as many as 37 gauges were used to adjust the radar. 3RWW provided rain data in 5-minute increments for 33 stations. In addition, rain gauge data were obtained from two United States Geological Survey (USGS) stations and two NWS Automated Surface Observing System (ASOS) stations. Figure 1 depicts the spatial distribution of the rain gauge network, KPBZ NEXRAD, RFM basins and 1-km² pixels. For the gauges shown in Figure 1, the ID, name and source of each gauge is listed in Table 1. Radar data review, preparation and sampling the radar over the gauges and 1-km² pixels were achieved using software developed at Vieux.

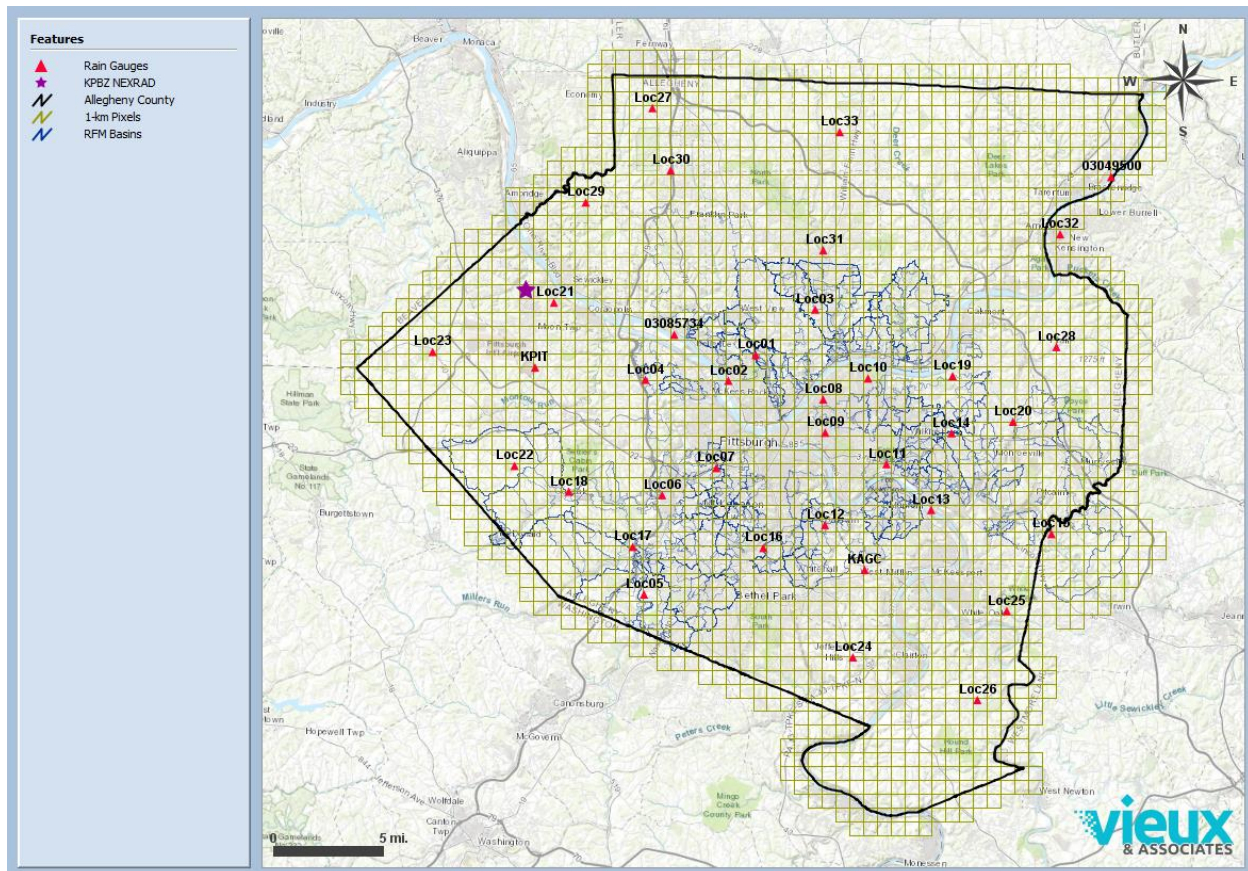


Figure 1. Spatial Distribution of the Rain Gauge Network, KPBZ NEXRAD, RFM Basins and 1-km² Pixels

Table 1. Rain Gauge ID, Name and Source

Gauge ID	Gauge Name	Source
Loc01	PWSA-Montana St.	3RWW
Loc02	ALCOSAN WWTP Lab	3RWW
Loc03	Shaler Munic Bldg	3RWW
Loc04	Kennedy Twp PS	3RWW
Loc05	Upper St. Clair	3RWW
Loc06	Carnegie Transit Time	3RWW
Loc07	Greentree Munic Bldg	3RWW
Loc08	AC Health Dept Bldg	3RWW
Loc09	Univ of Pittsburgh	3RWW
Loc10	PWSA-Highland Park	3RWW
Loc11	M-46 Access Shaft	3RWW
Loc12	Baldwin	3RWW
Loc13	M-59 Access Shaft	3RWW

Gauge ID	Gauge Name	Source
Loc14	Churchill Munic Bldg	3RWW
Loc15	Trafford Maint Bldg	3RWW
Loc16	Castle Shannon	3RWW
Loc17	Chartiers Pump Station	3RWW
Loc18	Oakdale Pump Station	3RWW
Loc19	Sandy Creek Eq Facility	3RWW
Loc20	Gascola Eq Facility	3RWW
Loc21	Moon TWP	3RWW
Loc22	North Fayette TWP	3RWW
Loc23	Clinton Munic Bldg	3RWW
Loc24	Jefferson Hills	3RWW
Loc25	White Oak Public Works Bldg	3RWW
Loc26	Elizabeth TWP Municipal Bldg	3RWW
Loc27	Marshall TWP	3RWW
Loc28	Plum Municipal Bldg	3RWW
Loc29	Bell Acres Munic Bldg	3RWW
Loc30	McCandless Twn Hall	3RWW
Loc31	Hampton Municipal Bldg	3RWW
Loc32	Arnold	3RWW
Loc33	Richland TWP	3RWW
KAGC	Pittsburgh Allegheny Cty	NWS - ASOS
KPIT	Greater Pittsburgh Int'l	NWS - ASOS
03049500	Allegheny River at Natrona	USGS
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	USGS

The 37 rain gauges and the two NWS NEXRAD radars are used to produce gauge-adjusted radar rainfall (GARR). The methodology used in production of the GARR and the dataset metadata are described in the following sections.

Methodology

Radar and rain gauge data are segmented into qualified storm event periods and then Quality Controlled (QC). Qualified rainfall events are defined based on the storm event definition where, for any given hour, at least 50% of all working 3RWW gauges have an accumulation of 0.05 inches. Only qualified rainfall events are included in the report, while the RainVieux online database contains continuous data. Both the qualified and inter-event periods receive QC to remove anomalous radar data and inconsistent rain gauges.

Statistical control of the data makes radar rainfall measurements more accurate. By statistical comparison between the radar and rain gauge accumulations during a GARR period, certain gauges may be identified as statistical outliers and excluded for all or part of an event. Radar data

is enhanced by correcting it for systematic errors called bias, which helps improve the accuracy of the rainfall product. The bias correction factors are multiplicative factors applied to the radar that enhances the accuracy of the radar rainfall for any accumulation period. By adjusting the radar data with rain gauge data, better maps of rainfall are produced than either sensor system could produce alone.

In the production of GARR, radar rainfall is bias corrected through comparison with rain gauge accumulations. To the extent possible, individual gauges are combined to cover the target area for use in bias adjustment. The method of adjustment depends on the hydrologic application and the spatial extent of the area of interest. The local bias (LB) approach to adjusting the radar rainfall uses the ratio of gauge to radar accumulations from surrounding gauges with the closest gauge having the most weight. The LB approach distributes the variation of bias over the region, and is computed and applied within each event period.

The LB uses the ratio between the sum of each gauge divided by the sum of the sampled radar values over each gauge. Gauge and radar accumulations were computed for each event period. A minimum storm total threshold (MSTT) check was used to remove radar/gauge (RG) pairs whose R or G cumulative values for a given event period were below a chosen threshold (i.e. 0.05 inches for this study). The remaining RG pairs were then checked for statistical outliers. Those RG pairs with individual bias (G/R) or average difference ($((G-R)/G)$) values greater than three standard deviations from the mean were then excluded from being used to adjust the radar.

After RG pairs have been removed on an event basis by either the MSTT, outlier check or gauge performance review, there must be at least two remaining RG pairs to proceed with gauge-adjustment of the radar. The individual biases of the remaining RG pairs are then distributed spatially over the analysis area using the LB weighted distance method. The resulting LB value over each radar bin is the multiplicative factor that adjusts the radar. For example, a bias of 1.5 can be interpreted as a 33% underestimation by the radar. The statistical measures reported are 1) average difference (AD) and 2) calibrated average difference (CAD). Both of these statistical measures are expressed as an absolute percentage about the mean of G/R accumulations for each event period. GARR is then spatially aggregated from the final adjusted radar bins to the basins and 1-km² pixels using an area-averaged technique.

After bias correction, though generally small, differences between rain gauge and radar rainfall accumulations still exist due to sampling differences or local meteorological conditions among other reasons. A major reason for departures is that radar collects data by averaging reflectivity over a 1-degree by 1-km sample volume, while rain gauges measure at a point. Another source of difference is that radar measures above the ground, while rain gauges measure close to the ground. Further, updrafts and downdrafts during storms can decrease or increase rain rates, respectively. However, radar cannot detect local wind effects, while rain gauges can be affected. Differences between the radar data and the rain gauge data are also affected by precipitation processes associated with the type of storm, which also are affected by the season of the year.

Metadata

Data accompanying this document provides a continuous rainfall record of all 2313 1-km pixels, 440 RFM basins and 871 RFM sheds in 15-minute intervals. The data are provided in CSV format for the period from 2019-08-01 00:00 EDT to 2019-09-01 00:00 EDT. Shapefiles of the 1-km pixels, RFM basins and RFM sheds are located in the Shapefiles subfolder.

1-km² Pixel CSV metadata:

- Individual CSV files are provided for each pixel.
- The pixel filenames use a "Ryymm_" (i.e. R, year, month) prefix in front of the pixel ID.
- The comma-delimited text files contain a header row in the 1st row and time/data values beginning on the 2nd row.
- The time/data columns consist of Month, Day, Year, Hour, Minute, Rainfall and Source, where R represents EOM GARR quality.
- Time stamps are in EST/EDT.
- Data values represent 15-min accumulation (inches) at end of interval.
- The 1-km Pixel ID field that was used from the shapefile DBF is "PIXEL".

Basin CSV metadata:

- Individual CSV files are provided for each RFM Basin and RFM Shed.
- The RFM Basin filenames use a "P-" prefix and a "yyyymmG" (i.e. year, month, G) suffix in front and after the RFM Basin ID.
- The RFM Shed filenames use a "P-" prefix and a "yyyymmN" (i.e. year, month, N) suffix in front and after the RFM Shed ID.
- The comma-delimited text files contain a header row in the 1st row and time/data values beginning on the 2nd row.
- The 1st column contains the date (yyyy/mm/dd hh:mm) and the 2nd column contains the corresponding rainfall value.
- Time stamps are in EST/EDT.
- Data values represent 15-min accumulation (inches) at end of interval.
- The RFM Basin ID field that was used from the shapefile DBF is "DS_METERNA".
- The RFM Shed ID field that was used from the shapefile DBF is "DELINID".

Shapefile metadata:

- NAD 1983, State Plane Pennsylvania South (feet).

Gauge-Adjusted Radar Rainfall (GARR)

Rainfall totals for August 2019 are shown in Figure 2. The rainfall amounts for the 2313 1-km² pixels range from 1.5 to 6.8 inches with a mean of 3.1 inches. The rainfall amounts for the 440 RFM basins range from 1.9 to 5.4 inches with a mean of 3.6 inches. The rainfall amounts for the 871 RFM sheds range from 1.6 to 5.4 inches with a mean of 3.6 inches.

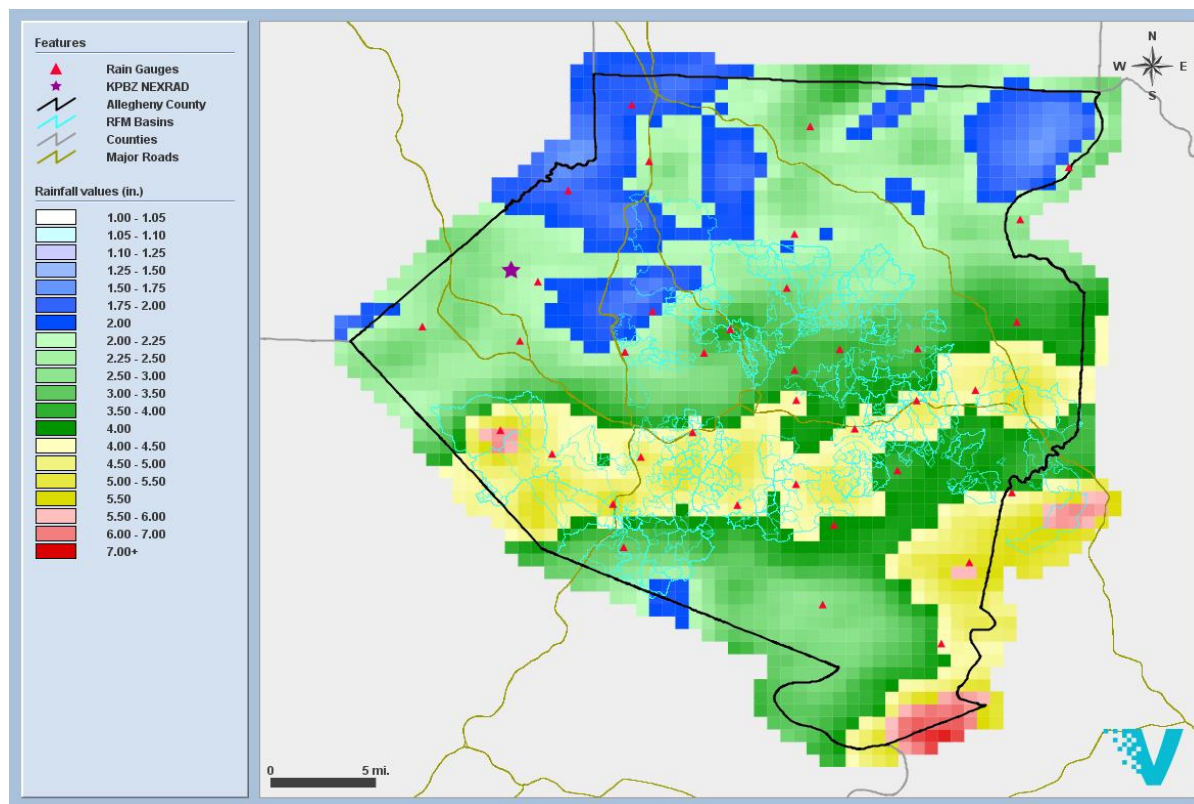


Figure 2. GARR Storm Total for August 2019

GARR was processed continuously at five-minute increments and covers the period from 2019-08-01 00:00 EDT to 2019-09-01 00:00 EDT. Seven rainfall events were identified as having met the storm definition during August 2019. The GARR statistics for each event are listed in Table 2. Six of the events were split into multiple sub-event periods to improve gauge-adjustment of the radar, resulting in a total of twenty-one event and sub-event periods. The events that were split into multiple periods are shown in the **Event#** column with the letter "a", "b", "c", etc. appended to the event number (e.g., E1a, E1b, E1c). The **Source** column shows what rainfall source was used to produce GARR for each event or sub-event period. The listed **Event Date** shown in Table 2 corresponds to the day or portion of the day when most of the rainfall occurred for that GARR event period. All seven rainfall events are discussed in more detail in the following Events section.

The **Bias** value shown in Table 2 is the sum of the gauges divided by the sum of the sampled radar values over the gauges. Those rain events with the lowest CAD values shown in Table 2 represent the best agreement between GARR and gauge values for all radar/gauge pairs used to adjust the radar. On average, lower values of CAD imply higher statistical confidence in the reliability of the

dataset. Typically, stratiform rainfall events (i.e., low spatial variability) have lower CAD values than convective rainfall events (i.e., high spatial variability). Based on all twenty-one event and sub-event periods, the event CAD averaged 2.2%, indicating that the mean GARR agrees with the mean gauge accumulation to within $\pm 1.1\%$.

Table 2. Storm Events and GARR Statistics

Event #	Source	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E1a	KPBZ LII	2019-08-07	2019-08-06 12:05	2019-08-06 21:30	6	0.050	0.874	17.0	0.9
E1b	KPBZ LII	2019-08-07	2019-08-06 21:35	2019-08-06 23:30	9	0.044	0.984	15.3	1.4
E1c	KPBZ LII	2019-08-07	2019-08-06 23:35	2019-08-07 01:00	26	0.156	0.850	31.6	2.6
E1d	KPBZ LII	2019-08-07	2019-08-07 01:05	2019-08-07 04:00	7	0.027	0.605	63.6	0.4
E2a	KPBZ LII	2019-08-13	2019-08-12 19:05	2019-08-13 08:00	5	0.026	1.175	18.5	1.8
E2b	KPBZ LII	2019-08-13	2019-08-13 08:05	2019-08-13 14:00	6	0.048	0.677	57.0	6.1
E2c	KPBZ LII	2019-08-13	2019-08-13 14:05	2019-08-13 15:20	16	0.076	1.065	12.0	2.6
E2d	KPBZ LII	2019-08-13	2019-08-13 15:25	2019-08-13 16:20	25	0.197	1.374	28.9	1.9
E2e	KPBZ LII	2019-08-13	2019-08-13 16:25	2019-08-13 17:15	20	0.118	1.012	12.3	1.7
E2f	KPBZ LII	2019-08-13	2019-08-13 17:20	2019-08-13 22:00	9	0.038	0.863	22.6	0.9
E3	KPBZ LII	2019-08-15	2019-08-15 11:05	2019-08-15 21:00	20	0.241	0.735	44.8	4.1
E4a	KPBZ LII	2019-08-20	2019-08-20 20:05	2019-08-21 00:00	20	0.221	0.908	24.2	1.7
E4b	KPBZ LII	2019-08-20	2019-08-21 00:05	2019-08-21 01:30	8	0.045	0.527	69.8	1.7
E4c	KPBZ LII	2019-08-20	2019-08-21 01:35	2019-08-21 03:30	17	0.062	1.053	28.1	5.2
E4d	KPBZ LII	2019-08-20	2019-08-21 03:35	2019-08-21 07:00	2	0.026	1.204	16.3	0.1
E5a	KPBZ LII	2019-08-22	2019-08-22 11:05	2019-08-22 16:00	19	0.170	0.999	14.1	2.8
E5b	KPBZ LII	2019-08-22	2019-08-22 16:05	2019-08-23 03:00	6	0.034	0.548	80.8	2.5

Event #	Source	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E6a	KPBZ LII	2019-08-27	2019-08-26 19:05	2019-08-27 04:30	24	0.127	1.795	41.7	1.5
E6b	Gauge Only	2019-08-27	2019-08-27 04:35	2019-08-27 10:00	25	0.162	---	---	---
E7a	KPBZ LII	2019-08-28	2019-08-27 23:05	2019-08-28 05:00	25	0.371	1.432	30.4	2.2
E7b	KPBZ LII	2019-08-28	2019-08-28 05:05	2019-08-28 11:00	17	0.098	1.631	38.2	2.3

Statistical review of the data can provide an indication of data quality. Depending on the quality of the radar and gauge data, CAD values for individual events less than 10% are considered excellent, 10 - 20% are considered good, and 20 - 30% are considered fair. However, CAD may not serve as a reliable indicator of data quality when abrupt changes in bias occur within the analysis period, particularly when compensating over- and under-estimation results due to using an assumed Z-R relationship throughout the period while atmospheric conditions merit different Z-R coefficients. The effects from abrupt changes in Z-R are mitigated by splitting the event periods.

Rain gauges were analyzed to identify those that were not consistent with the radar or surrounding gauges. Cumulative Distribution Plots (CDPs) at each gauge location showing gauge, unadjusted radar and GARR values were produced for each rainfall event and are presented in Appendices C - I. CDPs are useful for visualizing rain gauge performance. Figure 3 shows the rainfall accumulation at the Chartiers Pump Station (Loc17) gauge during the 2019-08-28 event as measured by the gauge (green), unadjusted radar (blue), and gauge-adjusted radar (red). Rain gauges that are not performing consistently with the radar or surrounding gauges have characteristics such as clogs, synchronization or other mechanical/transmission malfunctions that can be visually identified in the CDP graph.

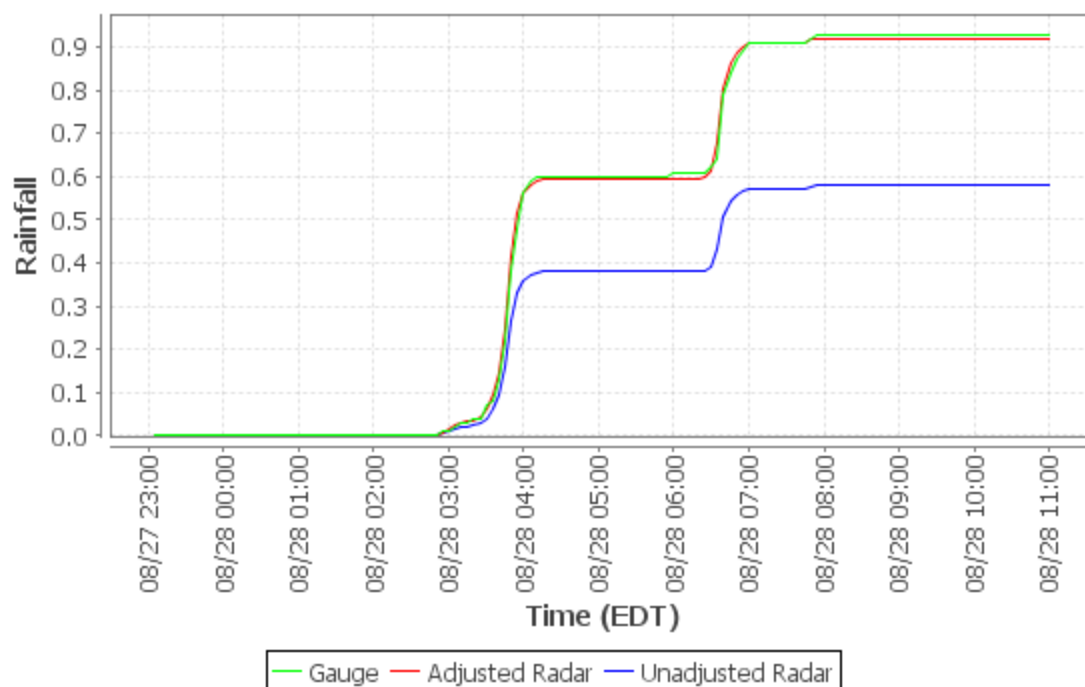


Figure 3. CDP Showing Rain Gauge Versus Unadjusted Radar Versus GARR

Reasons for not using gauges in rainfall analysis include clogs, significant under- or over-reporting of rainfall, gauges that stop reporting during rainfall, or a combination of these reasons. A list of possible reasons for not using a gauge based on CDP analysis is shown in Table 3. Those gauges that were excluded from analysis based on gauge performance are shown in [Appendix A](#). Additional gauges were not used to adjust the radar for a given event or sub-event period if they did not meet the statistical criteria outlined in the Methodology section. A list of reasons for not using a gauge based on statistical criteria is shown in Table 4. The gauges listed in [Appendix B](#) did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar.

Table 3. Reasons for Gauge Exclusion Based on Performance

Reason	Explanation
Clog (C)	Gauge appeared to be clogged
Zero (Z)	Gauge did not report any rainfall while radar rainfall estimates reported significant rainfall
Stop (S)	Gauge appeared to stop reporting rainfall while radar rainfall estimates reported significant rainfall
Over (O)	Gauge appeared to significantly over-report rainfall as compared to radar rainfall estimates and surrounding gauges (e.g. anomalously high rainfall values caused by field calibration, data transmission error, or switch malfunctions)
Under (U)	Gauge appeared to significantly under-report as compared to radar rainfall estimates and surrounding Gauges (e.g. half-tipper)
Sync (SY)	Gauge appeared to be reporting out-of-sync with the radar rainfall estimates

Reason	Explanation
Frozen/Melt (F/M)	Gauge not reporting properly due to frozen or melting precipitation
Other (T)	Combination of multiple reasons
No Data (ND)	Gauge reported "no data" for a significant amount of time

Table 4. Reasons for Gauge Exclusion Based on Statistical Criteria

Reason	Explanation
Minimum Storm Total Threshold (MSTT)	The radar or gauge cumulative sum during the event or sub-event period was less than MSTT
Outlier Based on Mean Field Bias (OMFB)	The RG pair bias (G/R) was greater than three standard deviations from the mean bias (e.g. $G \gg R$)
Outlier Based on Average Difference (OAD)	The RG pair average difference ($(G-R)/G$) was greater than three standard deviations from the mean average difference (e.g. $G \ll R$)

A synopsis for each event is described below in terms of the specific processing protocol applied to each event period as well as specific GARR information.

Events

Event 1: 2019-08-07

The analysis period was from 2019-08-06 12:00 EDT to 2019-08-07 04:00 EDT. The event was then split into four sub-event periods at 2019-08-06 21:30 EDT, 2019-08-06 23:30 EDT and 2019-08-07 01:00 EDT to improve gauge adjustment of the radar.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event. The gauges listed in [Appendix B](#) were not used to adjust the radar since they did not meet statistical criteria for gauge-adjustment.

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 5 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 6 - 9 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and Diff* (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 4 - 7 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 8 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.0 - 1.1 inches with a mean of 0.3 inches. The GARR amounts for the 440 RFM basins range from 0.1 - 0.4 inches with a mean of 0.2 inches. The GARR amounts for the 871 RFM sheds range from

0.1 - 0.4 inches with a mean of 0.2 inches. Table 10 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 5. GARR Statistics for Event 1

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E1a	KPBZ LII	2019-08-07	2019-08-06 12:05	2019-08-06 21:30	6	0.050	0.874	17.0	0.9
E1b	KPBZ LII	2019-08-07	2019-08-06 21:35	2019-08-06 23:30	9	0.044	0.984	15.3	1.4
E1c	KPBZ LII	2019-08-07	2019-08-06 23:35	2019-08-07 01:00	26	0.156	0.850	31.6	2.6
E1d	KPBZ LII	2019-08-07	2019-08-07 01:05	2019-08-07 04:00	7	0.027	0.605	63.6	0.4

Table 6. Summary of Individual RG Pairs for Event 1a

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc27	Marshall TWP	0.22	0.30	0.23	-0.01	-4.5	
Loc23	Clinton Munic Bldg	0.22	0.22	0.22	0.00	0.0	
Loc28	Plum Municipal Bldg	0.07	0.07	0.07	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.17	0.23	0.17	0.00	0.0	
Loc33	Richland TWP	0.20	0.18	0.20	0.00	0.0	
Loc30	McCandless Twn Hall	0.50	0.57	0.49	0.01	2.0	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.00	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.00	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.00	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.00	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.00	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.00	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.00	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.00	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc11	M-46 Access Shaft	0.00	---	---	---	---	MSTT
Loc12	Baldwin	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.00	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.00	---	---	---	---	MSTT
Loc16	Castle Shannon	0.00	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.00	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.01	---	---	---	---	MSTT
Loc21	Moon TWP	0.01	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc31	Hampton Municipal Bldg	0.00	---	---	---	---	MSTT
Loc32	Arnold	0.00	---	---	---	---	MSTT

Table 7. Summary of Individual RG Pairs for Event 1b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.16	0.16	0.16	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.07	0.06	0.07	0.00	0.0	
Loc01	PWSA-Montana St.	0.11	0.14	0.11	0.00	0.0	
Loc03	Shaler Munic Bldg	0.18	0.22	0.18	0.00	0.0	
Loc21	Moon TWP	0.08	0.06	0.08	0.00	0.0	
Loc22	North Fayette TWP	0.28	0.29	0.28	0.00	0.0	
Loc23	Clinton Munic Bldg	0.10	0.06	0.10	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.08	0.09	0.08	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.10	0.11	0.10	0.00	0.0	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	Z
KAGC	Pittsburgh Allegheny Cty	0.00	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.04	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.10	---	---	---	---	U

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc05	Upper St. Clair	0.00	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.00	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.02	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.00	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc11	M-46 Access Shaft	0.00	---	---	---	---	MSTT
Loc12	Baldwin	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.00	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.00	---	---	---	---	MSTT
Loc16	Castle Shannon	0.00	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.00	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.00	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc27	Marshall TWP	0.01	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.00	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.04	---	---	---	---	MSTT
Loc32	Arnold	0.01	---	---	---	---	MSTT
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

Table 8. Summary of Individual RG Pairs for Event 1c

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc05	Upper St. Clair	0.15	0.25	0.17	-0.02	-13.3	
Loc20	Gascola Eq Facility	0.09	0.18	0.10	-0.01	-11.1	
Loc06	Carnegie Transit Time	0.12	0.19	0.13	-0.01	-8.3	
Loc12	Baldwin	0.13	0.19	0.14	-0.01	-7.7	
03049500	Allegheny River at Natrona	0.09	0.10	0.09	0.00	0.0	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.12	0.14	0.12	0.00	0.0	

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
KAGC	Pittsburgh Allegheny Cty	0.08	0.10	0.08	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.17	0.17	0.17	0.00	0.0	
Loc02	ALCOSAN WWTP Lab	0.05	0.06	0.05	0.00	0.0	
Loc03	Shaler Munic Bldg	0.09	0.09	0.09	0.00	0.0	
Loc04	Kennedy Twp PS	0.07	0.09	0.07	0.00	0.0	
Loc07	Greentree Munic Bldg	0.10	0.16	0.10	0.00	0.0	
Loc08	AC Health Dept Bldg	0.09	0.14	0.09	0.00	0.0	
Loc09	Univ of Pittsburgh	0.10	0.15	0.10	0.00	0.0	
Loc11	M-46 Access Shaft	0.12	0.18	0.12	0.00	0.0	
Loc14	Churchill Munic Bldg	0.11	0.18	0.11	0.00	0.0	
Loc15	Trafford Maint Bldg	0.15	0.15	0.15	0.00	0.0	
Loc16	Castle Shannon	0.18	0.23	0.18	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.08	0.13	0.08	0.00	0.0	
Loc21	Moon TWP	0.06	0.05	0.06	0.00	0.0	
Loc24	Jefferson Hills	0.46	0.43	0.46	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.65	0.54	0.65	0.00	0.0	
Loc28	Plum Municipal Bldg	0.15	0.13	0.15	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.05	0.05	0.05	0.00	0.0	
Loc32	Arnold	0.11	0.12	0.11	0.00	0.0	
Loc17	Chartiers Pump Station	0.20	0.23	0.18	0.02	10.0	
Loc01	PWSA-Montana St.	0.04	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc22	North Fayette TWP	0.04	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.01	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc27	Marshall TWP	0.01	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.01	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.01	---	---	---	---	MSTT
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

Table 9. Summary of Individual RG Pairs for Event 1d

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc15	Trafford Maint Bldg	0.14	0.26	0.14	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.05	0.07	0.05	0.00	0.0	
Loc20	Gascola Eq Facility	0.05	0.08	0.05	0.00	0.0	
Loc24	Jefferson Hills	0.05	0.05	0.05	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.11	0.16	0.11	0.00	0.0	
Loc28	Plum Municipal Bldg	0.05	0.11	0.05	0.00	0.0	
Loc32	Arnold	0.05	0.10	0.05	0.00	0.0	
03049500	Allegheny River at Natrona	0.05	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.00	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.03	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.01	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.00	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.00	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.01	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.02	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.03	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc11	M-46 Access Shaft	0.02	---	---	---	---	MSTT
Loc12	Baldwin	0.02	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.03	---	---	---	---	MSTT
Loc16	Castle Shannon	0.02	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc21	Moon TWP	0.00	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc27	Marshall TWP	0.00	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.00	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc31	Hampton Municipal Bldg	0.01	---	---	---	---	MSTT
Loc33	Richland TWP	0.00	---	---	---	---	MSTT

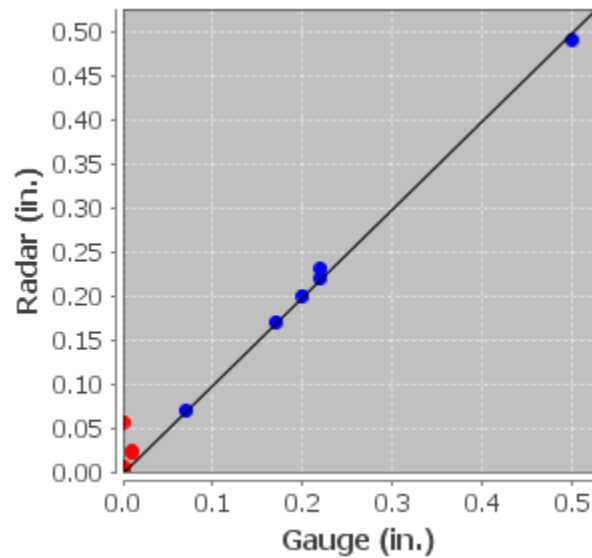


Figure 4. Scatter Plot of RG Pairs for Event 1a

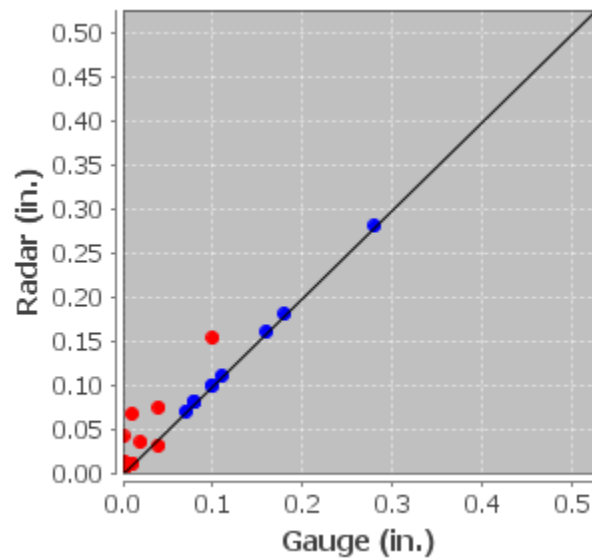


Figure 5. Scatter Plot of RG Pairs for Event 1b

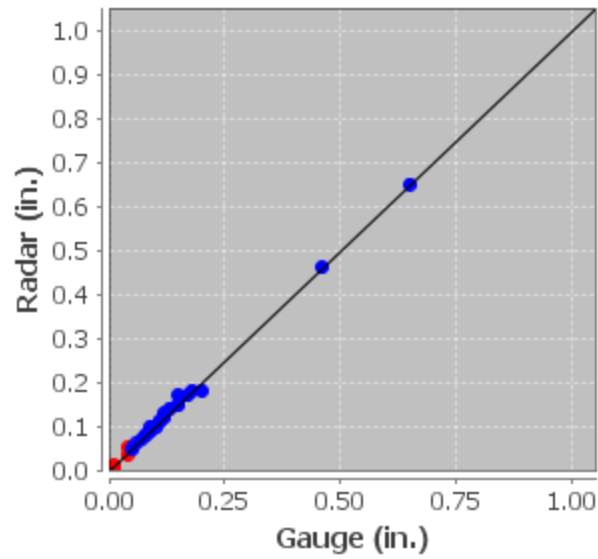


Figure 6. Scatter Plot of RG Pairs for Event 1c

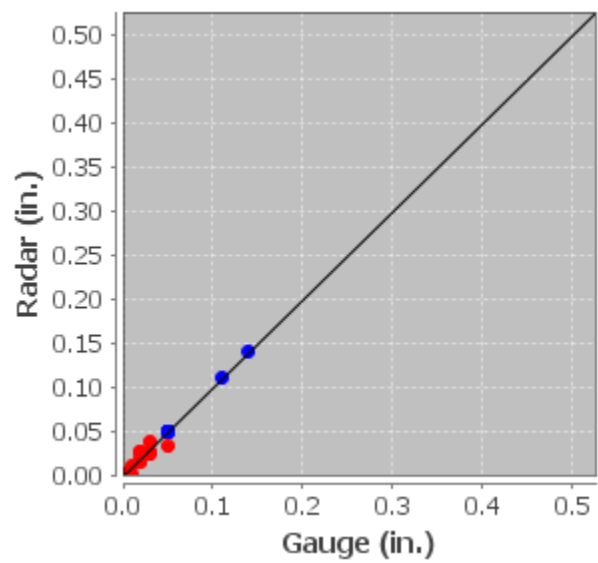


Figure 7. Scatter Plot of RG Pairs for Event 1d

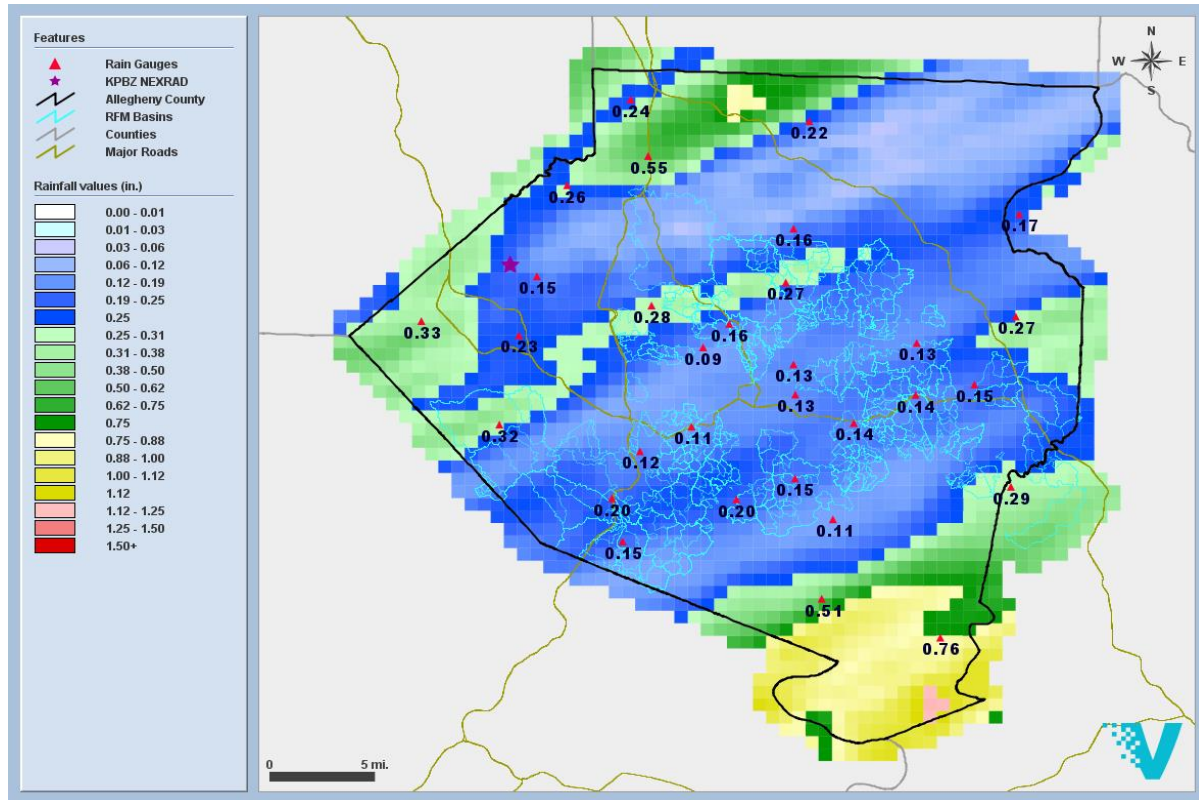


Figure 8. GARR Storm Total for Event 1

Table 10. Depth Duration Frequency Analyses for Event 1

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.733	161163	2019-08-07 00:45	2 yr.
30 minutes	0.925	160163	2019-08-07 00:50	1 yr.
1 hour	1.012	147163	2019-08-07 00:55	1 yr.
2 hour	1.071	147163	2019-08-07 01:25	<1 yr.
3 hour	1.095	147163	2019-08-07 02:15	<1 yr.
6 hour	1.145	160163	2019-08-07 02:30	<1 yr.
12 hour	1.145	160163	2019-08-07 02:30	<1 yr.

Event 2: 2019-08-13

The analysis period was from 2019-08-12 19:00 EDT to 2019-08-13 22:00 EDT. The event was then split into six sub-event periods at 2019-08-13 08:00 EDT, 2019-08-13 14:00 EDT, 2019-08-13 15:20 EDT, 2019-08-13 16:20 EDT and 2019-08-13 17:15 EDT to improve gauge adjustment of the radar.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event.

The gauges listed in [Appendix B](#) were not used to adjust the radar since they did not meet statistical criteria for gauge-adjustment.

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 11 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 12 - 17 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and Diff^* (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 9 - 14 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 15 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.1 - 1.2 inches with a mean of 0.5 inches. The GARR amounts for the 440 RFM basins range from 0.4 - 1.0 inches with a mean of 0.7 inches. The GARR amounts for the 871 RFM sheds range from 0.4 - 1.0 inches with a mean of 0.7 inches. Table 18 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 11. GARR Statistics for Event 2

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E2a	KPBZ LII	2019-08-13	2019-08-12 19:05	2019-08-13 08:00	5	0.026	1.175	18.5	1.8
E2b	KPBZ LII	2019-08-13	2019-08-13 08:05	2019-08-13 14:00	6	0.048	0.677	57.0	6.1
E2c	KPBZ LII	2019-08-13	2019-08-13 14:05	2019-08-13 15:20	16	0.076	1.065	12.0	2.6
E2d	KPBZ LII	2019-08-13	2019-08-13 15:25	2019-08-13 16:20	25	0.197	1.374	28.9	1.9
E2e	KPBZ LII	2019-08-13	2019-08-13 16:25	2019-08-13 17:15	20	0.118	1.012	12.3	1.7
E2f	KPBZ LII	2019-08-13	2019-08-13 17:20	2019-08-13 22:00	9	0.038	0.863	22.6	0.9

Table 12. Summary of Individual RG Pairs for Event 2a

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	Diff^* (in)	Diff^* (%)	Flag
Loc21	Moon TWP	0.08	0.07	0.08	0.00	0.0	
Loc23	Clinton Munic Bldg	0.06	0.06	0.06	0.00	0.0	
Loc27	Marshall TWP	0.11	0.07	0.11	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.07	0.08	0.07	0.00	0.0	
Loc30	McCandless Twn Hall	0.08	0.07	0.08	0.00	0.0	

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.00	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.00	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.01	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.00	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.01	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.01	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.00	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.00	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.00	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.00	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	0.00	---	---	---	---	MSTT
Loc11	M-46 Access Shaft	0.00	---	---	---	---	MSTT
Loc12	Baldwin	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.00	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.00	---	---	---	---	MSTT
Loc16	Castle Shannon	0.00	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.00	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.00	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.00	---	---	---	---	MSTT
Loc31	Hampton Municipal Bldg	0.01	---	---	---	---	MSTT
Loc32	Arnold	0.00	---	---	---	---	MSTT
Loc33	Richland TWP	0.02	---	---	---	---	MSTT

Table 13. Summary of Individual RG Pairs for Event 2b

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc05	Upper St. Clair	0.08	0.23	0.10	-0.02	-25.0	
KAGC	Pittsburgh Allegheny Cty	0.05	0.09	0.05	0.00	0.0	
Loc27	Marshall TWP	0.11	0.10	0.11	0.00	0.0	
Loc30	McCandless Twn Hall	0.06	0.06	0.06	0.00	0.0	
Loc33	Richland TWP	0.07	0.06	0.07	0.00	0.0	
Loc17	Chartiers Pump Station	0.09	0.13	0.08	0.01	11.1	
03049500	Allegheny River at Natrona	0.02	---	---	---	---	S
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.01	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.05	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.03	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.01	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.01	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.03	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.04	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.03	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.01	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.01	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	0.00	---	---	---	---	MSTT
Loc11	M-46 Access Shaft	0.01	---	---	---	---	MSTT
Loc12	Baldwin	0.02	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.02	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.03	---	---	---	---	MSTT
Loc16	Castle Shannon	0.04	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.02	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.01	---	---	---	---	MSTT
Loc21	Moon TWP	0.02	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.04	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.02	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.04	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.02	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.06	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.05	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc31	Hampton Municipal Bldg	0.04	---	---	---	---	MSTT
Loc32	Arnold	0.05	---	---	---	---	MSTT

Table 14. Summary of Individual RG Pairs for Event 2c

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc01	PWSA-Montana St.	0.08	0.08	0.09	-0.01	-12.5	
Loc17	Chartiers Pump Station	0.24	0.28	0.25	-0.01	-4.2	
Loc12	Baldwin	0.30	0.31	0.31	-0.01	-3.3	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.08	0.06	0.08	0.00	0.0	
Loc02	ALCOSAN WWTP Lab	0.07	0.05	0.07	0.00	0.0	
Loc04	Kennedy Twp PS	0.10	0.09	0.10	0.00	0.0	
Loc05	Upper St. Clair	0.13	0.14	0.13	0.00	0.0	
Loc07	Greentree Munic Bldg	0.28	0.25	0.28	0.00	0.0	
Loc09	Univ of Pittsburgh	0.09	0.09	0.09	0.00	0.0	
Loc11	M-46 Access Shaft	0.15	0.14	0.15	0.00	0.0	
Loc15	Trafford Maint Bldg	0.12	0.12	0.12	0.00	0.0	
Loc22	North Fayette TWP	0.14	0.12	0.14	0.00	0.0	
Loc23	Clinton Munic Bldg	0.10	0.08	0.10	0.00	0.0	
Loc24	Jefferson Hills	0.08	0.06	0.08	0.00	0.0	
Loc06	Carnegie Transit Time	0.30	0.28	0.29	0.01	3.3	
Loc16	Castle Shannon	0.28	0.24	0.27	0.01	3.6	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.27	---	---	---	---	O
KPIT	Greater Pittsburgh Int'l	0.10	---	---	---	---	U
Loc03	Shaler Munic Bldg	0.02	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.03	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.00	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.00	---	---	---	---	MSTT
Loc21	Moon TWP	0.04	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.02	---	---	---	---	MSTT
Loc27	Marshall TWP	0.00	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.01	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.02	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.00	---	---	---	---	MSTT
Loc31	Hampton Municipal Bldg	0.00	---	---	---	---	MSTT
Loc32	Arnold	0.03	---	---	---	---	MSTT
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

Table 15. Summary of Individual RG Pairs for Event 2d

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc09	Univ of Pittsburgh	0.06	0.05	0.07	-0.01	-16.7	
Loc06	Carnegie Transit Time	0.24	0.19	0.25	-0.01	-4.2	
Loc16	Castle Shannon	0.51	0.44	0.52	-0.01	-2.0	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.21	0.12	0.21	0.00	0.0	
Loc03	Shaler Munic Bldg	0.22	0.13	0.22	0.00	0.0	
Loc07	Greentree Munic Bldg	0.21	0.15	0.21	0.00	0.0	
Loc10	PWSA-Highland Park	0.14	0.09	0.14	0.00	0.0	
Loc11	M-46 Access Shaft	0.10	0.07	0.10	0.00	0.0	
Loc12	Baldwin	0.33	0.27	0.33	0.00	0.0	
Loc14	Churchill Munic Bldg	0.13	0.08	0.13	0.00	0.0	
Loc15	Trafford Maint Bldg	0.50	0.37	0.50	0.00	0.0	
Loc17	Chartiers Pump Station	0.47	0.35	0.47	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.10	0.06	0.10	0.00	0.0	
Loc20	Gascola Eq Facility	0.10	0.06	0.10	0.00	0.0	
Loc21	Moon TWP	0.34	0.24	0.34	0.00	0.0	
Loc22	North Fayette TWP	0.36	0.25	0.36	0.00	0.0	
Loc23	Clinton Munic Bldg	0.18	0.12	0.18	0.00	0.0	
Loc24	Jefferson Hills	0.13	0.11	0.13	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.08	0.06	0.08	0.00	0.0	
Loc27	Marshall TWP	0.11	0.08	0.11	0.00	0.0	
Loc28	Plum Municipal Bldg	0.11	0.07	0.11	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc29	Bell Acres Munic Bldg	0.23	0.16	0.23	0.00	0.0	
Loc30	McCandless Twn Hall	0.19	0.12	0.19	0.00	0.0	
Loc32	Arnold	0.22	0.19	0.22	0.00	0.0	
Loc08	AC Health Dept Bldg	0.11	0.07	0.10	0.01	9.1	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.45	---	---	---	---	U
KPIT	Greater Pittsburgh Int'l	0.14	---	---	---	---	U
Loc01	PWSA-Montana St.	0.09	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.08	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.06	---	---	---	---	U
Loc05	Upper St. Clair	0.22	---	---	---	---	U
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc31	Hampton Municipal Bldg	0.43	---	---	---	---	O
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

Table 16. Summary of Individual RG Pairs for Event 2e

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc11	M-46 Access Shaft	0.39	0.48	0.42	-0.03	-7.7	
Loc03	Shaler Munic Bldg	0.22	0.26	0.23	-0.01	-4.5	
Loc07	Greentree Munic Bldg	0.26	0.25	0.27	-0.01	-3.8	
Loc20	Gascola Eq Facility	0.36	0.37	0.37	-0.01	-2.8	
Loc02	ALCOSAN WWTP Lab	0.39	0.43	0.40	-0.01	-2.6	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.29	0.31	0.29	0.00	0.0	
Loc04	Kennedy Twp PS	0.35	0.37	0.35	0.00	0.0	
Loc06	Carnegie Transit Time	0.11	0.09	0.11	0.00	0.0	
Loc09	Univ of Pittsburgh	0.46	0.45	0.46	0.00	0.0	
Loc10	PWSA-Highland Park	0.42	0.41	0.42	0.00	0.0	
Loc12	Baldwin	0.14	0.11	0.14	0.00	0.0	
Loc15	Trafford Maint Bldg	0.11	0.10	0.11	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.35	0.33	0.35	0.00	0.0	
Loc21	Moon TWP	0.16	0.11	0.16	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc23	Clinton Munic Bldg	0.08	0.06	0.08	0.00	0.0	
Loc28	Plum Municipal Bldg	0.26	0.20	0.26	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.09	0.11	0.09	0.00	0.0	
Loc01	PWSA-Montana St.	0.59	0.61	0.58	0.01	1.7	
Loc08	AC Health Dept Bldg	0.35	0.33	0.34	0.01	2.9	
Loc14	Churchill Munic Bldg	0.52	0.46	0.50	0.02	3.8	
03049500	Allegheny River at Natrona	0.01	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.09	---	---	---	---	O
KPIT	Greater Pittsburgh Int'l	0.16	---	---	---	---	O
Loc05	Upper St. Clair	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc16	Castle Shannon	0.03	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.03	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc22	North Fayette TWP	0.07	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc27	Marshall TWP	0.02	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.03	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.04	---	---	---	---	MSTT
Loc32	Arnold	0.05	---	---	---	---	MSTT
Loc33	Richland TWP	0.05	---	---	---	---	MSTT

Table 17. Summary of Individual RG Pairs for Event 2f

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc01	PWSA-Montana St.	0.05	0.07	0.05	0.00	0.0	
Loc03	Shaler Munic Bldg	0.07	0.09	0.07	0.00	0.0	
Loc10	PWSA-Highland Park	0.08	0.11	0.08	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.10	0.13	0.10	0.00	0.0	
Loc20	Gascola Eq Facility	0.05	0.06	0.05	0.00	0.0	
Loc21	Moon TWP	0.06	0.06	0.06	0.00	0.0	
Loc28	Plum Municipal Bldg	0.07	0.09	0.07	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.05	0.05	0.05	0.00	0.0	

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc32	Arnold	0.19	0.17	0.19	0.00	0.0	
03049500	Allegheny River at Natrona	0.03	---	---	---	---	U
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.05	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.05	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.03	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.02	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.02	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.03	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.02	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.02	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.03	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.04	---	---	---	---	MSTT
Loc11	M-46 Access Shaft	0.01	---	---	---	---	MSTT
Loc12	Baldwin	0.02	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.04	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.03	---	---	---	---	MSTT
Loc16	Castle Shannon	0.04	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.03	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc22	North Fayette TWP	0.03	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.02	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.03	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.01	---	---	---	---	MSTT
Loc27	Marshall TWP	0.00	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.00	---	---	---	---	MSTT
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

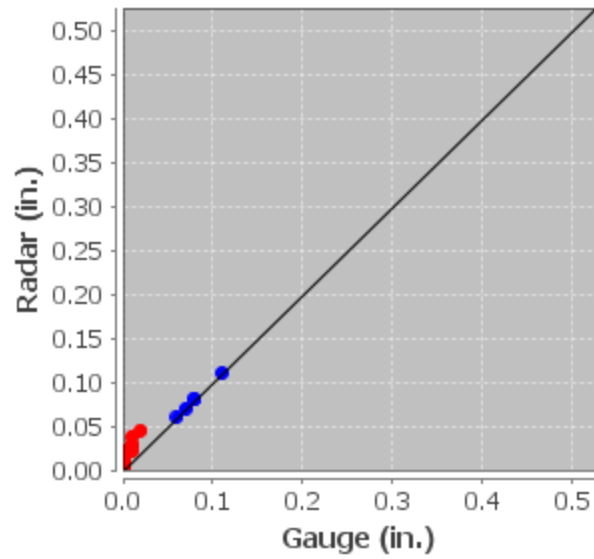


Figure 9. Scatter Plot of RG Pairs for Event 2a

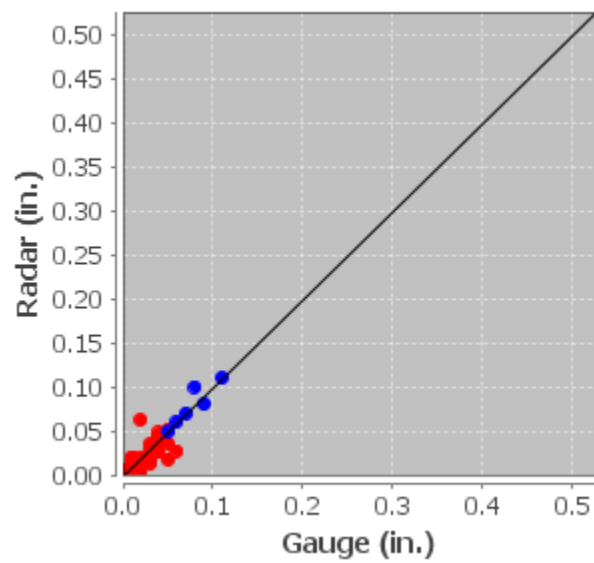


Figure 10. Scatter Plot of RG Pairs for Event 2b

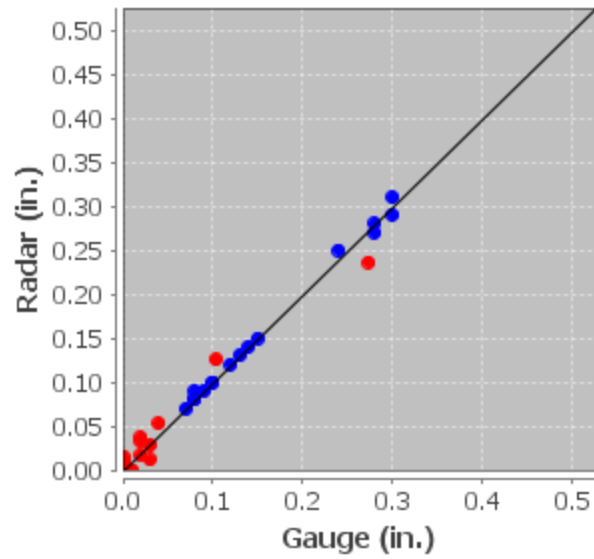


Figure 11. Scatter Plot of RG Pairs for Event 2c

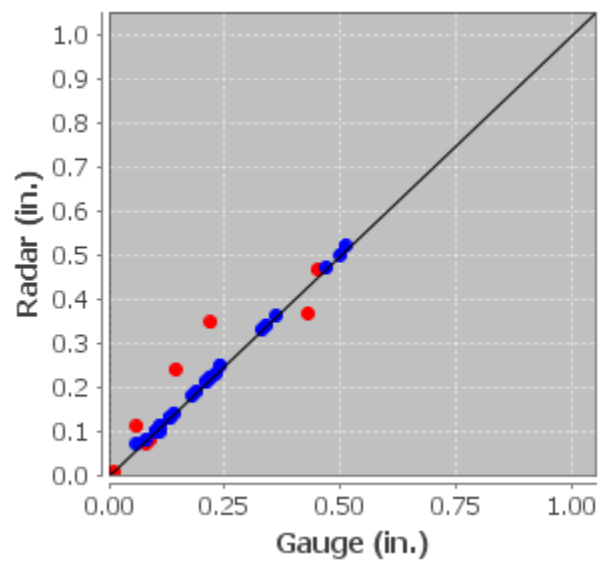


Figure 12. Scatter Plot of RG Pairs for Event 2d

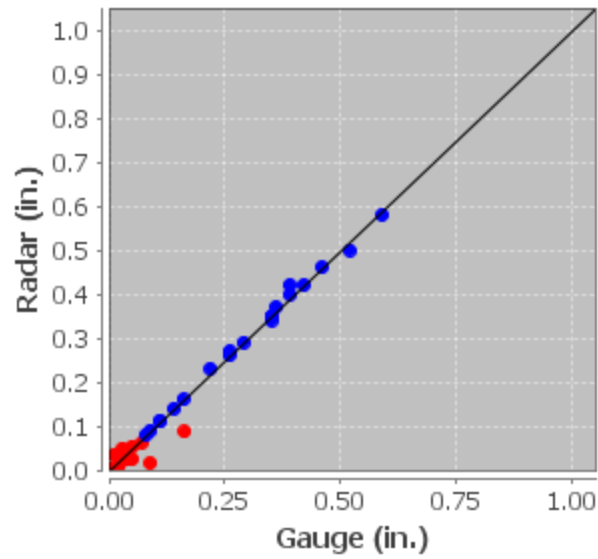


Figure 13. Scatter Plot of RG Pairs for Event 2e

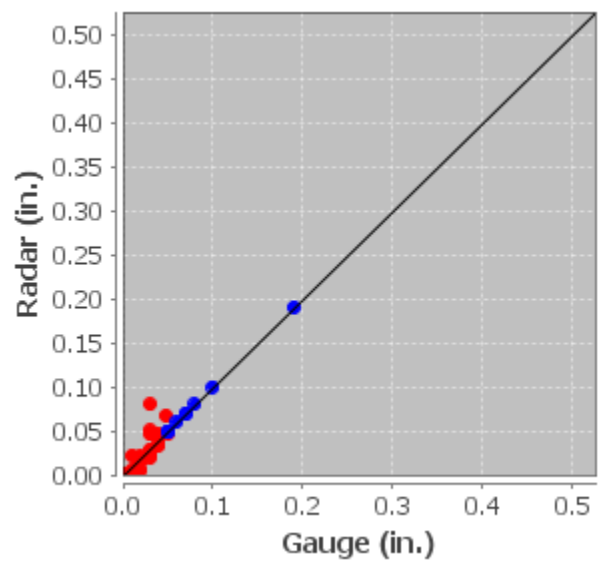


Figure 14. Scatter Plot of RG Pairs for Event 2f

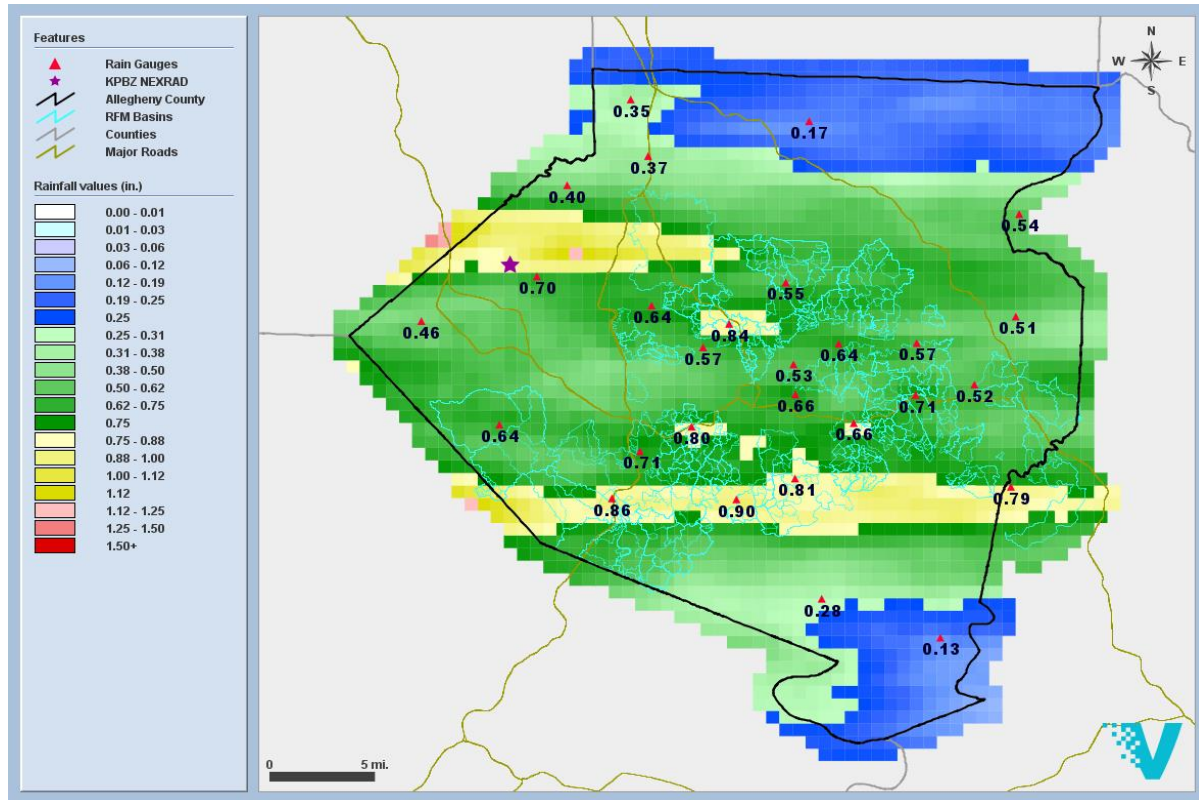


Figure 15. GARR Storm Total for Event 2

Table 18. Depth Duration Frequency Analyses for Event 2

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.494	147133	2019-08-13 16:45	<1 yr.
30 minutes	0.607	142127	2019-08-13 15:50	<1 yr.
1 hour	0.758	122126	2019-08-13 16:10	<1 yr.
2 hour	0.982	122126	2019-08-13 16:50	<1 yr.
3 hour	1.089	122126	2019-08-13 17:25	<1 yr.
6 hour	1.089	122126	2019-08-13 17:25	<1 yr.
12 hour	1.127	125147	2019-08-13 18:20	<1 yr.
24 hour	1.228	122126	2019-08-13 19:00	<1 yr.

Event 3: 2019-08-15

The analysis period was from 2019-08-15 11:00 EDT to 2019-08-15 21:00 EDT.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event. The gauges listed in [Appendix B](#) were not used to adjust the radar since they did not meet statistical criteria for gauge-adjustment.

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 19 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Table 20 summarizes the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, Diff* (in) is the difference in inches between the gauge and GARR estimate, and Diff* (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figure 16 shows the scatter plot of the RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 17 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.0 - 1.0 inches with a mean of 0.2 inches. The GARR amounts for the 440 RFM basins range from 0.0 - 0.9 inches with a mean of 0.4 inches. The GARR amounts for the 871 RFM sheds range from 0.0 - 0.9 inches with a mean of 0.4 inches. Table 21 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 19. GARR Statistics for Event 3

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E3	KPBZ LII	2019-08-15	2019-08-15 11:05	2019-08-15 21:00	20	0.241	0.735	44.8	4.1

Table 20. Summary of Individual RG Pairs for Event 3

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	Diff* (in)	Diff* (%)	Flag
Loc10	PWSA-Highland Park	0.15	0.30	0.18	-0.03	-20.0	
Loc14	Churchill Munic Bldg	0.14	0.36	0.16	-0.02	-14.3	
Loc16	Castle Shannon	0.60	0.93	0.63	-0.03	-5.0	
KAGC	Pittsburgh Allegheny Cty	0.72	1.05	0.75	-0.03	-4.2	
Loc17	Chartiers Pump Station	0.85	1.05	0.87	-0.02	-2.4	
Loc03	Shaler Munic Bldg	0.48	0.62	0.49	-0.01	-2.1	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.10	0.12	0.10	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.06	0.09	0.06	0.00	0.0	
Loc04	Kennedy Twp PS	0.27	0.33	0.27	0.00	0.0	
Loc11	M-46 Access Shaft	0.26	0.39	0.26	0.00	0.0	
Loc15	Trafford Maint Bldg	0.57	1.15	0.57	0.00	0.0	
Loc22	North Fayette TWP	0.76	0.73	0.76	0.00	0.0	
Loc27	Marshall TWP	0.09	0.07	0.09	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.05	0.05	0.05	0.00	0.0	
Loc06	Carnegie Transit Time	0.48	0.53	0.47	0.01	2.1	

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc09	Univ of Pittsburgh	0.78	1.00	0.76	0.02	2.6	
Loc08	AC Health Dept Bldg	0.51	0.65	0.48	0.03	5.9	
Loc20	Gascola Eq Facility	0.17	0.28	0.16	0.01	5.9	
Loc12	Baldwin	0.77	0.89	0.72	0.05	6.5	
Loc19	Sandy Creek Eq Facility	0.14	0.25	0.13	0.01	7.1	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.29	---	---	---	---	U
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	Z
Loc05	Upper St. Clair	0.29	---	---	---	---	U
Loc07	Greentree Munic Bldg	0.28	---	---	---	---	U
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc21	Moon TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.02	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.04	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.04	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.06	---	---	---	---	OAD
Loc29	Bell Acres Munic Bldg	0.03	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.00	---	---	---	---	MSTT
Loc32	Arnold	0.01	---	---	---	---	MSTT
Loc33	Richland TWP	0.00	---	---	---	---	MSTT

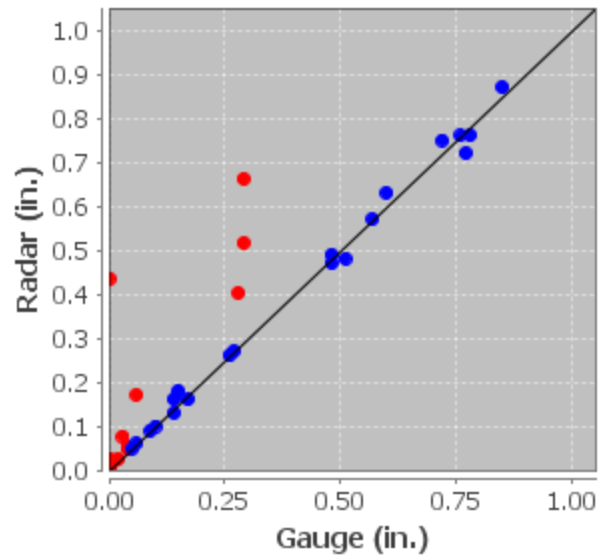


Figure 16. Scatter Plot of RG Pairs for Event 3

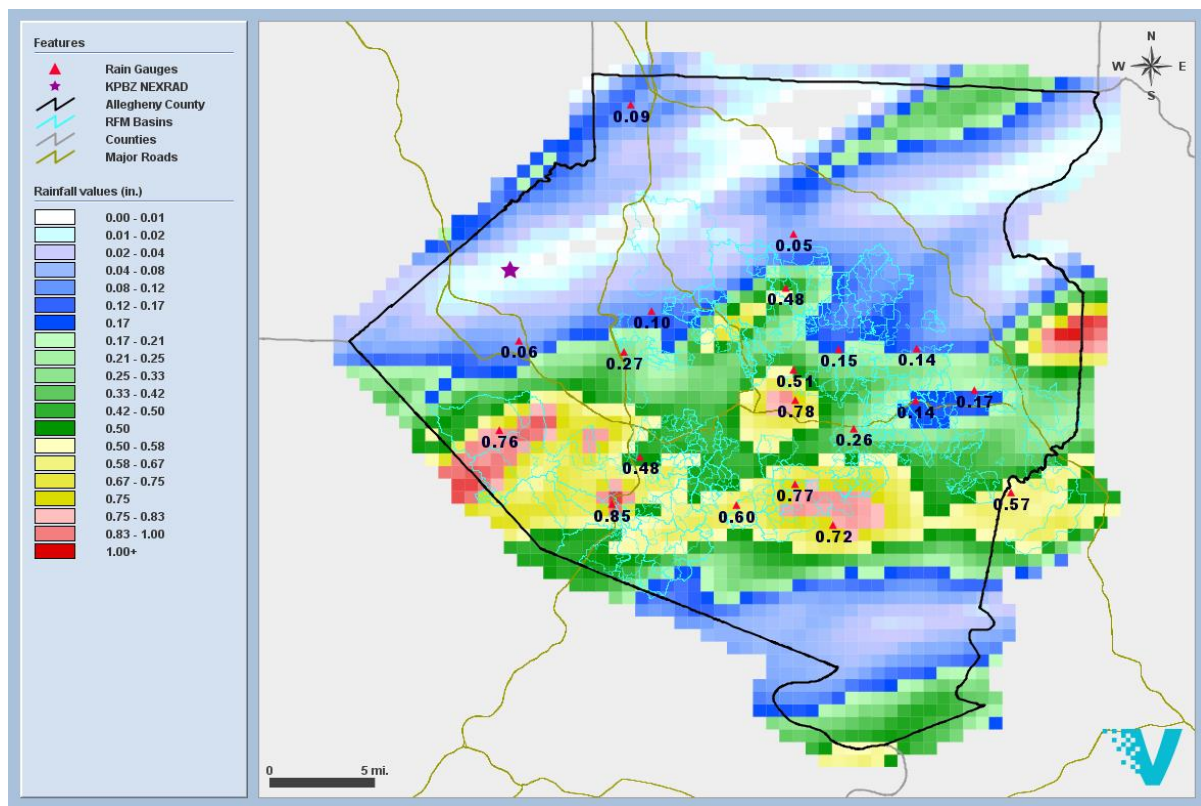


Figure 17. GARR Storm Total for Event 3

Table 21. Depth Duration Frequency Analyses for Event 3

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.770	136146	2019-08-15 15:00	2 yr.
30 minutes	0.877	136146	2019-08-15 15:05	1 yr.
1 hour	0.915	136146	2019-08-15 15:30	<1 yr.
2 hour	0.961	171133	2019-08-15 15:55	<1 yr.
3 hour	0.970	171133	2019-08-15 16:00	<1 yr.
6 hour	0.970	171133	2019-08-15 17:00	<1 yr.

Event 4: 2019-08-20

The analysis period was from 2019-08-20 20:00 EDT to 2019-08-21 07:00 EDT. The event was then split into four sub-event periods at 2019-08-21 00:00 EDT, 2019-08-21 01:30 EDT and 2019-08-21 03:30 EDT to improve gauge adjustment of the radar.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event. The gauges listed in [Appendix B](#) were not used to adjust the radar since they did not meet statistical criteria for gauge-adjustment.

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 22 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 23 - 26 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and Diff^* (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 18 - 21 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 22 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.1 - 0.9 inches with a mean of 0.4 inches. The GARR amounts for the 440 RFM basins range from 0.1 - 0.8 inches with a mean of 0.4 inches. The GARR amounts for the 871 RFM sheds range from 0.1 - 0.9 inches with a mean of 0.4 inches. Table 27 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 22. GARR Statistics for Event 4

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E4a	KPBZ LII	2019-08-20	2019-08-20 20:05	2019-08-21 00:00	20	0.221	0.908	24.2	1.7
E4b	KPBZ LII	2019-08-20	2019-08-21 00:05	2019-08-21 01:30	8	0.045	0.527	69.8	1.7

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E4c	KPBZ LII	2019-08-20	2019-08-21 01:35	2019-08-21 03:30	17	0.062	1.053	28.1	5.2
E4d	KPBZ LII	2019-08-20	2019-08-21 03:35	2019-08-21 07:00	2	0.026	1.204	16.3	0.1

Table 23. Summary of Individual RG Pairs for Event 4a

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc11	M-46 Access Shaft	0.10	0.17	0.11	-0.01	-10.0	
Loc06	Carnegie Transit Time	0.21	0.23	0.22	-0.01	-4.8	
Loc32	Arnold	0.22	0.41	0.23	-0.01	-4.5	
Loc20	Gascola Eq Facility	0.29	0.30	0.30	-0.01	-3.4	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.18	0.32	0.18	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.12	0.15	0.12	0.00	0.0	
Loc03	Shaler Munic Bldg	0.34	0.28	0.34	0.00	0.0	
Loc07	Greentree Munic Bldg	0.22	0.22	0.22	0.00	0.0	
Loc09	Univ of Pittsburgh	0.11	0.14	0.11	0.00	0.0	
Loc16	Castle Shannon	0.06	0.08	0.06	0.00	0.0	
Loc17	Chartiers Pump Station	0.18	0.18	0.18	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.32	0.27	0.32	0.00	0.0	
Loc23	Clinton Munic Bldg	0.26	0.31	0.26	0.00	0.0	
Loc24	Jefferson Hills	0.10	0.16	0.10	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.16	0.16	0.16	0.00	0.0	
Loc28	Plum Municipal Bldg	0.45	0.43	0.45	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.38	0.33	0.38	0.00	0.0	
Loc33	Richland TWP	0.58	0.60	0.58	0.00	0.0	
03049500	Allegheny River at Natrona	0.30	0.32	0.29	0.01	3.3	
Loc08	AC Health Dept Bldg	0.17	0.19	0.16	0.01	5.9	
KAGC	Pittsburgh Allegheny Cty	0.01	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	Z
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc05	Upper St. Clair	0.01	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	0.10	---	---	---	---	U
Loc12	Baldwin	0.02	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.08	---	---	---	---	U
Loc15	Trafford Maint Bldg	0.04	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc21	Moon TWP	0.23	---	---	---	---	S
Loc22	North Fayette TWP	0.34	---	---	---	---	O
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	ND
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND

Table 24. Summary of Individual RG Pairs for Event 4b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc05	Upper St. Clair	0.13	0.30	0.13	0.00	0.0	
Loc07	Greentree Munic Bldg	0.24	0.51	0.24	0.00	0.0	
Loc08	AC Health Dept Bldg	0.09	0.09	0.09	0.00	0.0	
Loc10	PWSA-Highland Park	0.08	0.07	0.08	0.00	0.0	
Loc12	Baldwin	0.05	0.06	0.05	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.05	0.10	0.05	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.18	0.46	0.18	0.00	0.0	
Loc32	Arnold	0.06	0.07	0.06	0.00	0.0	
03049500	Allegheny River at Natrona	0.03	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.00	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.03	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.01	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc06	Carnegie Transit Time	0.03	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.11	---	---	---	---	U
Loc11	M-46 Access Shaft	0.04	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc14	Churchill Munic Bldg	0.04	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.03	---	---	---	---	MSTT
Loc16	Castle Shannon	0.03	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.02	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	0.02	---	---	---	---	MSTT
Loc21	Moon TWP	0.00	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.00	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc28	Plum Municipal Bldg	0.04	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND
Loc31	Hampton Municipal Bldg	0.00	---	---	---	---	MSTT
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

Table 25. Summary of Individual RG Pairs for Event 4c

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc12	Baldwin	0.08	0.19	0.10	-0.02	-25.0	
Loc09	Univ of Pittsburgh	0.21	0.21	0.24	-0.03	-14.3	
Loc19	Sandy Creek Eq Facility	0.16	0.16	0.17	-0.01	-6.3	
Loc20	Gascola Eq Facility	0.26	0.26	0.27	-0.01	-3.8	
Loc05	Upper St. Clair	0.08	0.08	0.08	0.00	0.0	
Loc06	Carnegie Transit Time	0.21	0.19	0.21	0.00	0.0	
Loc07	Greentree Munic Bldg	0.22	0.19	0.22	0.00	0.0	
Loc14	Churchill Munic Bldg	0.26	0.23	0.26	0.00	0.0	
Loc15	Trafford Maint Bldg	0.08	0.08	0.08	0.00	0.0	
Loc16	Castle Shannon	0.07	0.16	0.07	0.00	0.0	
Loc17	Chartiers Pump Station	0.45	0.43	0.45	0.00	0.0	
Loc24	Jefferson Hills	0.10	0.06	0.10	0.00	0.0	
Loc28	Plum Municipal Bldg	0.08	0.06	0.08	0.00	0.0	
Loc11	M-46 Access Shaft	0.31	0.23	0.29	0.02	6.5	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc08	AC Health Dept Bldg	0.14	0.11	0.13	0.01	7.1	
Loc10	PWSA-Highland Park	0.13	0.08	0.12	0.01	7.7	
KAGC	Pittsburgh Allegheny Cty	0.06	0.05	0.05	0.01	16.7	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.00	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc21	Moon TWP	0.00	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.07	---	---	---	---	MSTT
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND
Loc31	Hampton Municipal Bldg	0.00	---	---	---	---	MSTT
Loc32	Arnold	0.01	---	---	---	---	MSTT
Loc33	Richland TWP	0.00	---	---	---	---	MSTT

Table 26. Summary of Individual RG Pairs for Event 4d

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
KPIT	Greater Pittsburgh Int'l	0.12	0.10	0.12	0.00	0.0	
Loc23	Clinton Munic Bldg	0.07	0.06	0.07	0.00	0.0	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.01	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc05	Upper St. Clair	0.00	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.01	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.00	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.00	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.00	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	0.00	---	---	---	---	MSTT
Loc11	M-46 Access Shaft	0.00	---	---	---	---	MSTT
Loc12	Baldwin	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.01	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.03	---	---	---	---	MSTT
Loc16	Castle Shannon	0.00	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.00	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.00	---	---	---	---	MSTT
Loc21	Moon TWP	0.07	---	---	---	---	O
Loc22	North Fayette TWP	0.03	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.02	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc28	Plum Municipal Bldg	0.00	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	Z
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND
Loc31	Hampton Municipal Bldg	0.02	---	---	---	---	MSTT
Loc32	Arnold	0.00	---	---	---	---	MSTT
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

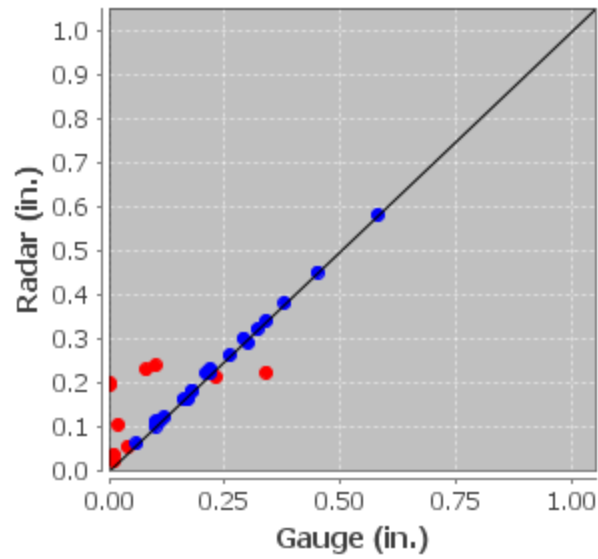


Figure 18. Scatter Plot of RG Pairs for Event 4a

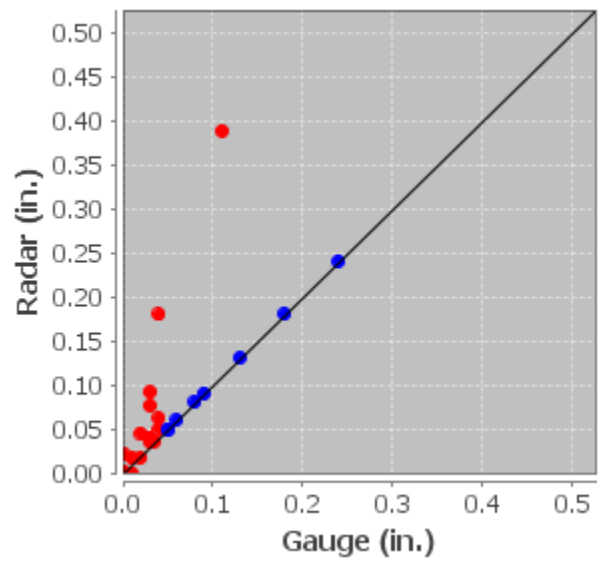


Figure 19. Scatter Plot of RG Pairs for Event 4b

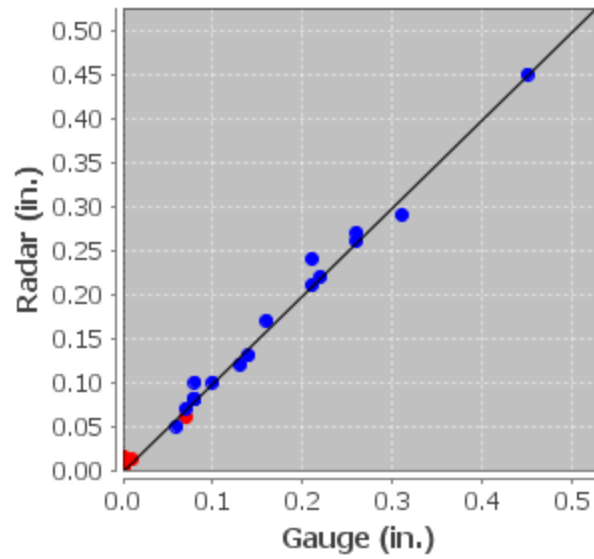


Figure 20. Scatter Plot of RG Pairs for Event 4c

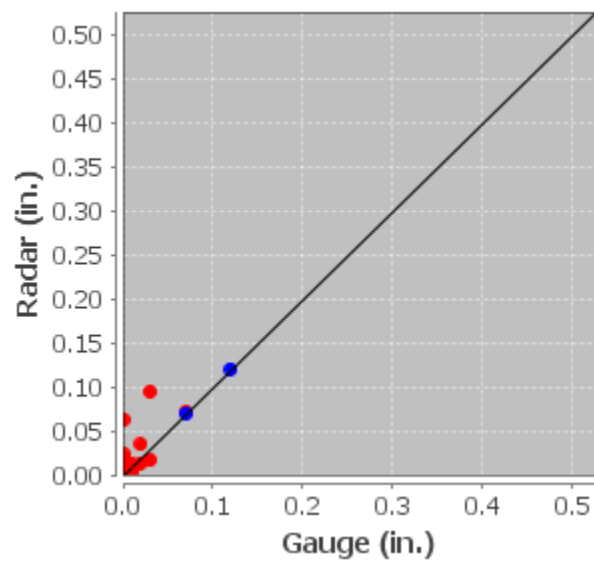


Figure 21. Scatter Plot of RG Pairs for Event 4d

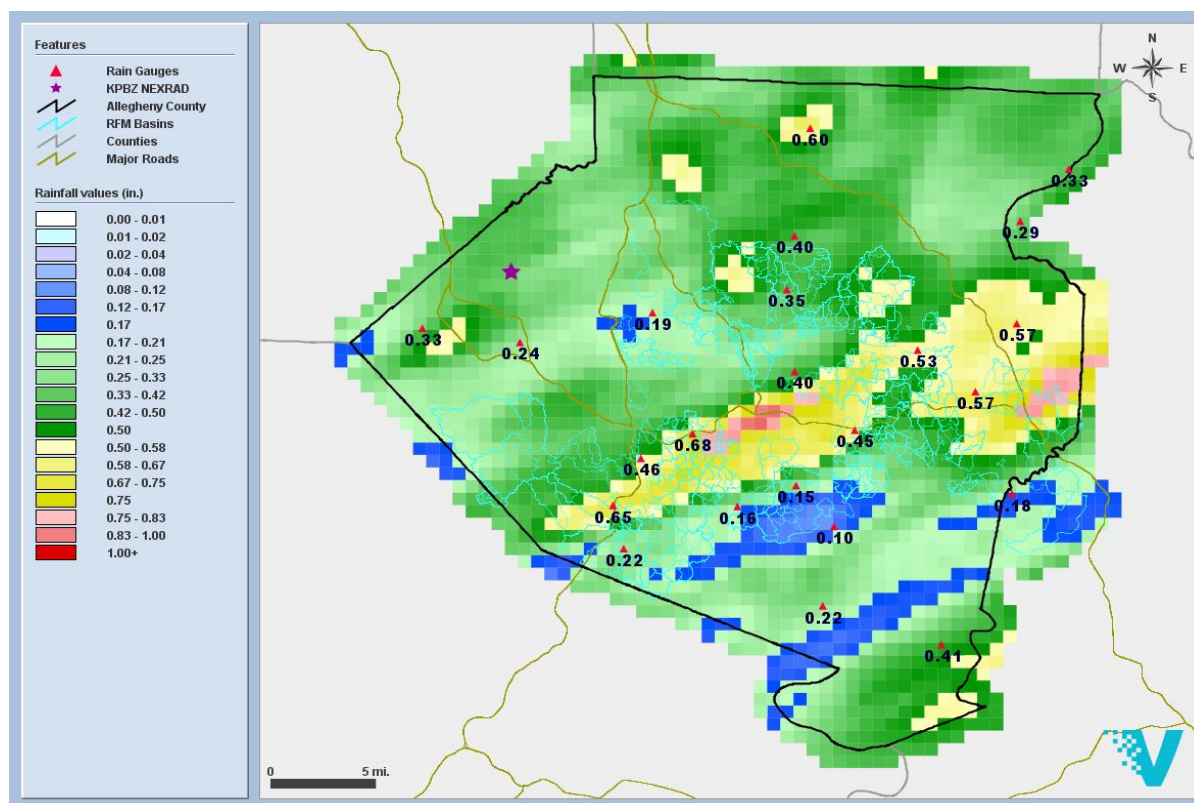


Figure 22. GARR Storm Total for Event 4

Table 27. Depth Duration Frequency Analyses for Event 4

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.461	150116	2019-08-20 23:05	<1 yr.
30 minutes	0.537	150116	2019-08-20 23:15	<1 yr.
1 hour	0.614	150116	2019-08-20 23:45	<1 yr.
2 hour	0.629	147139	2019-08-21 00:50	<1 yr.
3 hour	0.702	148139	2019-08-21 02:35	<1 yr.
6 hour	0.865	147140	2019-08-21 04:30	<1 yr.

Event 5: 2019-08-22

The analysis period was from 2019-08-22 11:00 EDT to 2019-08-23 03:00 EDT. The event was then split into two sub-event periods at 2019-08-22 16:00 EDT to improve gauge adjustment of the radar.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event. The gauges listed in [Appendix B](#) were not used to adjust the radar since they did not meet statistical criteria for gauge-adjustment.

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 28 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 29 - 30 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and Diff* (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 23 - 24 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 25 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.0 - 1.1 inches with a mean of 0.2 inches. The GARR amounts for the 440 RFM basins range from 0.0 - 1.1 inches with a mean of 0.2 inches. The GARR amounts for the 871 RFM sheds range from 0.0 - 1.1 inches with a mean of 0.3 inches. Table 31 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 28. GARR Statistics for Event 5

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E5a	KPBZ LII	2019-08-22	2019-08-22 11:05	2019-08-22 16:00	19	0.170	0.999	14.1	2.8
E5b	KPBZ LII	2019-08-22	2019-08-22 16:05	2019-08-23 03:00	6	0.034	0.548	80.8	2.5

Table 29. Summary of Individual RG Pairs for Event 5a

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	Diff* (in)	Diff* (%)	Flag
Loc16	Castle Shannon	0.05	0.11	0.06	-0.01	-20.0	
Loc09	Univ of Pittsburgh	0.46	0.47	0.48	-0.02	-4.3	
Loc10	PWSA-Highland Park	0.29	0.32	0.30	-0.01	-3.4	
Loc06	Carnegie Transit Time	0.72	0.73	0.73	-0.01	-1.4	
KAGC	Pittsburgh Allegheny Cty	0.09	0.08	0.09	0.00	0.0	
Loc05	Upper St. Clair	0.06	0.06	0.06	0.00	0.0	
Loc14	Churchill Munic Bldg	0.19	0.19	0.19	0.00	0.0	
Loc15	Trafford Maint Bldg	0.51	0.40	0.51	0.00	0.0	
Loc17	Chartiers Pump Station	0.16	0.14	0.16	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.15	0.16	0.15	0.00	0.0	
Loc20	Gascola Eq Facility	0.20	0.19	0.20	0.00	0.0	
Loc22	North Fayette TWP	0.26	0.32	0.26	0.00	0.0	
Loc24	Jefferson Hills	0.19	0.21	0.19	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.41	0.42	0.41	0.00	0.0	
Loc28	Plum Municipal Bldg	0.35	0.33	0.35	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc07	Greentree Munic Bldg	0.99	1.02	0.98	0.01	1.0	
Loc11	M-46 Access Shaft	0.39	0.36	0.38	0.01	2.6	
Loc12	Baldwin	0.24	0.23	0.23	0.01	4.2	
Loc08	AC Health Dept Bldg	0.32	0.30	0.30	0.02	6.3	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	Z
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.00	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	Z
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc21	Moon TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	Z
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND
Loc31	Hampton Municipal Bldg	0.00	---	---	---	---	MSTT
Loc32	Arnold	0.05	---	---	---	---	OAD
Loc33	Richland TWP	0.00	---	---	---	---	MSTT

Table 30. Summary of Individual RG Pairs for Event 5b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc17	Chartiers Pump Station	0.08	0.14	0.09	-0.01	-12.5	
KAGC	Pittsburgh Allegheny Cty	0.06	0.11	0.06	0.00	0.0	
Loc06	Carnegie Transit Time	0.08	0.10	0.08	0.00	0.0	
Loc16	Castle Shannon	0.05	0.05	0.05	0.00	0.0	
Loc24	Jefferson Hills	0.05	0.15	0.05	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.36	0.68	0.36	0.00	0.0	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.00	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.04	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc05	Upper St. Clair	0.02	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.03	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.01	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.01	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	0.02	---	---	---	---	MSTT
Loc11	M-46 Access Shaft	0.00	---	---	---	---	MSTT
Loc12	Baldwin	0.01	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.01	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.01	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.01	---	---	---	---	MSTT
Loc21	Moon TWP	0.01	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.02	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.03	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	ND
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc28	Plum Municipal Bldg	0.01	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	ND
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND
Loc31	Hampton Municipal Bldg	0.01	---	---	---	---	MSTT
Loc32	Arnold	0.01	---	---	---	---	MSTT
Loc33	Richland TWP	0.00	---	---	---	---	MSTT

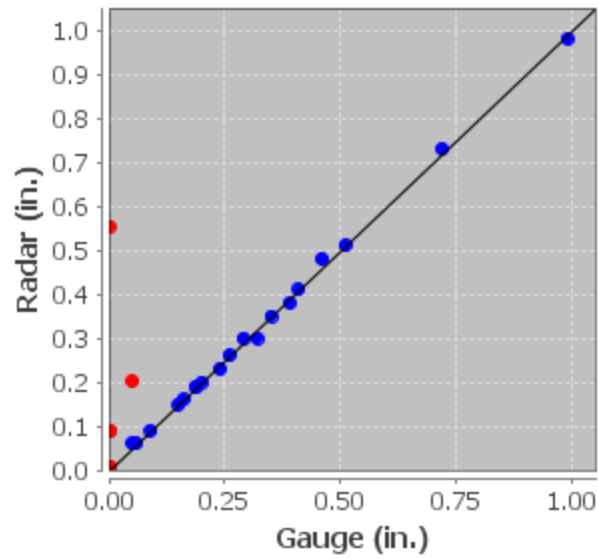


Figure 23. Scatter Plot of RG Pairs for Event 5a

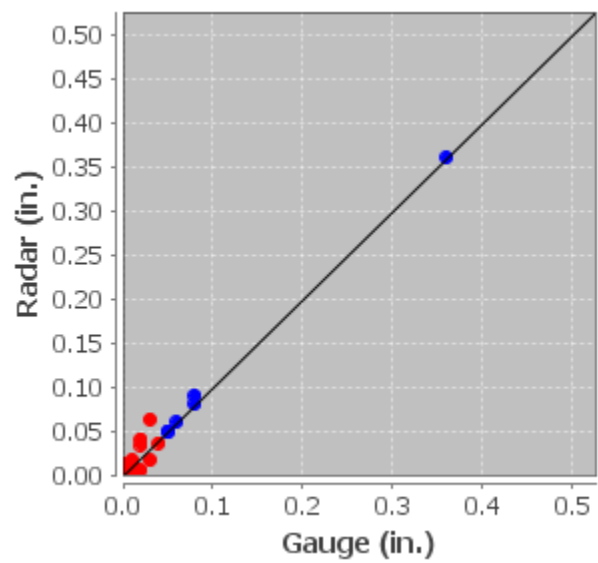


Figure 24. Scatter Plot of RG Pairs for Event 5b

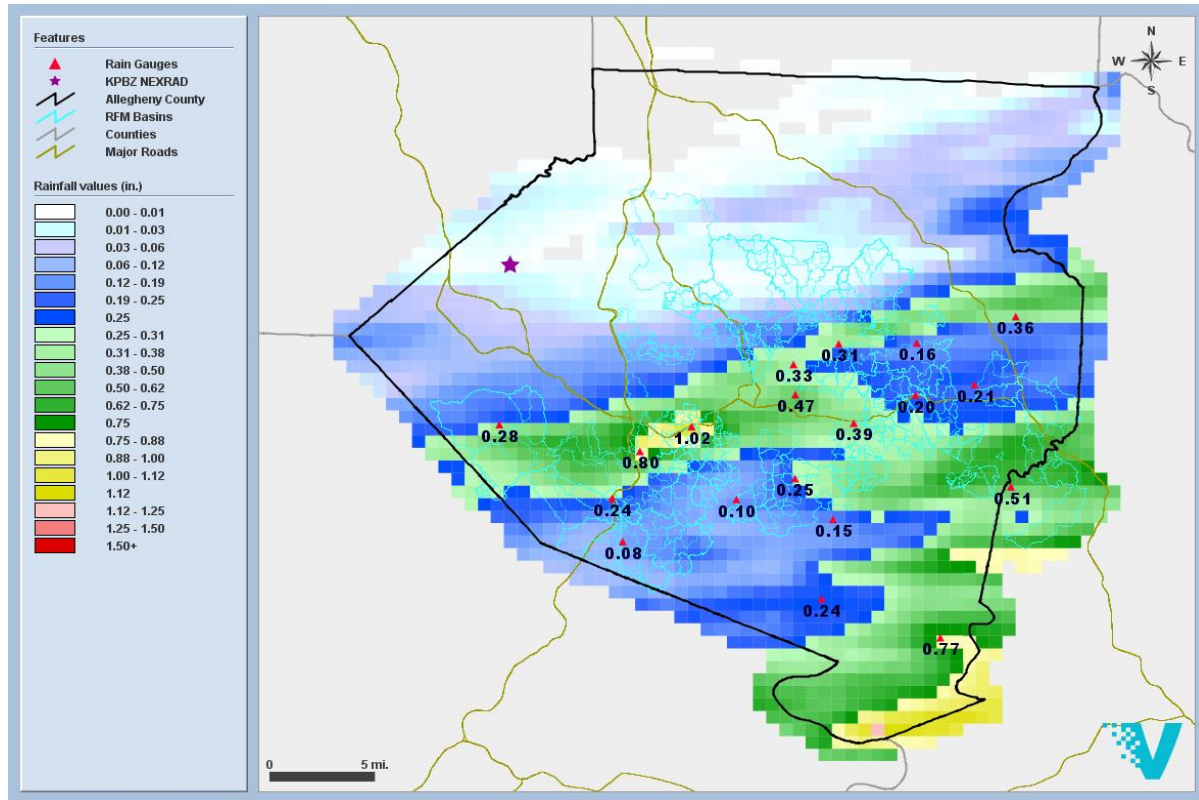


Figure 25. GARR Storm Total for Event 5

Table 31. Depth Duration Frequency Analyses for Event 5

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.767	141141	2019-08-22 14:40	2 yr.
30 minutes	0.975	141141	2019-08-22 14:45	2 yr.
1 hour	1.010	141141	2019-08-22 14:50	1 yr.
2 hour	1.010	141141	2019-08-22 14:50	<1 yr.
3 hour	1.010	141141	2019-08-22 14:50	<1 yr.
6 hour	1.125	156165	2019-08-22 19:50	<1 yr.
12 hour	1.130	156165	2019-08-23 00:50	<1 yr.

Event 6: 2019-08-27

The analysis period was from 2019-08-26 19:00 EDT to 2019-08-27 10:00 EDT. The event was then split into two sub-event periods at 2019-08-27 04:30 EDT to improve gauge adjustment of the radar. Gauge Only was used during Event 6b since all radar sources were either unavailable or provided insufficient rainfall information.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event.

The gauges listed in [Appendix B](#) were not used to adjust the radar since they did not meet statistical criteria for gauge-adjustment.

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 32 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 33 - 34 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and Diff^* (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figure 26 shows the scatter plot of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 27 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.1 - 0.4 inches with a mean of 0.3 inches. The GARR amounts for the 440 RFM basins range from 0.1 - 0.4 inches with a mean of 0.3 inches. The GARR amounts for the 871 RFM sheds range from 0.1 - 0.4 inches with a mean of 0.3 inches. Table 35 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 32. GARR Statistics for Event 6

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E6a	KPBZ LII	2019-08-27	2019-08-26 19:05	2019-08-27 04:30	24	0.127	1.795	41.7	1.5
E6b	Gauge Only	2019-08-27	2019-08-27 04:35	2019-08-27 10:00	25	0.162	---	---	---

Table 33. Summary of Individual RG Pairs for Event 6a

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	Diff^* (in)	Diff^* (%)	Flag
Loc14	Churchill Munic Bldg	0.16	0.11	0.17	-0.01	-6.3	
Loc09	Univ of Pittsburgh	0.18	0.11	0.19	-0.01	-5.6	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.08	0.07	0.08	0.00	0.0	
Loc03	Shaler Munic Bldg	0.20	0.10	0.20	0.00	0.0	
Loc06	Carnegie Transit Time	0.17	0.08	0.17	0.00	0.0	
Loc07	Greentree Munic Bldg	0.18	0.08	0.18	0.00	0.0	
Loc08	AC Health Dept Bldg	0.12	0.07	0.12	0.00	0.0	
Loc11	M-46 Access Shaft	0.18	0.12	0.18	0.00	0.0	
Loc12	Baldwin	0.18	0.12	0.18	0.00	0.0	
Loc16	Castle Shannon	0.18	0.10	0.18	0.00	0.0	
Loc17	Chartiers Pump Station	0.23	0.10	0.23	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.14	0.08	0.14	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc20	Gascola Eq Facility	0.15	0.10	0.15	0.00	0.0	
Loc21	Moon TWP	0.15	0.06	0.15	0.00	0.0	
Loc22	North Fayette TWP	0.14	0.05	0.14	0.00	0.0	
Loc23	Clinton Munic Bldg	0.13	0.05	0.13	0.00	0.0	
Loc24	Jefferson Hills	0.10	0.07	0.10	0.00	0.0	
Loc25	White Oak Public Works Bldg	0.11	0.08	0.11	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.08	0.06	0.08	0.00	0.0	
Loc28	Plum Municipal Bldg	0.09	0.05	0.09	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.17	0.08	0.17	0.00	0.0	
Loc32	Arnold	0.09	0.09	0.09	0.00	0.0	
Loc33	Richland TWP	0.20	0.09	0.20	0.00	0.0	
Loc10	PWSA-Highland Park	0.16	0.07	0.15	0.01	6.3	
03049500	Allegheny River at Natrona	0.03	---	---	---	---	U
KAGC	Pittsburgh Allegheny Cty	0.09	---	---	---	---	U
KPIT	Greater Pittsburgh Int'l	0.10	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	Z
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc05	Upper St. Clair	0.12	---	---	---	---	U
Loc13	M-59 Access Shaft	0.10	---	---	---	---	U
Loc15	Trafford Maint Bldg	0.00	---	---	---	---	Z
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc29	Bell Acres Munic Bldg	ND	---	---	---	---	ND
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND

Table 34. Summary of Individual RG Pairs for Event 6b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc21	Moon TWP	0.05	---	---	---	---	
Loc23	Clinton Munic Bldg	0.05	---	---	---	---	
Loc22	North Fayette TWP	0.08	---	---	---	---	
Loc09	Univ of Pittsburgh	0.09	---	---	---	---	
Loc05	Upper St. Clair	0.11	---	---	---	---	
Loc17	Chartiers Pump Station	0.11	---	---	---	---	

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc08	AC Health Dept Bldg	0.13	---	---	---	---	
Loc31	Hampton Municipal Bldg	0.13	---	---	---	---	
Loc10	PWSA-Highland Park	0.14	---	---	---	---	
Loc19	Sandy Creek Eq Facility	0.14	---	---	---	---	
Loc33	Richland TWP	0.14	---	---	---	---	
Loc06	Carnegie Transit Time	0.15	---	---	---	---	
Loc07	Greentree Munic Bldg	0.16	---	---	---	---	
Loc11	M-46 Access Shaft	0.16	---	---	---	---	
Loc13	M-59 Access Shaft	0.18	---	---	---	---	
Loc14	Churchill Munic Bldg	0.18	---	---	---	---	
Loc16	Castle Shannon	0.19	---	---	---	---	
Loc28	Plum Municipal Bldg	0.19	---	---	---	---	
Loc03	Shaler Munic Bldg	0.20	---	---	---	---	
Loc32	Arnold	0.20	---	---	---	---	
Loc12	Baldwin	0.23	---	---	---	---	
Loc20	Gascola Eq Facility	0.26	---	---	---	---	
Loc24	Jefferson Hills	0.26	---	---	---	---	
Loc26	Elizabeth TWP Municipal Bldg	0.27	---	---	---	---	
Loc25	White Oak Public Works Bldg	0.28	---	---	---	---	
03049500	Allegheny River at Natrona	0.18	---	---	---	---	T
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.07	---	---	---	---	T
KAGC	Pittsburgh Allegheny Cty	0.28	---	---	---	---	T
KPIT	Greater Pittsburgh Int'l	0.04	---	---	---	---	T
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	Z
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc15	Trafford Maint Bldg	0.00	---	---	---	---	Z
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc29	Bell Acres Munic Bldg	ND	---	---	---	---	ND
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND

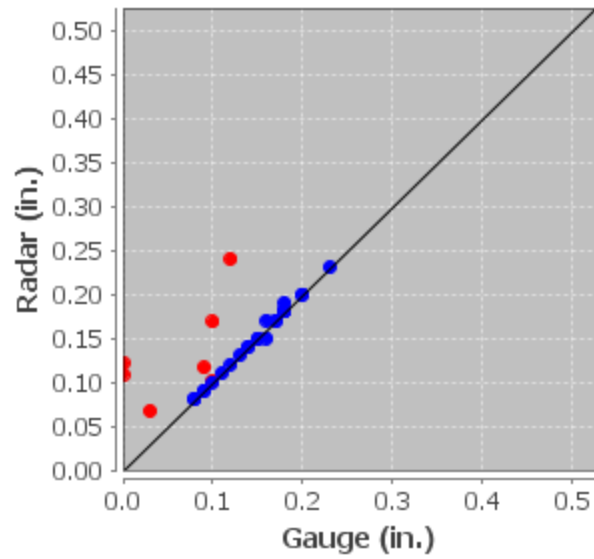


Figure 26. Scatter Plot of RG Pairs for Event 6a

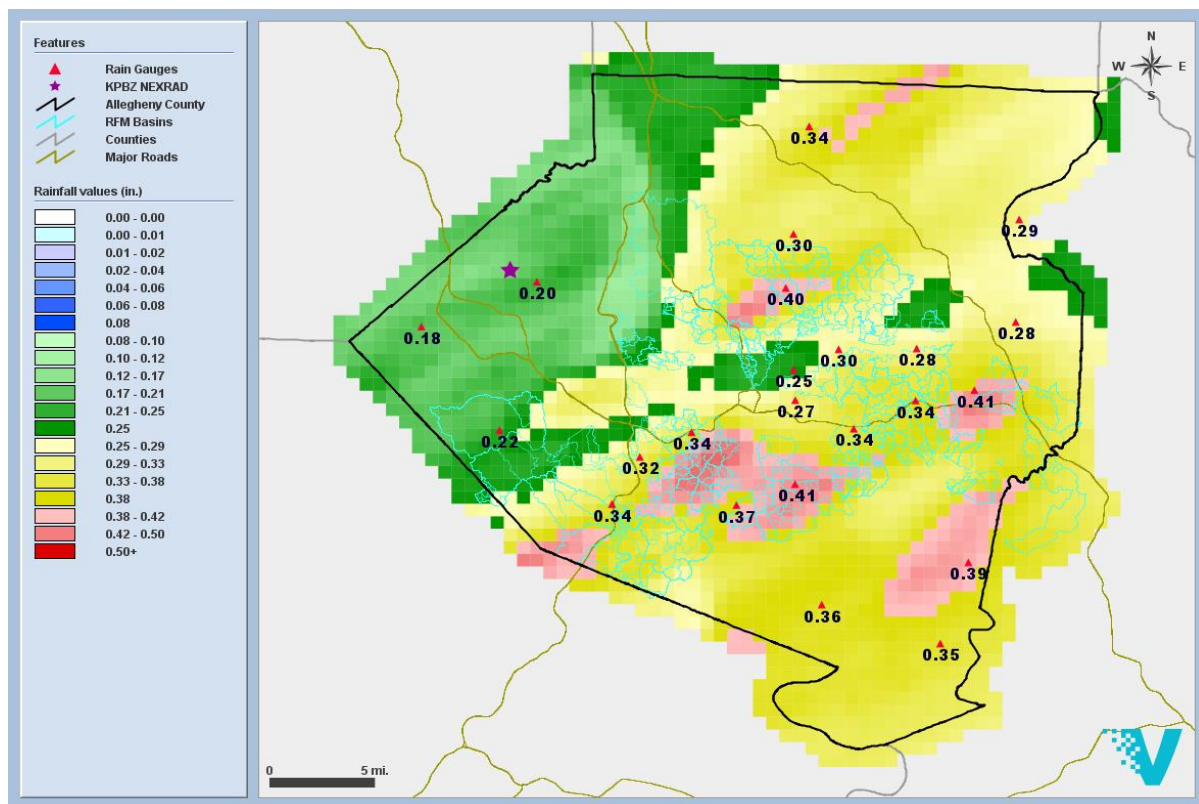


Figure 27. GARR Storm Total for Event 6

Table 35. Depth Duration Frequency Analyses for Event 6

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.128	157114	2019-08-27 04:05	<1 yr.
30 minutes	0.199	161112	2019-08-27 04:20	<1 yr.
1 hour	0.231	161112	2019-08-27 04:30	<1 yr.
2 hour	0.314	163139	2019-08-27 05:55	<1 yr.
3 hour	0.348	163139	2019-08-27 06:45	<1 yr.
6 hour	0.414	143143	2019-08-27 07:00	<1 yr.
12 hour	0.435	143143	2019-08-27 09:00	<1 yr.

Event 7: 2019-08-28

The analysis period was from 2019-08-27 23:00 EDT to 2019-08-28 11:00 EDT. The event was then split into two sub-event periods at 2019-08-28 05:00 EDT to improve gauge adjustment of the radar.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event. The gauges listed in [Appendix B](#) were not used to adjust the radar since they did not meet statistical criteria for gauge-adjustment.

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 36 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 37 - 38 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and $Diff^*$ (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 28 - 29 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 30 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.2 - 0.9 inches with a mean of 0.5 inches. The GARR amounts for the 440 RFM basins range from 0.4 - 0.9 inches with a mean of 0.6 inches. The GARR amounts for the 871 RFM sheds range from 0.3 - 0.9 inches with a mean of 0.6 inches. Table 39 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 36. GARR Statistics for Event 7

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E7a	KPBZ LII	2019-08-28	2019-08-27 23:05	2019-08-28 05:00	25	0.371	1.432	30.4	2.2
E7b	KPBZ LII	2019-08-28	2019-08-28 05:05	2019-08-28 11:00	17	0.098	1.631	38.2	2.3

Table 37. Summary of Individual RG Pairs for Event 7a

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc09	Univ of Pittsburgh	0.38	0.33	0.42	-0.04	-10.5	
Loc05	Upper St. Clair	0.43	0.32	0.45	-0.02	-4.7	
Loc10	PWSA-Highland Park	0.44	0.35	0.46	-0.02	-4.5	
Loc31	Hampton Municipal Bldg	0.27	0.18	0.28	-0.01	-3.7	
Loc20	Gascola Eq Facility	0.36	0.30	0.37	-0.01	-2.8	
Loc12	Baldwin	0.44	0.29	0.45	-0.01	-2.3	
Loc16	Castle Shannon	0.52	0.40	0.53	-0.01	-1.9	
03049500	Allegheny River at Natrona	0.42	0.27	0.42	0.00	0.0	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.29	0.19	0.29	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.40	0.23	0.40	0.00	0.0	
Loc11	M-46 Access Shaft	0.63	0.46	0.63	0.00	0.0	
Loc13	M-59 Access Shaft	0.34	0.24	0.34	0.00	0.0	
Loc17	Chartiers Pump Station	0.60	0.38	0.60	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.31	0.24	0.31	0.00	0.0	
Loc23	Clinton Munic Bldg	0.34	0.24	0.34	0.00	0.0	
Loc24	Jefferson Hills	0.45	0.29	0.45	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.83	0.66	0.83	0.00	0.0	
Loc28	Plum Municipal Bldg	0.41	0.31	0.41	0.00	0.0	
Loc32	Arnold	0.44	0.31	0.44	0.00	0.0	
Loc33	Richland TWP	0.23	0.16	0.23	0.00	0.0	
Loc06	Carnegie Transit Time	0.42	0.22	0.41	0.01	2.4	
Loc03	Shaler Munic Bldg	0.32	0.19	0.31	0.01	3.1	
Loc14	Churchill Munic Bldg	0.58	0.41	0.56	0.02	3.4	
KAGC	Pittsburgh Allegheny Cty	0.51	0.26	0.48	0.03	5.9	
Loc08	AC Health Dept Bldg	0.46	0.32	0.42	0.04	8.7	
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.00	---	---	---	---	Z
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc07	Greentree Munic Bldg	0.57	---	---	---	---	O
Loc15	Trafford Maint Bldg	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc21	Moon TWP	0.26	---	---	---	---	S
Loc22	North Fayette TWP	0.50	---	---	---	---	O

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	Z
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc29	Bell Acres Munic Bldg	0.02	---	---	---	---	ND
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND

Table 38. Summary of Individual RG Pairs for Event 7b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc19	Sandy Creek Eq Facility	0.15	0.12	0.17	-0.02	-13.3	
Loc10	PWSA-Highland Park	0.14	0.10	0.15	-0.01	-7.1	
Loc16	Castle Shannon	0.19	0.11	0.20	-0.01	-5.3	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.09	0.05	0.09	0.00	0.0	
Loc03	Shaler Munic Bldg	0.12	0.08	0.12	0.00	0.0	
Loc05	Upper St. Clair	0.20	0.13	0.20	0.00	0.0	
Loc06	Carnegie Transit Time	0.34	0.21	0.34	0.00	0.0	
Loc08	AC Health Dept Bldg	0.18	0.11	0.18	0.00	0.0	
Loc11	M-46 Access Shaft	0.23	0.12	0.23	0.00	0.0	
Loc17	Chartiers Pump Station	0.33	0.20	0.33	0.00	0.0	
Loc20	Gascola Eq Facility	0.23	0.14	0.23	0.00	0.0	
Loc22	North Fayette TWP	0.11	0.07	0.11	0.00	0.0	
Loc28	Plum Municipal Bldg	0.19	0.14	0.19	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.10	0.06	0.10	0.00	0.0	
Loc33	Richland TWP	0.11	0.06	0.11	0.00	0.0	
Loc12	Baldwin	0.22	0.10	0.21	0.01	4.5	
Loc14	Churchill Munic Bldg	0.20	0.11	0.19	0.01	5.0	
03049500	Allegheny River at Natrona	0.06	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.06	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.12	---	---	---	---	O
Loc01	PWSA-Montana St.	ND	---	---	---	---	ND
Loc02	ALCOSAN WWTP Lab	0.27	---	---	---	---	O
Loc04	Kennedy Twp PS	ND	---	---	---	---	ND
Loc07	Greentree Munic Bldg	0.22	---	---	---	---	U
Loc09	Univ of Pittsburgh	0.14	---	---	---	---	U
Loc13	M-59 Access Shaft	0.08	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc15	Trafford Maint Bldg	0.00	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc21	Moon TWP	0.00	---	---	---	---	Z
Loc23	Clinton Munic Bldg	0.01	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.05	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.03	---	---	---	---	MSTT
Loc27	Marshall TWP	ND	---	---	---	---	ND
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	Z
Loc30	McCandless Twn Hall	ND	---	---	---	---	ND
Loc32	Arnold	0.08	---	---	---	---	MSTT

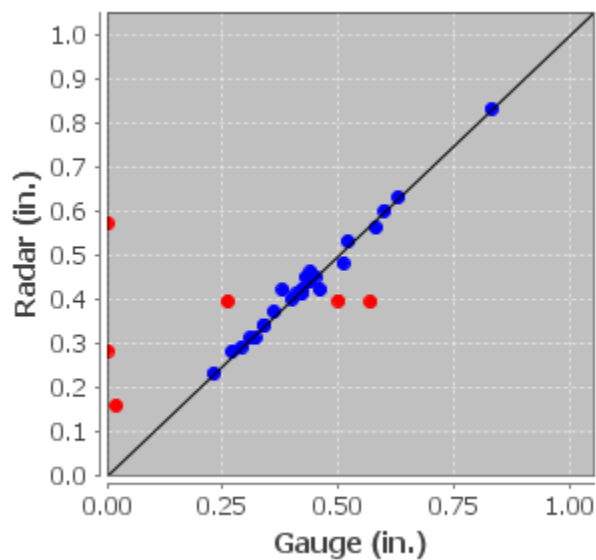


Figure 28. Scatter Plot of RG Pairs for Event 7a

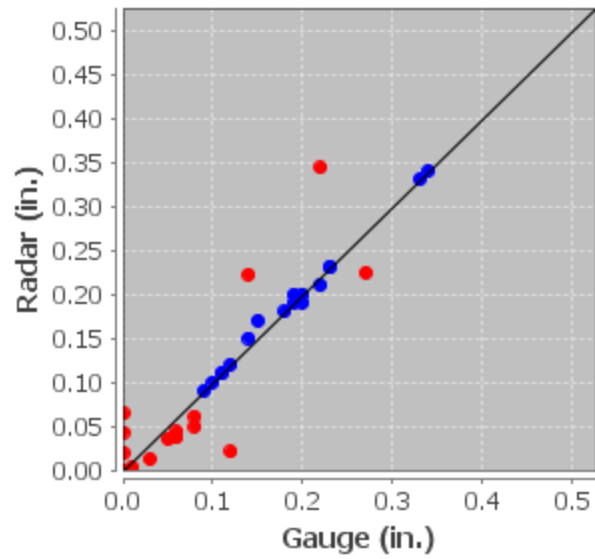


Figure 29. Scatter Plot of RG Pairs for Event 7b

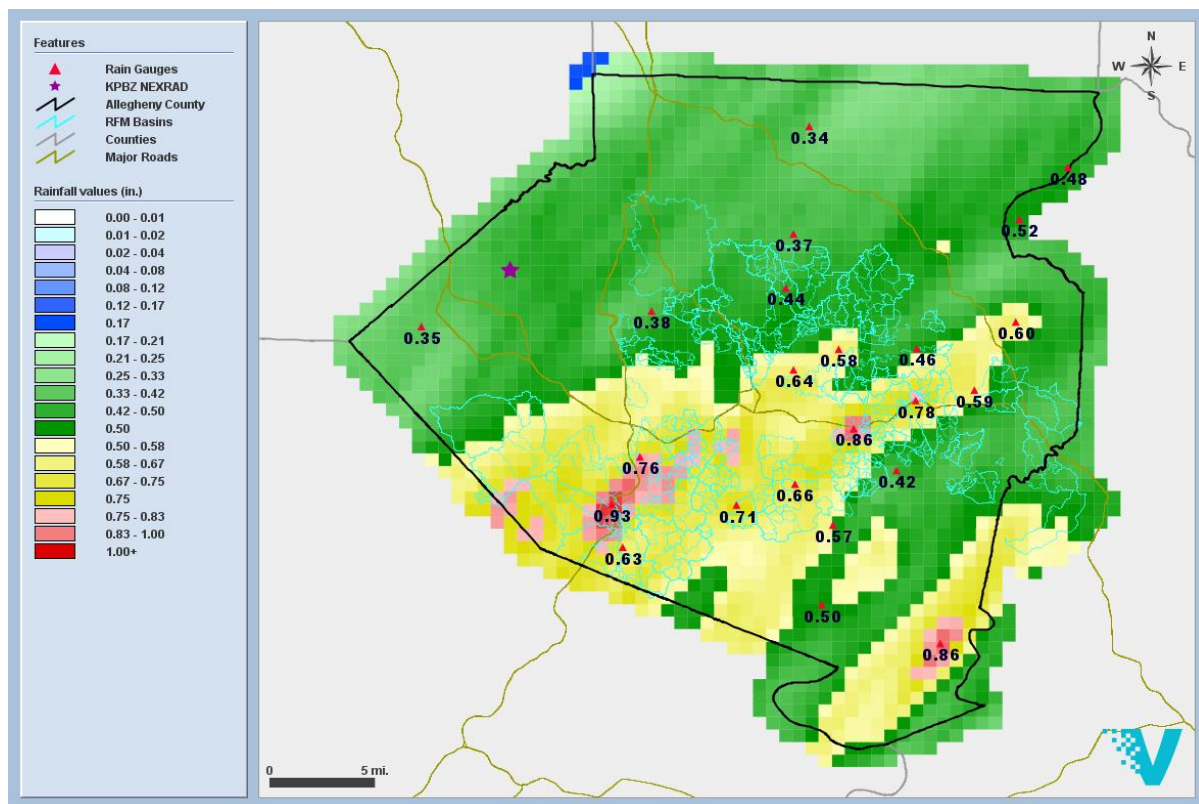


Figure 30. GARR Storm Total for Event 7

Table 39. Depth Duration Frequency Analyses for Event 7

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.569	161158	2019-08-28 04:25	<1 yr.
30 minutes	0.745	161158	2019-08-28 04:30	<1 yr.
1 hour	0.845	161158	2019-08-28 04:45	<1 yr.
2 hour	0.853	161158	2019-08-28 04:55	<1 yr.
3 hour	0.853	161158	2019-08-28 04:55	<1 yr.
6 hour	0.935	136147	2019-08-28 08:00	<1 yr.
12 hour	0.935	136147	2019-08-28 11:00	<1 yr.

Appendices

[Appendix A](#) - Gauge Performance Exclusion Table
[Appendix B](#) - Gauge Statistical Criteria Exclusion Table
[Appendix C](#) - Event 1 (2019-08-07) CDPs
[Appendix D](#) - Event 2 (2019-08-13) CDPs
[Appendix E](#) - Event 3 (2019-08-15) CDPs
[Appendix F](#) - Event 4 (2019-08-20) CDPs
[Appendix G](#) - Event 5 (2019-08-22) CDPs
[Appendix H](#) - Event 6 (2019-08-27) CDPs
[Appendix I](#) - Event 7 (2019-08-28) CDPs

Appendix A - Gauge Performance Exclusion Table

Reason	Explanation
Clog (C)	Gauge appeared to be clogged
Zero (Z)	Gauge did not report any rainfall while radar rainfall estimates reported significant rainfall
Stop (S)	Gauge appeared to stop reporting rainfall while radar rainfall estimates reported significant rainfall
Over (O)	Gauge appeared to significantly over-report rainfall as compared to radar rainfall estimates and surrounding gauges (e.g. anomalously high rainfall values caused by field calibration, data transmission error, or switch malfunctions)
Under (U)	Gauge appeared to significantly under-report as compared to radar rainfall estimates and surrounding Gauges (e.g. half-tipper)
Sync (SY)	Gauge appeared to be reporting out-of-sync with the radar rainfall estimates
Frozen/Melt (F/M)	Gauge not reporting properly due to frozen or melting precipitation
Other (T)	Combination of multiple reasons
No Data (ND)	Gauge reported "no data" for a significant amount of time

Event #	E1a	E1b	E1c	E1d	E2a
Event Date	2019-08-07	2019-08-07	2019-08-07	2019-08-07	2019-08-13
Start Time (EDT)	2019-08-06 12:05	2019-08-06 21:35	2019-08-06 23:35	2019-08-07 01:05	2019-08-12 19:05
End Time (EDT)	2019-08-06 21:30	2019-08-06 23:30	2019-08-07 01:00	2019-08-07 04:00	2019-08-13 08:00
Loc01					
Loc02					
Loc03					
Loc04		U			
Loc05					
Loc06					
Loc07					
Loc08					
Loc09					
Loc10	ND	ND	ND	ND	
Loc11					
Loc12					
Loc13	ND	ND	ND	ND	ND
Loc14					
Loc15					
Loc16					
Loc17					
Loc18	ND	ND	ND	ND	ND
Loc19					
Loc20					
Loc21					
Loc22					
Loc23					
Loc24					
Loc25	ND	ND	ND	ND	ND

Event #	E1a	E1b	E1c	E1d	E2a
Event Date	2019-08-07	2019-08-07	2019-08-07	2019-08-07	2019-08-13
Start Time (EDT)	2019-08-06 12:05	2019-08-06 21:35	2019-08-06 23:35	2019-08-07 01:05	2019-08-12 19:05
End Time (EDT)	2019-08-06 21:30	2019-08-06 23:30	2019-08-07 01:00	2019-08-07 04:00	2019-08-13 08:00
Loc26					
Loc27					
Loc28					
Loc29					
Loc30					
Loc31					
Loc32					
Loc33					
KAGC					
KPIT					
03049500		Z			
03085734					

Event #	E2b	E2c	E2d	E2e	E2f
Event Date	2019-08-13	2019-08-13	2019-08-13	2019-08-13	2019-08-13
Start Time (EDT)	2019-08-13 08:05	2019-08-13 14:05	2019-08-13 15:25	2019-08-13 16:25	2019-08-13 17:20
End Time (EDT)	2019-08-13 14:00	2019-08-13 15:20	2019-08-13 16:20	2019-08-13 17:15	2019-08-13 22:00
Loc01					
Loc02					
Loc03					
Loc04			U		
Loc05			U		
Loc06					
Loc07					
Loc08					
Loc09					
Loc10					
Loc11					
Loc12					
Loc13	ND	ND	ND	ND	ND
Loc14					
Loc15					
Loc16					
Loc17					
Loc18	ND	ND	ND	ND	ND
Loc19					
Loc20					
Loc21					
Loc22					
Loc23					

Event #	E2b	E2c	E2d	E2e	E2f
Event Date	2019-08-13	2019-08-13	2019-08-13	2019-08-13	2019-08-13
Start Time (EDT)	2019-08-13 08:05	2019-08-13 14:05	2019-08-13 15:25	2019-08-13 16:25	2019-08-13 17:20
End Time (EDT)	2019-08-13 14:00	2019-08-13 15:20	2019-08-13 16:20	2019-08-13 17:15	2019-08-13 22:00
Loc24					
Loc25	ND	ND	ND	ND	ND
Loc26					
Loc27					
Loc28					
Loc29					
Loc30					
Loc31			O		
Loc32					
Loc33					
KAGC		O	U	O	
KPIT		U	U	O	
03049500	S				U
03085734					

Event #	E3	E4a	E4b	E4c	E4d
Event Date	2019-08-15	2019-08-20	2019-08-20	2019-08-20	2019-08-20
Start Time (EDT)	2019-08-15 11:05	2019-08-20 20:05	2019-08-21 00:05	2019-08-21 01:35	2019-08-21 03:35
End Time (EDT)	2019-08-15 21:00	2019-08-21 00:00	2019-08-21 01:30	2019-08-21 03:30	2019-08-21 07:00
Loc01	U	ND	ND	ND	ND
Loc02	Z	Z			
Loc03					
Loc04		ND	ND	ND	ND
Loc05	U				
Loc06					
Loc07	U				
Loc08					
Loc09			U		
Loc10		U			
Loc11					
Loc12					
Loc13	ND	ND	ND	ND	ND
Loc14		U			
Loc15					
Loc16					
Loc17					
Loc18	ND	ND	ND	ND	ND
Loc19					
Loc20					
Loc21		S			O
Loc22		O			
Loc23					

Event #	E3	E4a	E4b	E4c	E4d
Event Date	2019-08-15	2019-08-20	2019-08-20	2019-08-20	2019-08-20
Start Time (EDT)	2019-08-15 11:05	2019-08-20 20:05	2019-08-21 00:05	2019-08-21 01:35	2019-08-21 03:35
End Time (EDT)	2019-08-15 21:00	2019-08-21 00:00	2019-08-21 01:30	2019-08-21 03:30	2019-08-21 07:00
Loc24					
Loc25	ND	ND	ND	ND	ND
Loc26					
Loc27		ND	ND	ND	ND
Loc28					
Loc29		ND			Z
Loc30		ND	ND	ND	ND
Loc31					
Loc32					
Loc33					
KAGC					
KPIT					
03049500					
03085734					

Event #	E5a	E5b	E6a	E6b	E7a
Event Date	2019-08-22	2019-08-22	2019-08-27	2019-08-27	2019-08-28
Start Time (EDT)	2019-08-22 11:05	2019-08-22 16:05	2019-08-26 19:05	2019-08-27 04:35	2019-08-27 23:05
End Time (EDT)	2019-08-22 16:00	2019-08-23 03:00	2019-08-27 04:30	2019-08-27 10:00	2019-08-28 05:00
Loc01	ND	ND	ND	ND	ND
Loc02	Z		Z	Z	Z
Loc03					
Loc04	ND	ND	ND	ND	ND
Loc05			U		
Loc06					
Loc07					O
Loc08					
Loc09					
Loc10					
Loc11					
Loc12					
Loc13	ND	ND	U		
Loc14					
Loc15			Z	Z	ND
Loc16					
Loc17					
Loc18	ND	ND	ND	ND	ND
Loc19					
Loc20					
Loc21					S
Loc22					O
Loc23					

Event #	E5a	E5b	E6a	E6b	E7a
Event Date	2019-08-22	2019-08-22	2019-08-27	2019-08-27	2019-08-28
Start Time (EDT)	2019-08-22 11:05	2019-08-22 16:05	2019-08-26 19:05	2019-08-27 04:35	2019-08-27 23:05
End Time (EDT)	2019-08-22 16:00	2019-08-23 03:00	2019-08-27 04:30	2019-08-27 10:00	2019-08-28 05:00
Loc24					
Loc25	Z	ND			Z
Loc26					
Loc27	ND	ND	ND	ND	ND
Loc28					
Loc29		ND	ND	ND	ND
Loc30	ND	ND	ND	ND	ND
Loc31					
Loc32					
Loc33					
KAGC			U	T	
KPIT				T	
03049500	Z		U	T	
03085734				T	

Event #	<u>E7b</u>
Event Date	2019-08-28
Start Time (EDT)	2019-08-28 05:05
End Time (EDT)	2019-08-28 11:00
Loc01	ND
Loc02	O
Loc03	
Loc04	ND
Loc05	
Loc06	
Loc07	U
Loc08	
Loc09	U
Loc10	
Loc11	
Loc12	
Loc13	
Loc14	
Loc15	ND
Loc16	
Loc17	
Loc18	ND
Loc19	
Loc20	
Loc21	Z
Loc22	
Loc23	
Loc24	
Loc25	ND

Event #	E7b
Event Date	2019-08-28
Start Time (EDT)	2019-08-28 05:05
End Time (EDT)	2019-08-28 11:00
Loc26	
Loc27	ND
Loc28	
Loc29	Z
Loc30	ND
Loc31	
Loc32	
Loc33	
KAGC	
KPIT	O
03049500	
03085734	

Appendix B - Gauge Statistical Criteria Exclusion Table

Reason	Explanation
Minimum Storm Total Threshold (MSTT)	The radar or gauge cumulative sum during the event or sub-event period was less than MSTT
Outlier Based on Mean Field Bias (OMFB)	The RG pair bias (G/R) was greater than three standard deviations from the mean bias (e.g. $G \gg R$)
Outlier Based on Average Difference (OAD)	The RG pair average difference ($(G-R)/G$) was greater than three standard deviations from the mean average difference (e.g. $G \ll R$)

Event #	E1a	E1b	E1c	E1d	E2a
Event Date	2019-08-07	2019-08-07	2019-08-07	2019-08-07	2019-08-13
Start Time (EDT)	2019-08-06 12:05	2019-08-06 21:35	2019-08-06 23:35	2019-08-07 01:05	2019-08-12 19:05
End Time (EDT)	2019-08-06 21:30	2019-08-06 23:30	2019-08-07 01:00	2019-08-07 04:00	2019-08-13 08:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc01	MSTT		MSTT	MSTT	MSTT
Loc02	MSTT	MSTT		MSTT	MSTT
Loc03	MSTT			MSTT	MSTT
Loc04	MSTT			MSTT	MSTT
Loc05	MSTT	MSTT		MSTT	MSTT
Loc06	MSTT	MSTT		MSTT	MSTT
Loc07	MSTT	MSTT		MSTT	MSTT
Loc08	MSTT	MSTT		MSTT	MSTT
Loc09	MSTT	MSTT		MSTT	MSTT
Loc10					MSTT
Loc11	MSTT	MSTT		MSTT	MSTT
Loc12	MSTT	MSTT		MSTT	MSTT
Loc13					
Loc14	MSTT	MSTT		MSTT	MSTT
Loc15	MSTT	MSTT			MSTT
Loc16	MSTT	MSTT		MSTT	MSTT
Loc17	MSTT	MSTT		MSTT	MSTT
Loc18					
Loc19	MSTT	MSTT			MSTT
Loc20	MSTT	MSTT			MSTT
Loc21	MSTT			MSTT	
Loc22	MSTT		MSTT	MSTT	MSTT
Loc23			MSTT	MSTT	
Loc24	MSTT	MSTT			MSTT

Event #	E1a	E1b	E1c	E1d	E2a
Event Date	2019-08-07	2019-08-07	2019-08-07	2019-08-07	2019-08-13
Start Time (EDT)	2019-08-06 12:05	2019-08-06 21:35	2019-08-06 23:35	2019-08-07 01:05	2019-08-12 19:05
End Time (EDT)	2019-08-06 21:30	2019-08-06 23:30	2019-08-07 01:00	2019-08-07 04:00	2019-08-13 08:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc25					
Loc26	MSTT	MSTT			MSTT
Loc27		MSTT	MSTT	MSTT	
Loc28		MSTT			MSTT
Loc29			MSTT	MSTT	
Loc30		MSTT	MSTT	MSTT	
Loc31	MSTT			MSTT	MSTT
Loc32	MSTT	MSTT			MSTT
Loc33		MSTT	MSTT	MSTT	MSTT
KAGC	MSTT	MSTT		MSTT	MSTT
KPIT	MSTT			MSTT	MSTT
03049500	MSTT			MSTT	MSTT
03085734	MSTT			MSTT	MSTT

Event #	E2b	E2c	E2d	E2e	E2f
Event Date	2019-08-13	2019-08-13	2019-08-13	2019-08-13	2019-08-13
Start Time (EDT)	2019-08-13 08:05	2019-08-13 14:05	2019-08-13 15:25	2019-08-13 16:25	2019-08-13 17:20
End Time (EDT)	2019-08-13 14:00	2019-08-13 15:20	2019-08-13 16:20	2019-08-13 17:15	2019-08-13 22:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc01	MSTT		MSTT		
Loc02	MSTT		MSTT		MSTT
Loc03	MSTT	MSTT			
Loc04	MSTT				MSTT
Loc05				MSTT	MSTT
Loc06	MSTT				MSTT
Loc07	MSTT				MSTT
Loc08	MSTT	MSTT			MSTT
Loc09	MSTT				MSTT
Loc10	MSTT	MSTT			
Loc11	MSTT				MSTT
Loc12	MSTT				MSTT
Loc13					
Loc14	MSTT	MSTT			MSTT
Loc15	MSTT				MSTT
Loc16	MSTT			MSTT	MSTT
Loc17				MSTT	MSTT
Loc18					
Loc19	MSTT	MSTT			
Loc20	MSTT	MSTT			
Loc21	MSTT	MSTT			
Loc22	MSTT			MSTT	MSTT

Event #	E2b	E2c	E2d	E2e	E2f
Event Date	2019-08-13	2019-08-13	2019-08-13	2019-08-13	2019-08-13
Start Time (EDT)	2019-08-13 08:05	2019-08-13 14:05	2019-08-13 15:25	2019-08-13 16:25	2019-08-13 17:20
End Time (EDT)	2019-08-13 14:00	2019-08-13 15:20	2019-08-13 16:20	2019-08-13 17:15	2019-08-13 22:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc23	MSTT				MSTT
Loc24	MSTT			MSTT	MSTT
Loc25					
Loc26	MSTT	MSTT		MSTT	MSTT
Loc27		MSTT		MSTT	MSTT
Loc28	MSTT	MSTT			
Loc29	MSTT	MSTT		MSTT	MSTT
Loc30		MSTT		MSTT	MSTT
Loc31	MSTT	MSTT			
Loc32	MSTT	MSTT		MSTT	
Loc33		MSTT	MSTT	MSTT	MSTT
KAGC					MSTT
KPIT	MSTT				MSTT
03049500		MSTT	MSTT	MSTT	
03085734	MSTT				MSTT

Event #	E3	E4a	E4b	E4c	E4d
Event Date	2019-08-15	2019-08-20	2019-08-20	2019-08-20	2019-08-20
Start Time (EDT)	2019-08-15 11:05	2019-08-20 20:05	2019-08-21 00:05	2019-08-21 01:35	2019-08-21 03:35
End Time (EDT)	2019-08-15 21:00	2019-08-21 00:00	2019-08-21 01:30	2019-08-21 03:30	2019-08-21 07:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc01					
Loc02			MSTT	MSTT	MSTT
Loc03			MSTT	MSTT	MSTT
Loc04					
Loc05		MSTT			MSTT
Loc06			MSTT		MSTT
Loc07					MSTT
Loc08					MSTT
Loc09					MSTT
Loc10					MSTT
Loc11			MSTT		MSTT
Loc12		MSTT			MSTT
Loc13					
Loc14			MSTT		MSTT
Loc15		MSTT	MSTT		MSTT
Loc16			MSTT		MSTT
Loc17			MSTT		MSTT
Loc18					
Loc19					MSTT
Loc20			MSTT		MSTT
Loc21	MSTT		MSTT	MSTT	
Loc22			MSTT	MSTT	MSTT

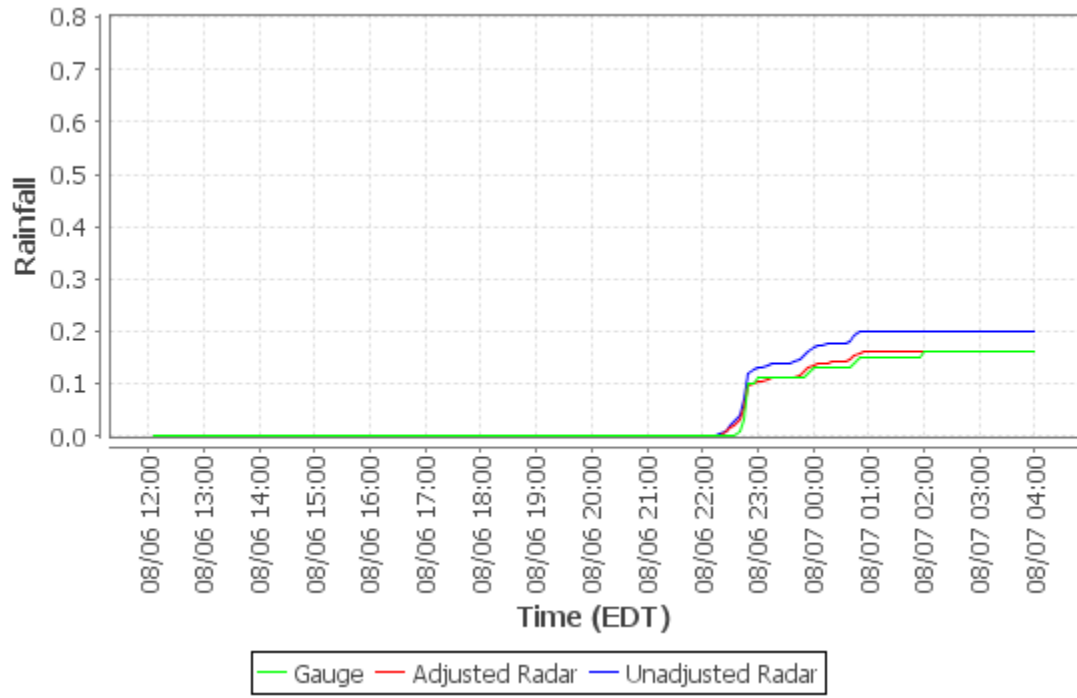
Event #	E3	E4a	E4b	E4c	E4d
Event Date	2019-08-15	2019-08-20	2019-08-20	2019-08-20	2019-08-20
Start Time (EDT)	2019-08-15 11:05	2019-08-20 20:05	2019-08-21 00:05	2019-08-21 01:35	2019-08-21 03:35
End Time (EDT)	2019-08-15 21:00	2019-08-21 00:00	2019-08-21 01:30	2019-08-21 03:30	2019-08-21 07:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc23	MSTT		MSTT	MSTT	
Loc24	MSTT		MSTT		MSTT
Loc25					
Loc26	MSTT			MSTT	MSTT
Loc27					
Loc28	OAD		MSTT		MSTT
Loc29	MSTT		MSTT	MSTT	
Loc30	MSTT				
Loc31			MSTT	MSTT	MSTT
Loc32	MSTT			MSTT	MSTT
Loc33	MSTT		MSTT	MSTT	MSTT
KAGC		MSTT	MSTT		MSTT
KPIT			MSTT	MSTT	
03049500	MSTT		MSTT	MSTT	MSTT
03085734			MSTT	MSTT	MSTT

Event #	E5a	E5b	E6a	E7a	E7b
Event Date	2019-08-22	2019-08-22	2019-08-27	2019-08-28	2019-08-28
Start Time (EDT)	2019-08-22 11:05	2019-08-22 16:05	2019-08-26 19:05	2019-08-27 23:05	2019-08-28 05:05
End Time (EDT)	2019-08-22 16:00	2019-08-23 03:00	2019-08-27 04:30	2019-08-28 05:00	2019-08-28 11:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc01					
Loc02		MSTT			
Loc03	MSTT	MSTT			
Loc04					
Loc05		MSTT			
Loc06					
Loc07		MSTT			
Loc08		MSTT			
Loc09		MSTT			
Loc10		MSTT			
Loc11		MSTT			
Loc12		MSTT			
Loc13					MSTT
Loc14		MSTT			
Loc15		MSTT			
Loc16					
Loc17					
Loc18					
Loc19		MSTT			
Loc20		MSTT			
Loc21	MSTT	MSTT			
Loc22		MSTT			

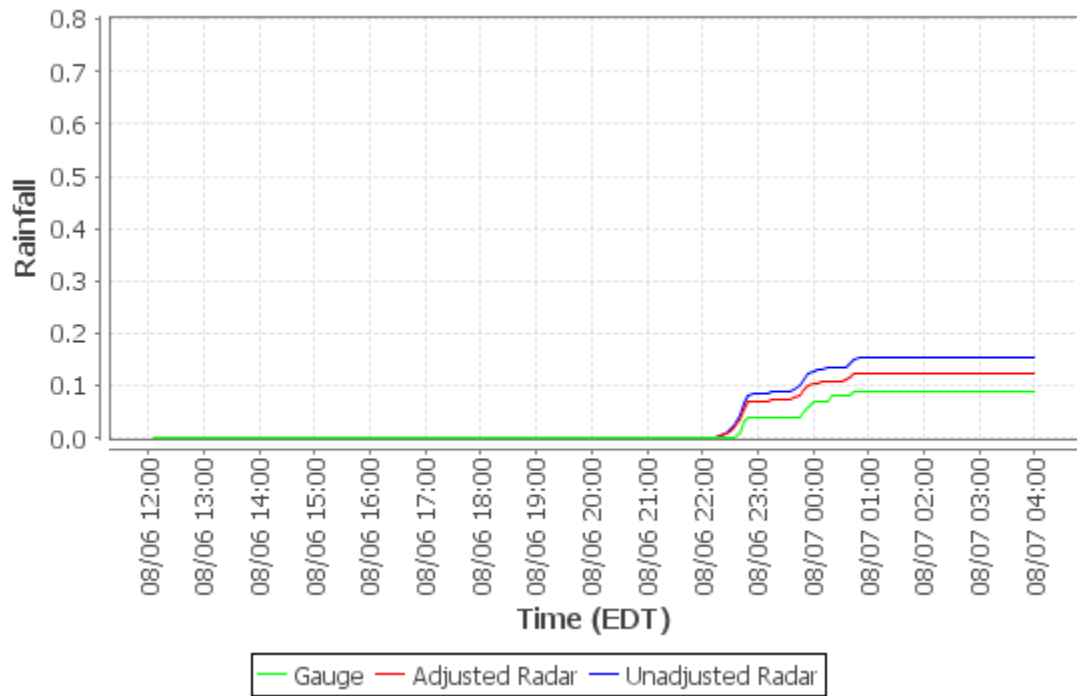
Event #	E5a	E5b	E6a	E7a	E7b
Event Date	2019-08-22	2019-08-22	2019-08-27	2019-08-28	2019-08-28
Start Time (EDT)	2019-08-22 11:05	2019-08-22 16:05	2019-08-26 19:05	2019-08-27 23:05	2019-08-28 05:05
End Time (EDT)	2019-08-22 16:00	2019-08-23 03:00	2019-08-27 04:30	2019-08-28 05:00	2019-08-28 11:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc23	MSTT	MSTT			MSTT
Loc24					MSTT
Loc25					
Loc26					MSTT
Loc27					
Loc28		MSTT			
Loc29	MSTT				
Loc30					
Loc31	MSTT	MSTT			
Loc32	OAD	MSTT			MSTT
Loc33	MSTT	MSTT			
KAGC					MSTT
KPIT	MSTT	MSTT	MSTT		
03049500		MSTT			MSTT
03085734	MSTT	MSTT			

Appendix C - Event 1 (2019-08-07) CDPs

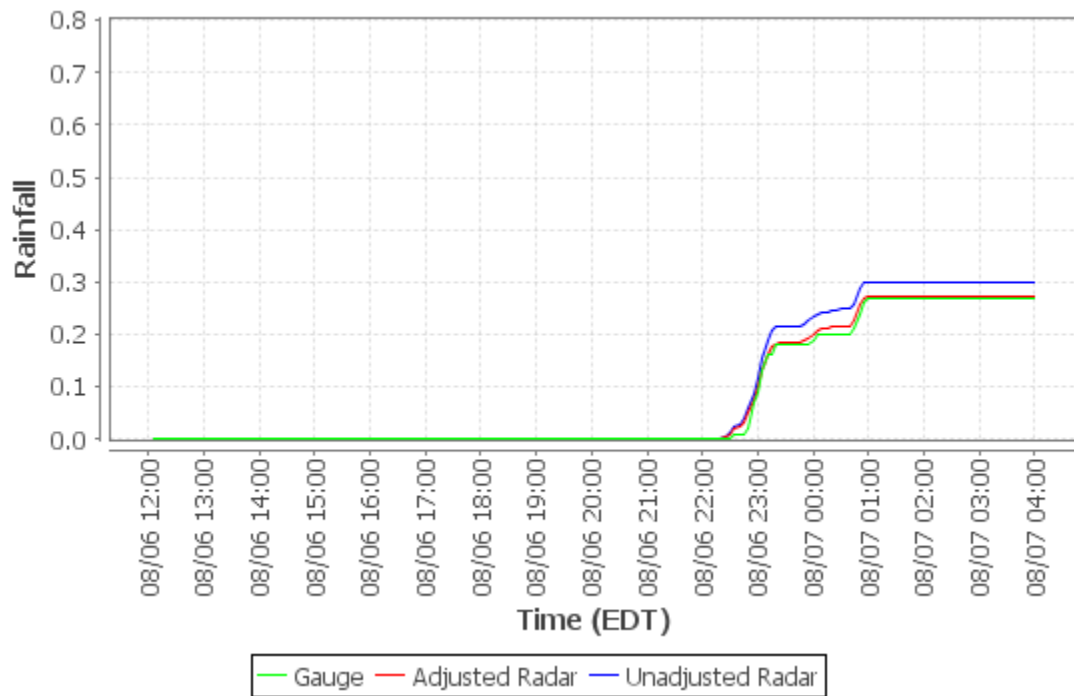
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



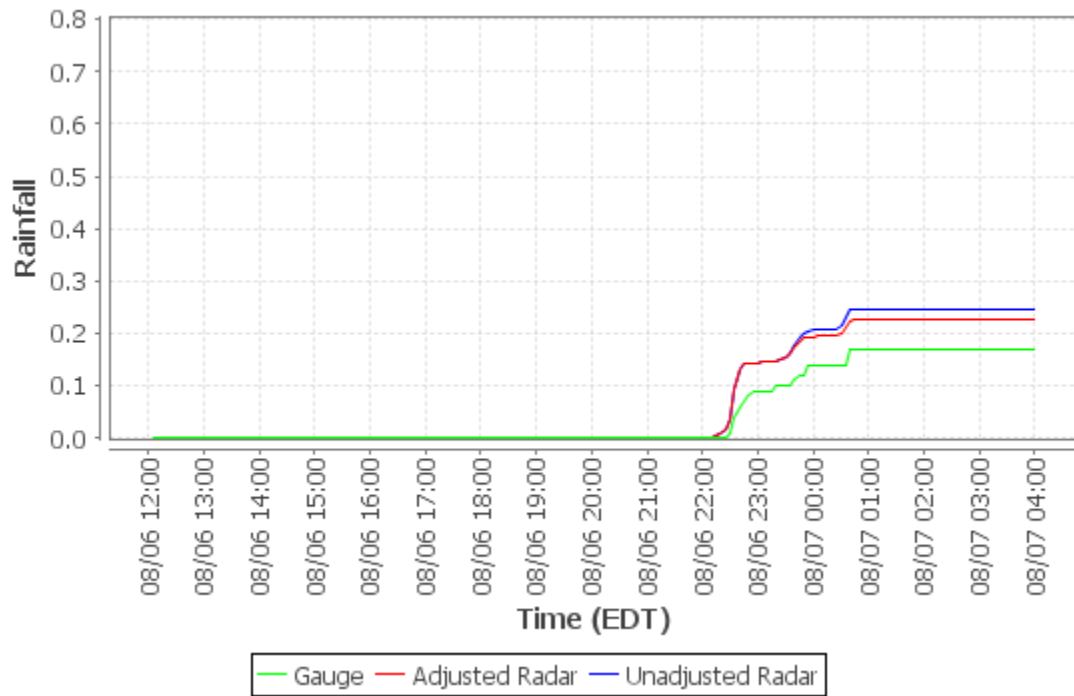
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



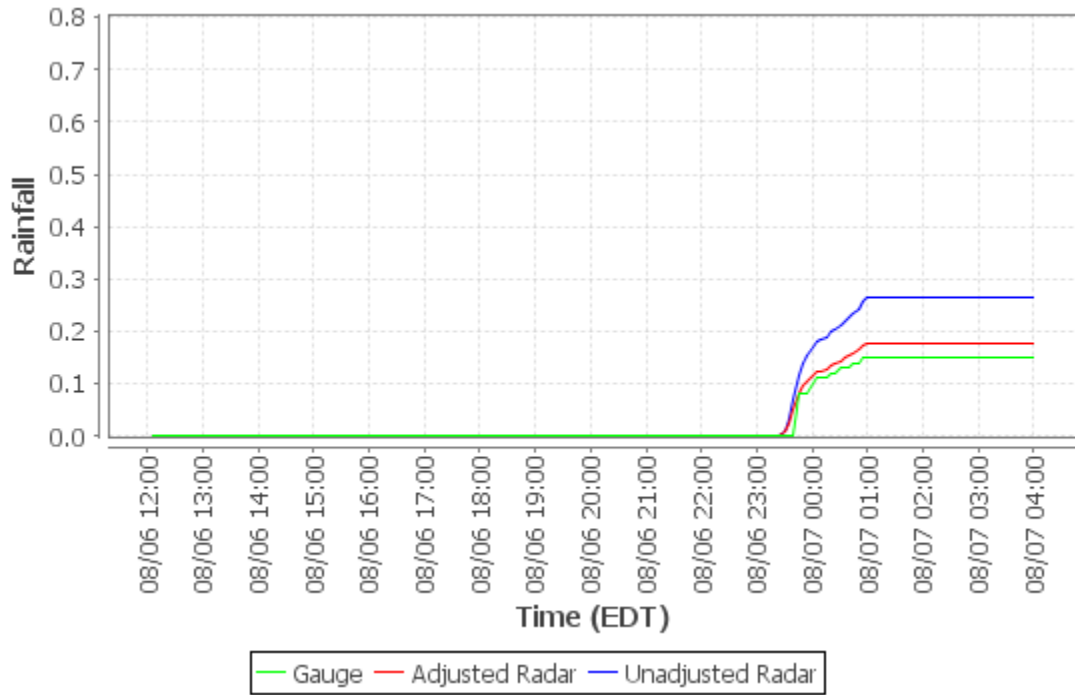
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



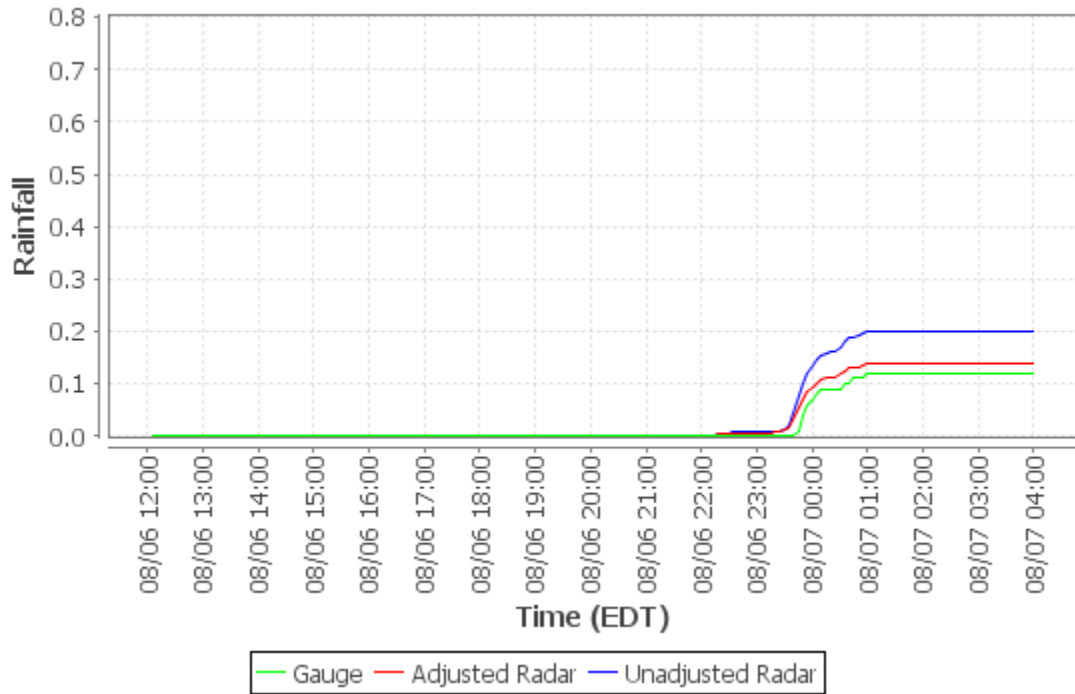
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



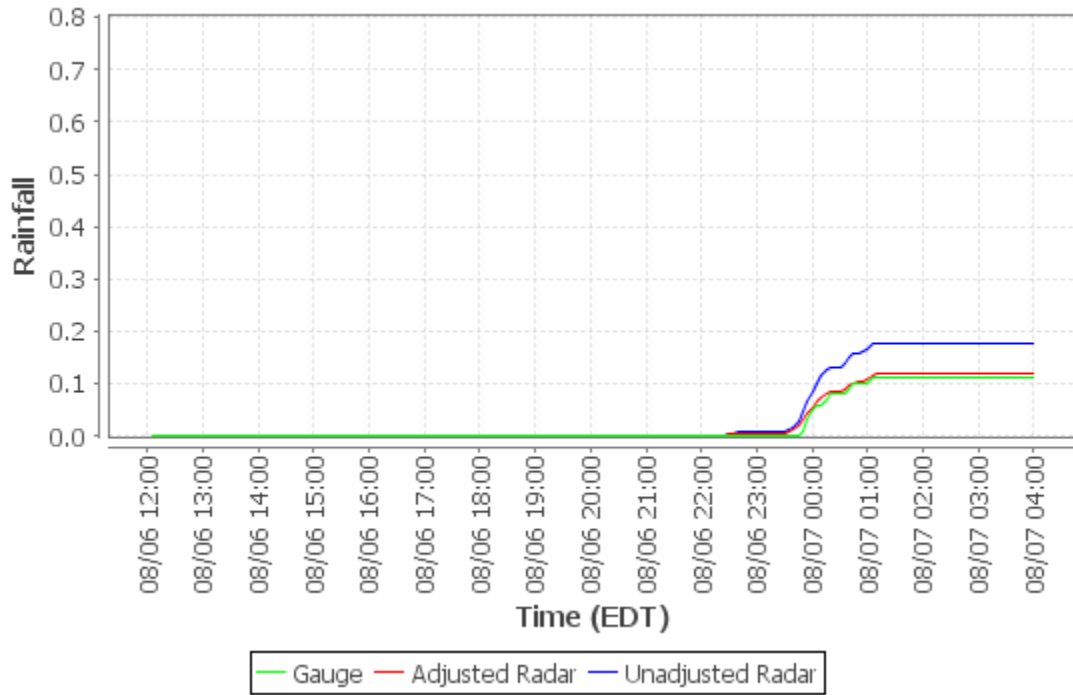
Cumulative Distribution Plot - Upper St. Clair (Loc05)



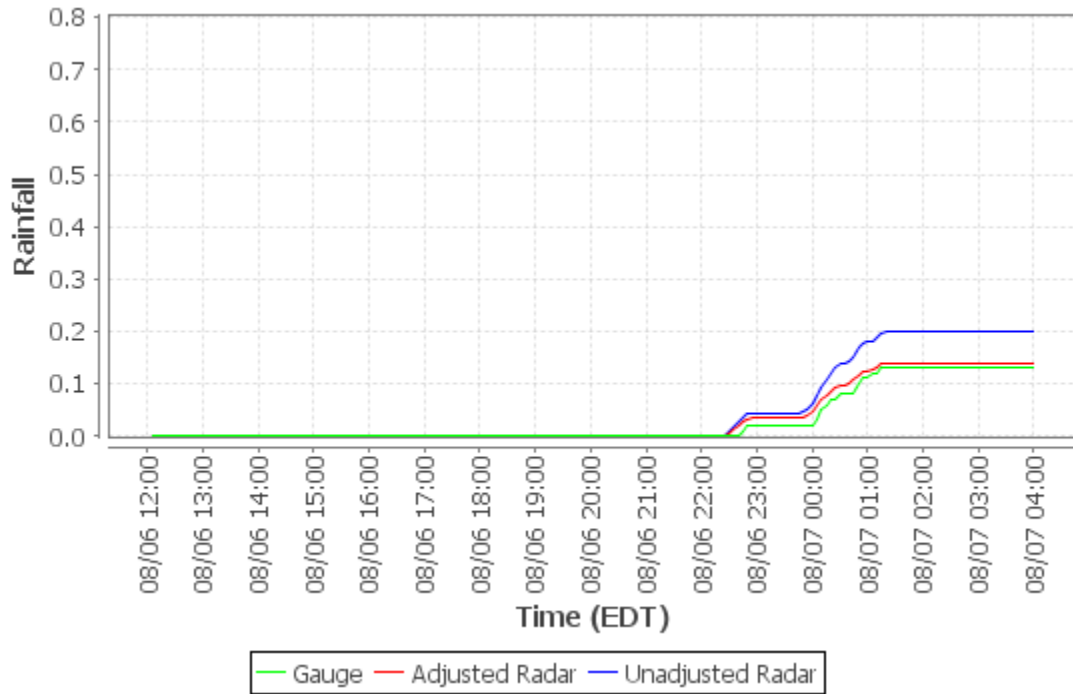
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



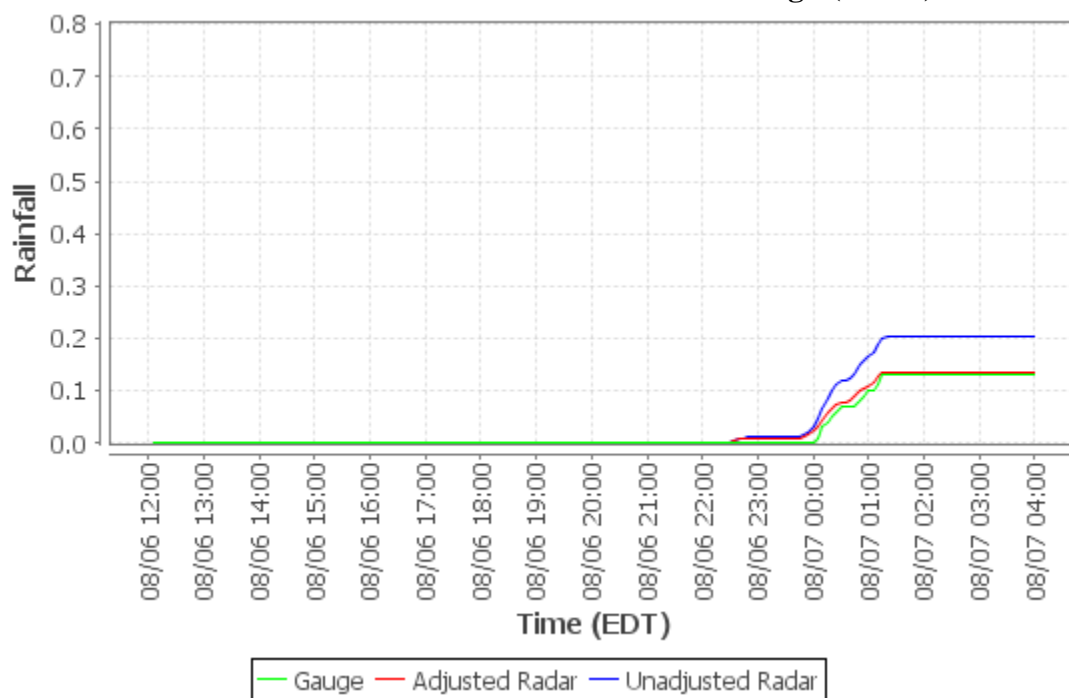
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



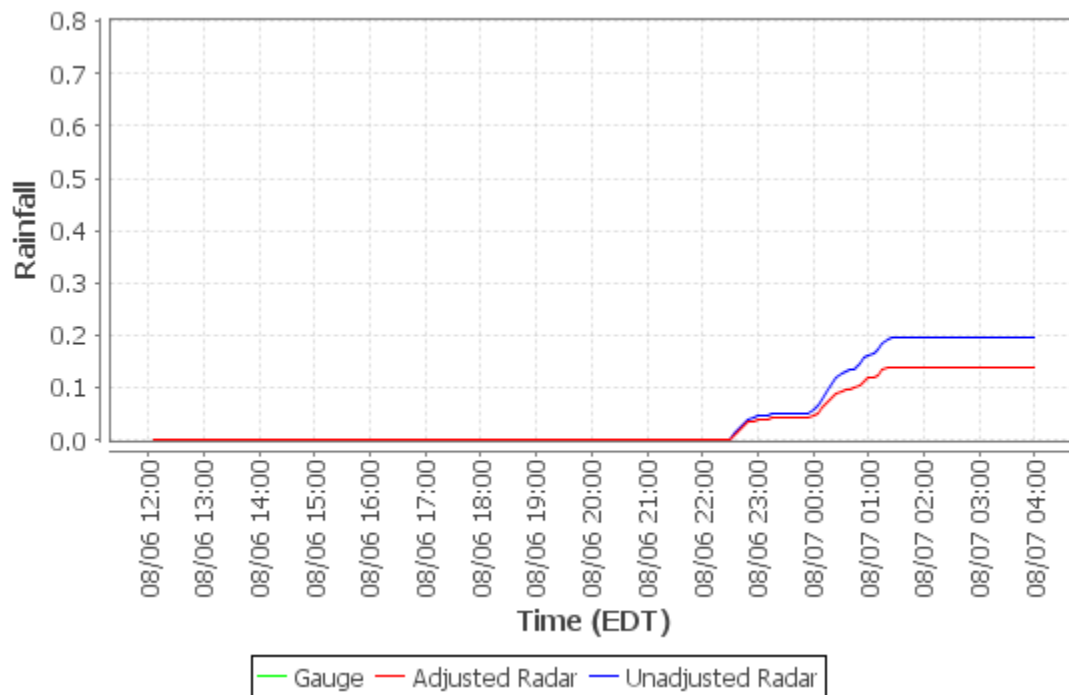
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



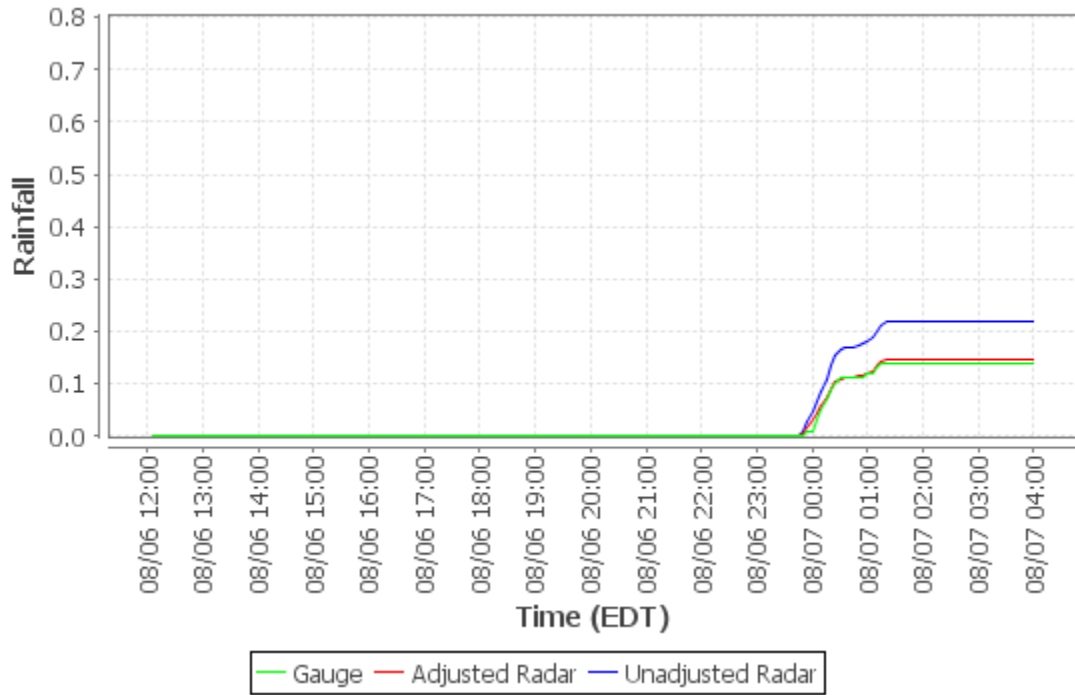
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



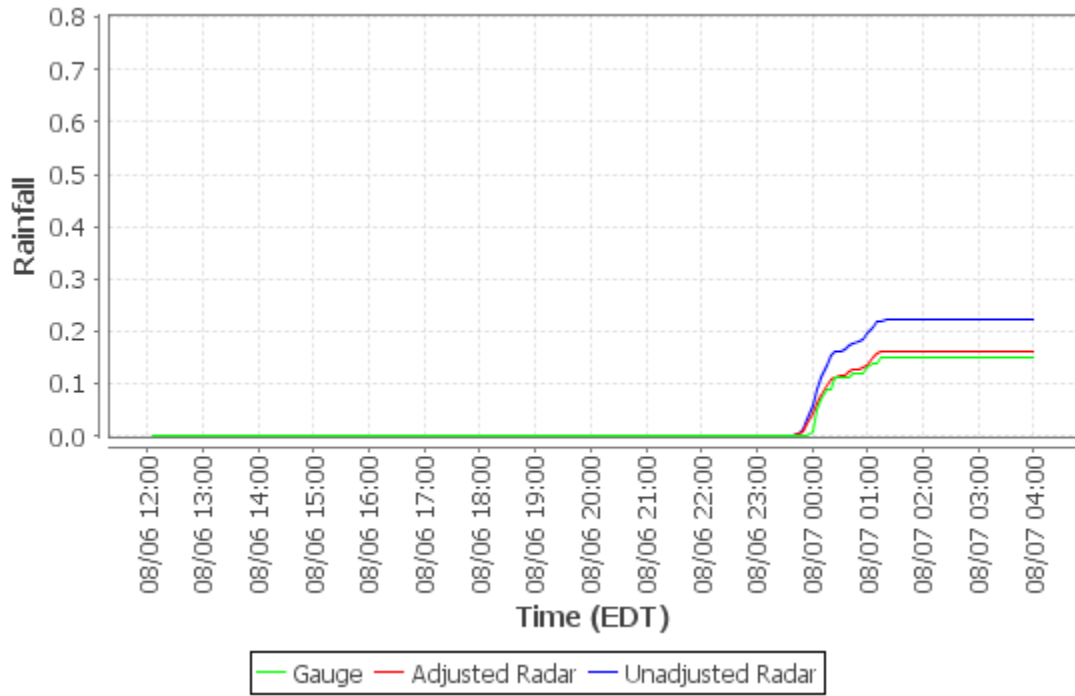
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



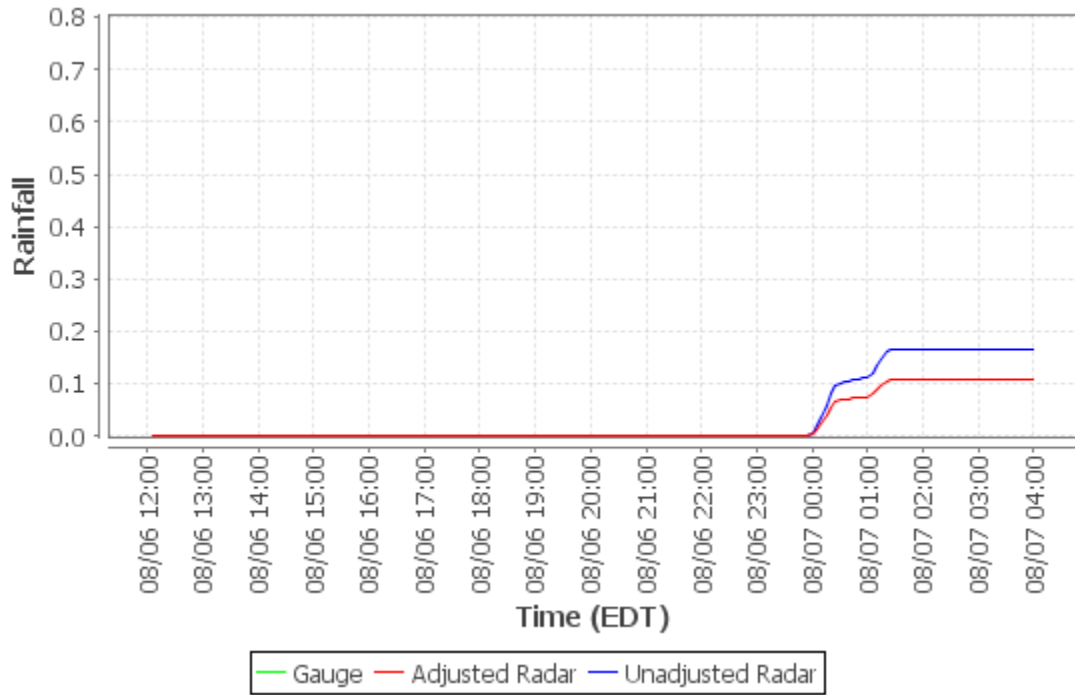
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



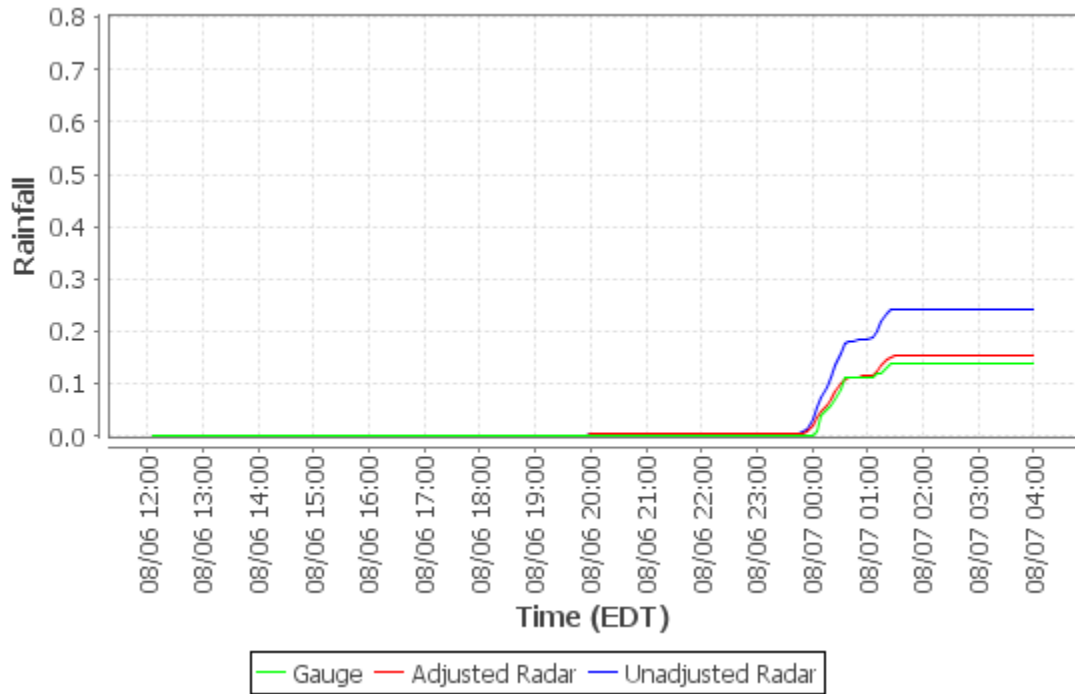
Cumulative Distribution Plot - Baldwin (Loc12)



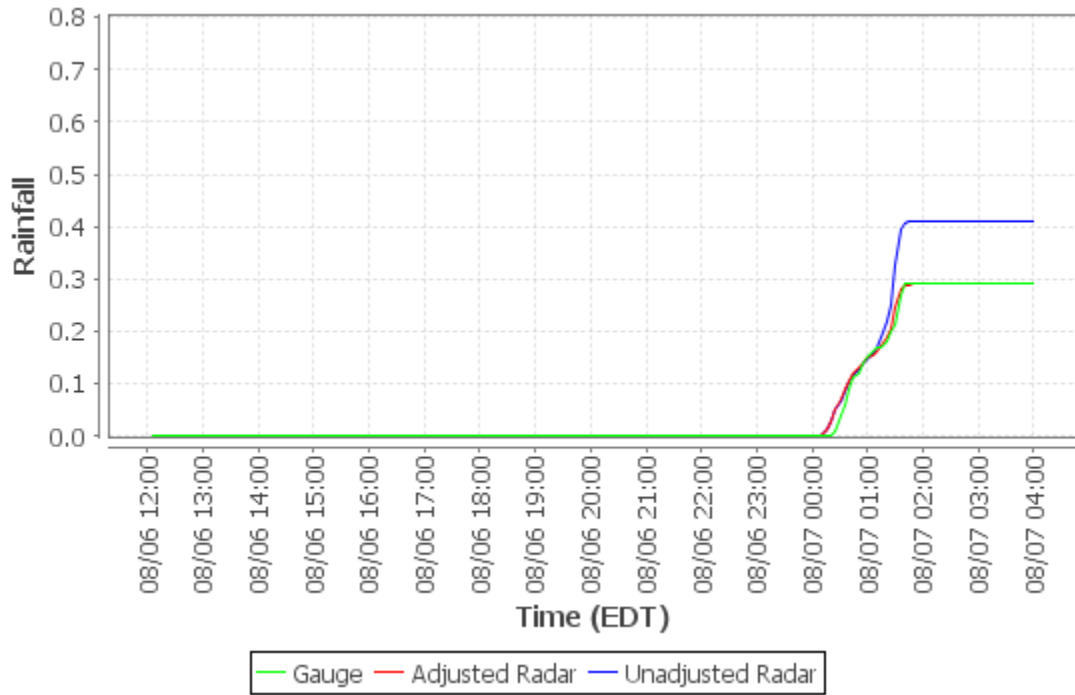
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



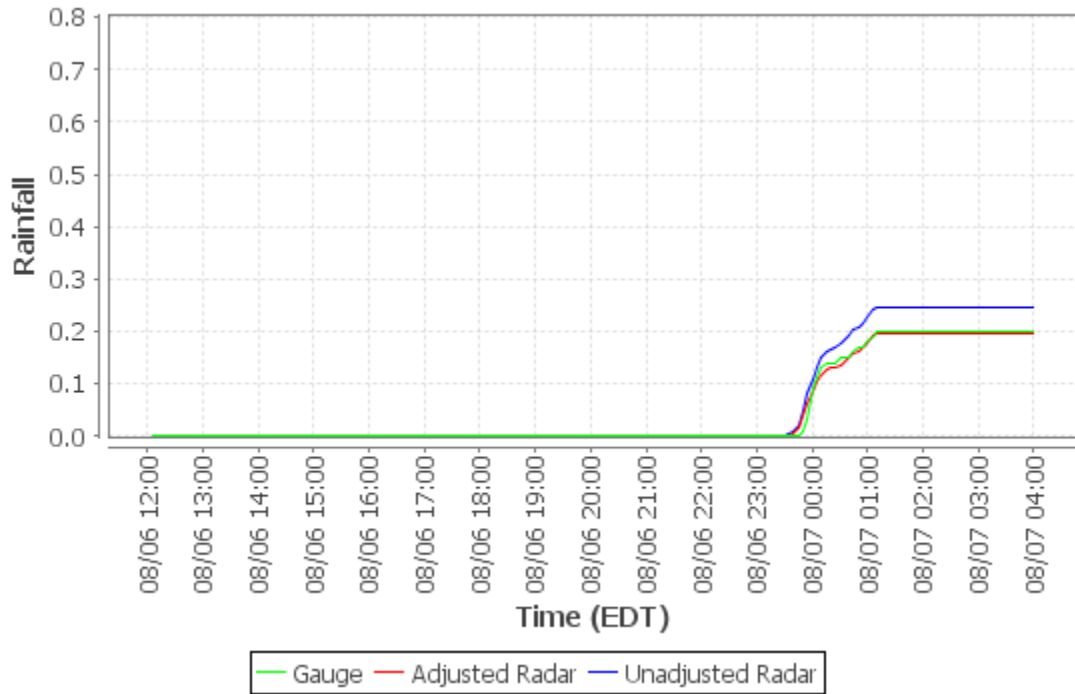
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



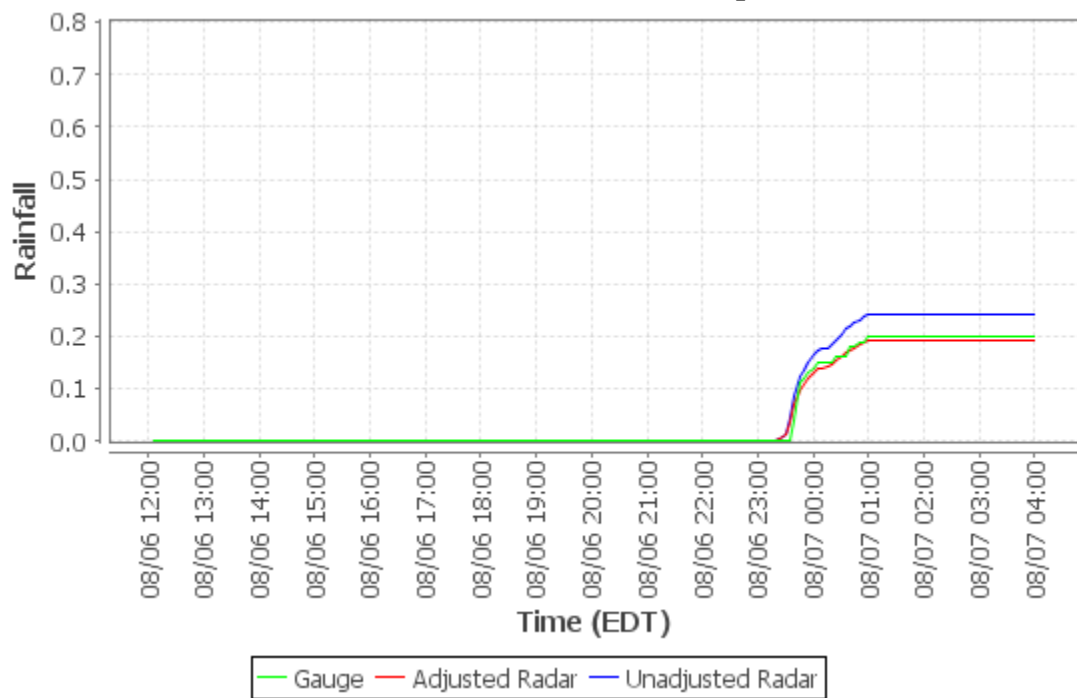
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



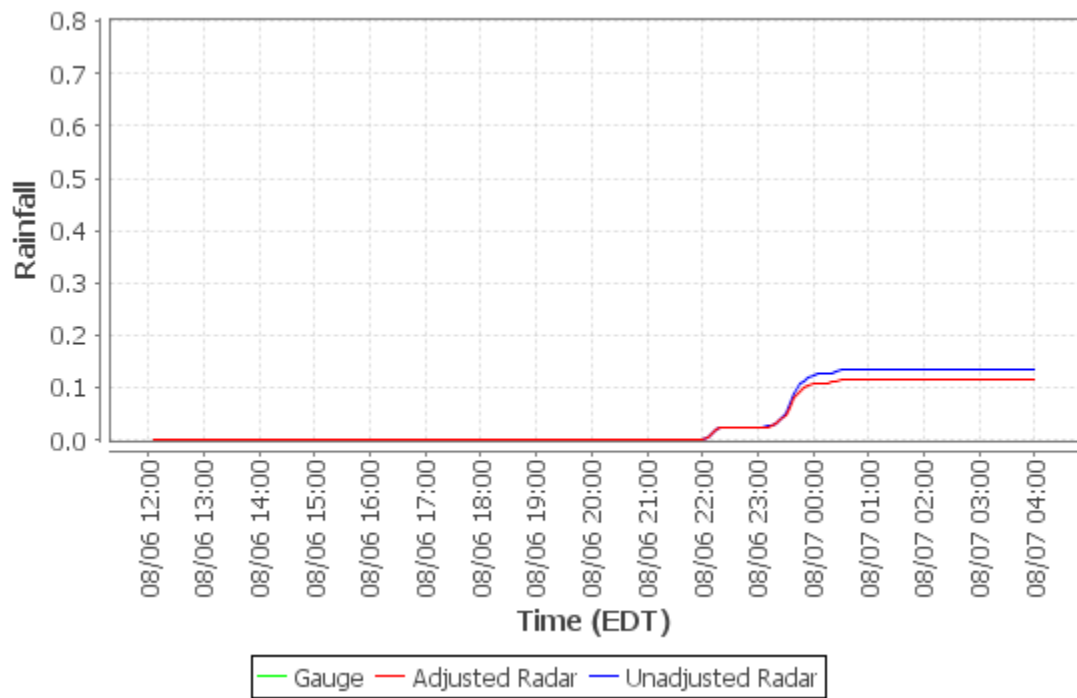
Cumulative Distribution Plot - Castle Shannon (Loc16)



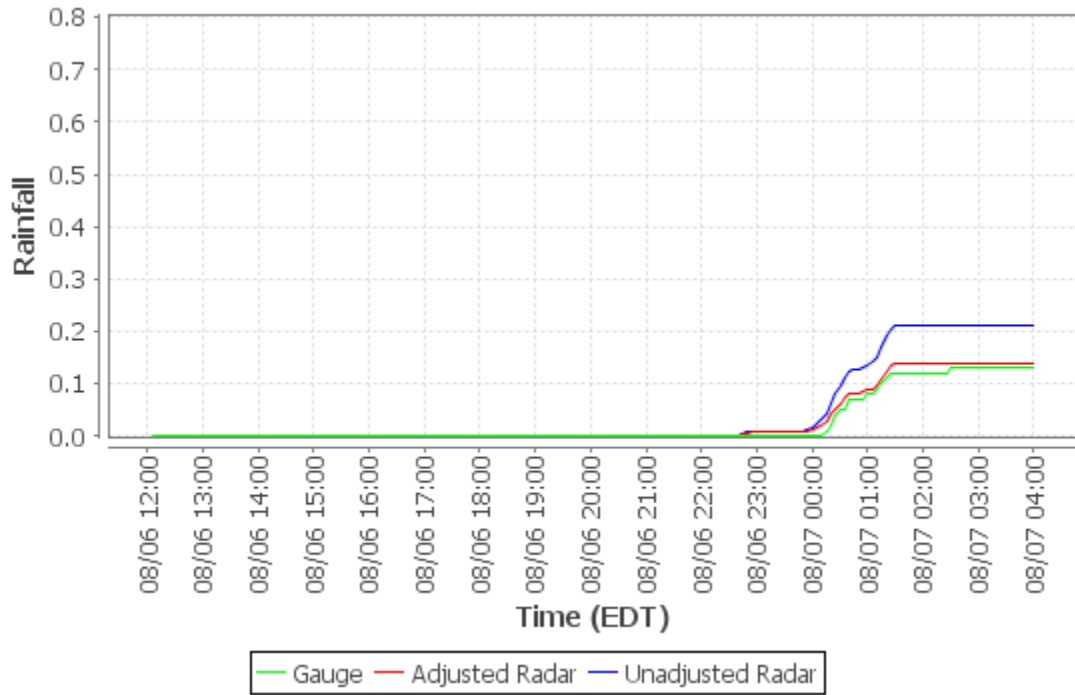
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



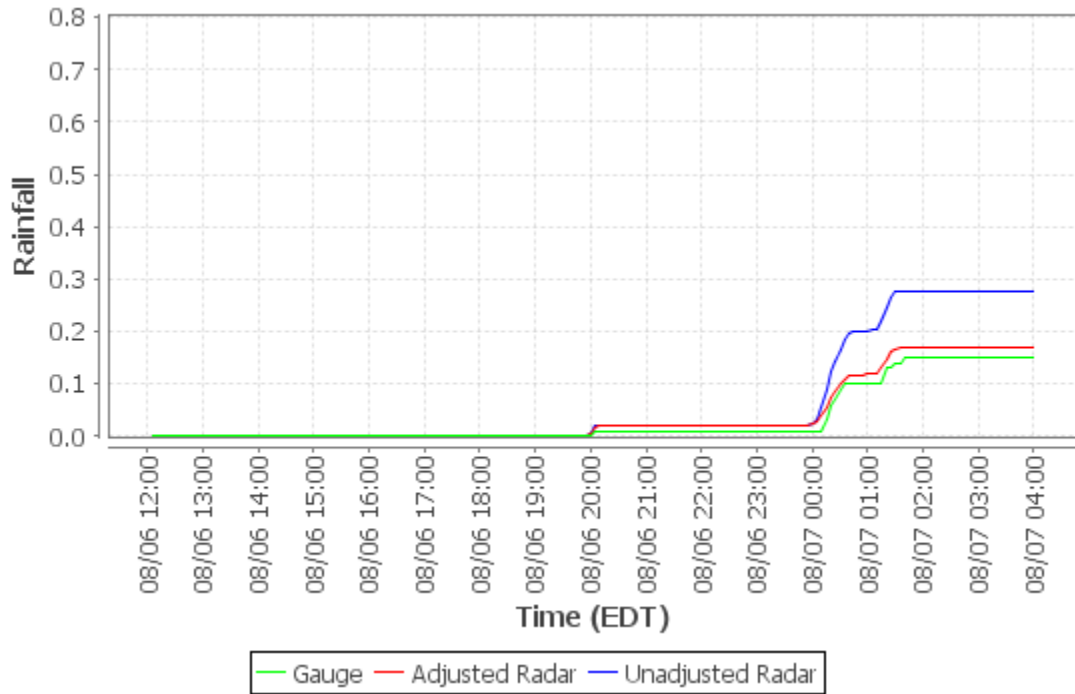
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



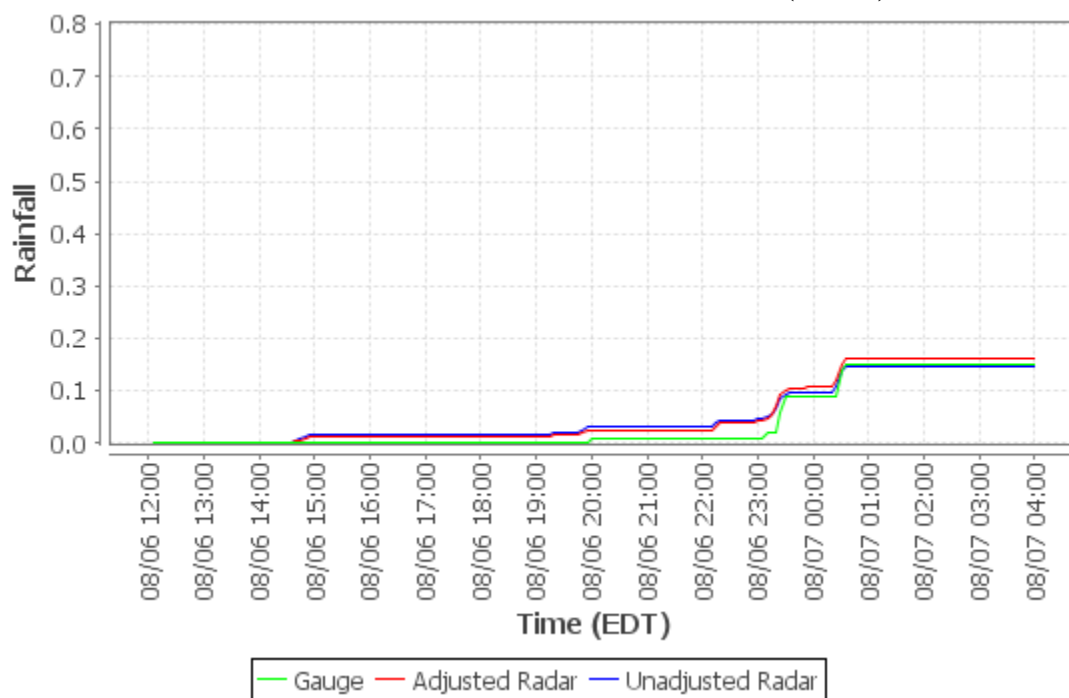
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



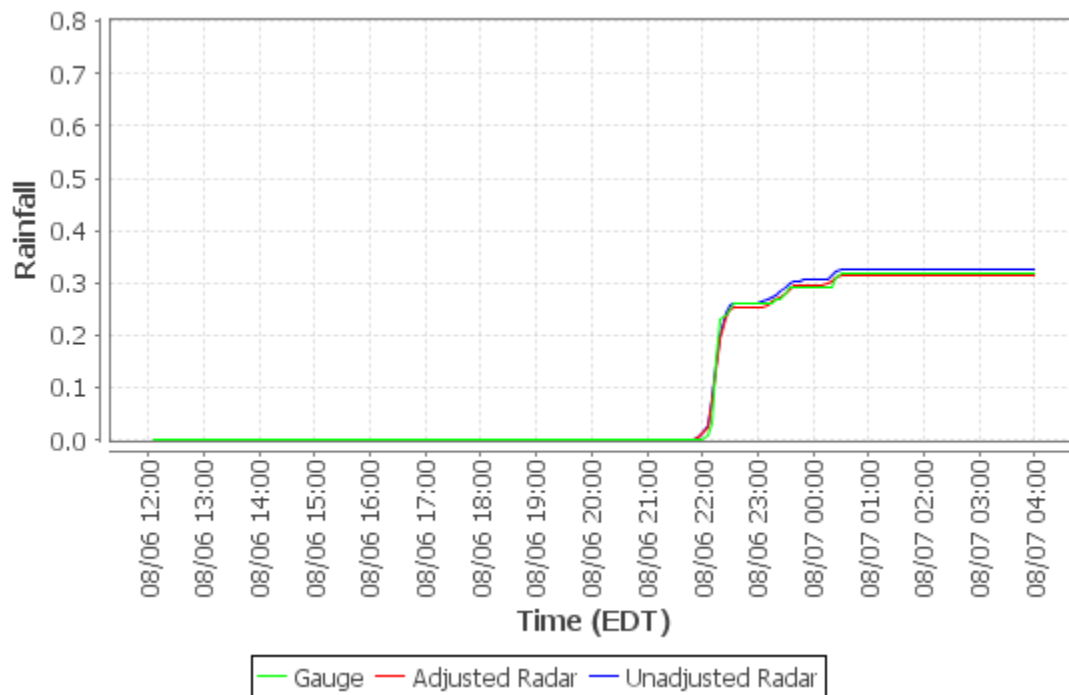
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



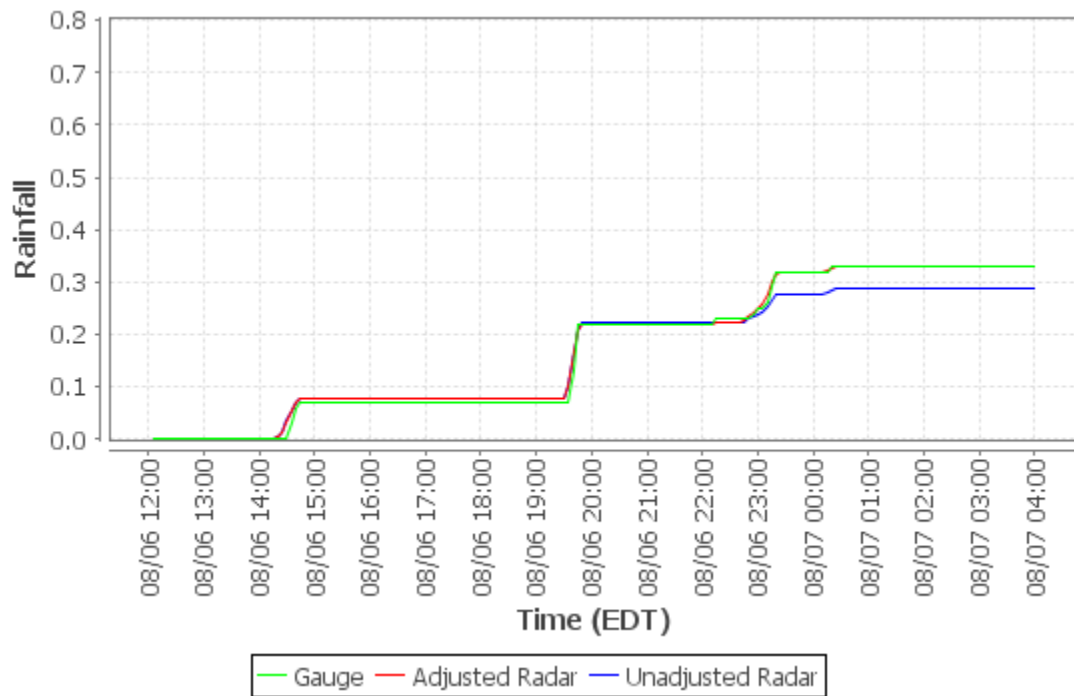
Cumulative Distribution Plot - Moon TWP (Loc21)



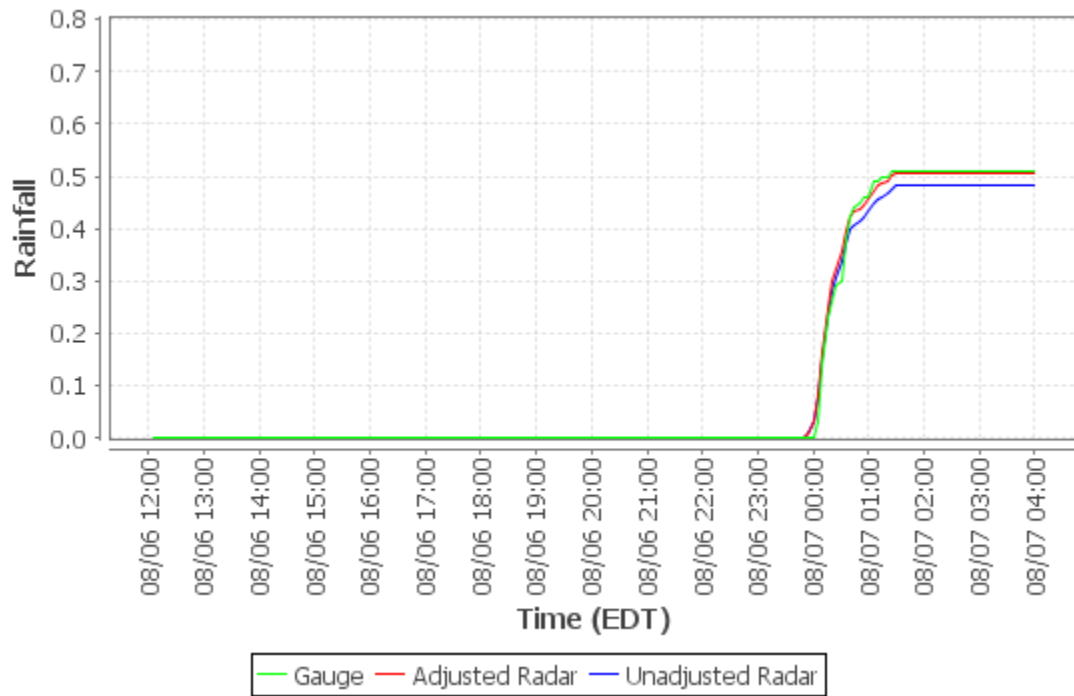
Cumulative Distribution Plot - North Fayette TWP (Loc22)



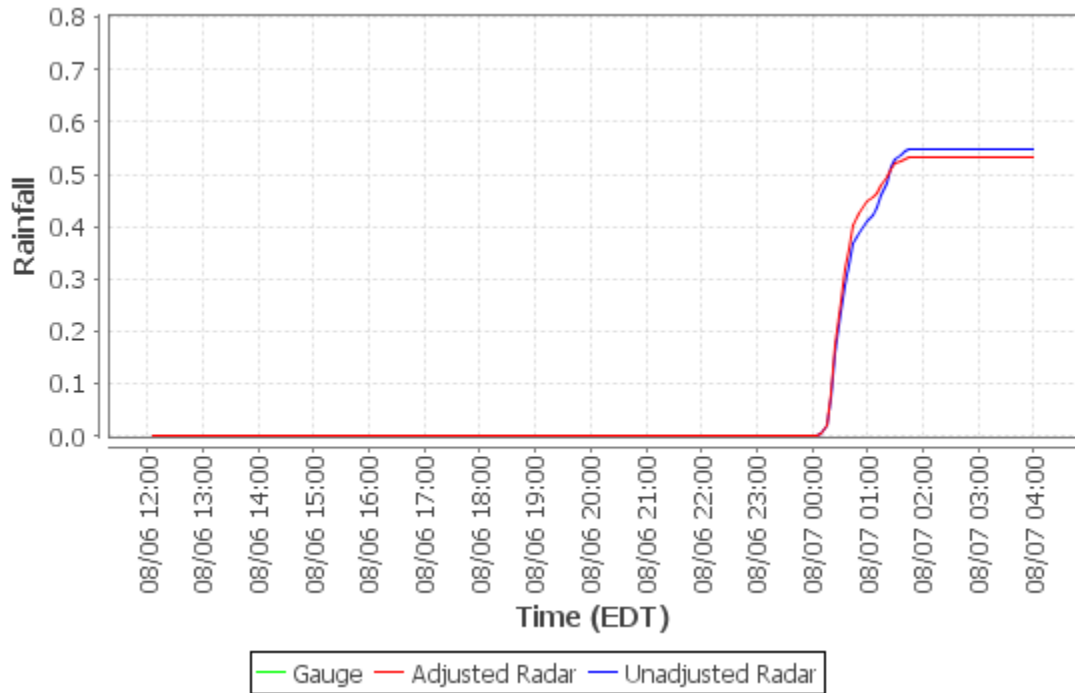
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



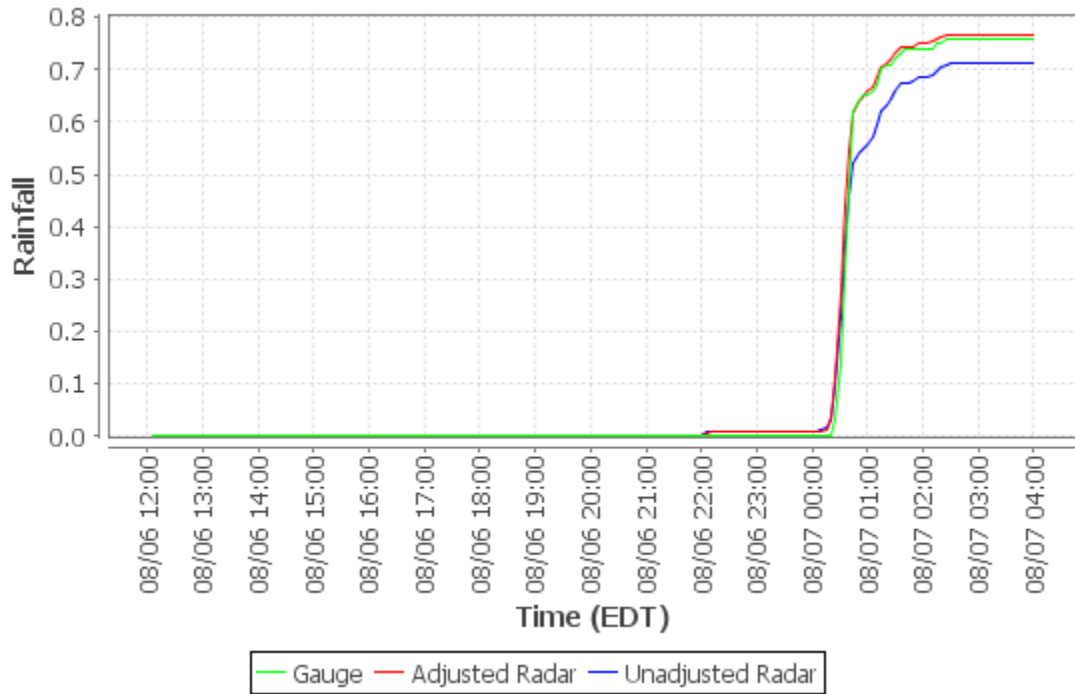
Cumulative Distribution Plot - Jefferson Hills (Loc24)



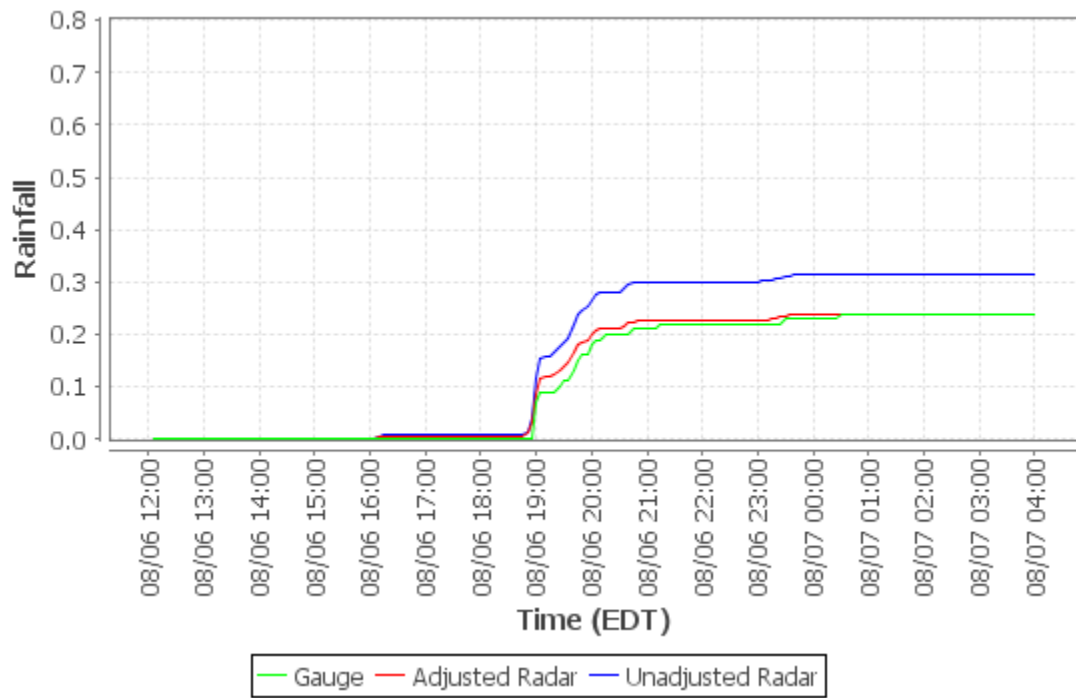
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



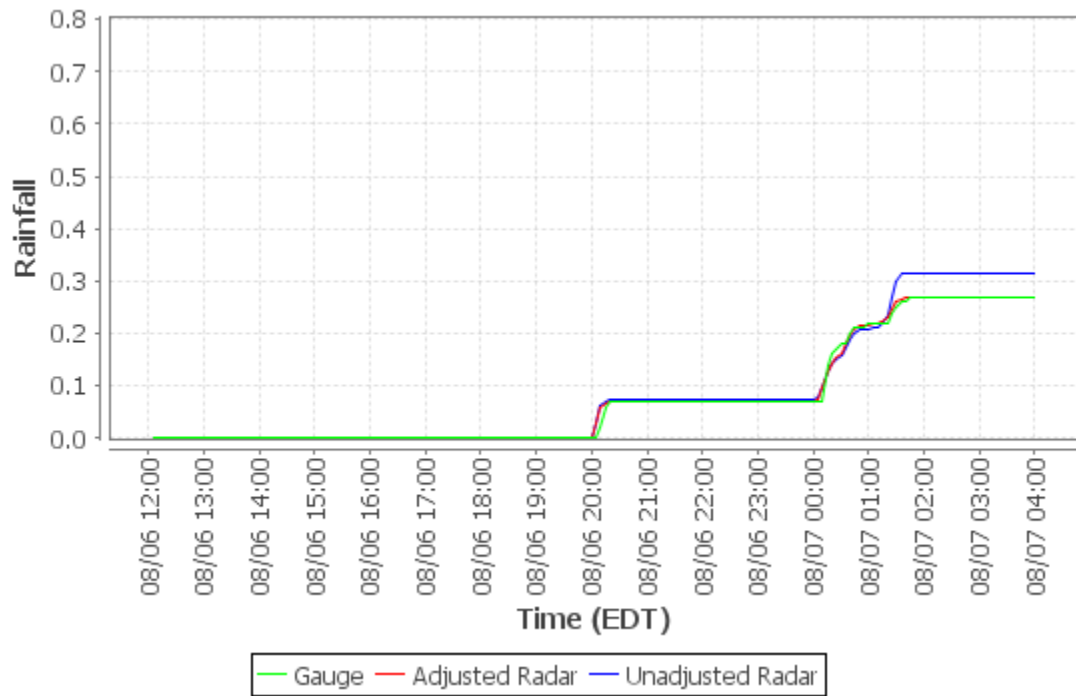
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



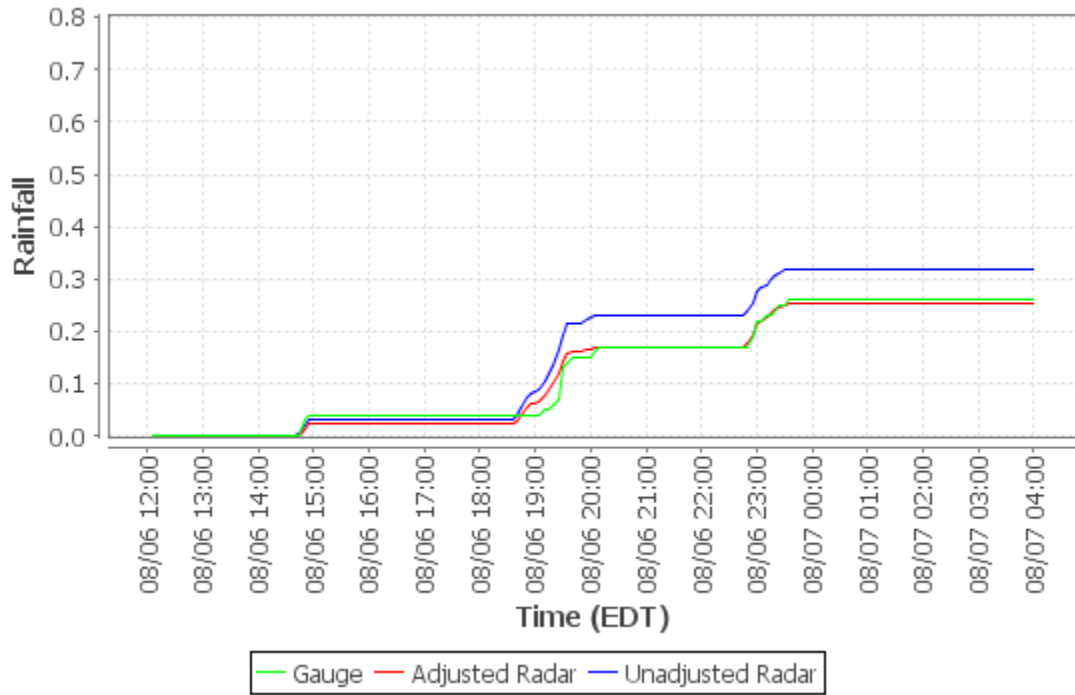
Cumulative Distribution Plot - Marshall TWP (Loc27)



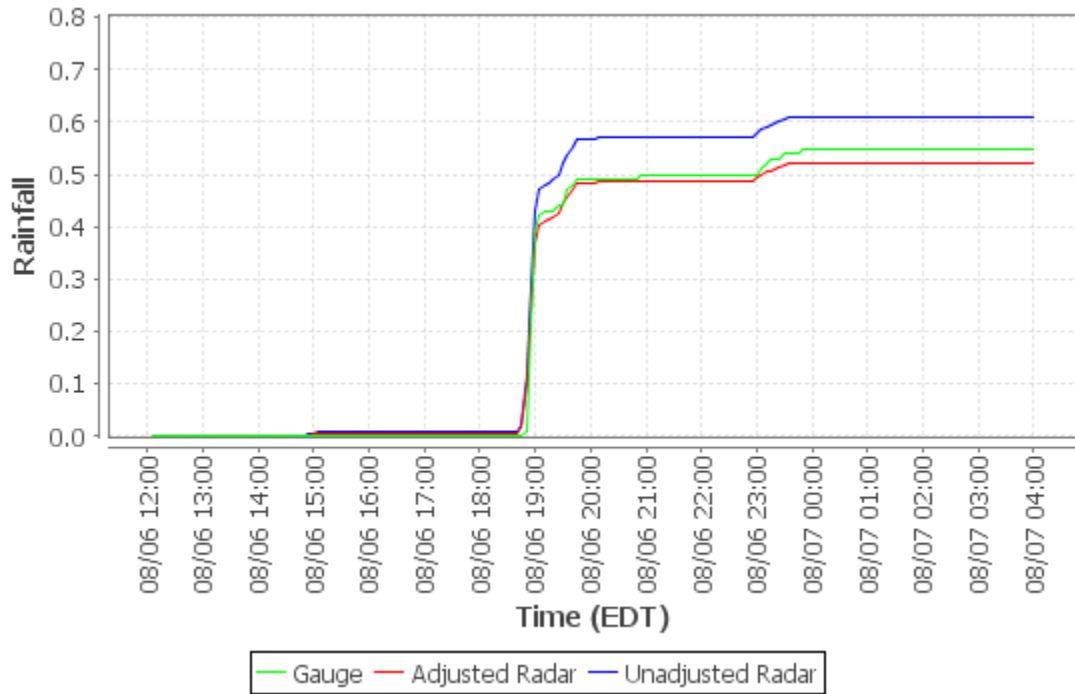
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



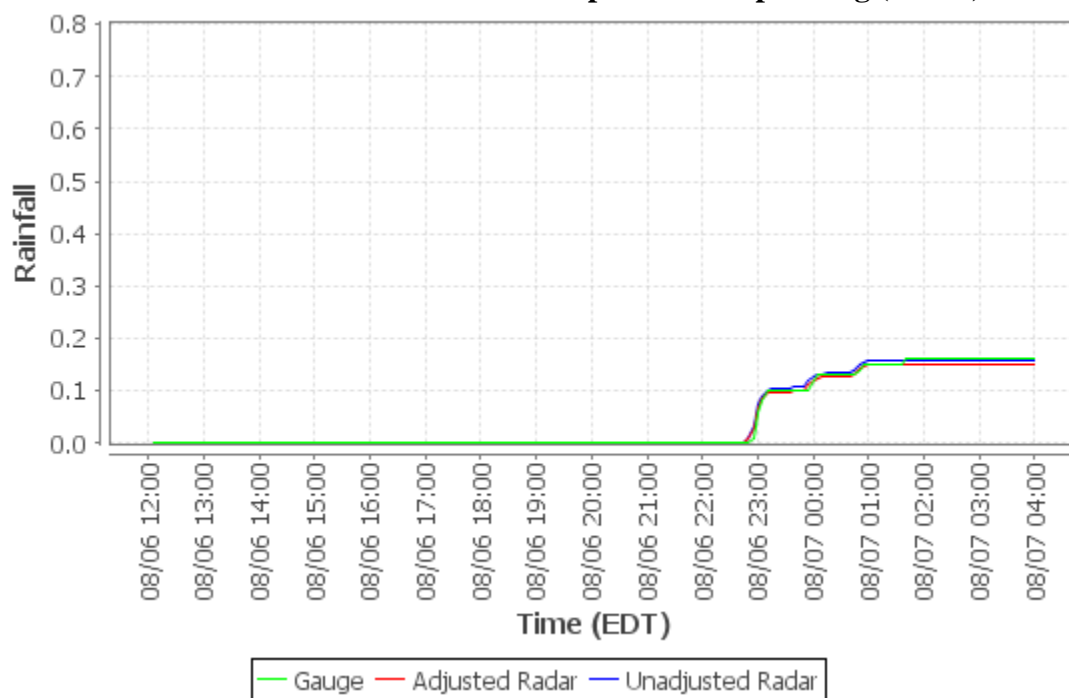
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



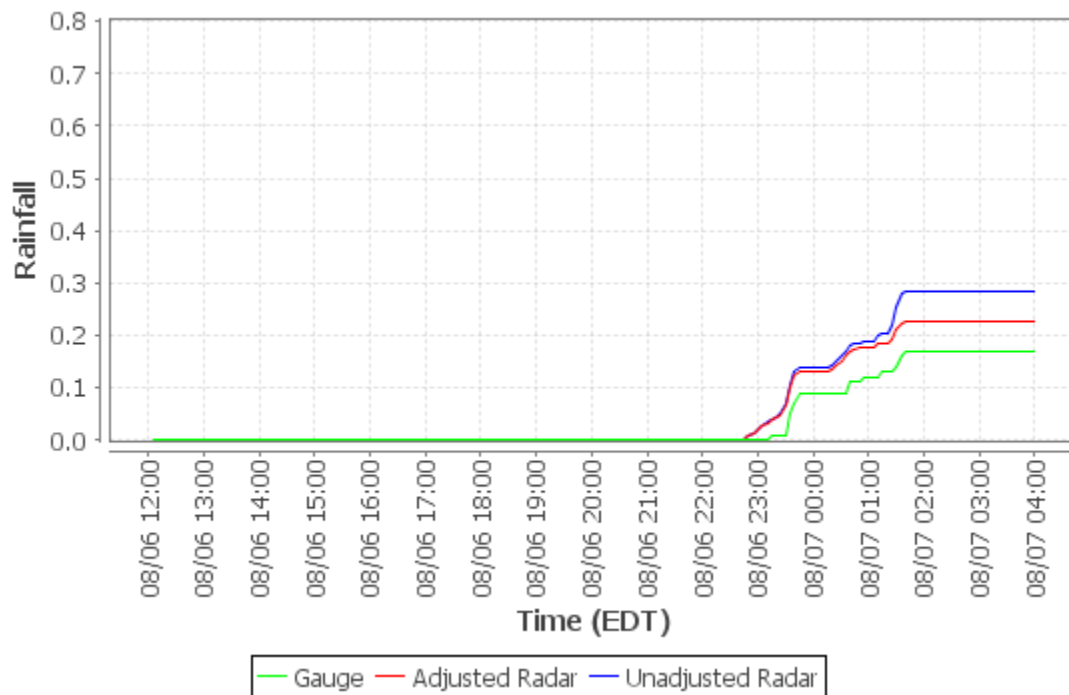
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



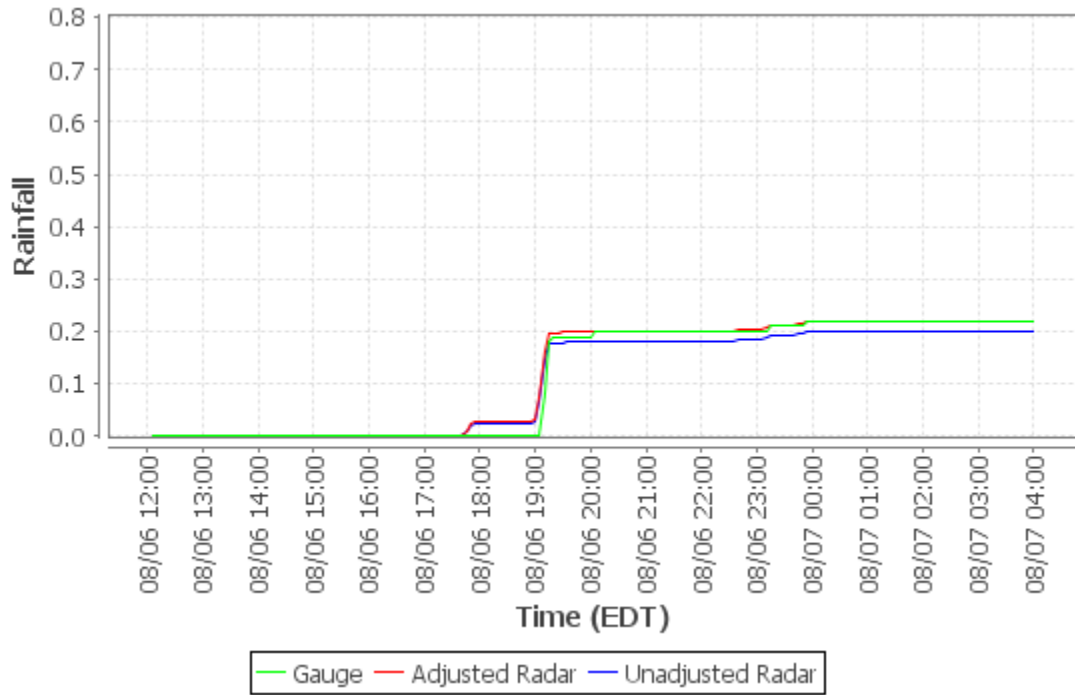
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



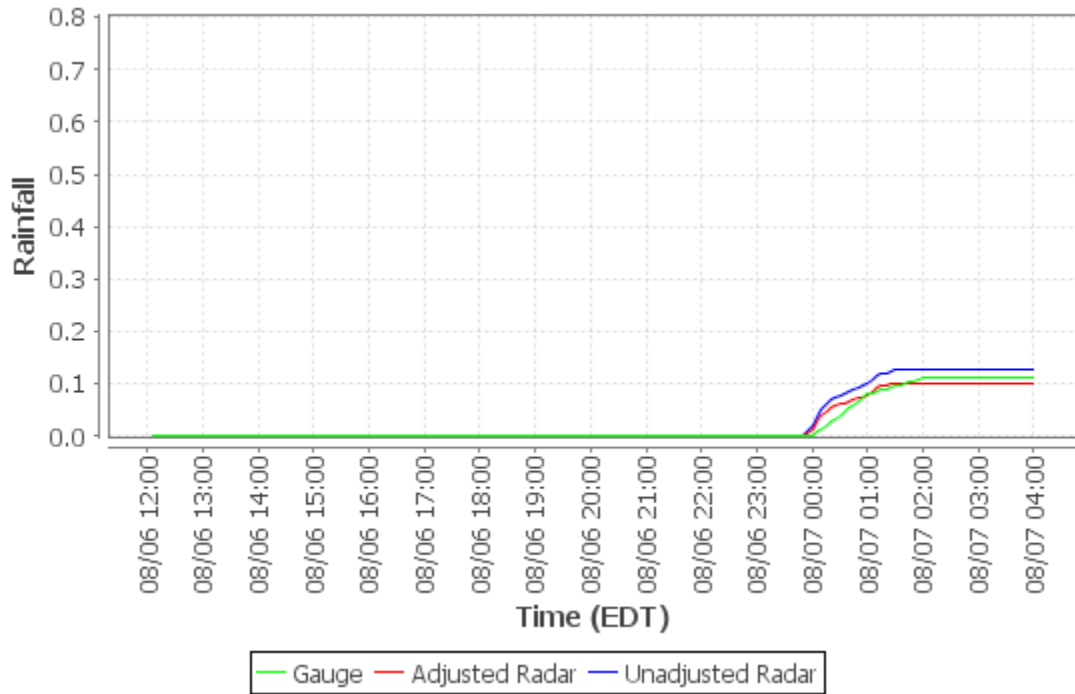
Cumulative Distribution Plot - Arnold (Loc32)



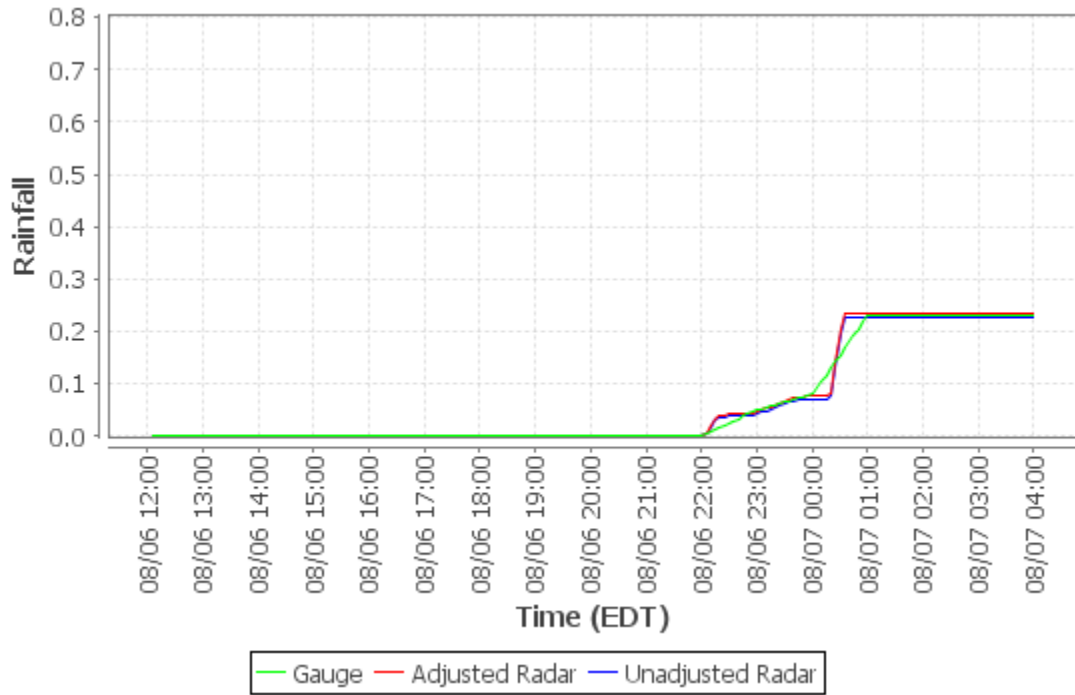
Cumulative Distribution Plot - Richland TWP (Loc33)



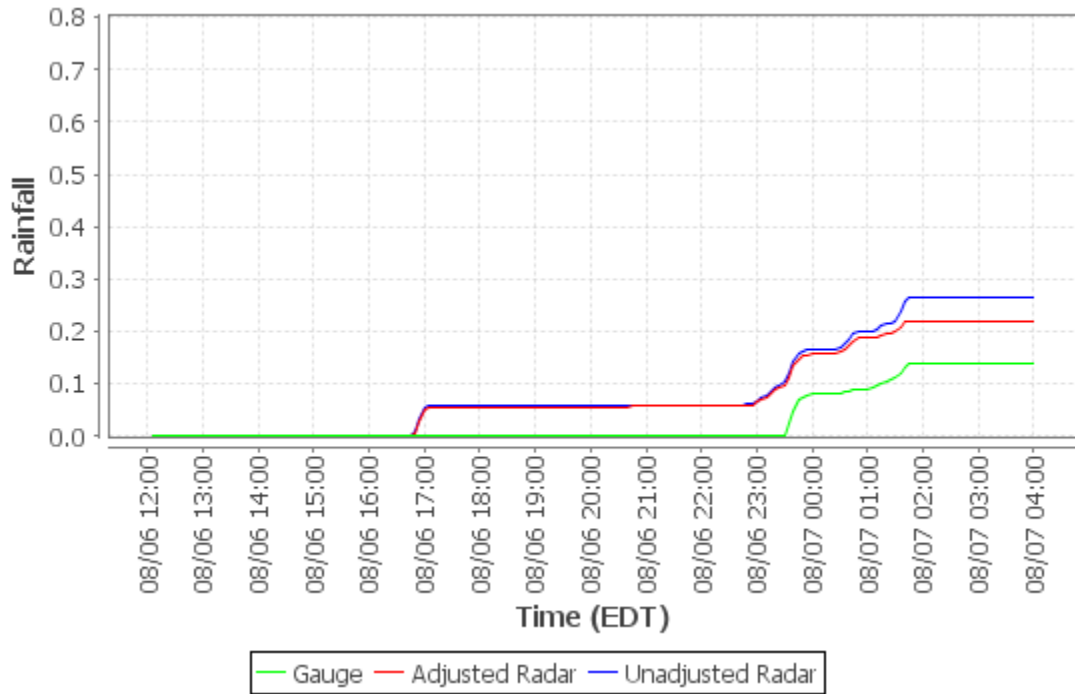
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



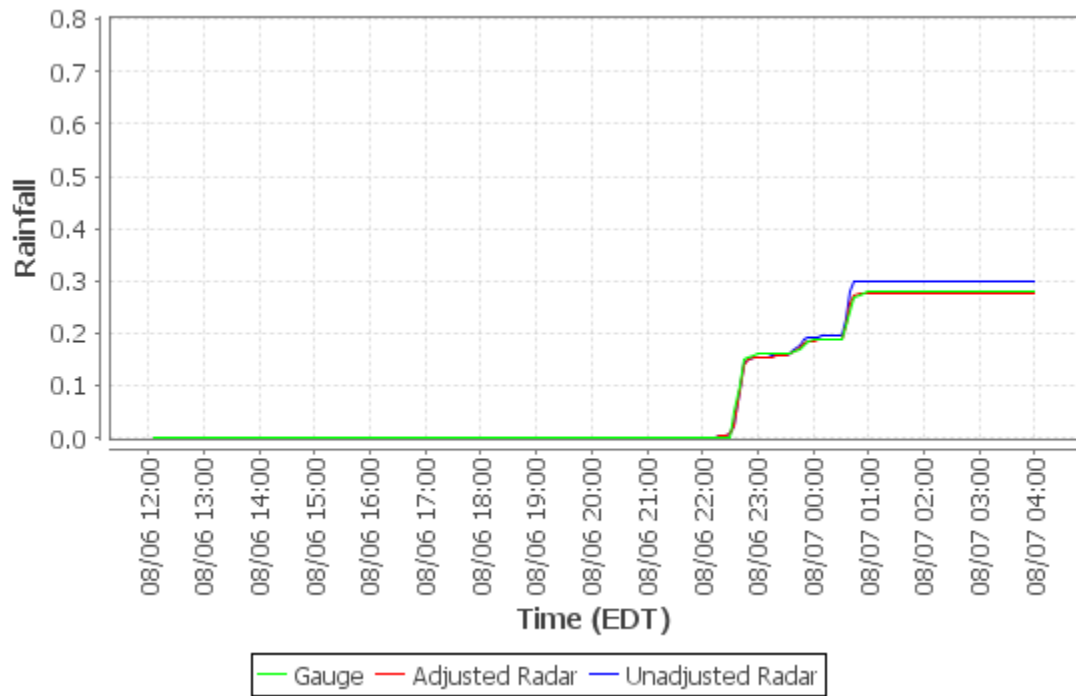
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

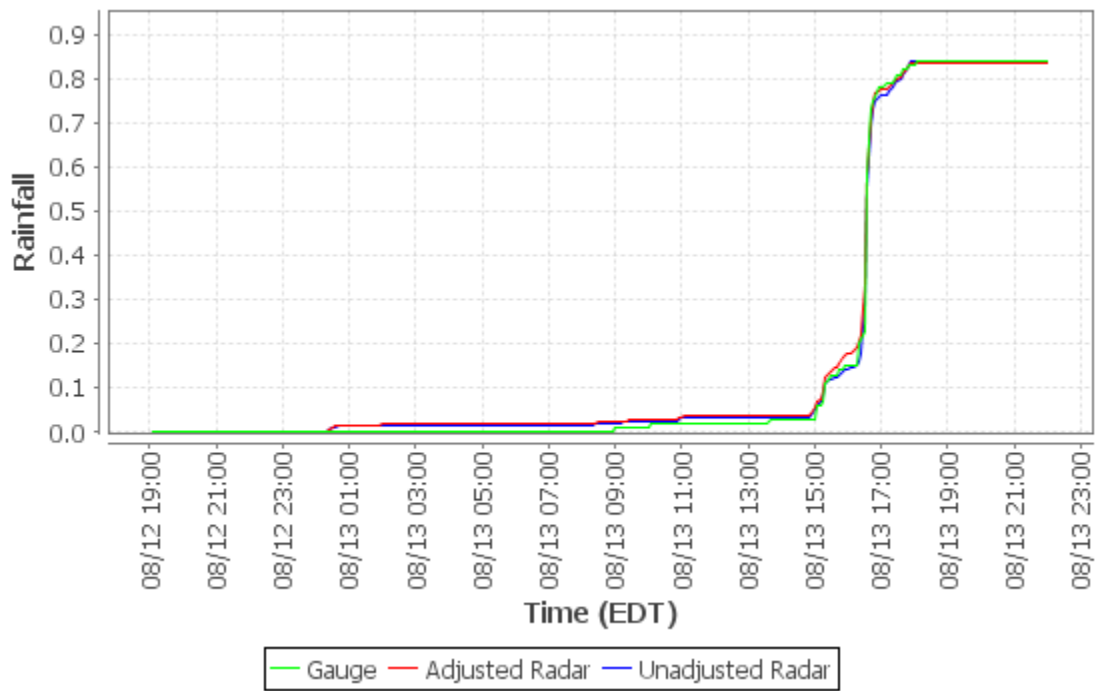


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

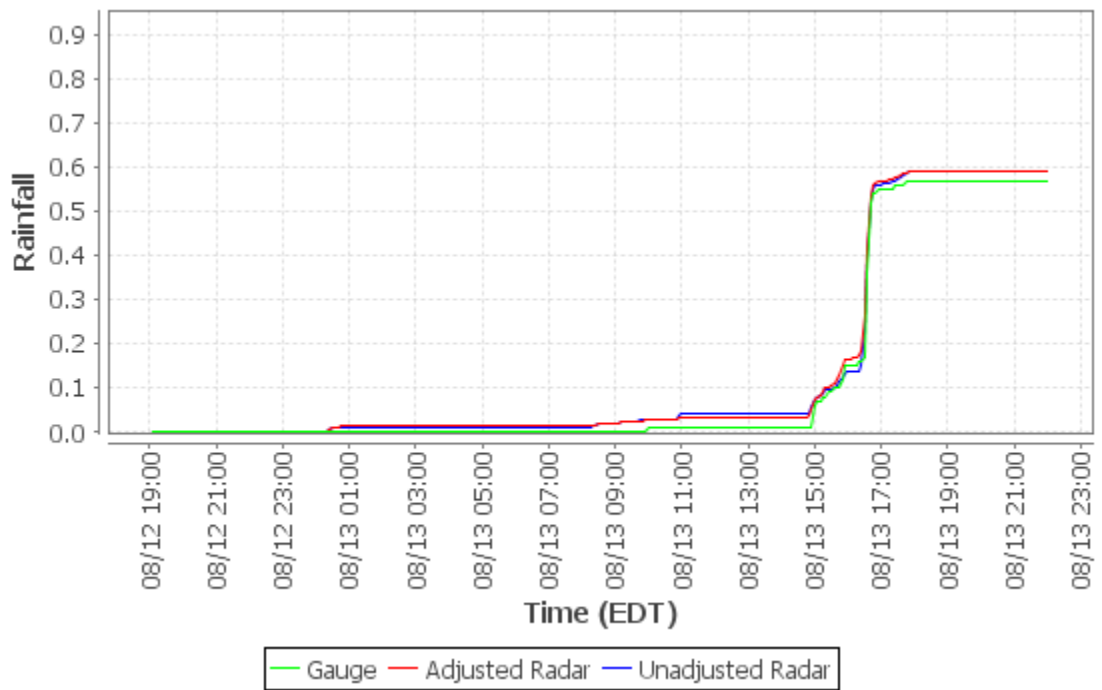


Appendix D - Event 2 (2019-08-13) CDPs

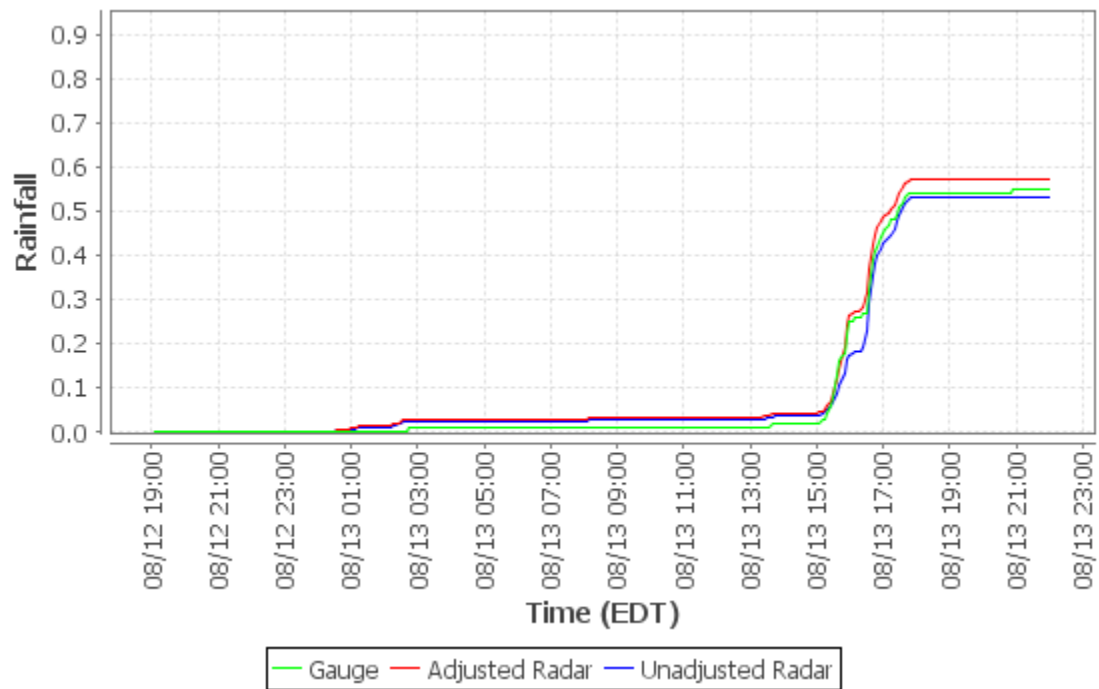
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



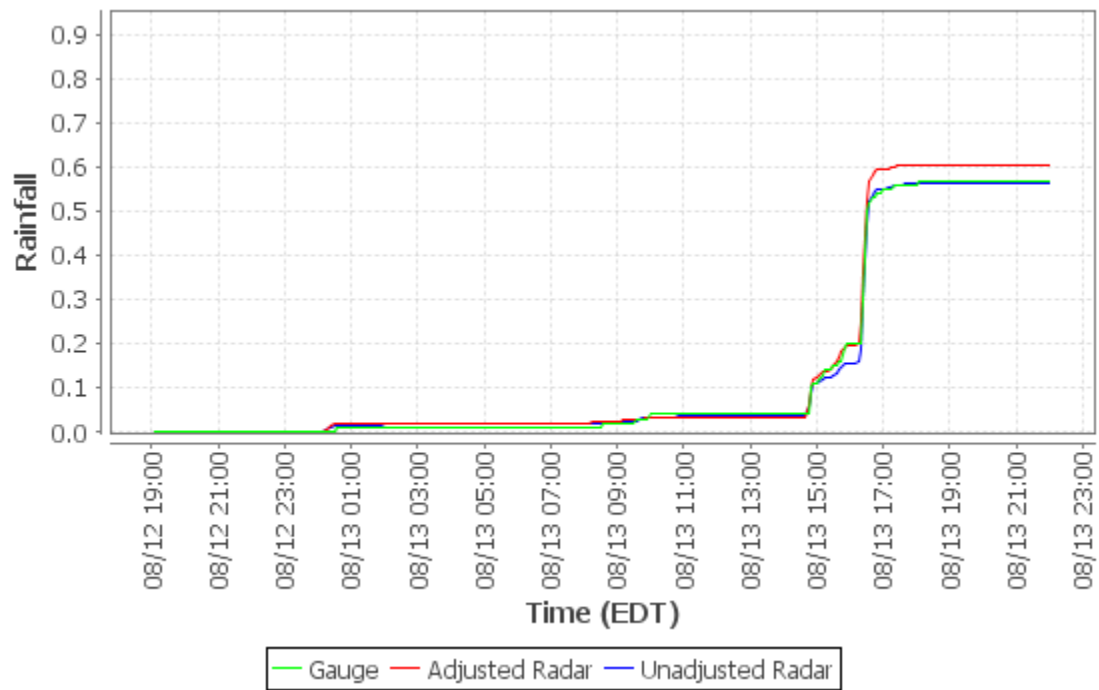
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



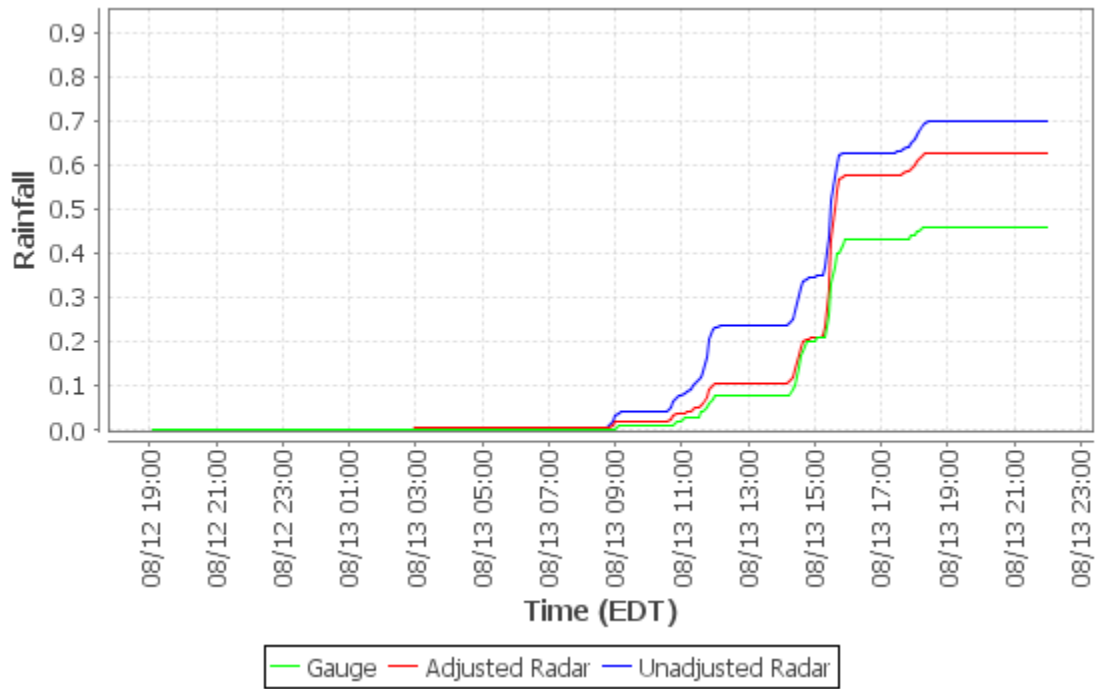
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



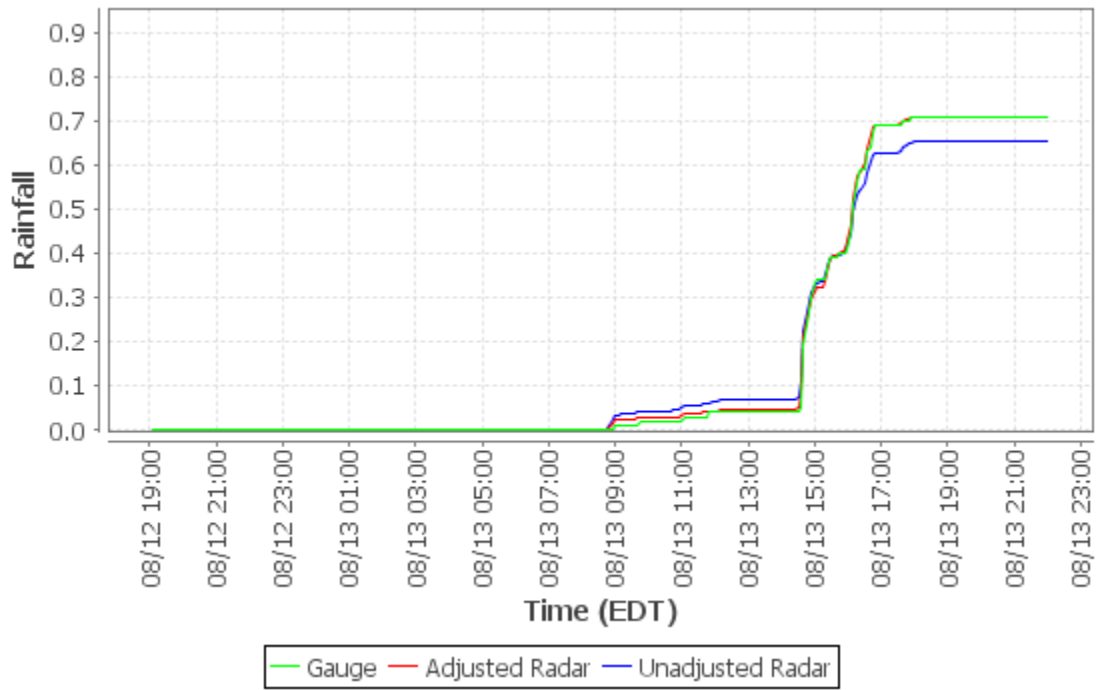
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



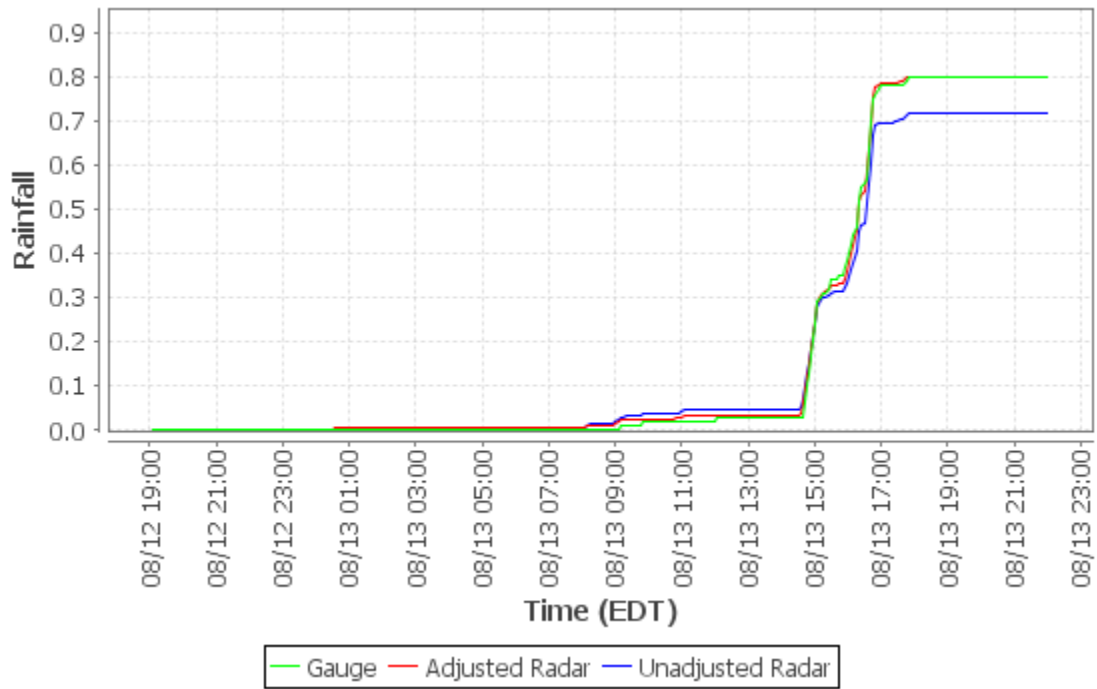
Cumulative Distribution Plot - Upper St. Clair (Loc05)



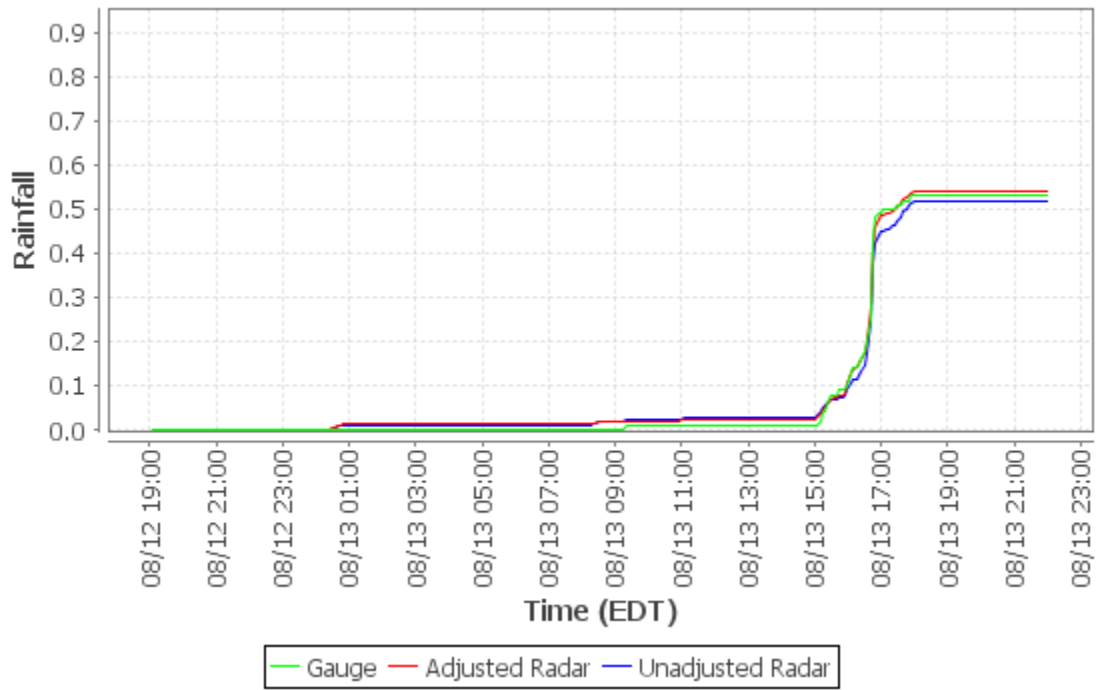
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



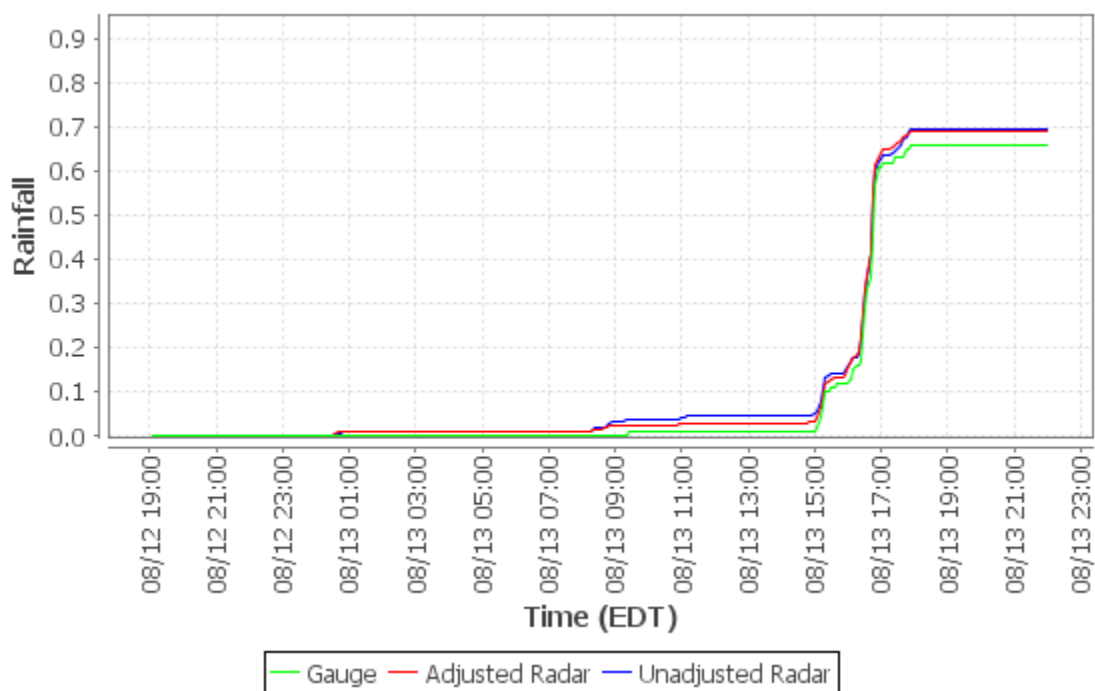
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



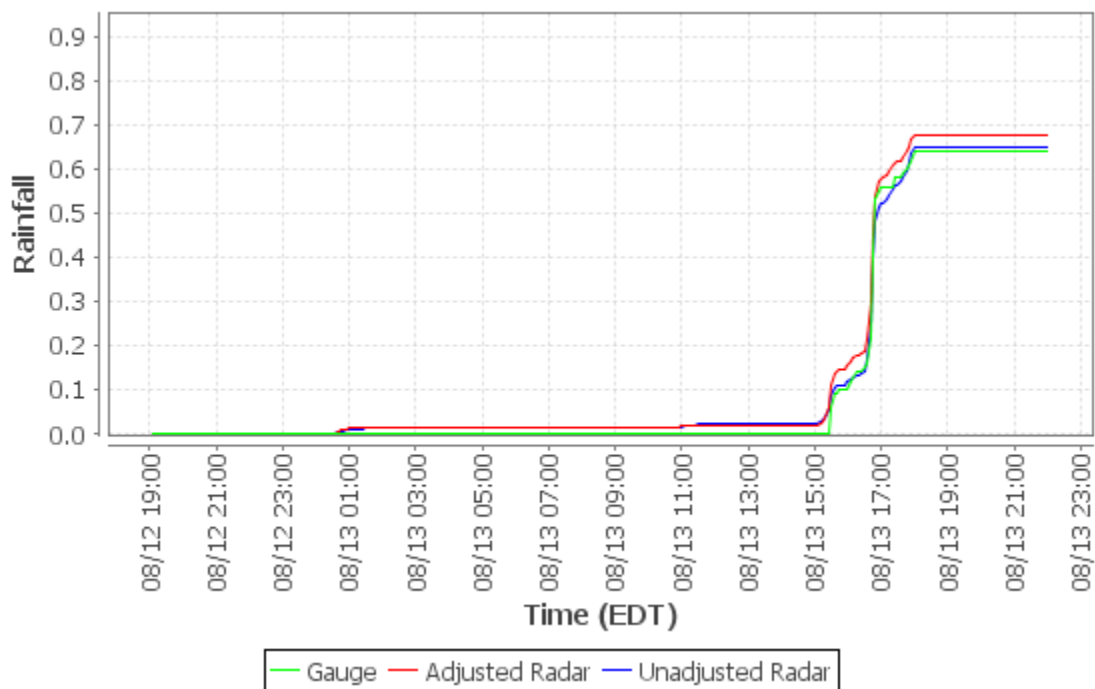
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



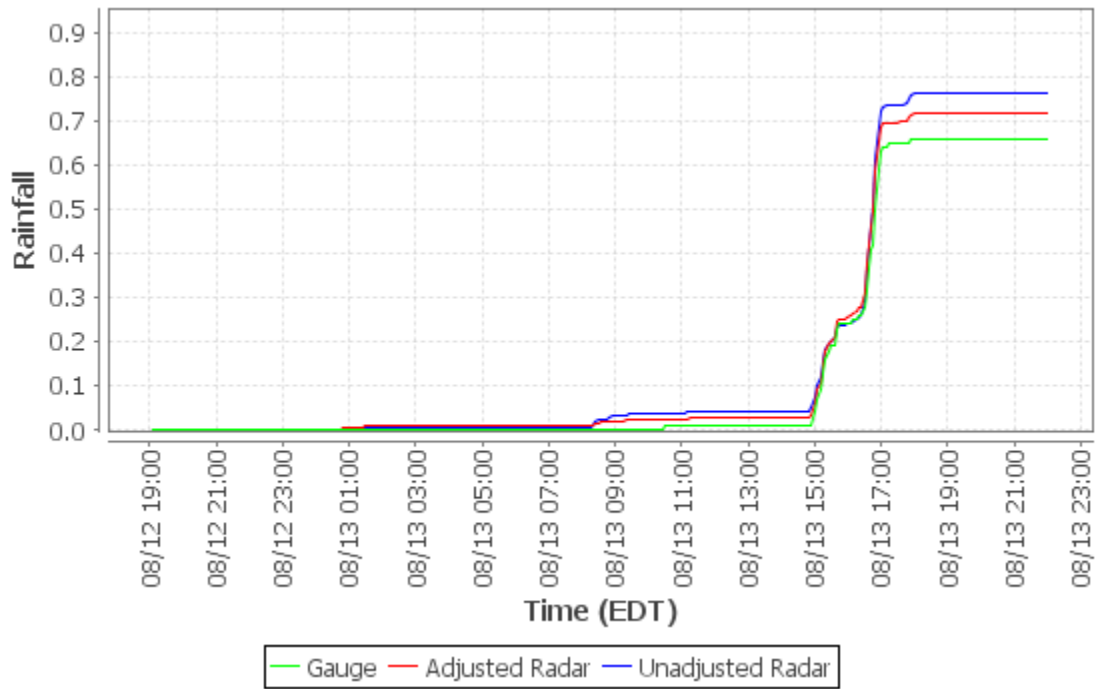
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



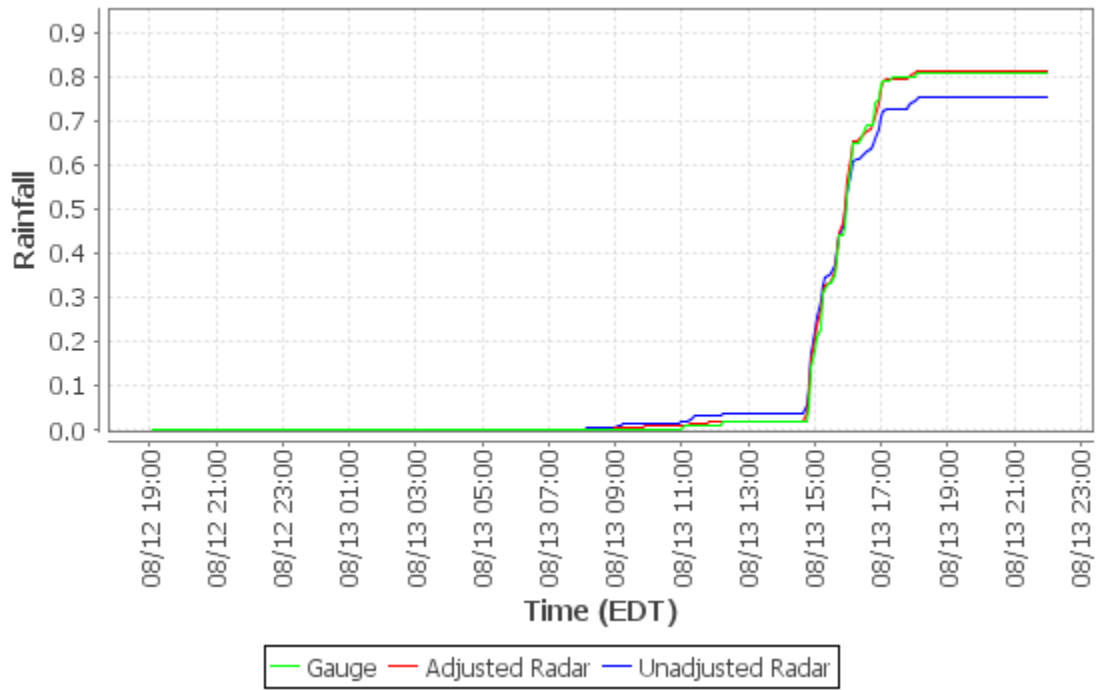
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



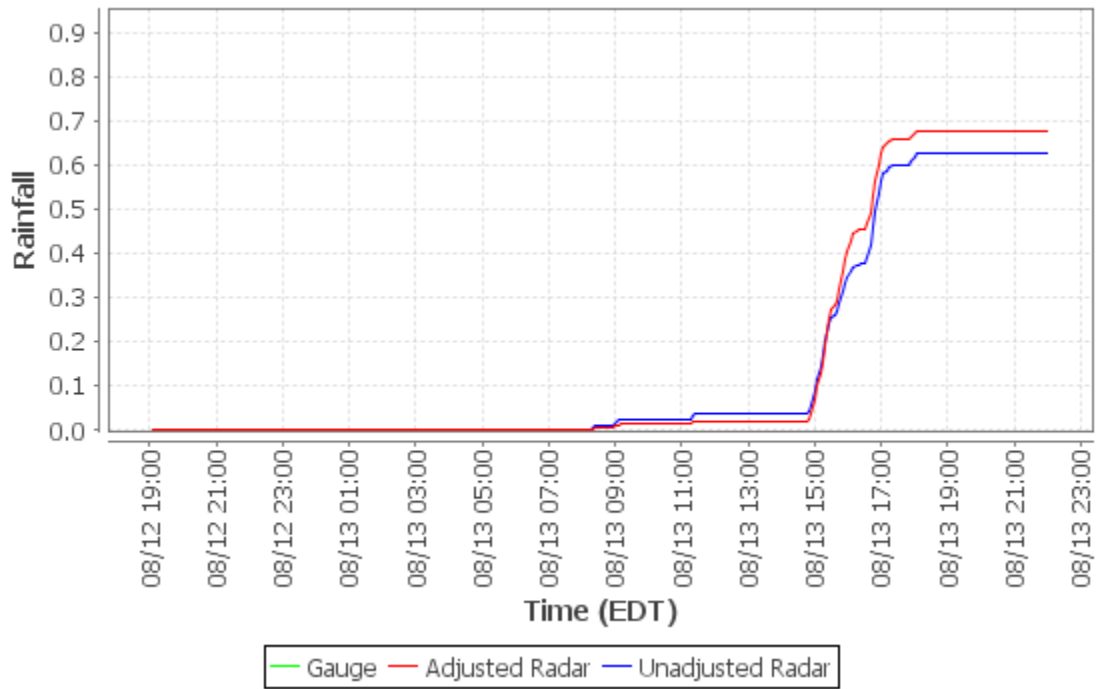
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



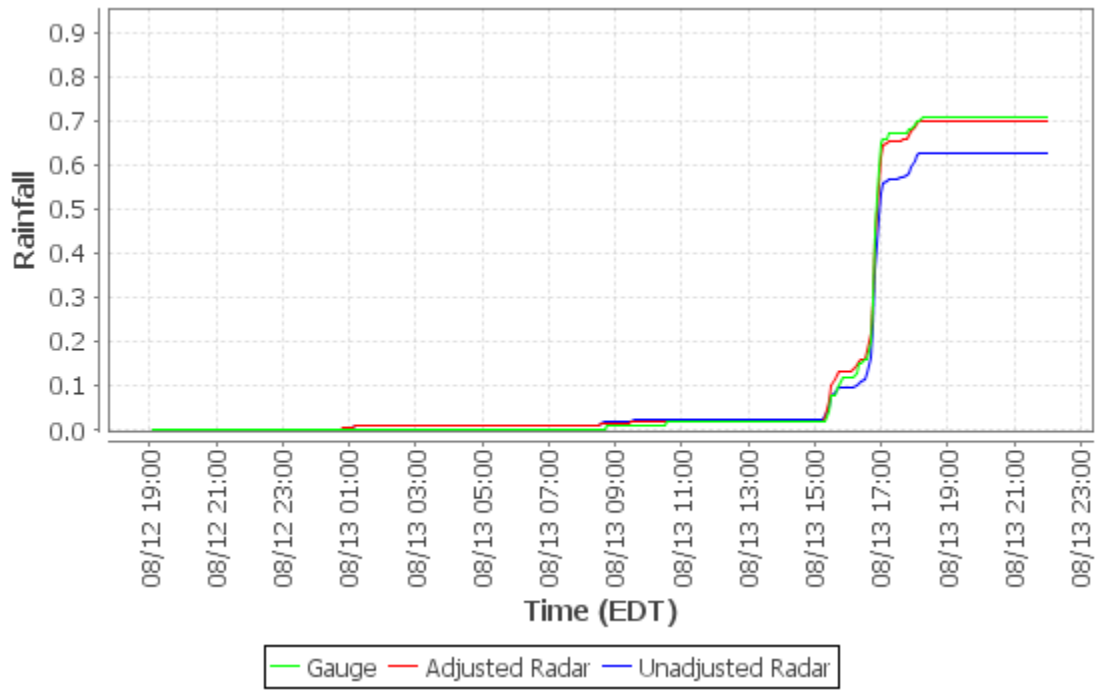
Cumulative Distribution Plot - Baldwin (Loc12)



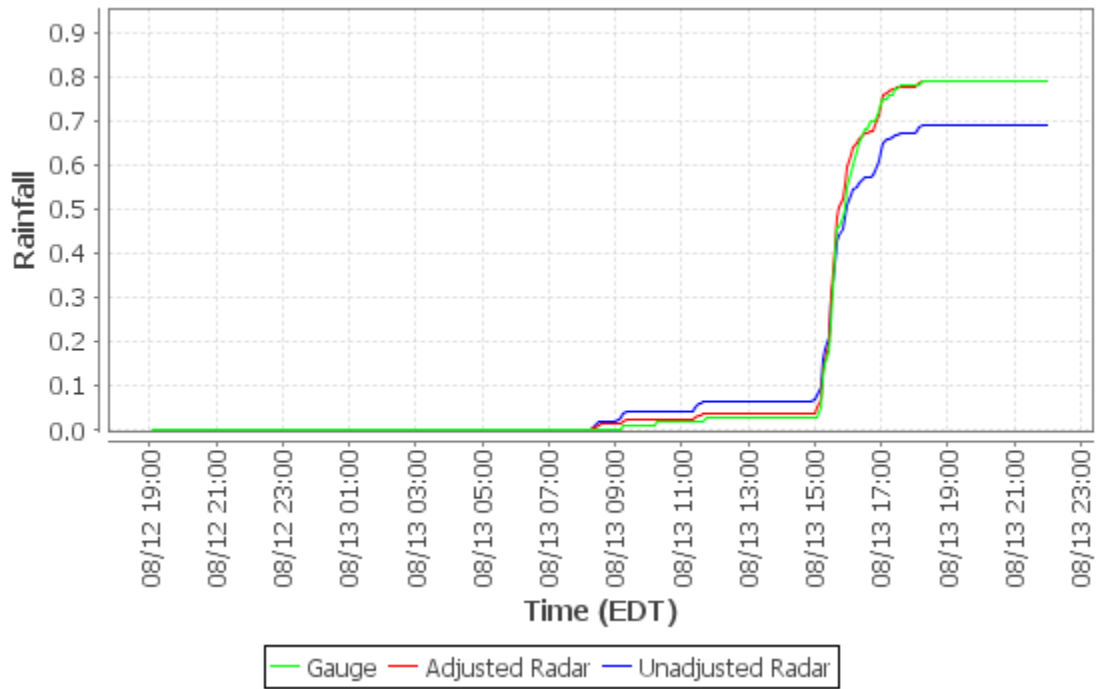
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



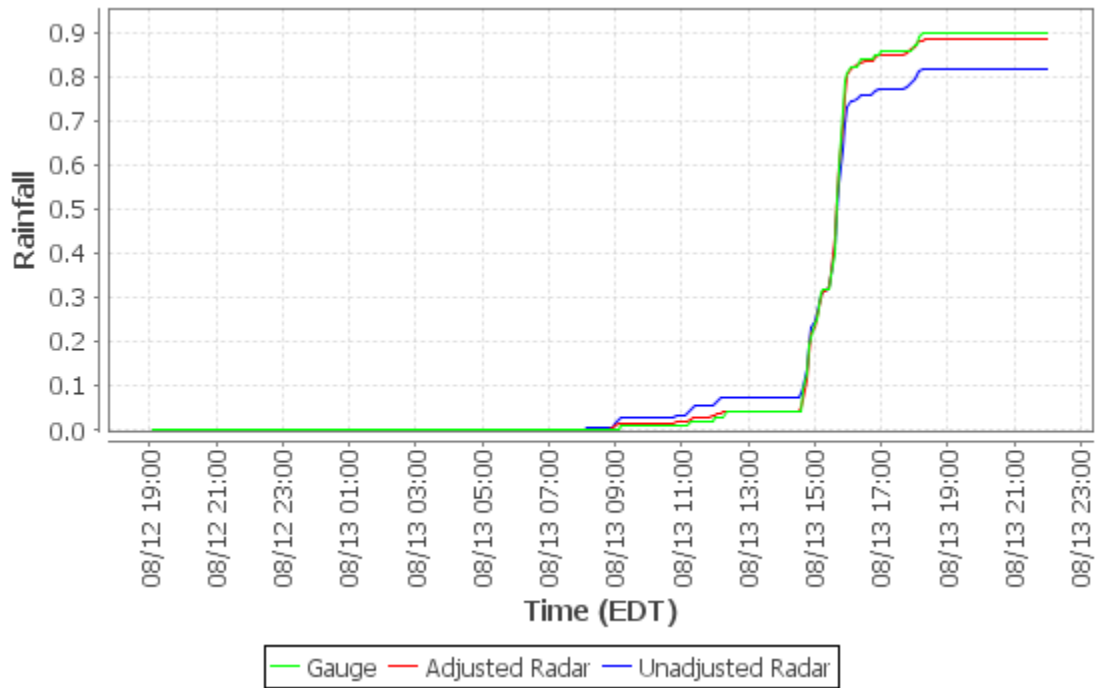
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



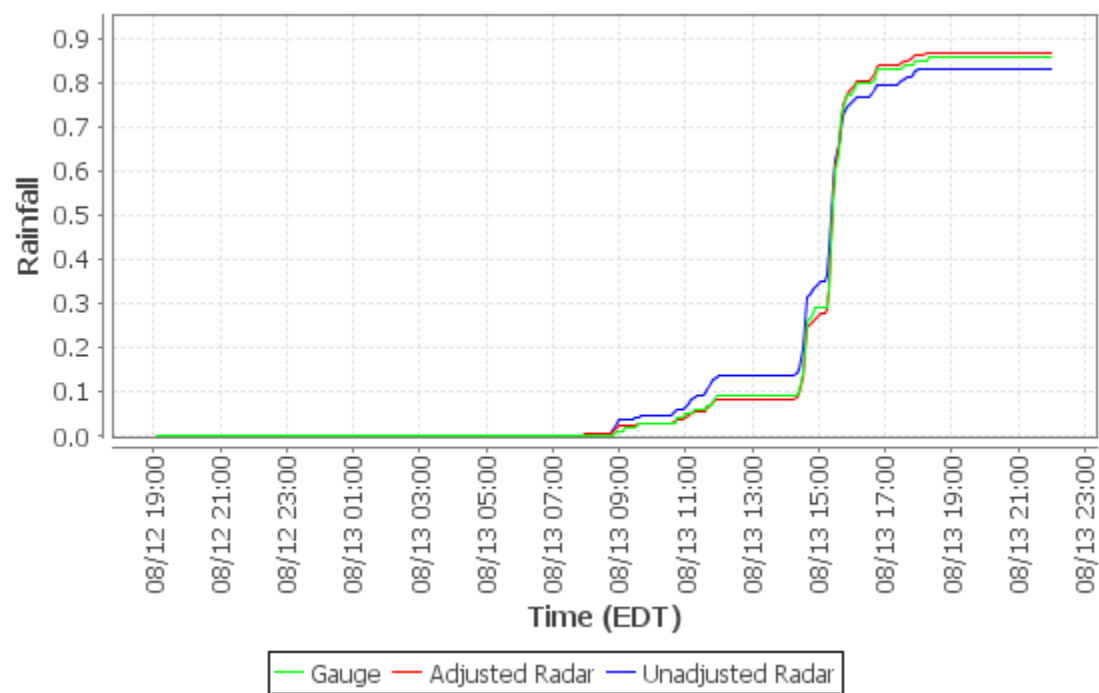
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



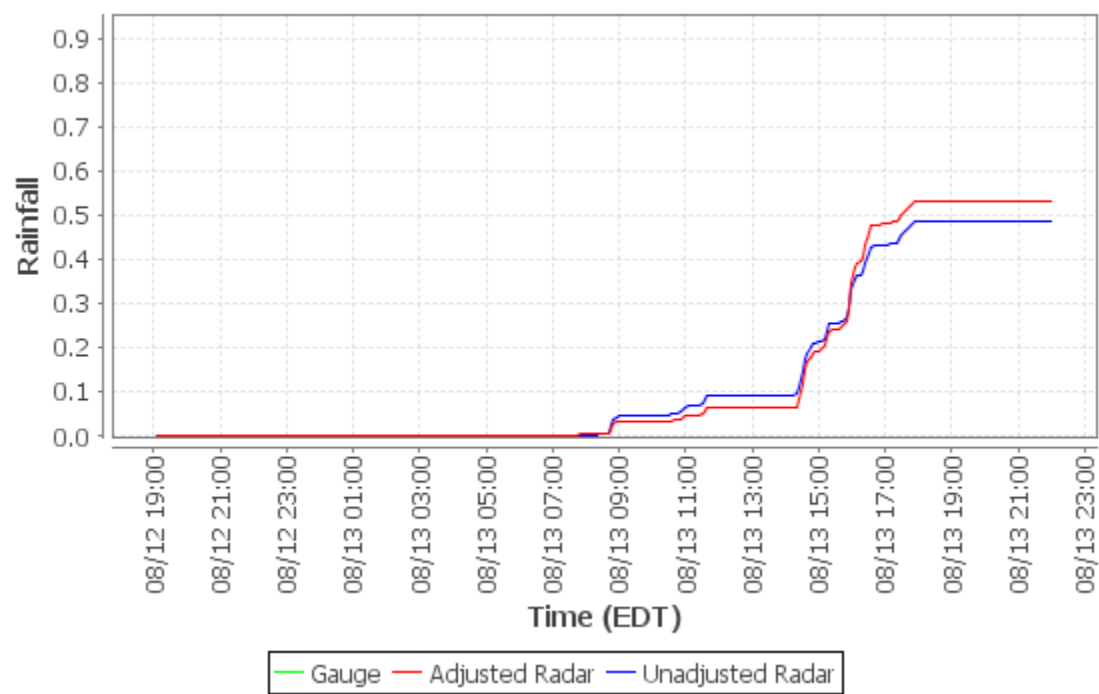
Cumulative Distribution Plot - Castle Shannon (Loc16)



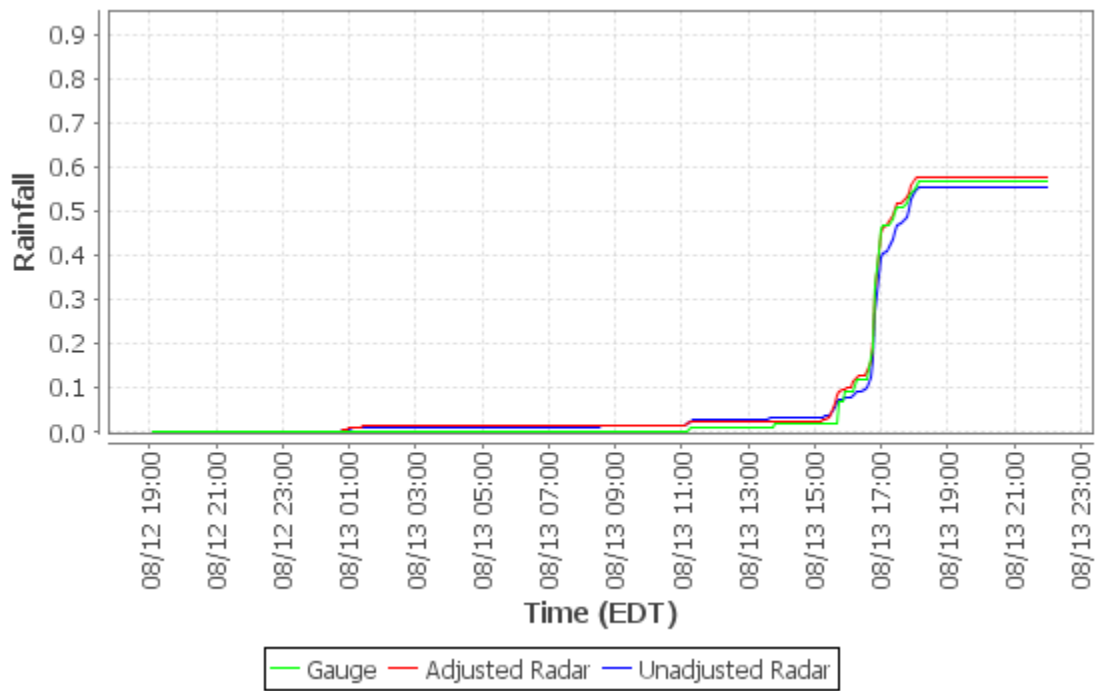
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



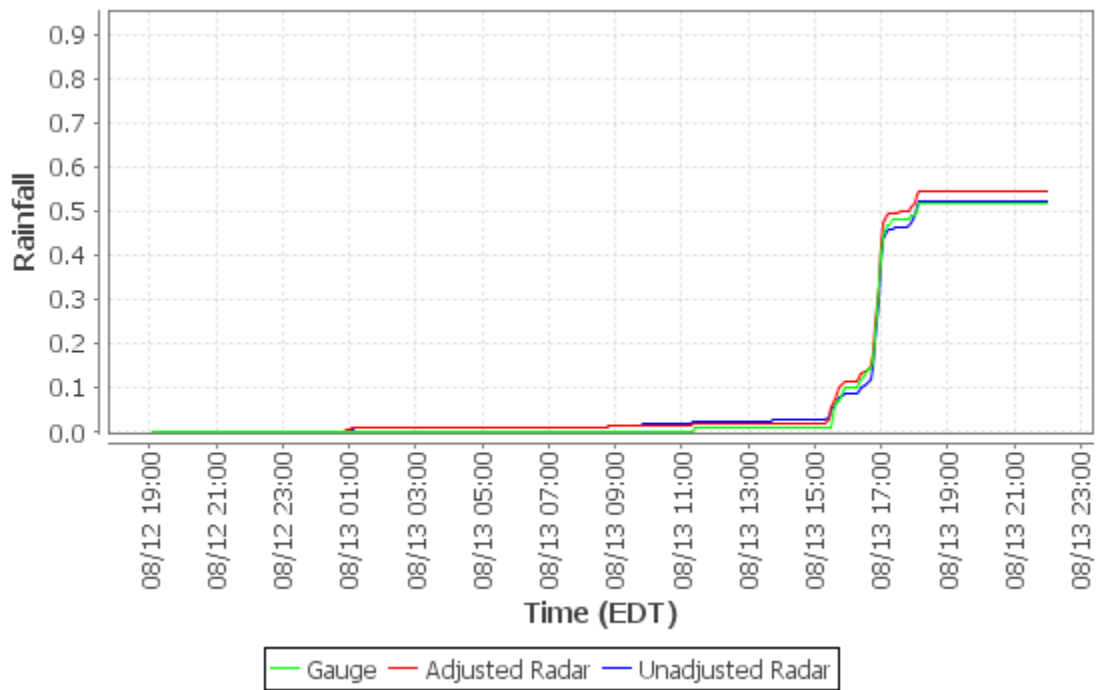
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



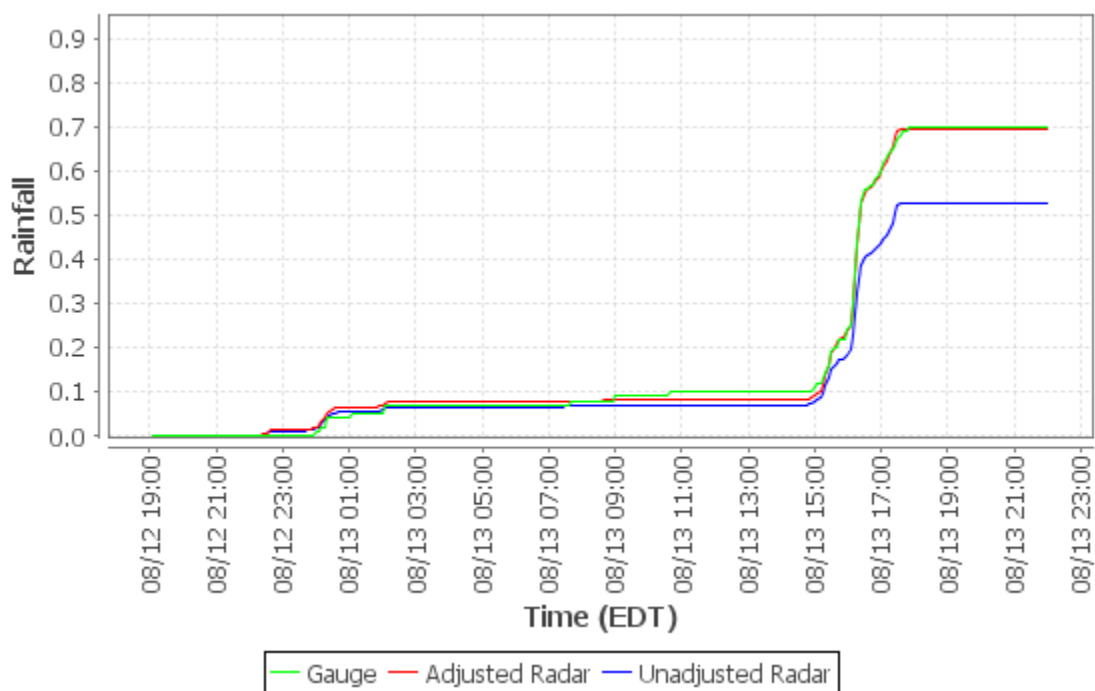
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



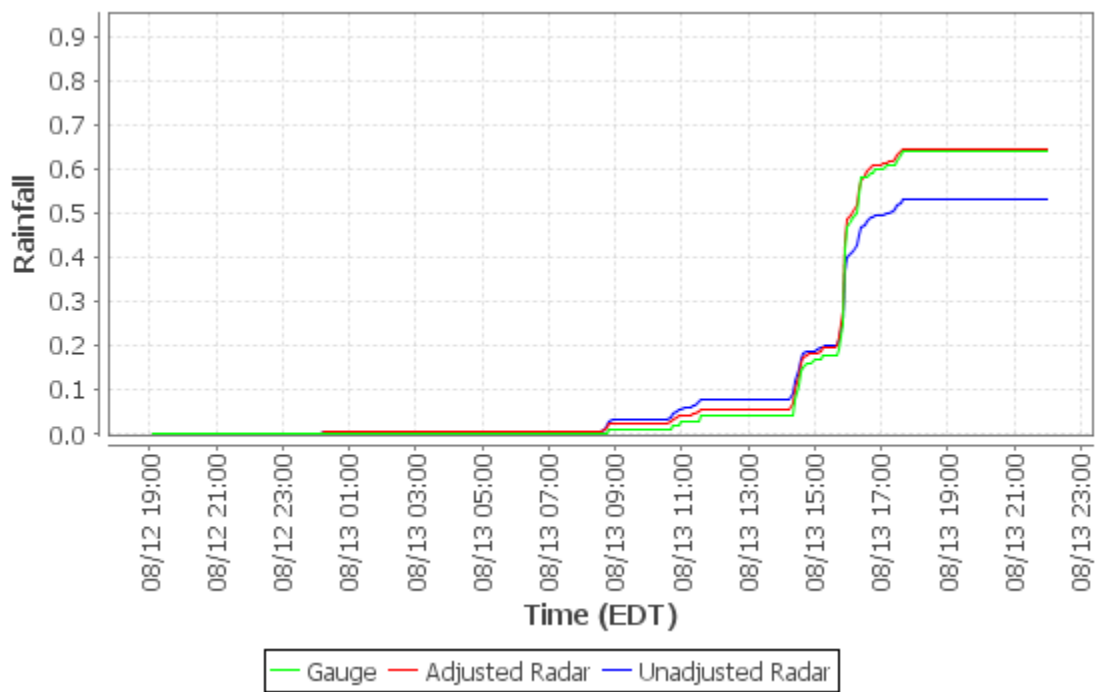
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



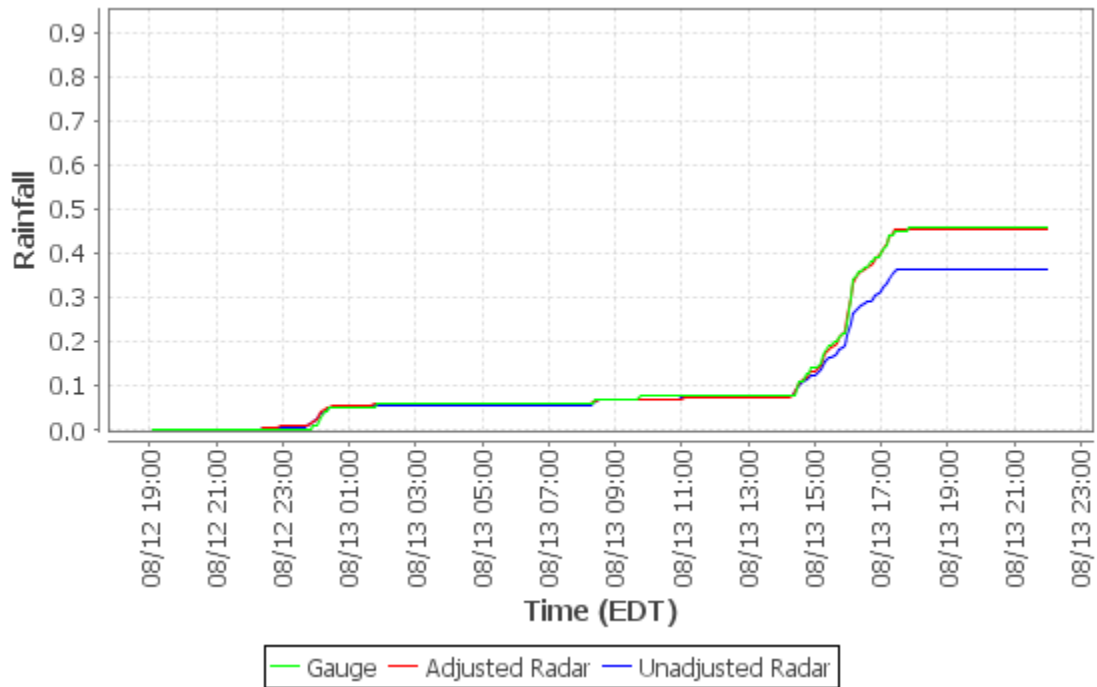
Cumulative Distribution Plot - Moon TWP (Loc21)



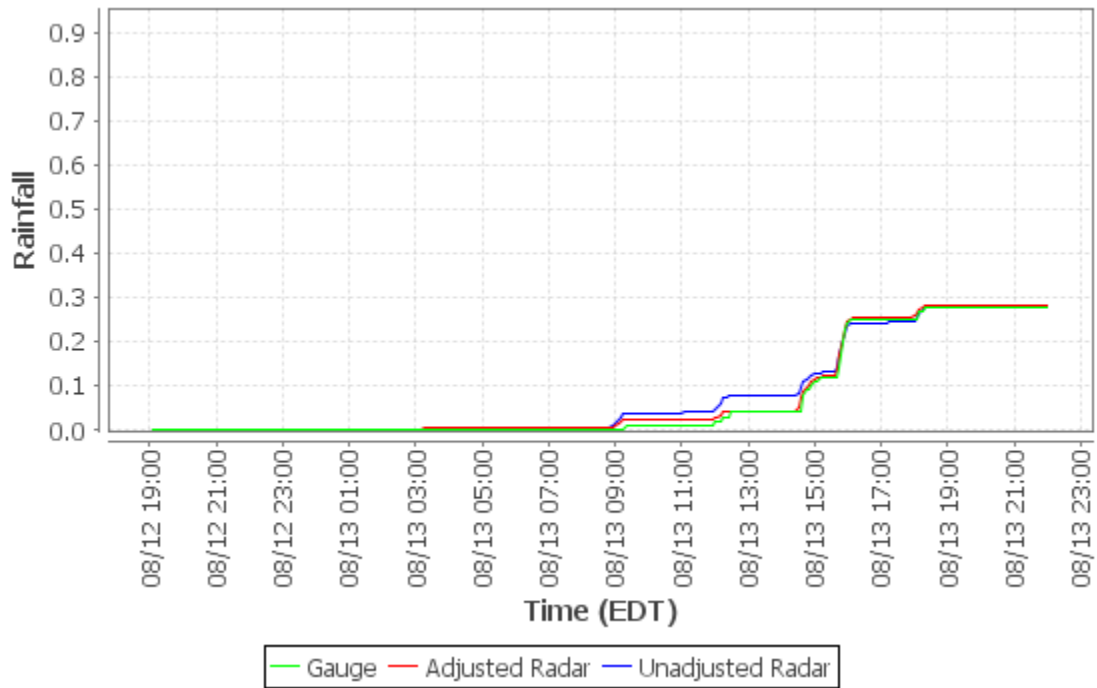
Cumulative Distribution Plot - North Fayette TWP (Loc22)



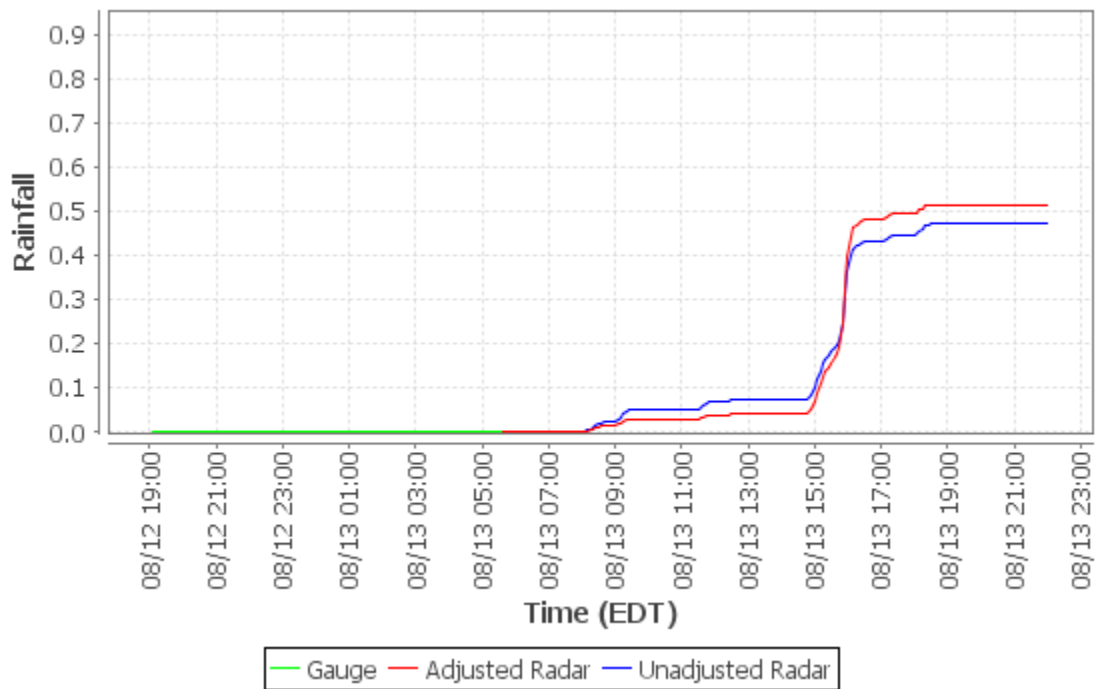
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



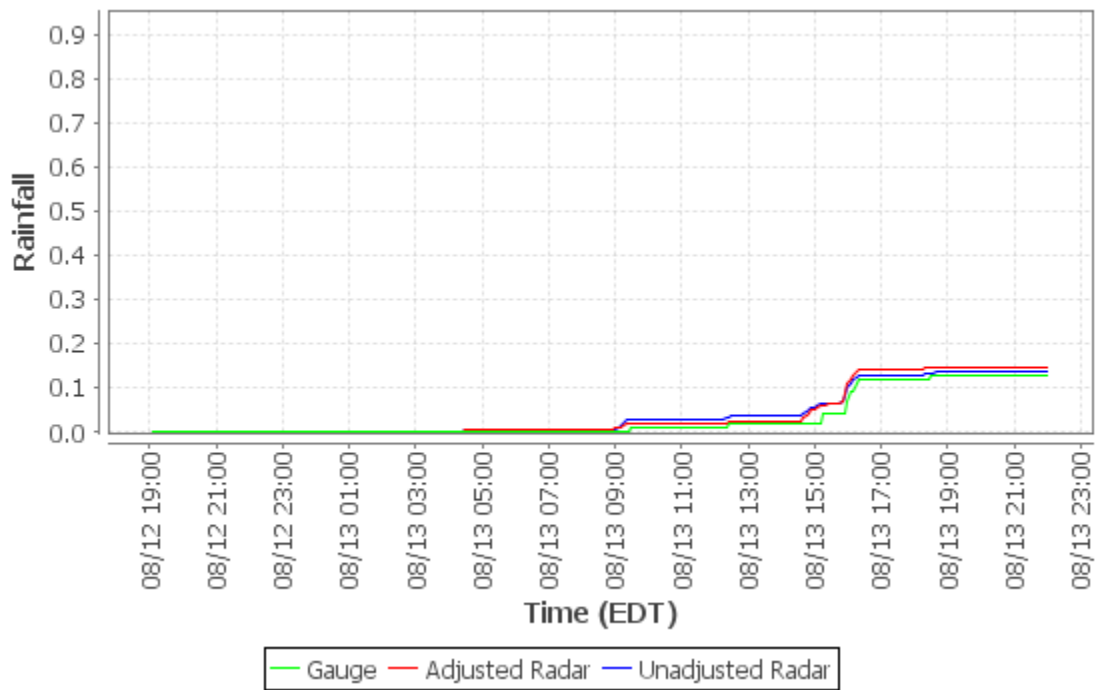
Cumulative Distribution Plot - Jefferson Hills (Loc24)



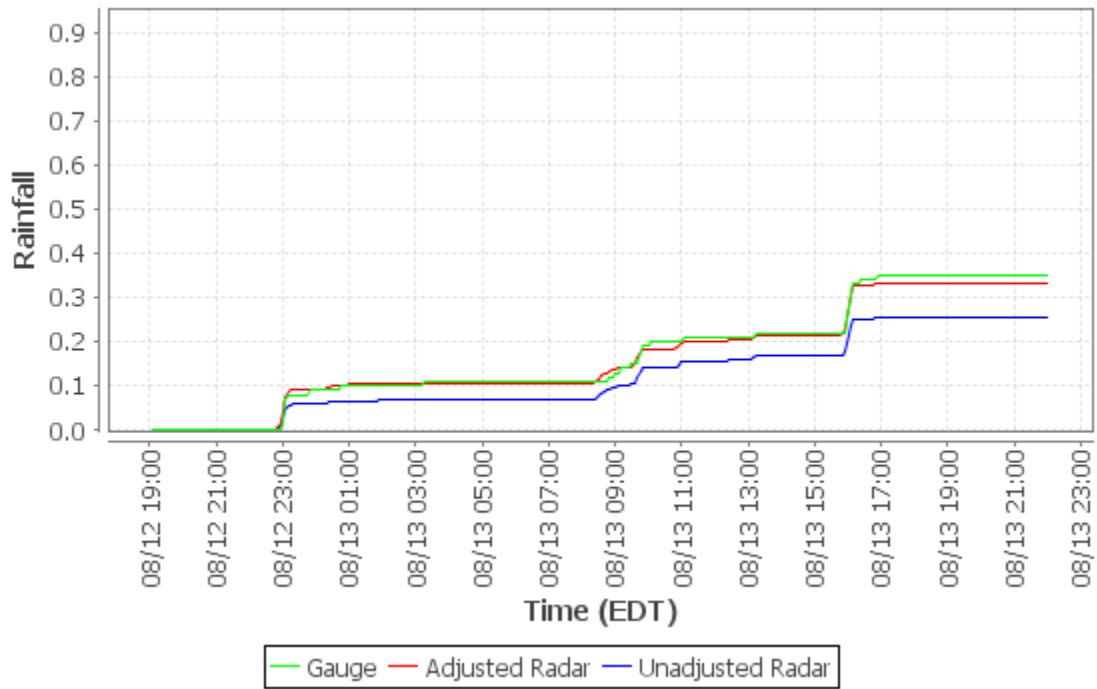
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



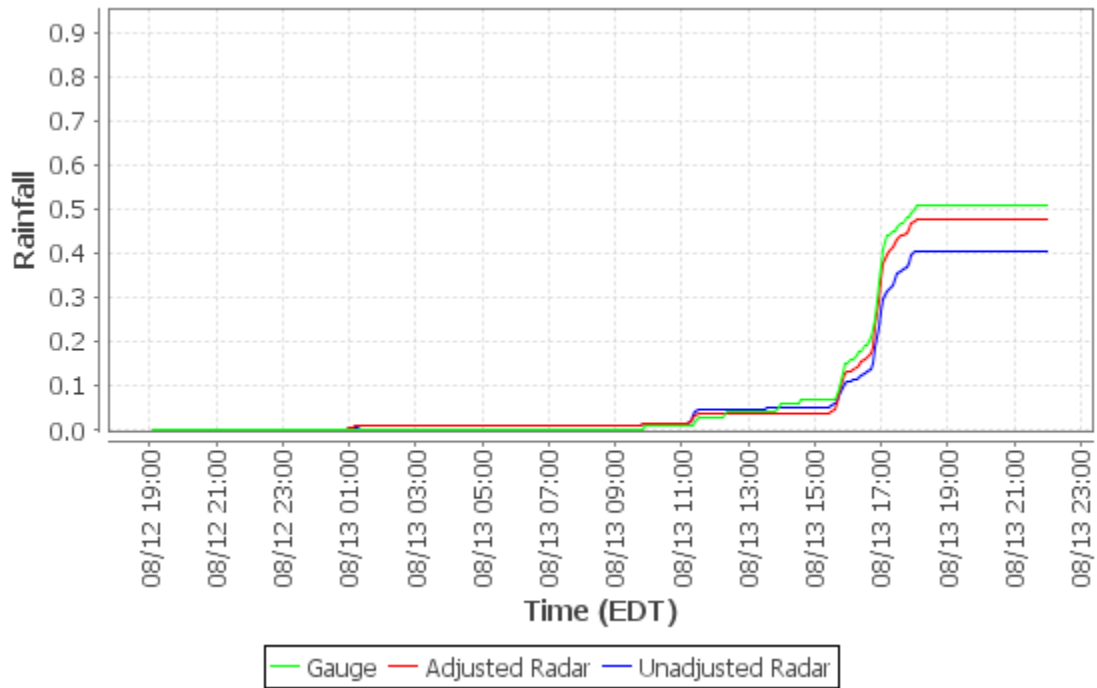
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



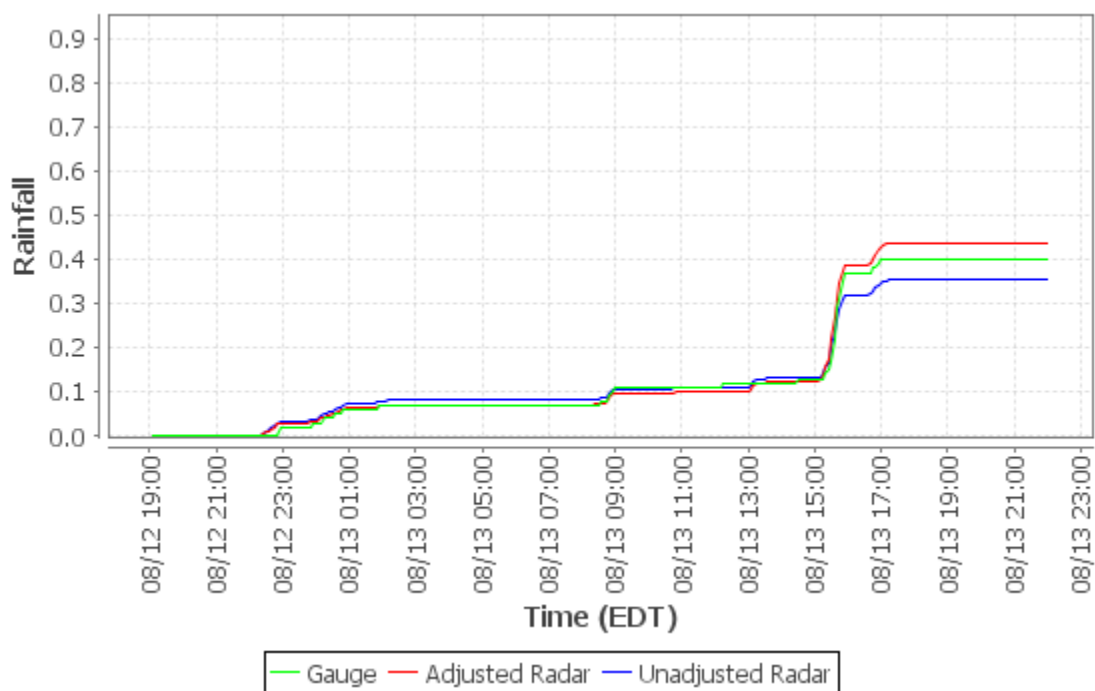
Cumulative Distribution Plot - Marshall TWP (Loc27)



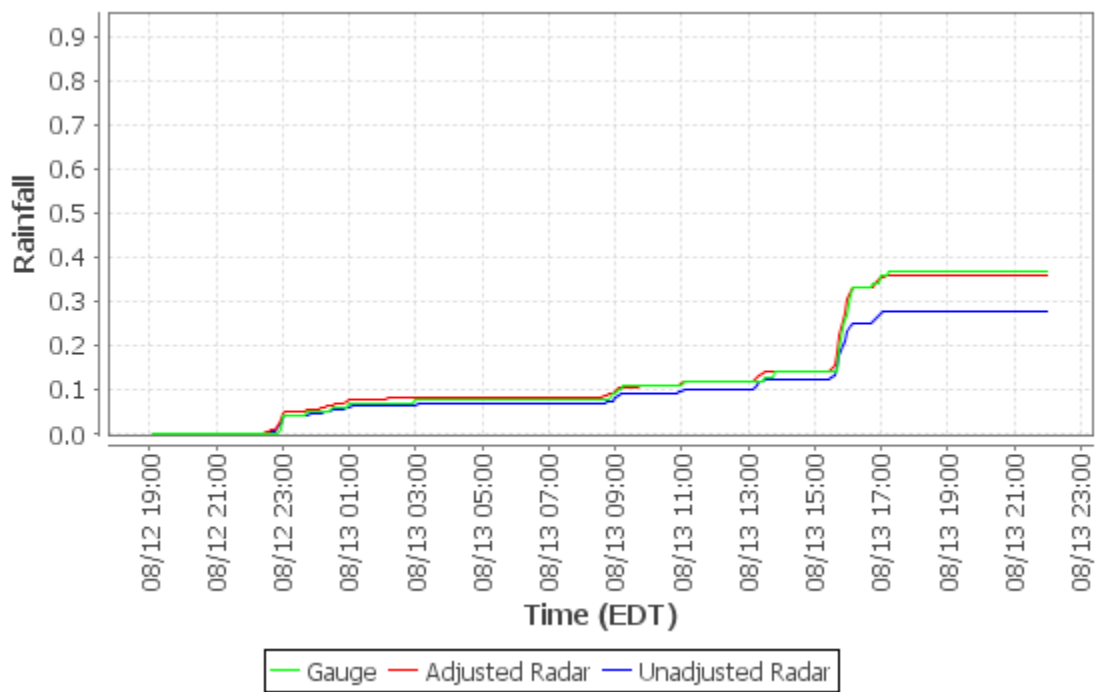
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



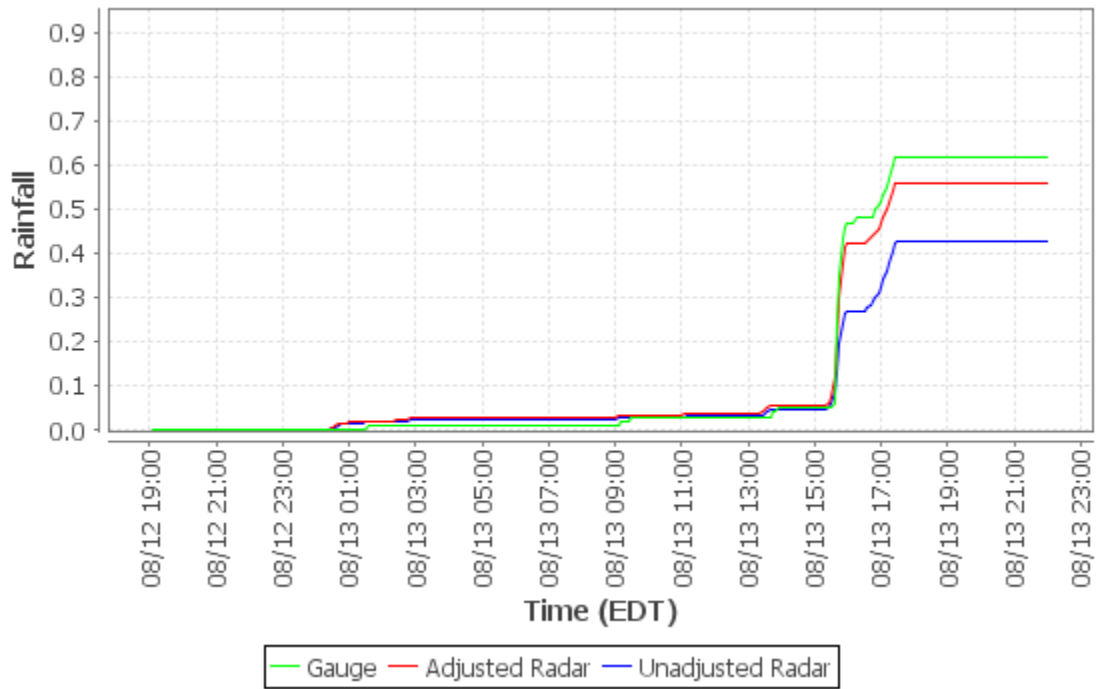
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



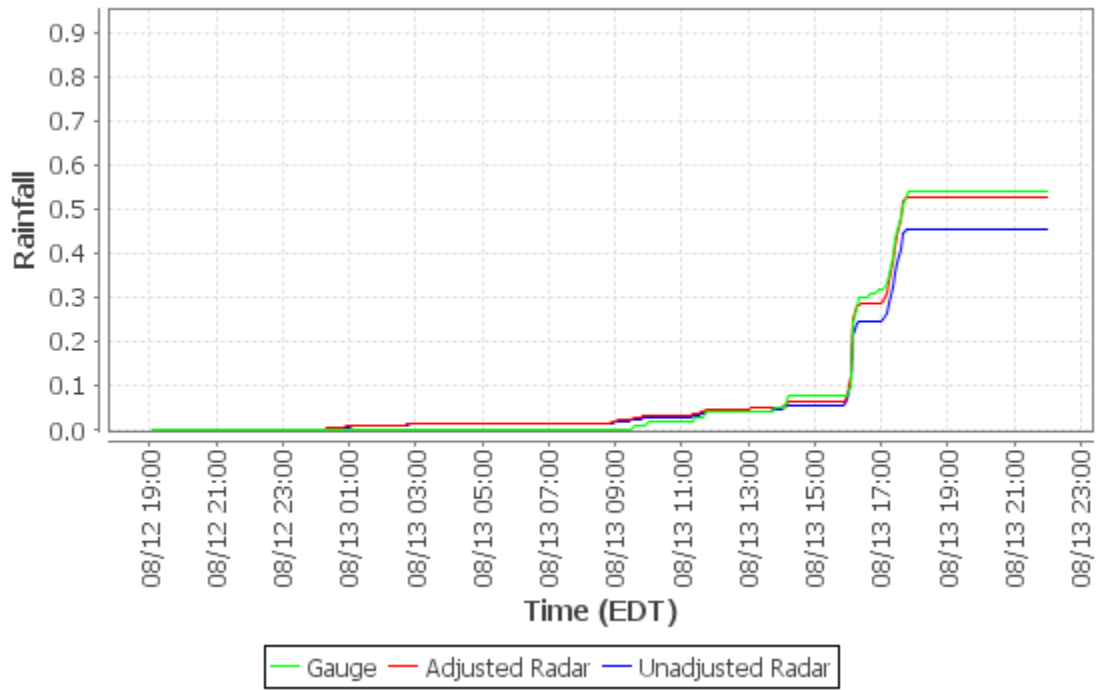
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



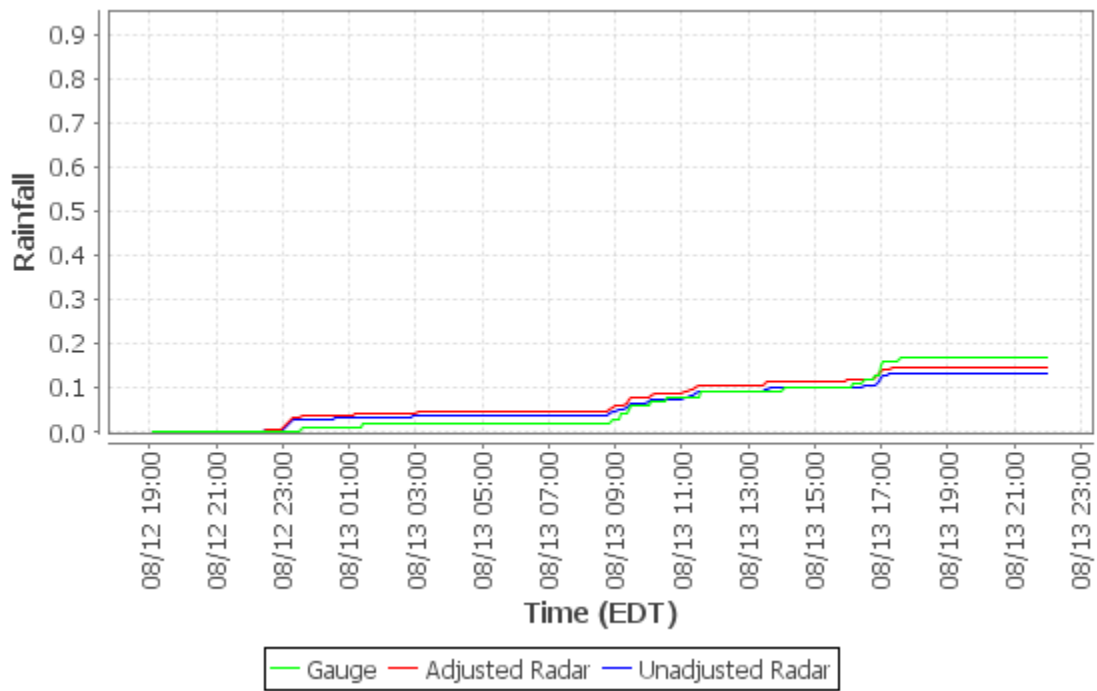
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



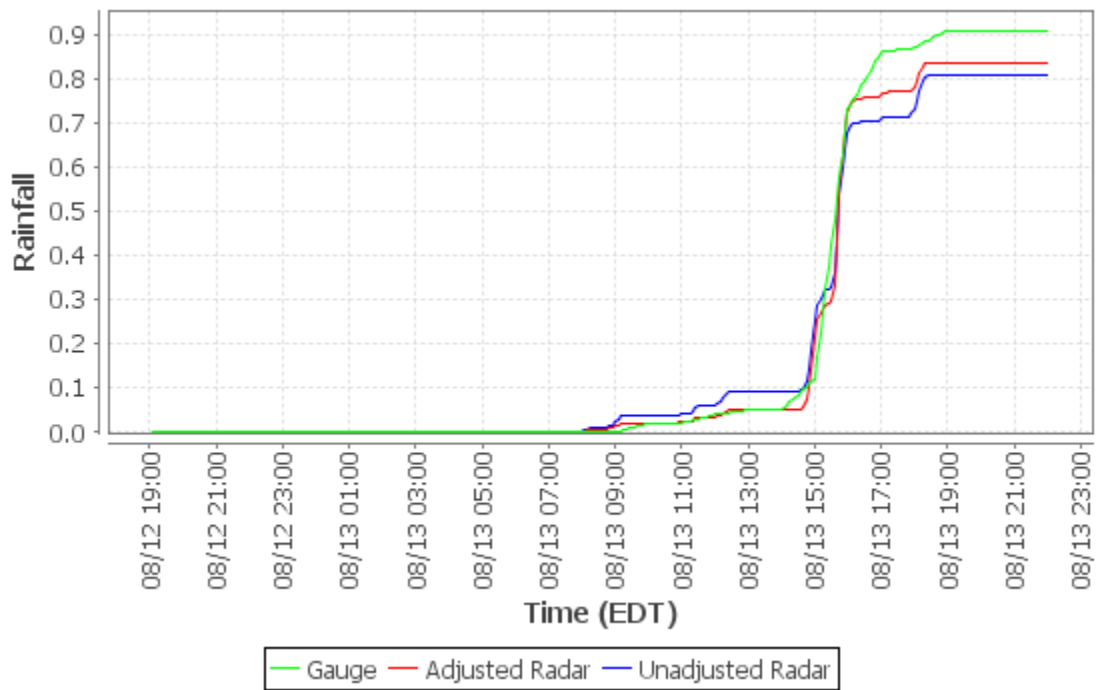
Cumulative Distribution Plot - Arnold (Loc32)



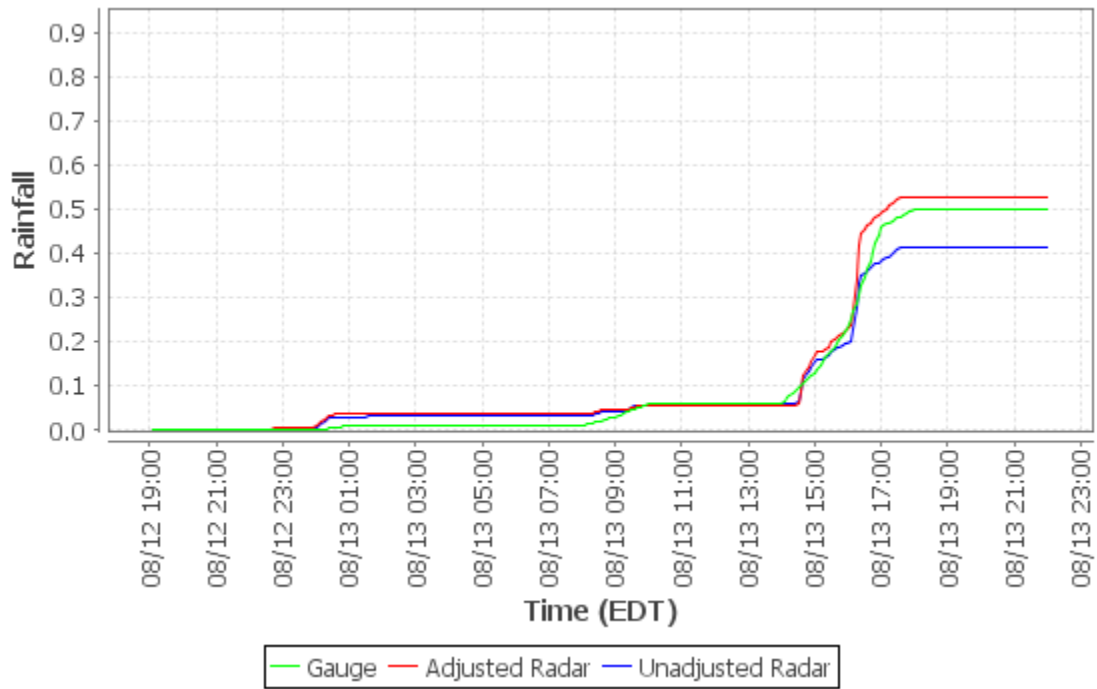
Cumulative Distribution Plot - Richland TWP (Loc33)



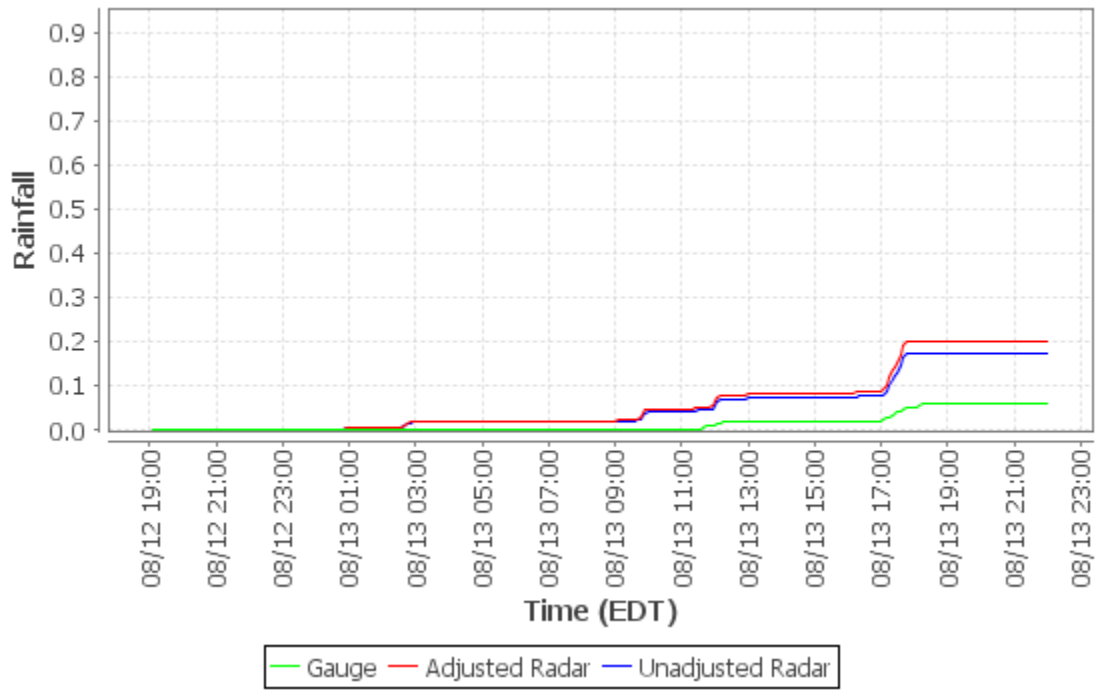
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



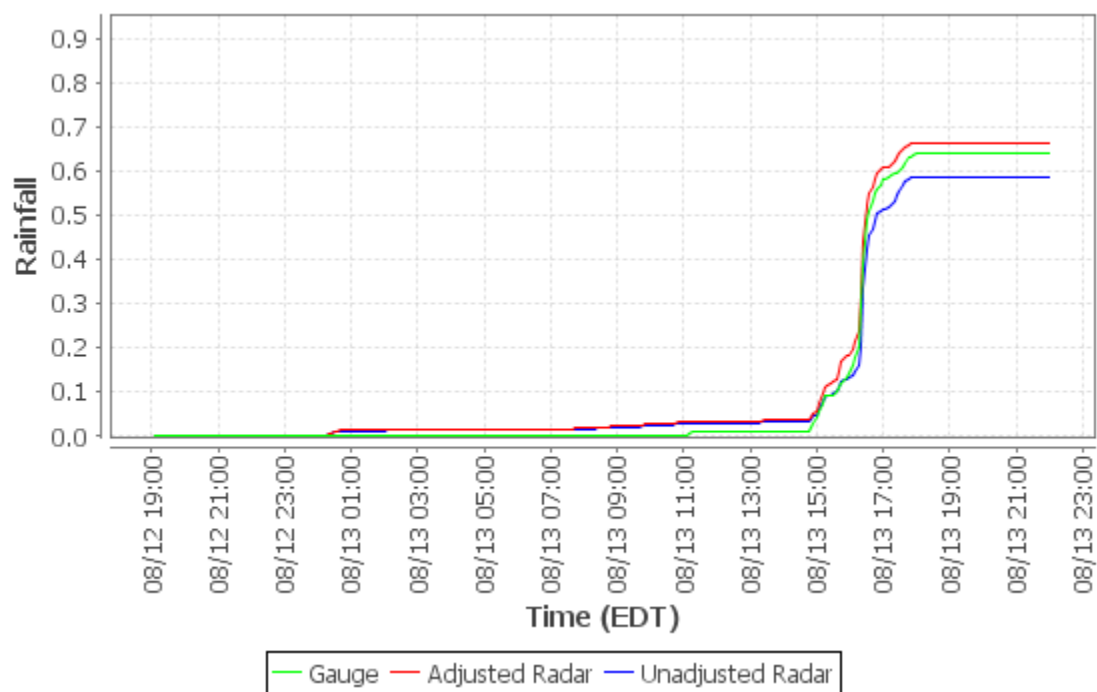
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

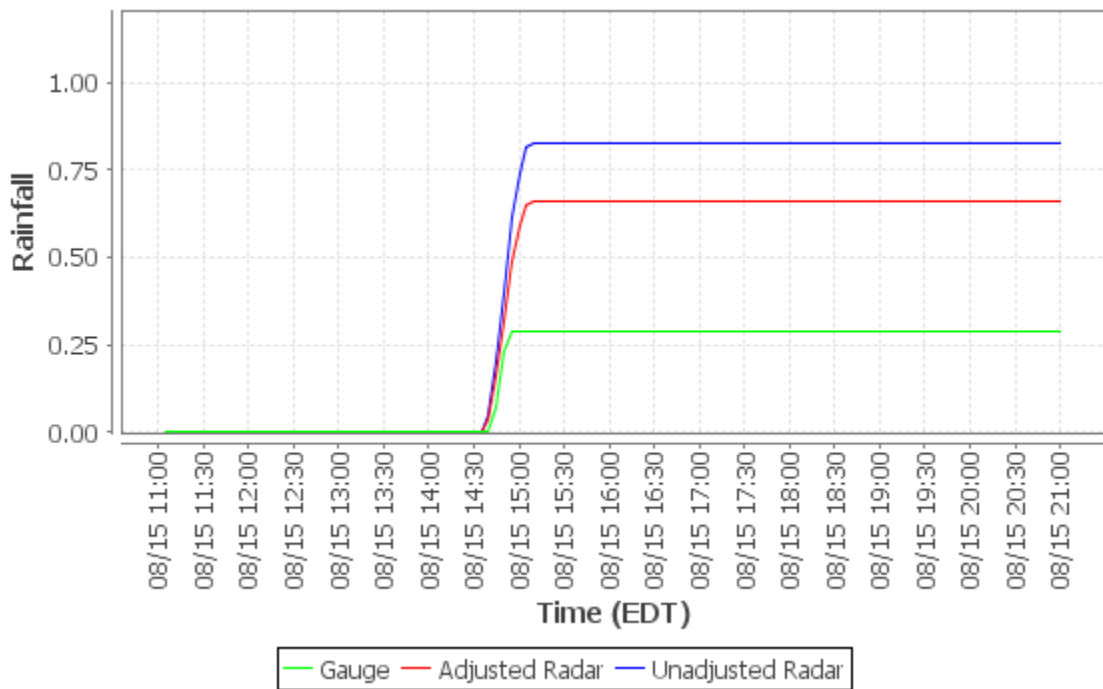


Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth (03085734)

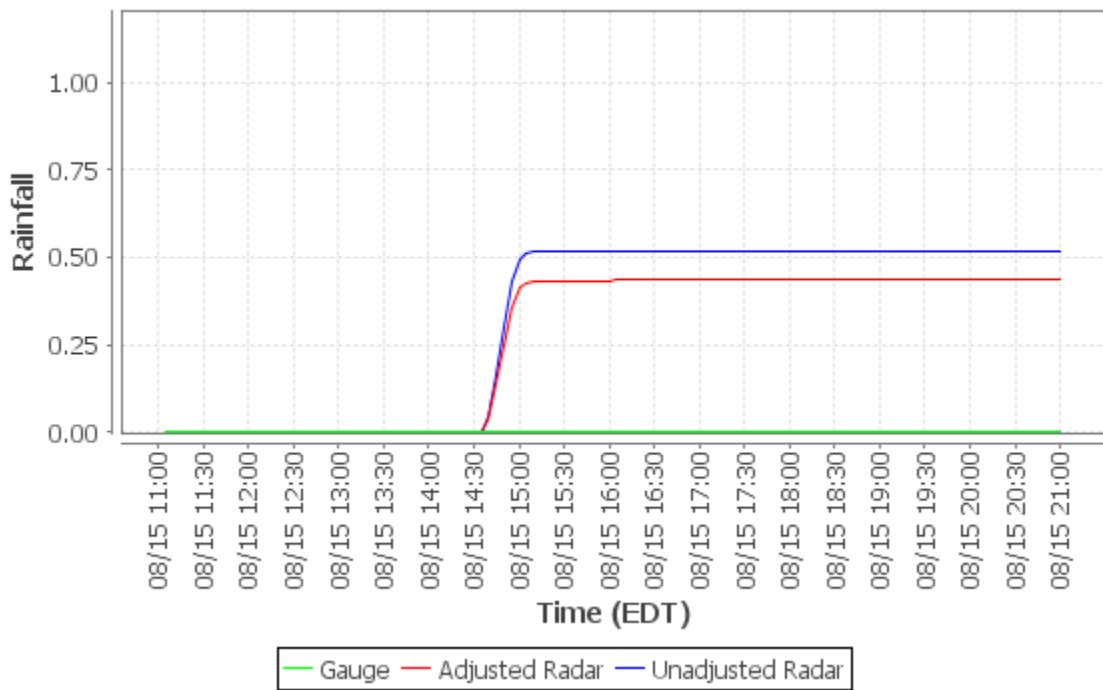


Appendix E - Event 3 (2019-08-15) CDPs

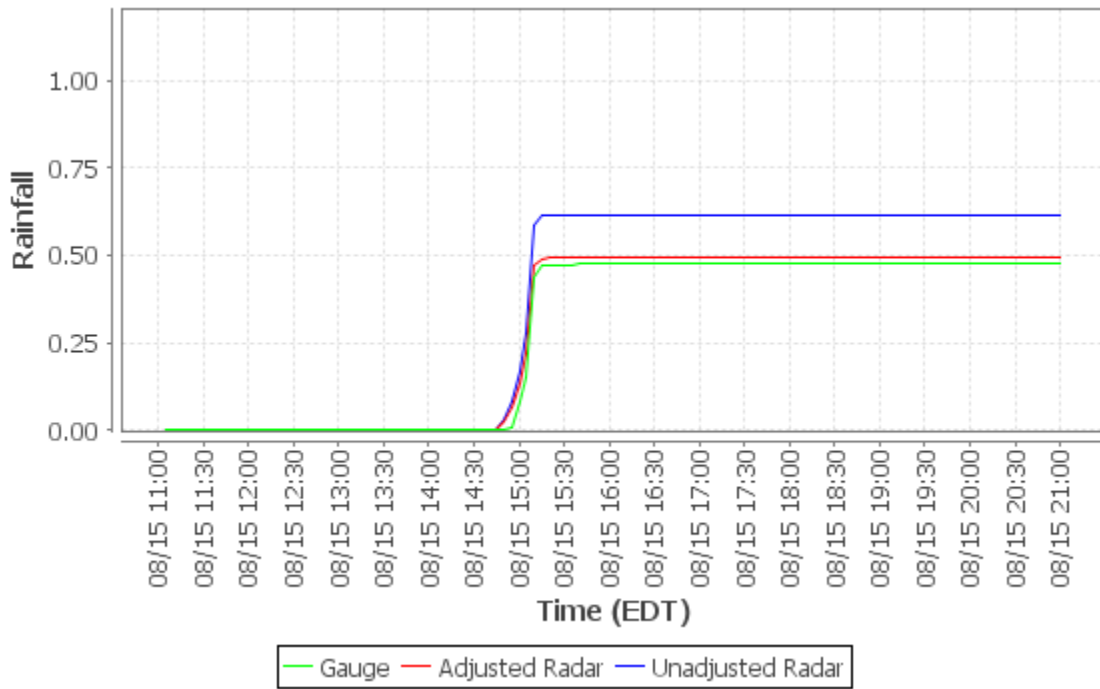
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



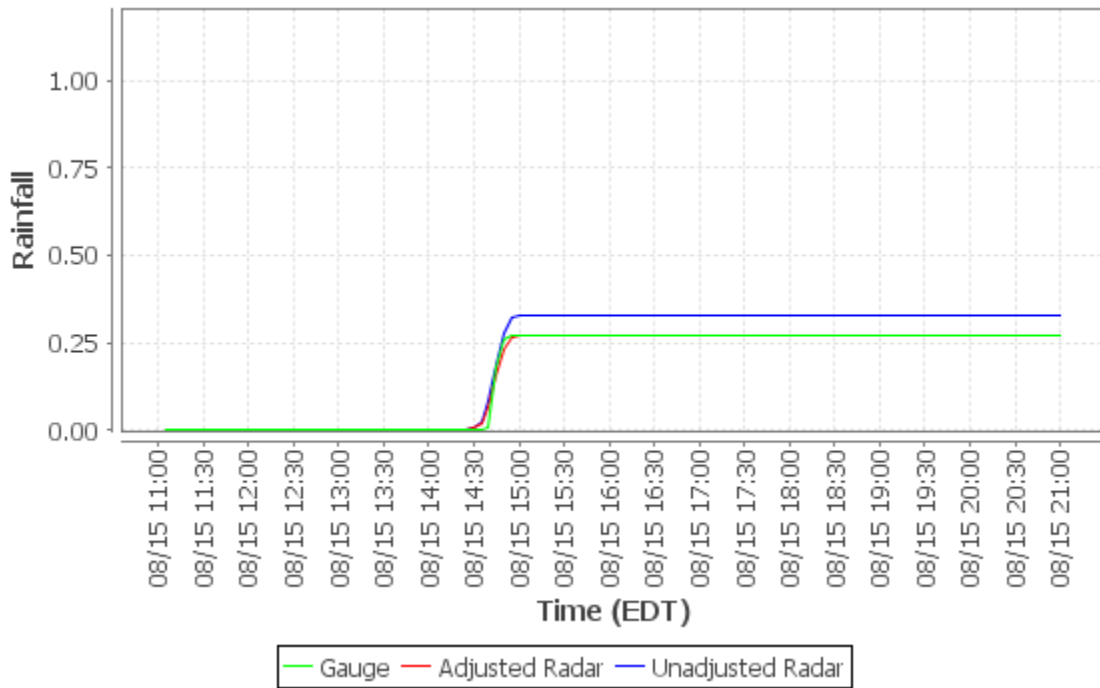
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



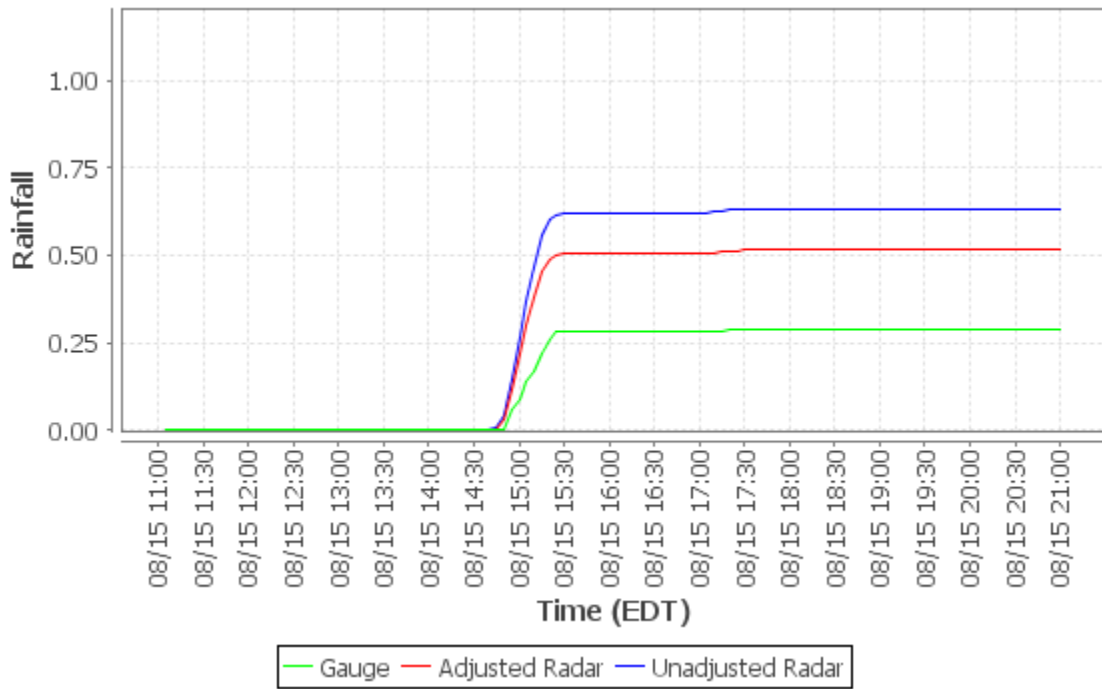
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



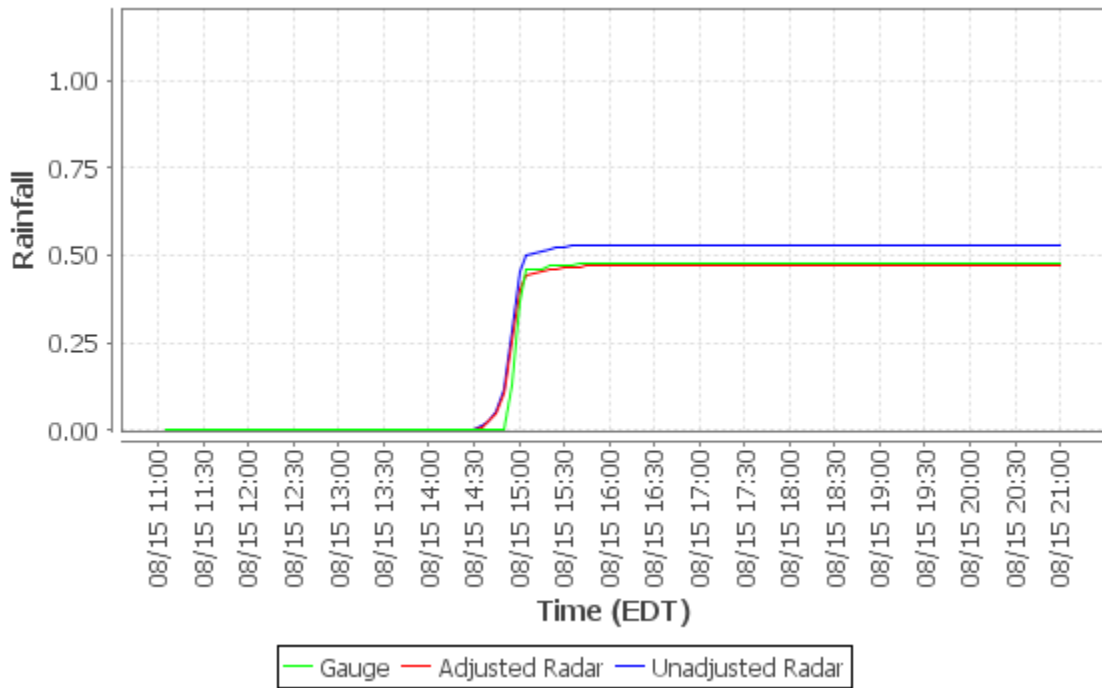
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



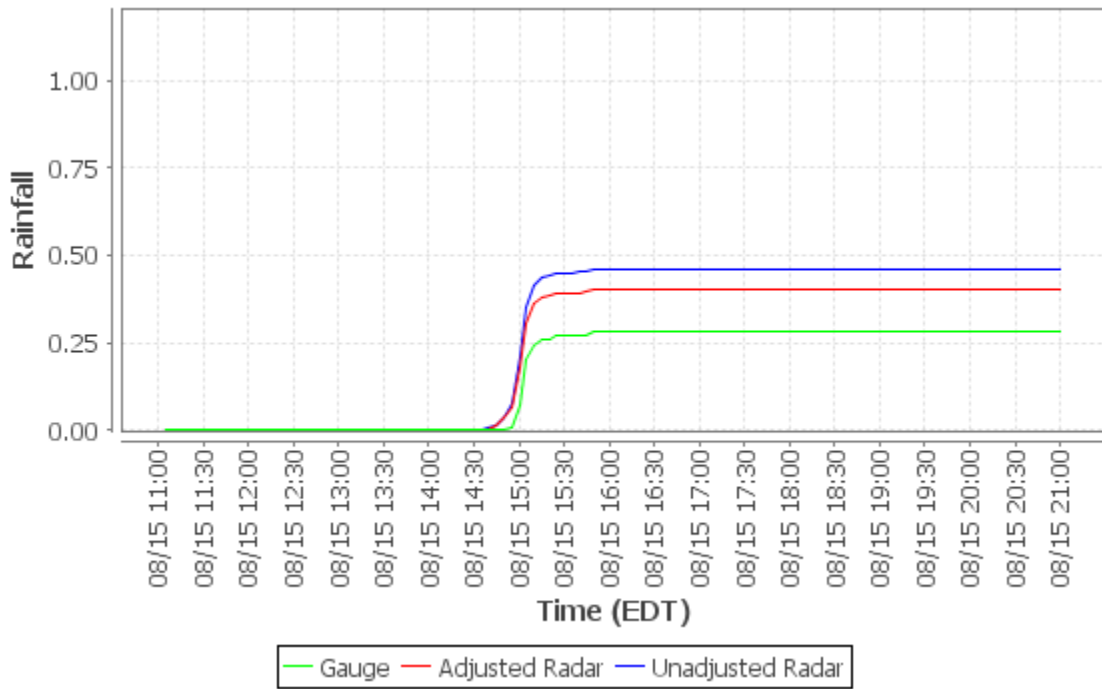
Cumulative Distribution Plot - Upper St. Clair (Loc05)



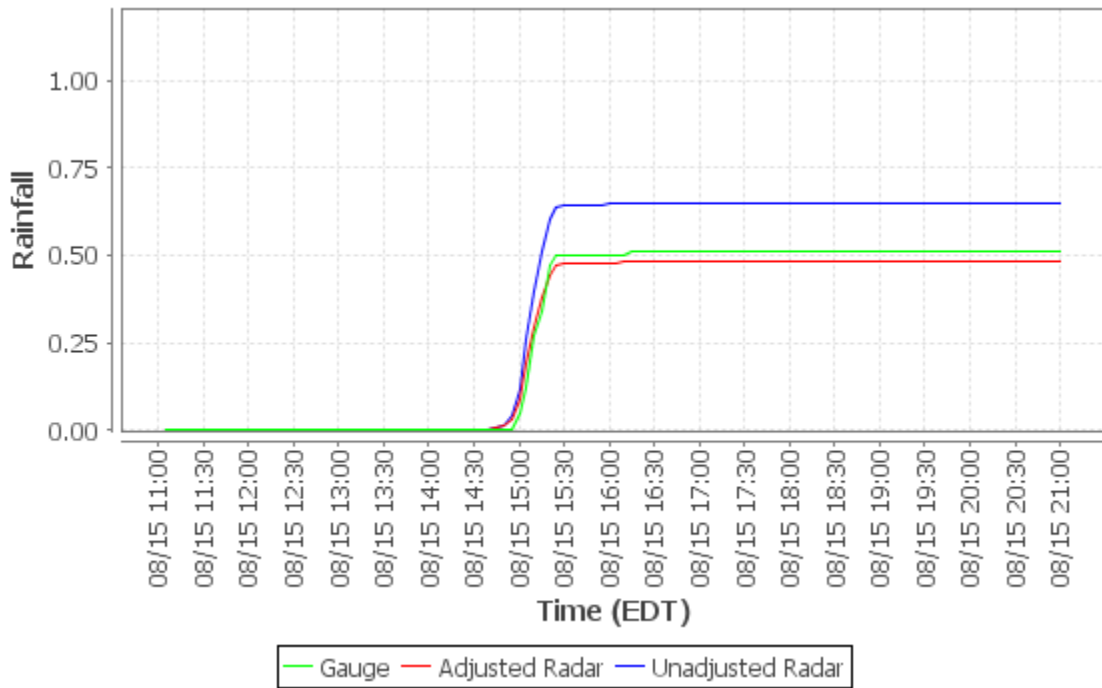
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



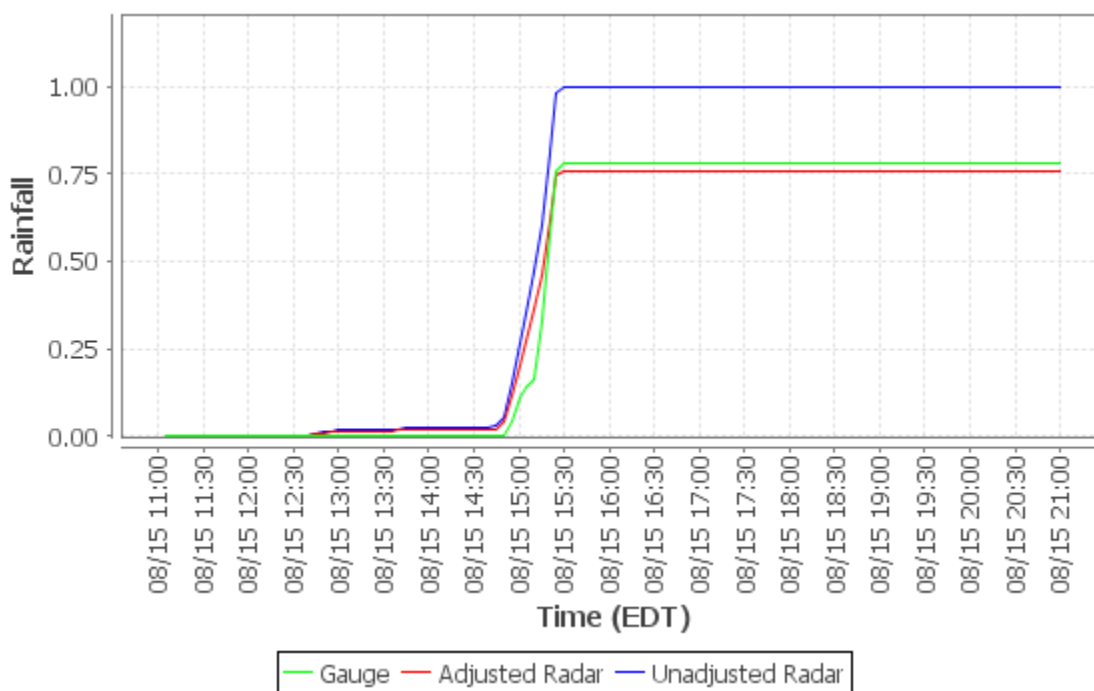
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



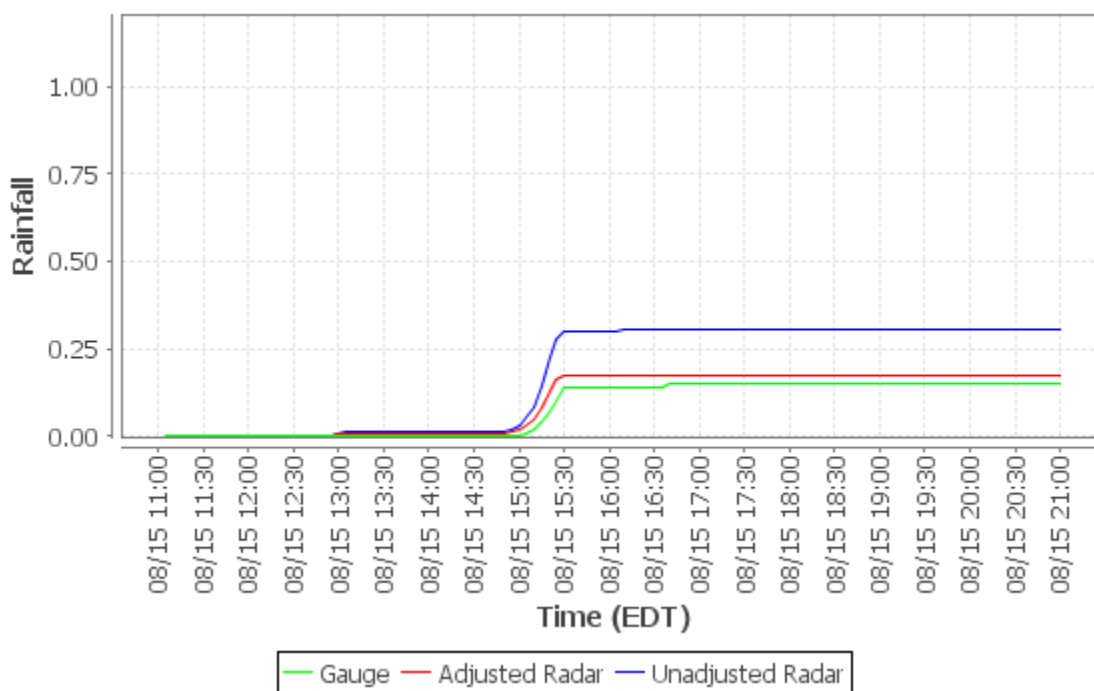
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



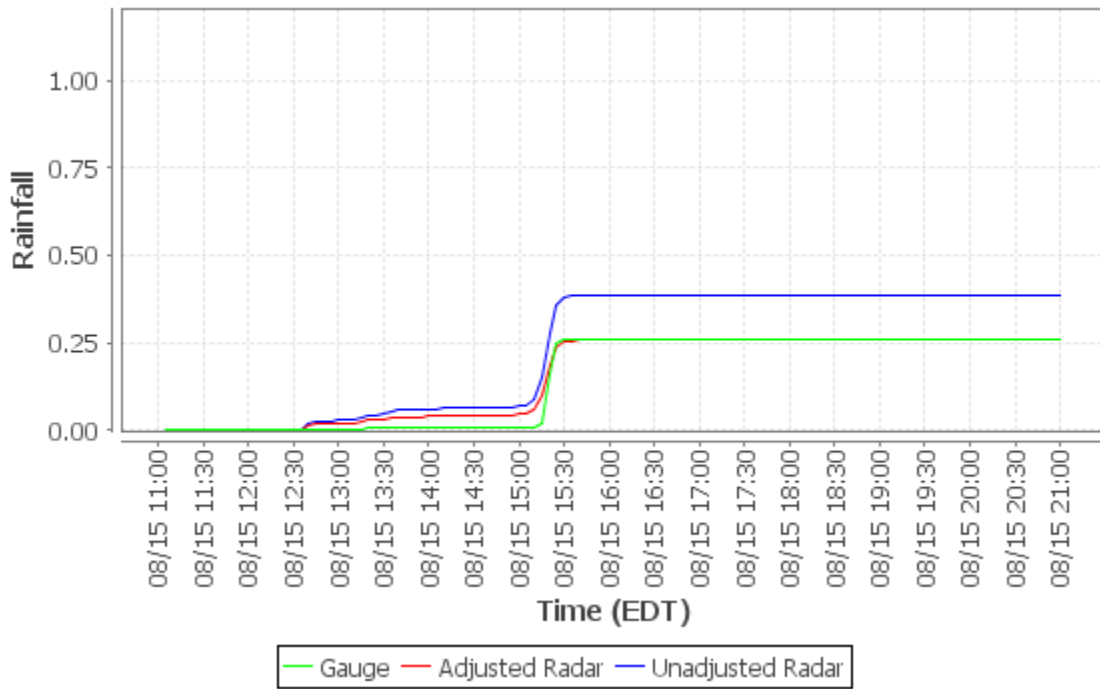
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



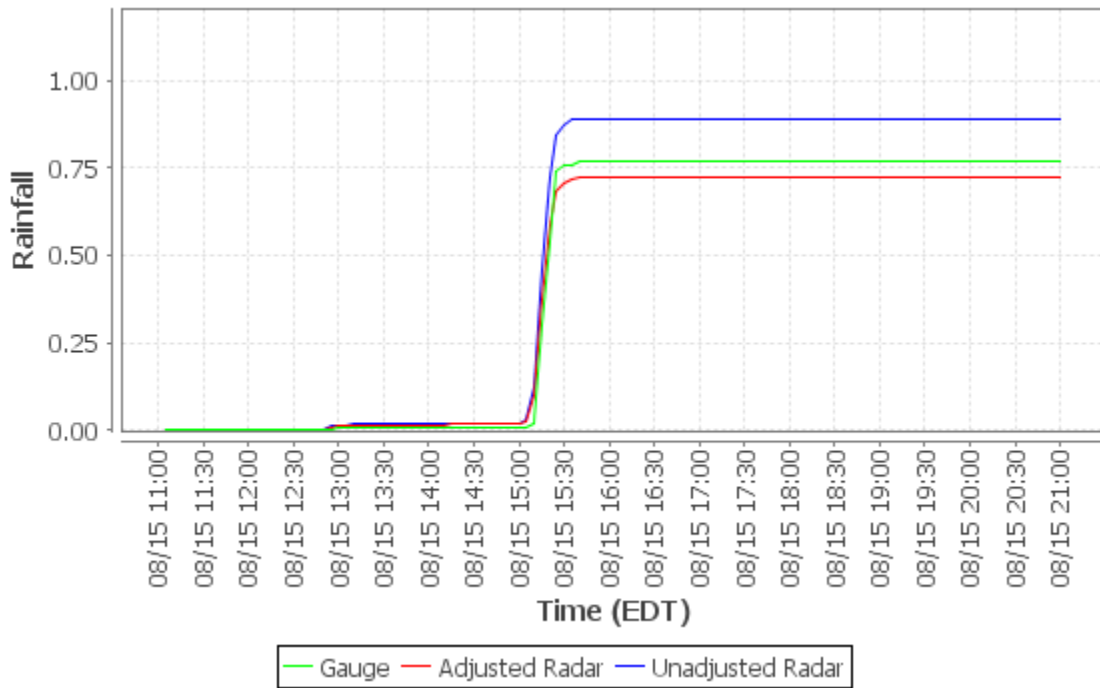
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



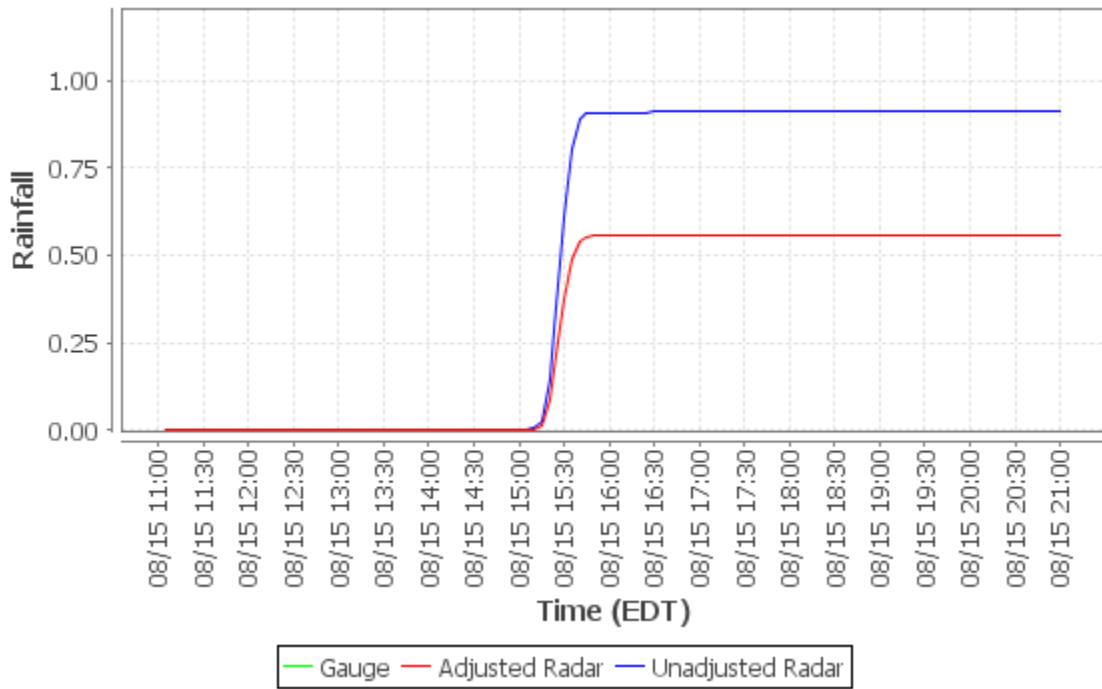
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



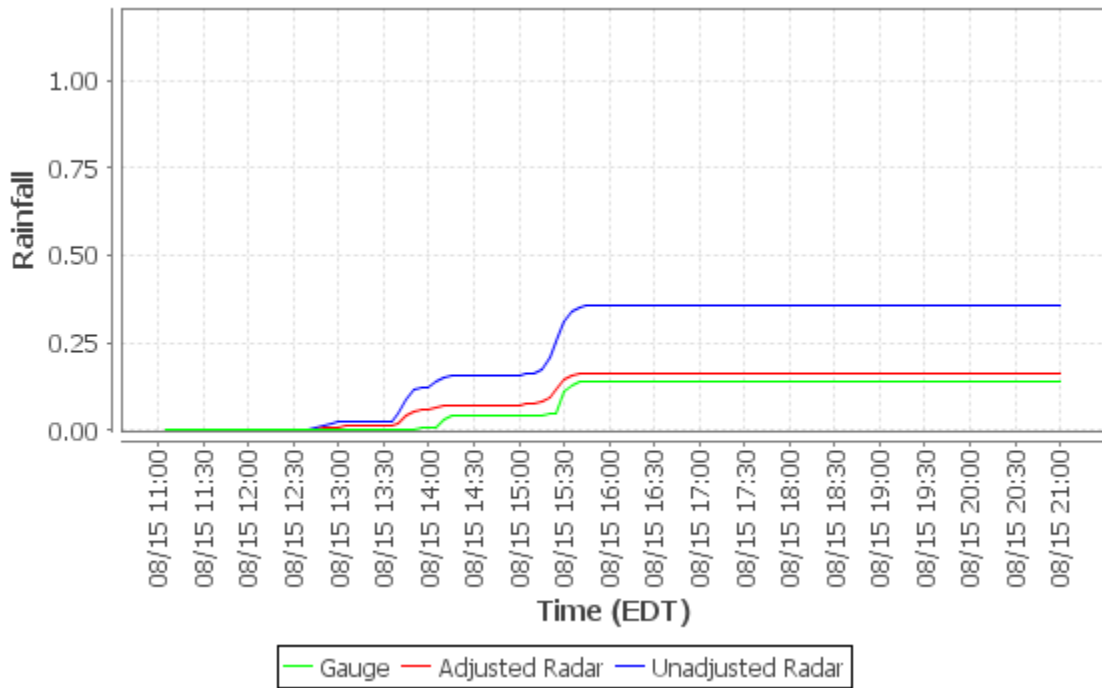
Cumulative Distribution Plot - Baldwin (Loc12)



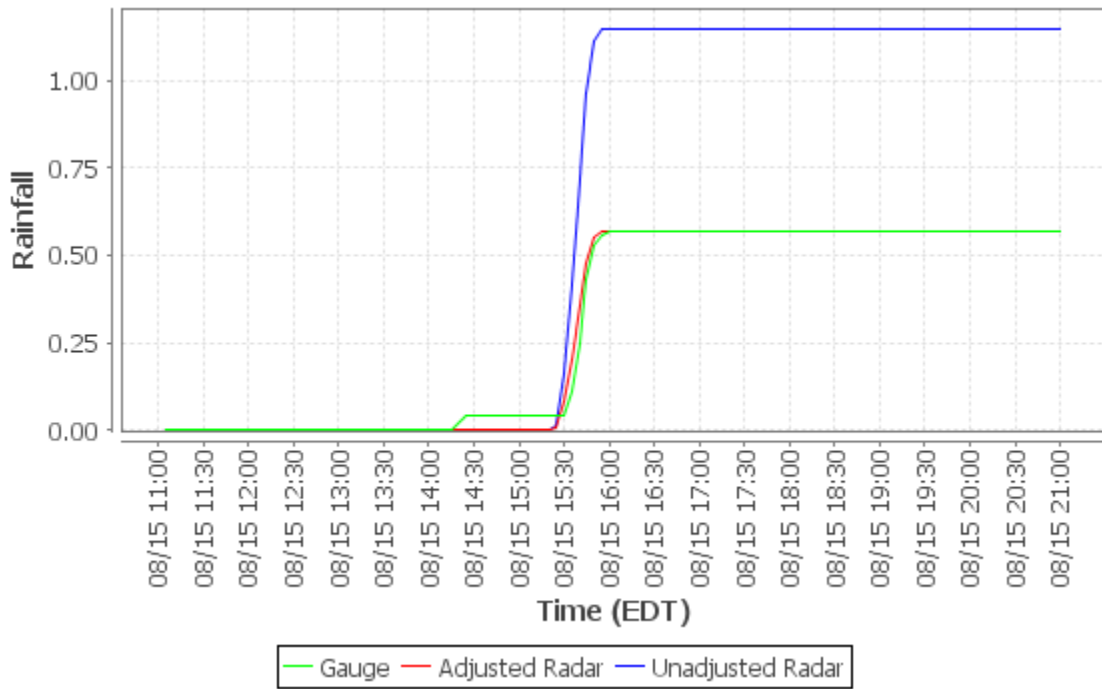
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



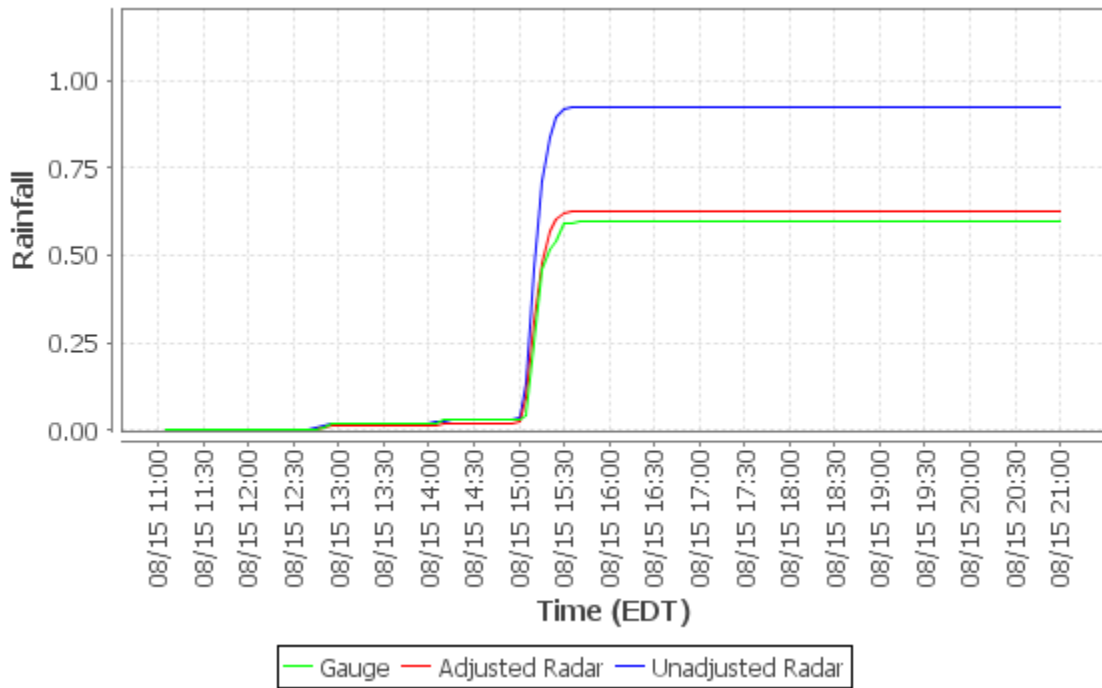
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



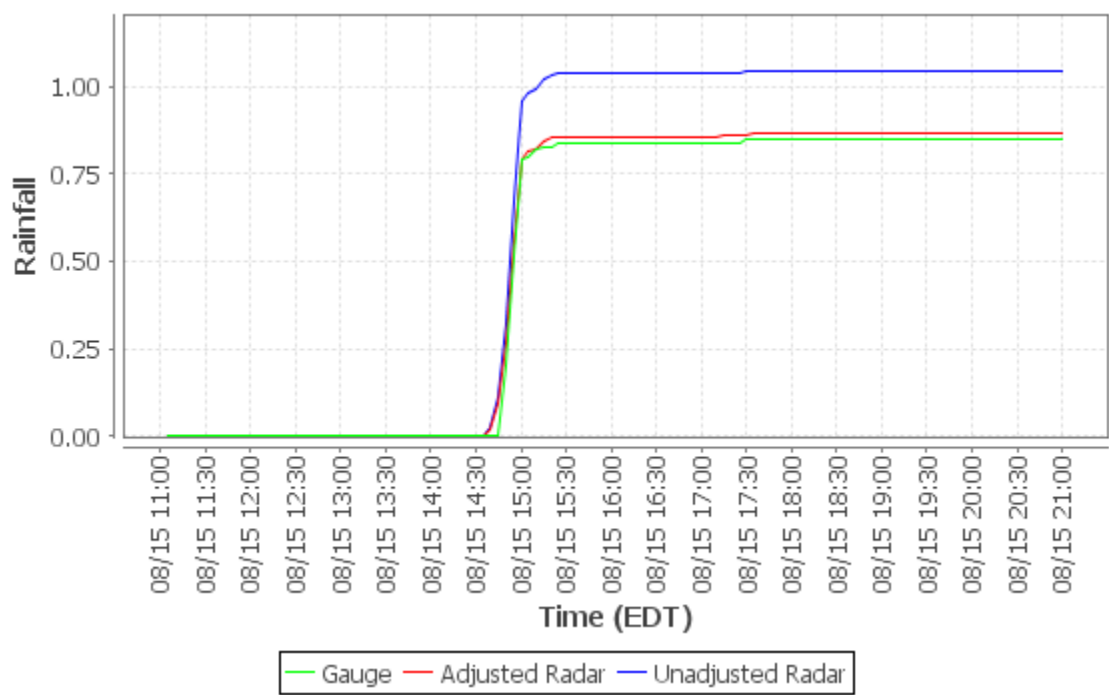
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



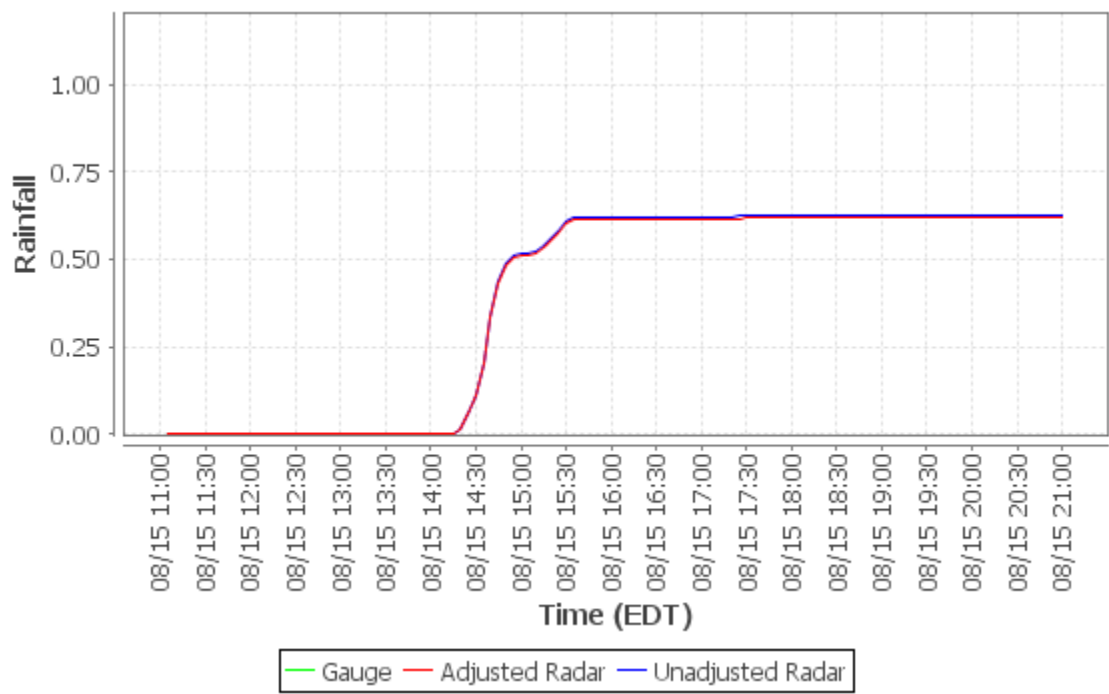
Cumulative Distribution Plot - Castle Shannon (Loc16)



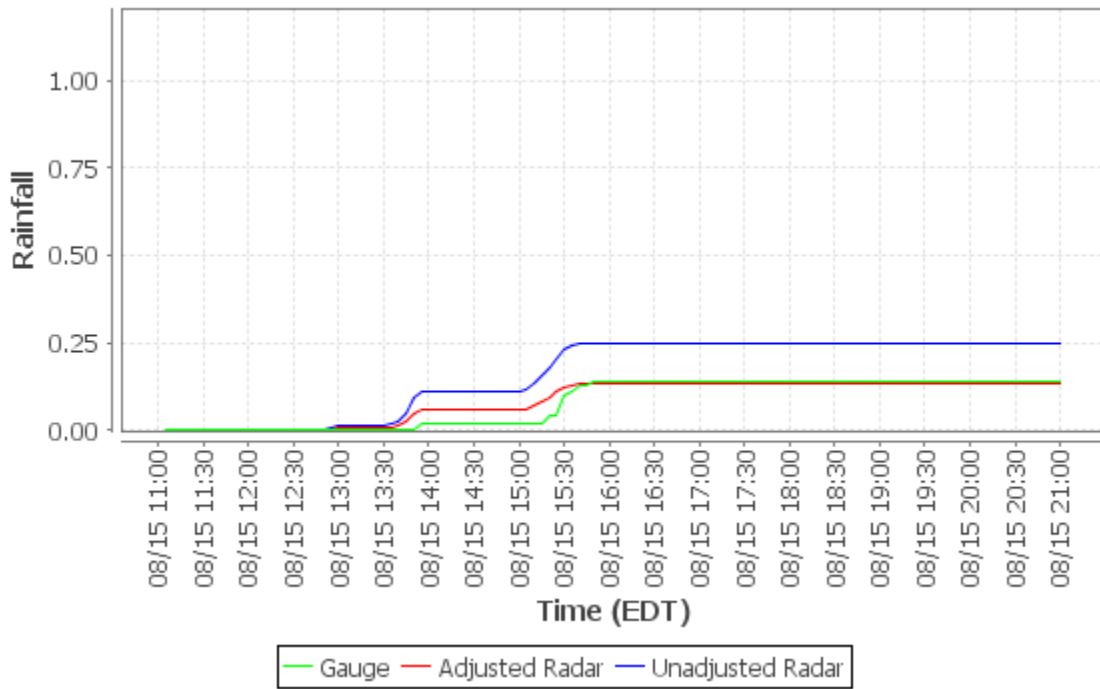
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



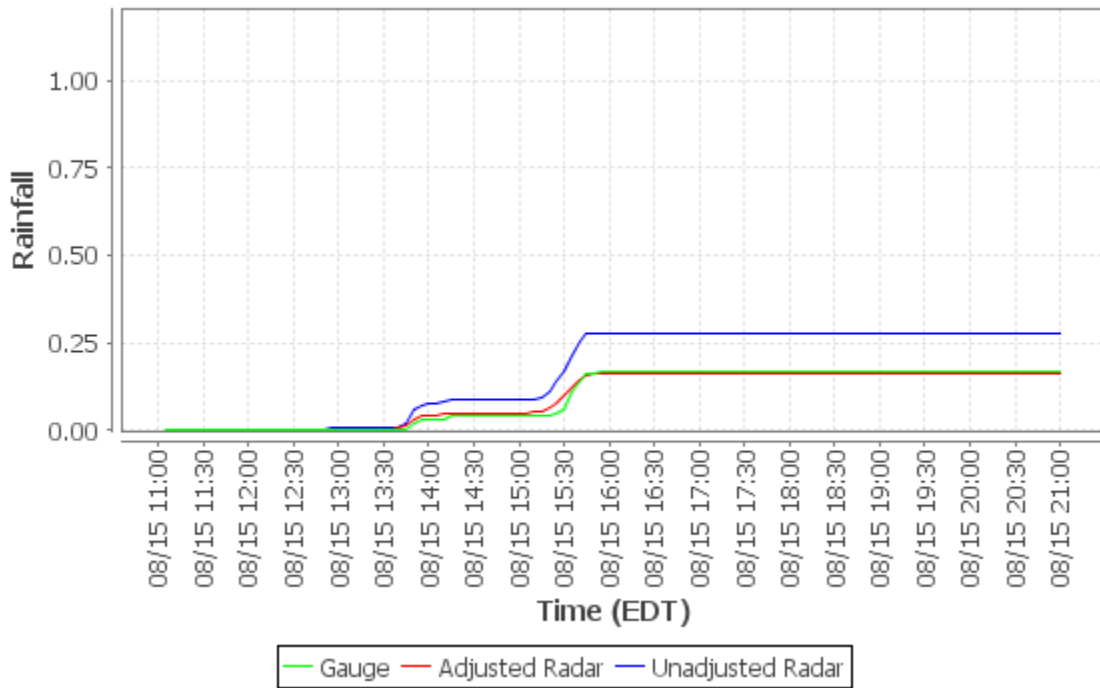
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



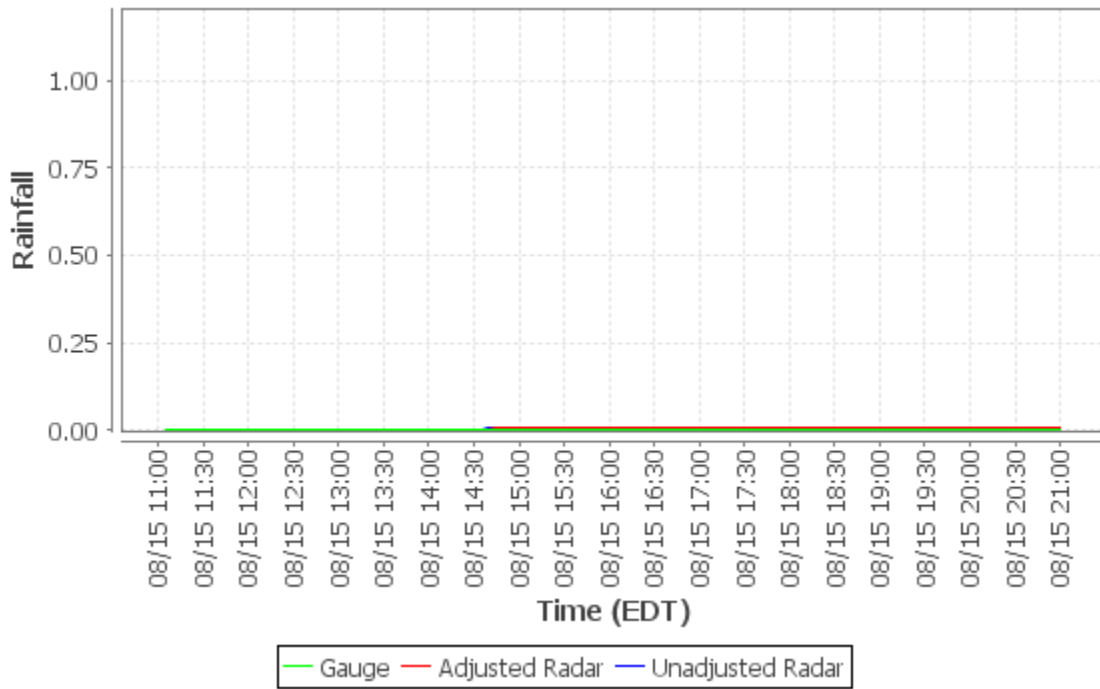
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



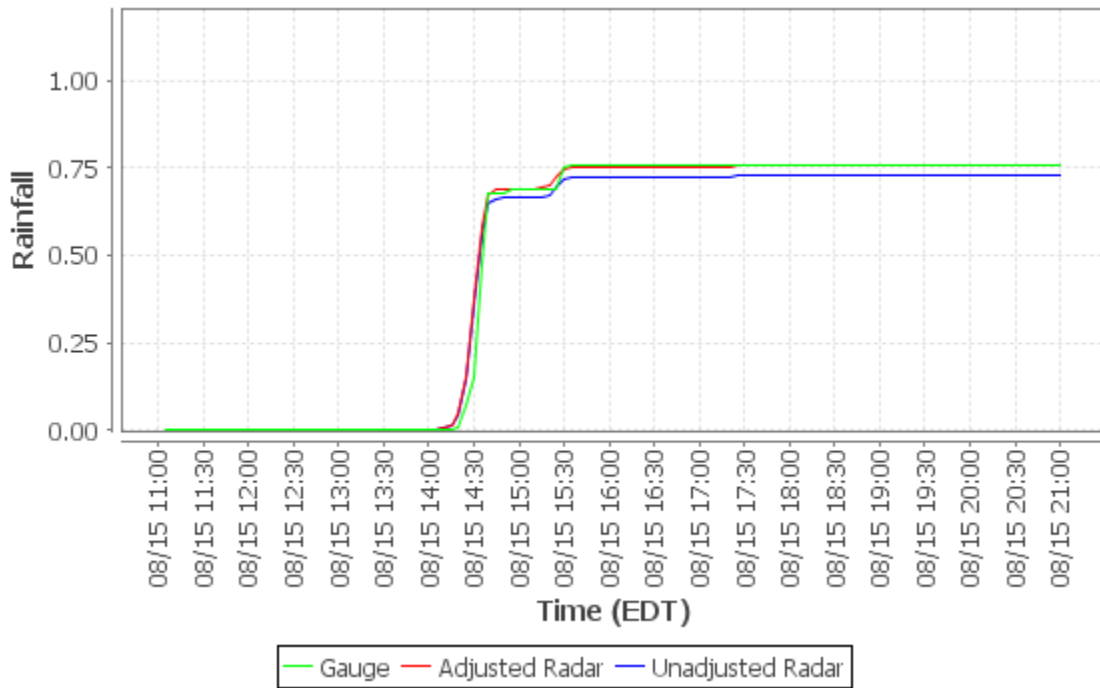
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



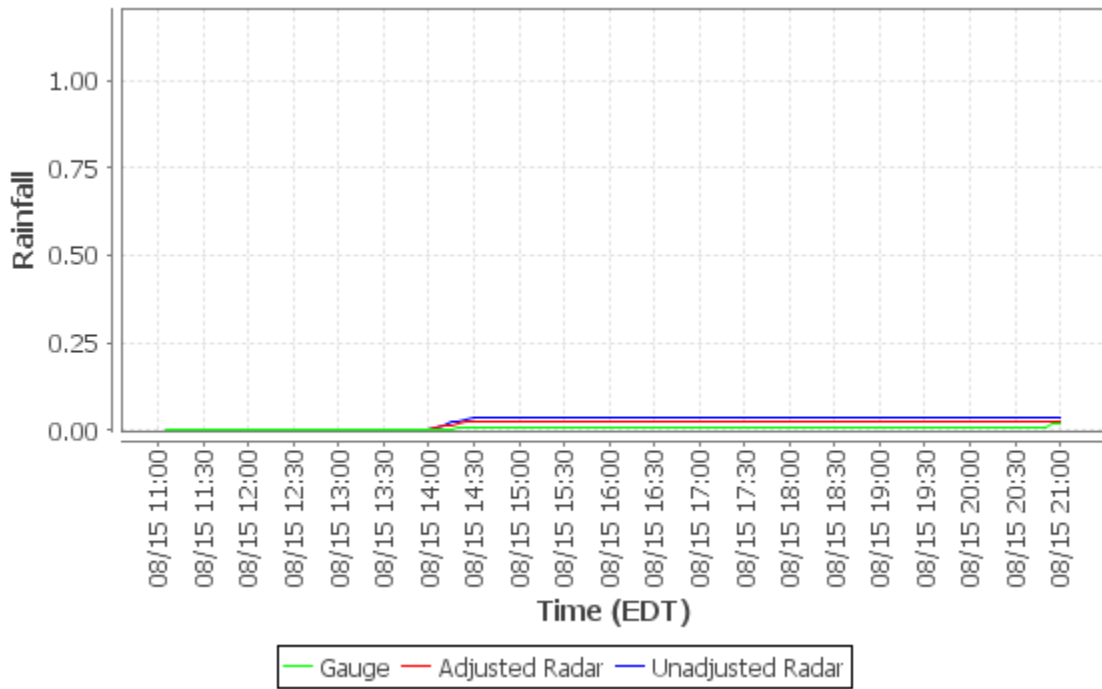
Cumulative Distribution Plot - Moon TWP (Loc21)



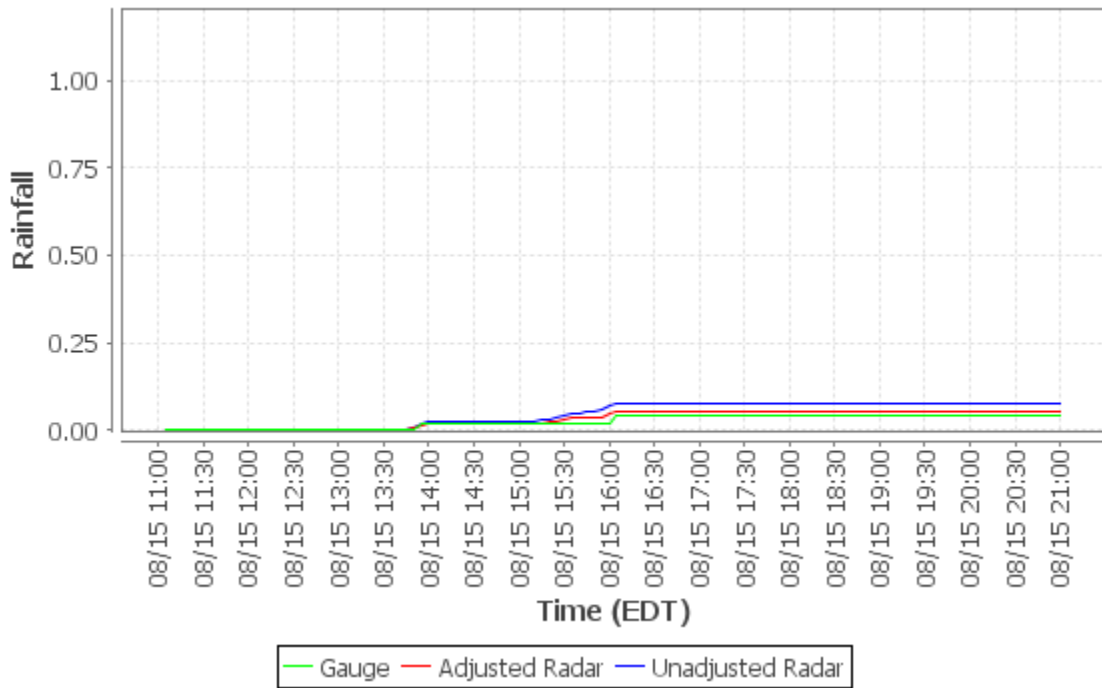
Cumulative Distribution Plot - North Fayette TWP (Loc22)



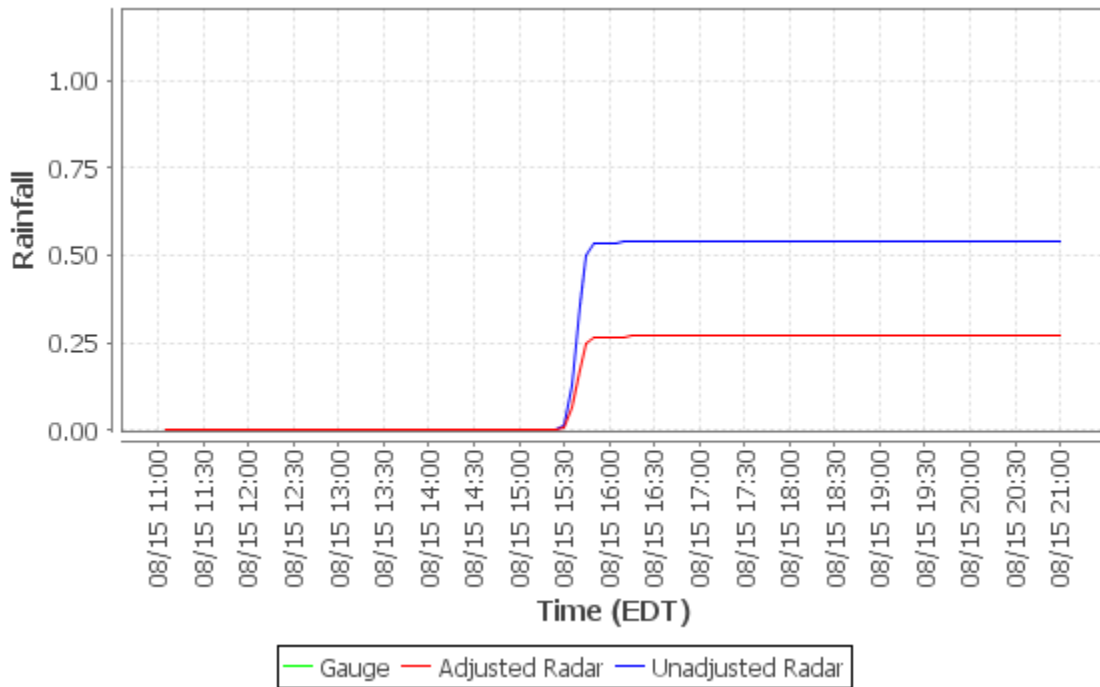
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



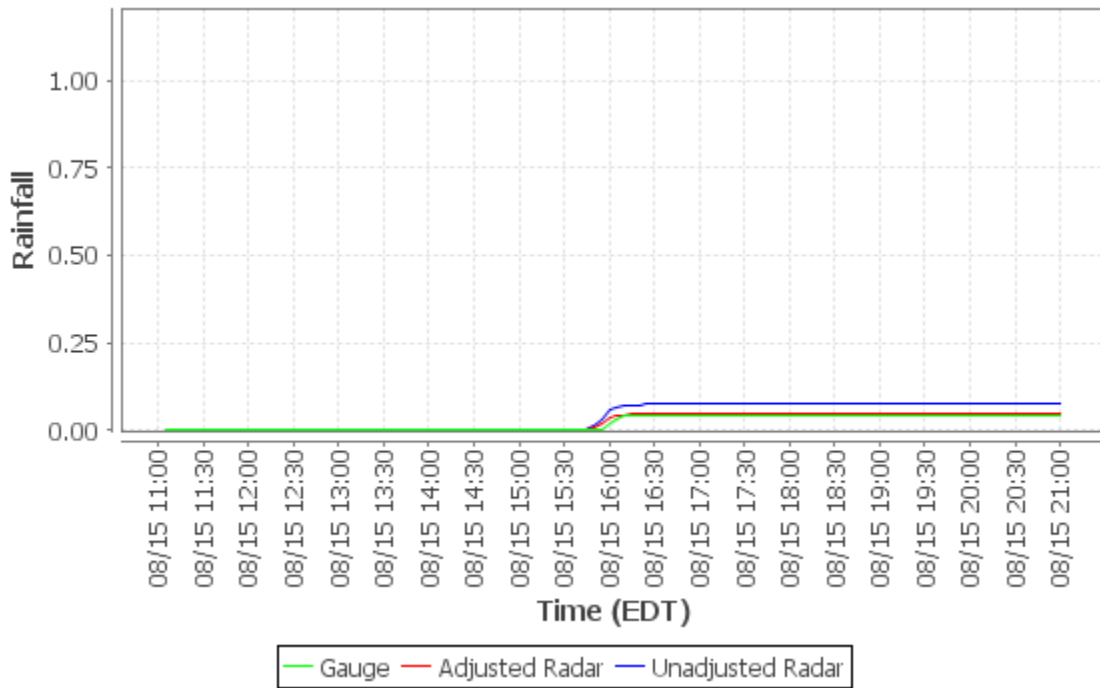
Cumulative Distribution Plot - Jefferson Hills (Loc24)



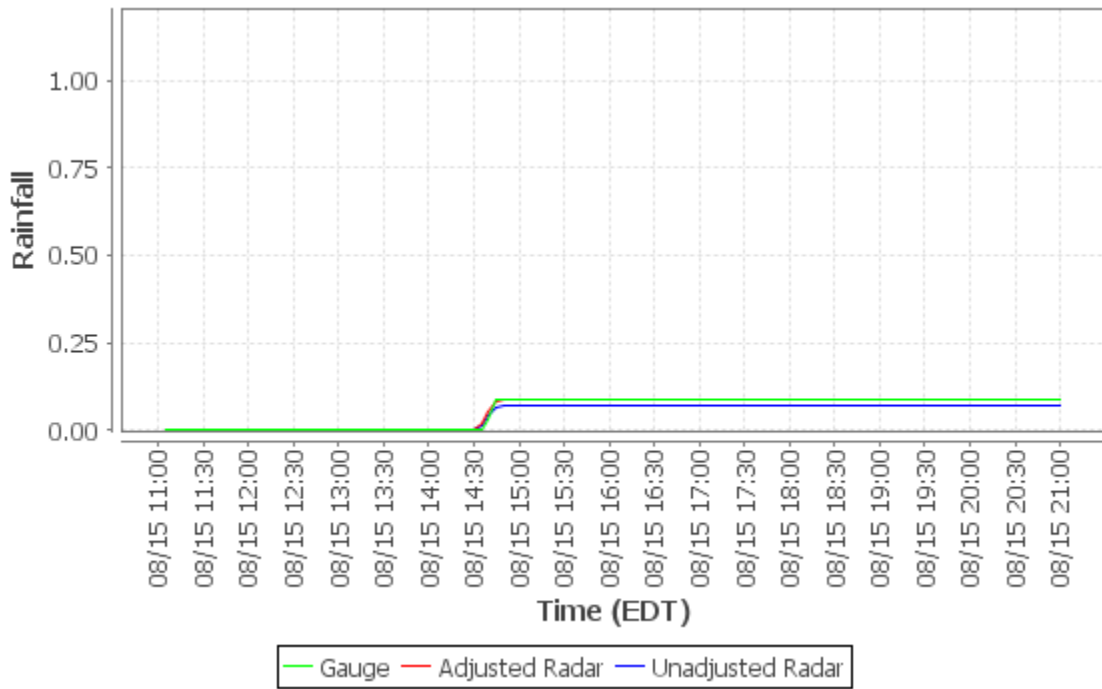
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



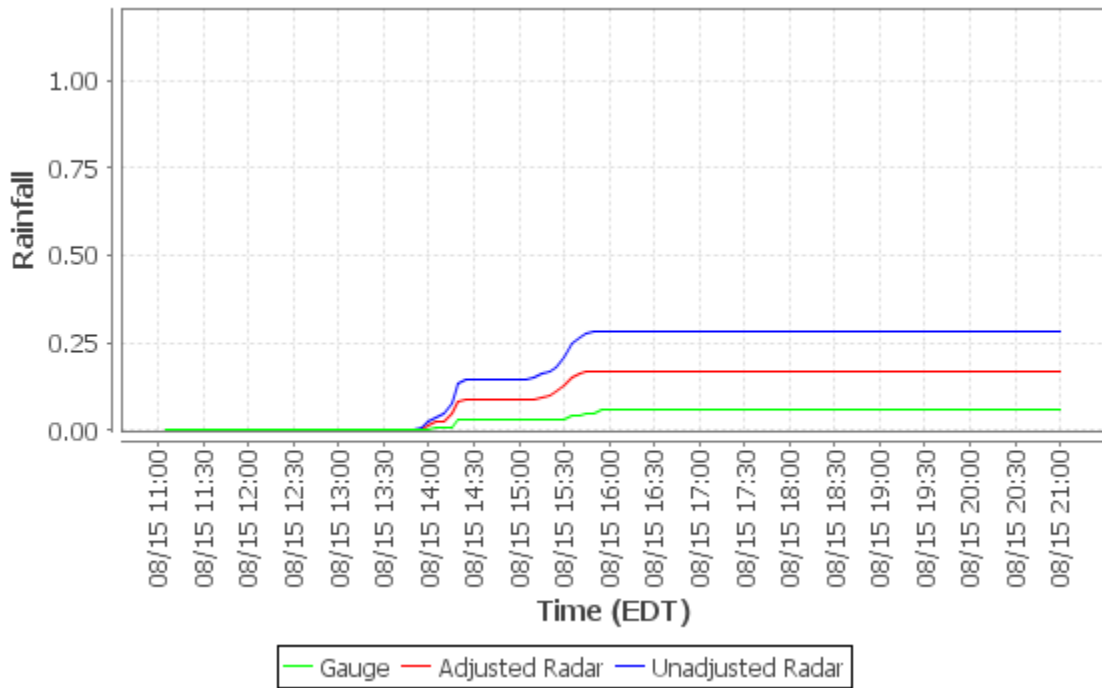
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



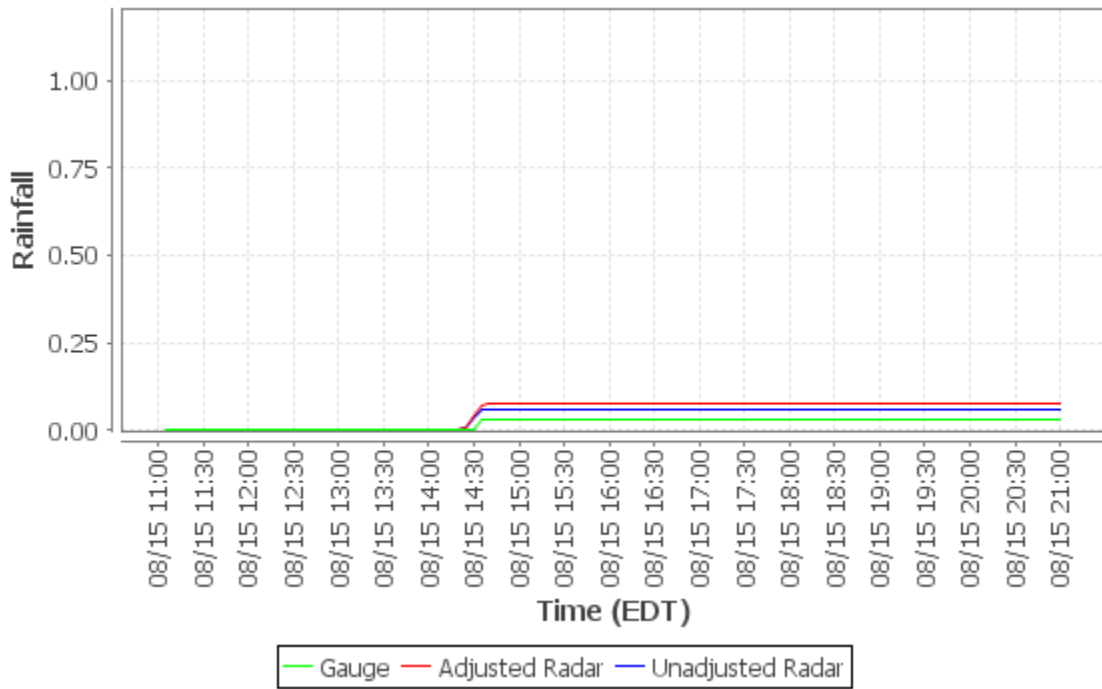
Cumulative Distribution Plot - Marshall TWP (Loc27)



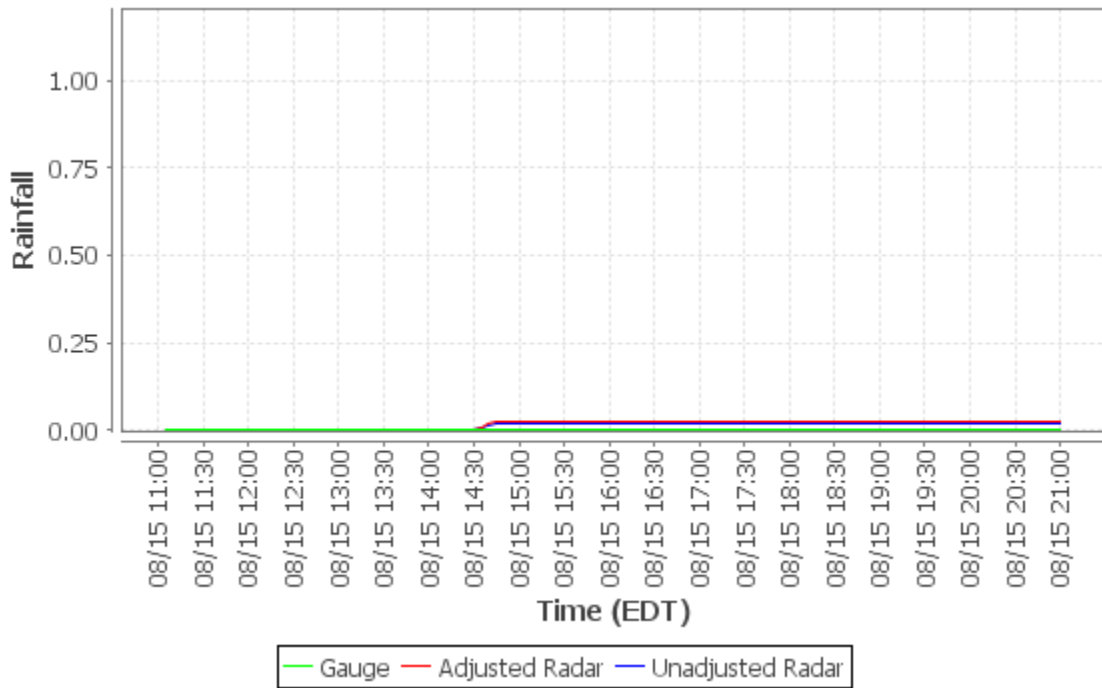
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



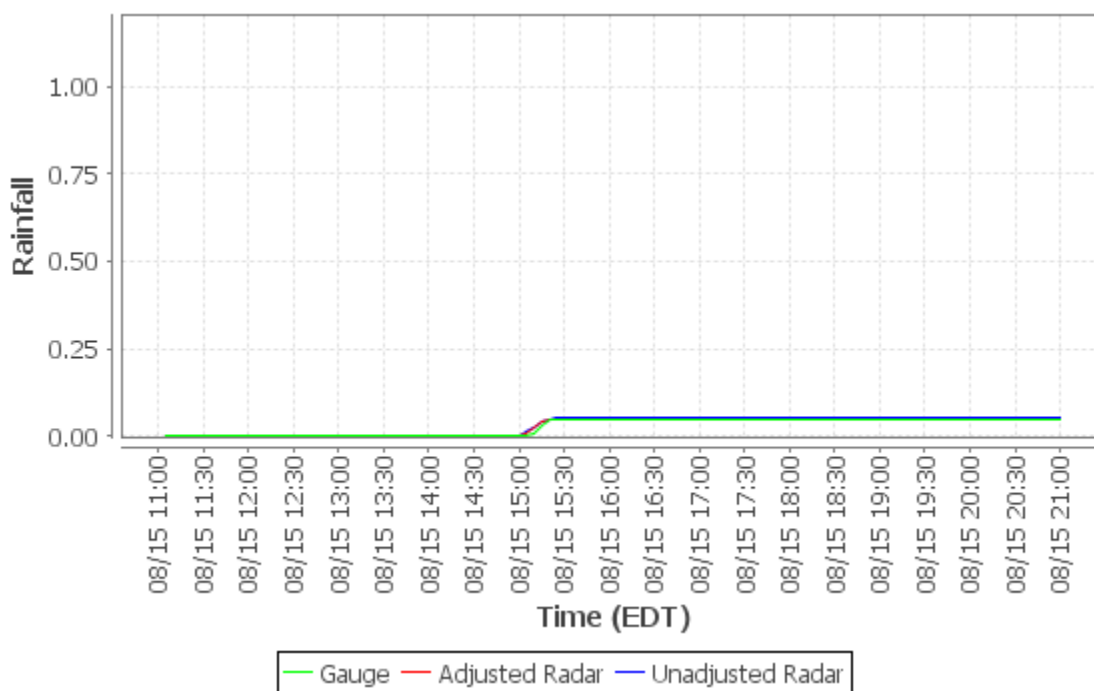
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



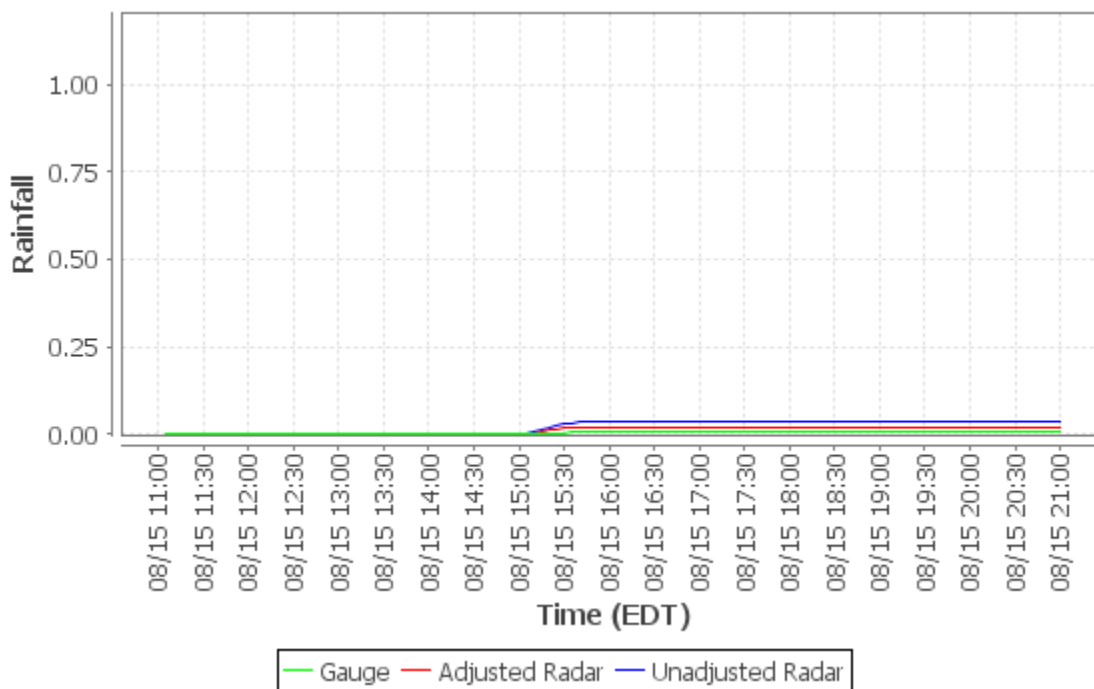
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



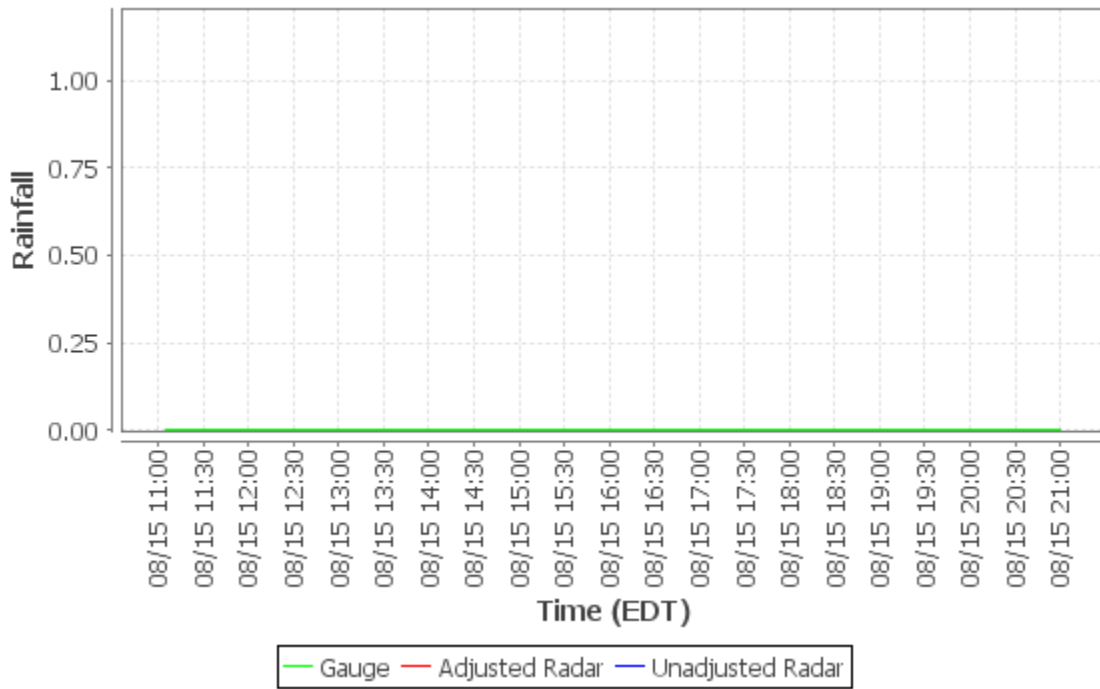
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



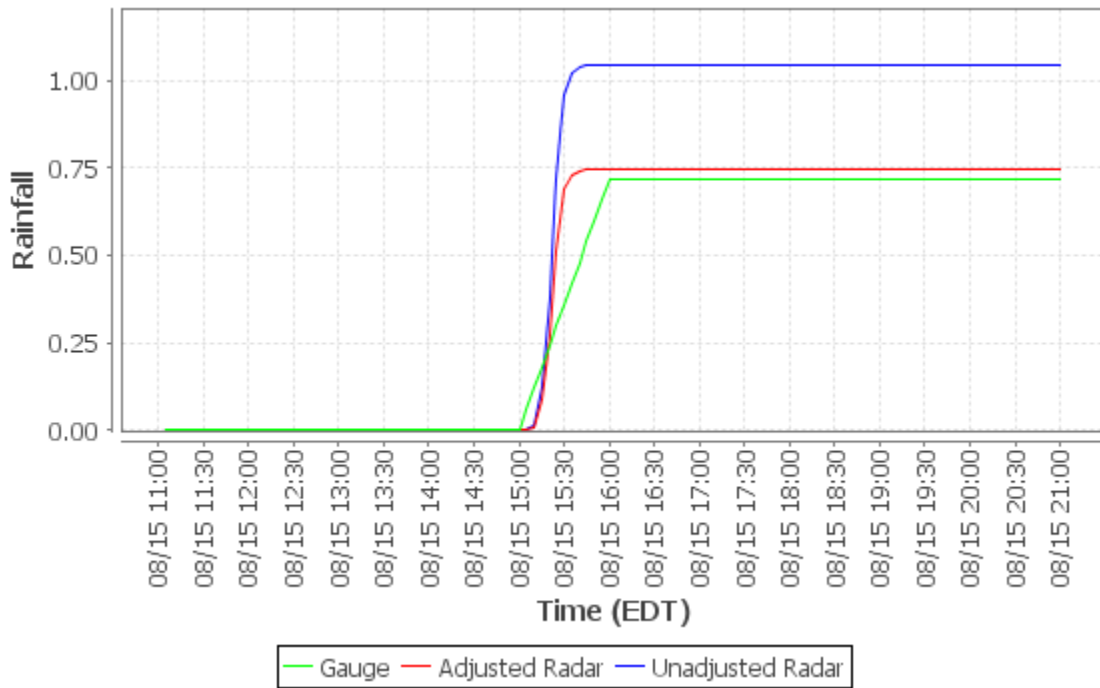
Cumulative Distribution Plot - Arnold (Loc32)



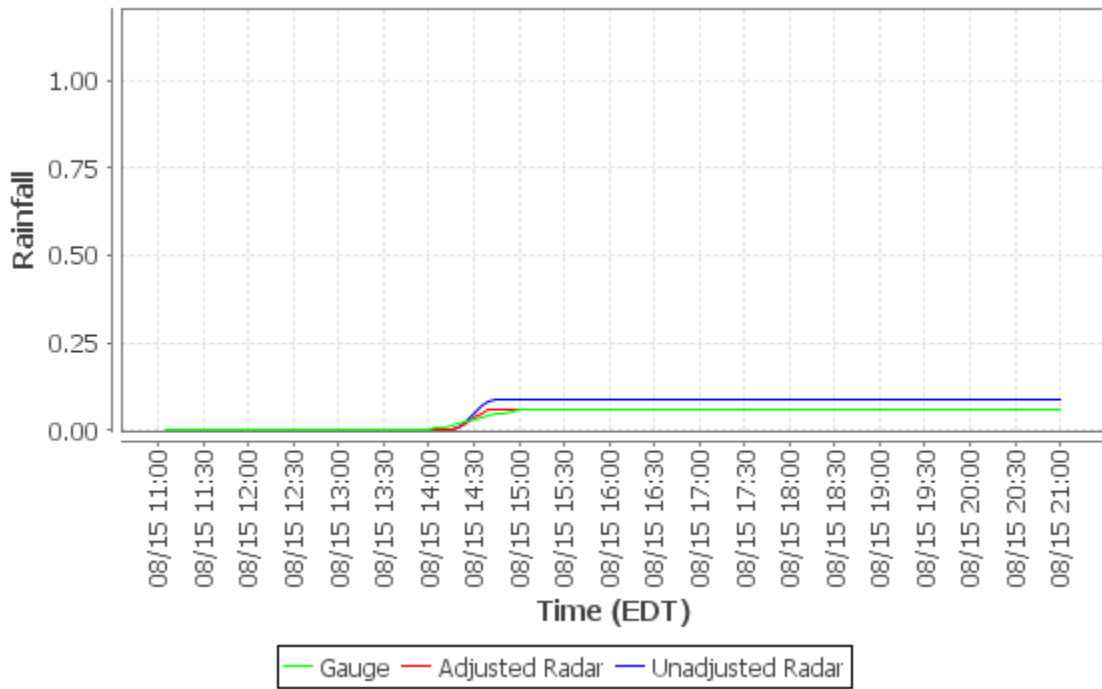
Cumulative Distribution Plot - Richland TWP (Loc33)



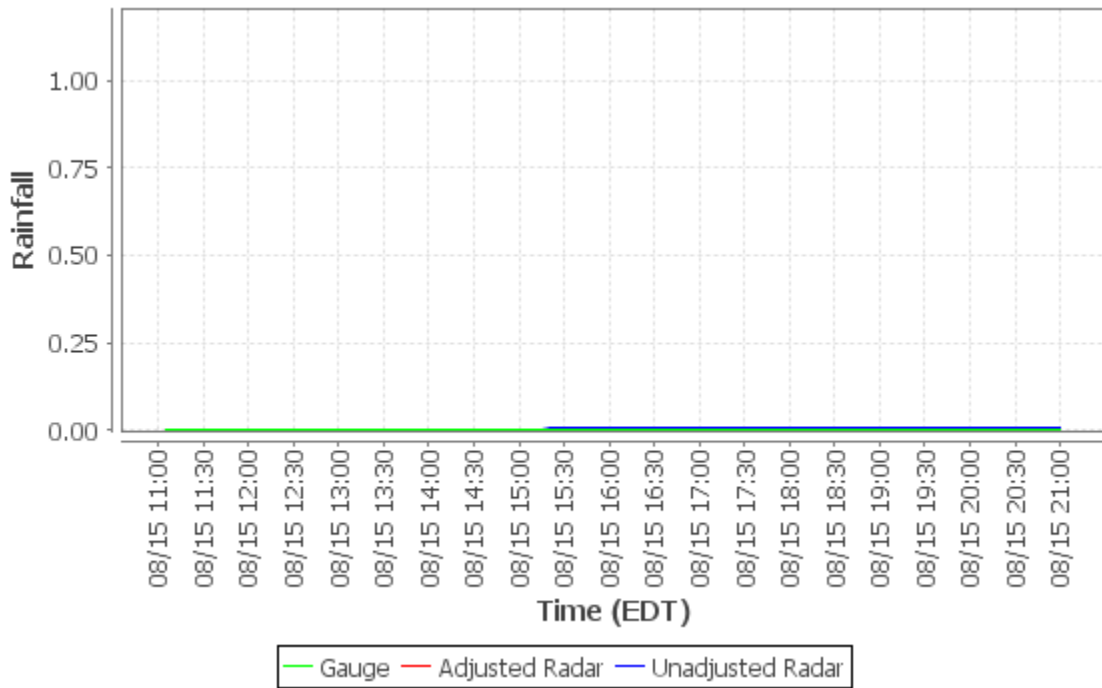
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



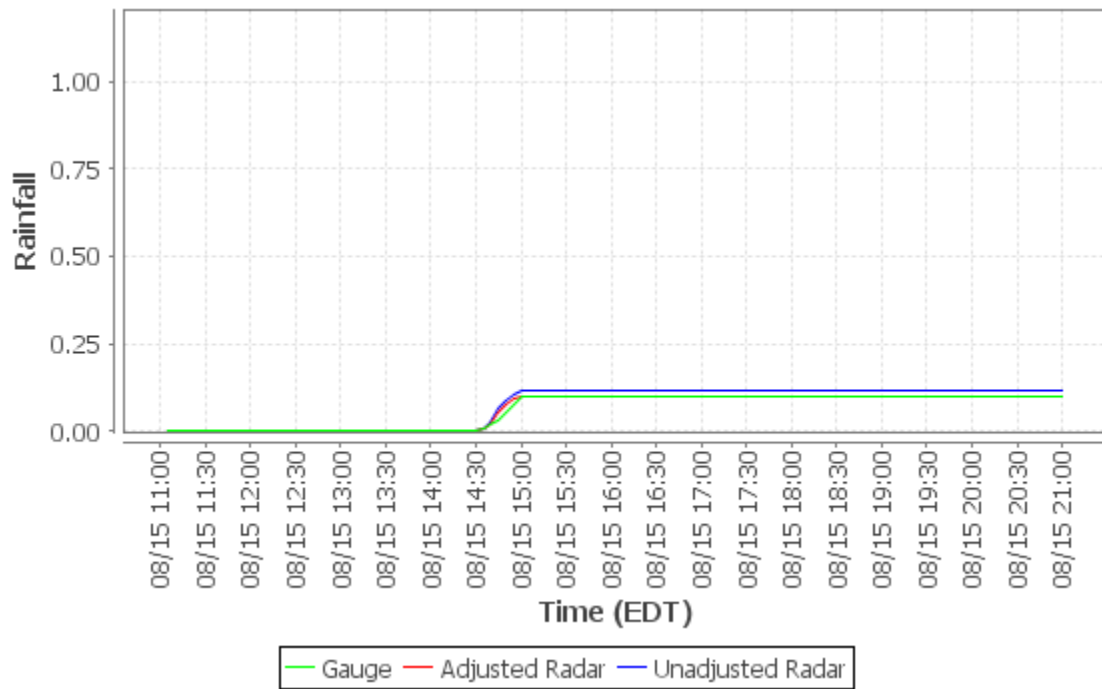
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

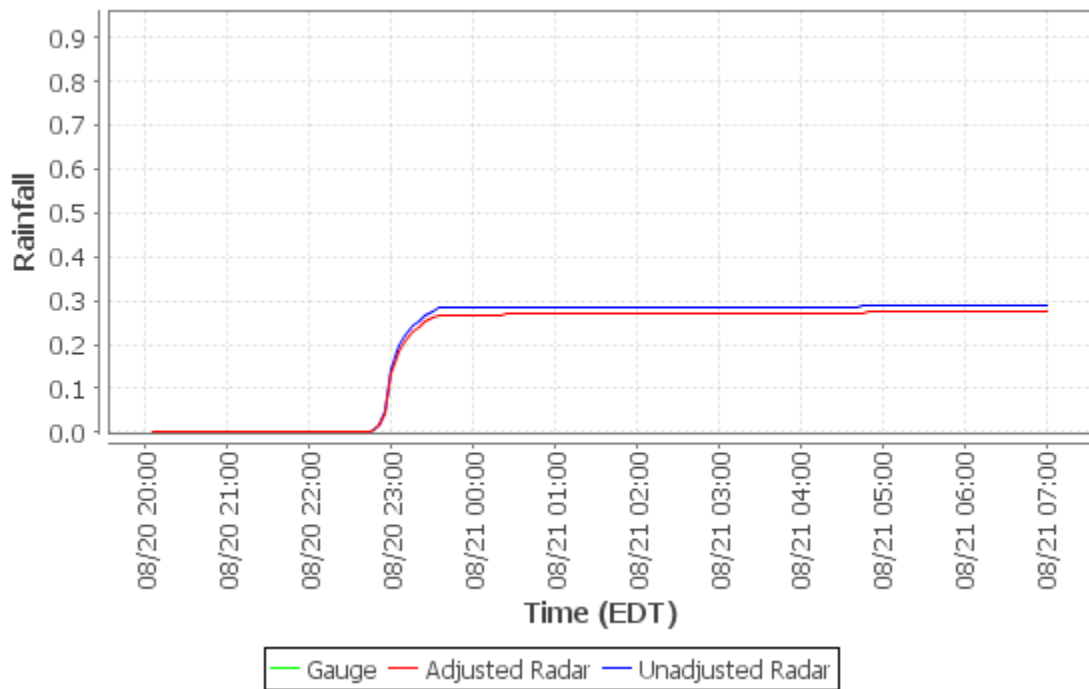


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

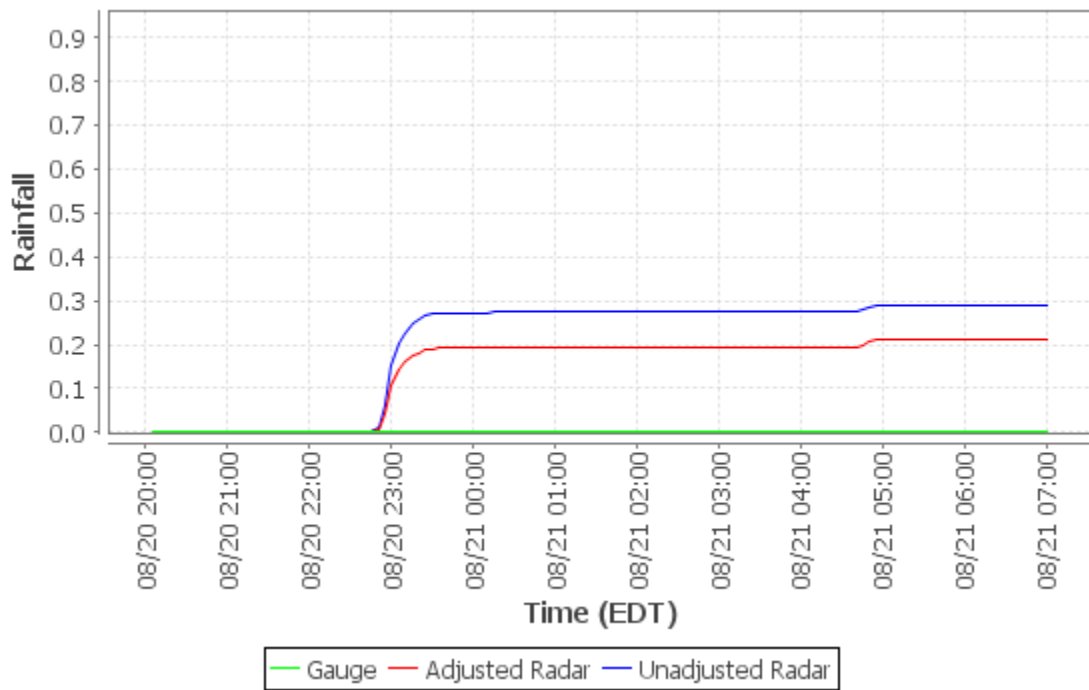


Appendix F - Event 4 (2019-08-20) CDPs

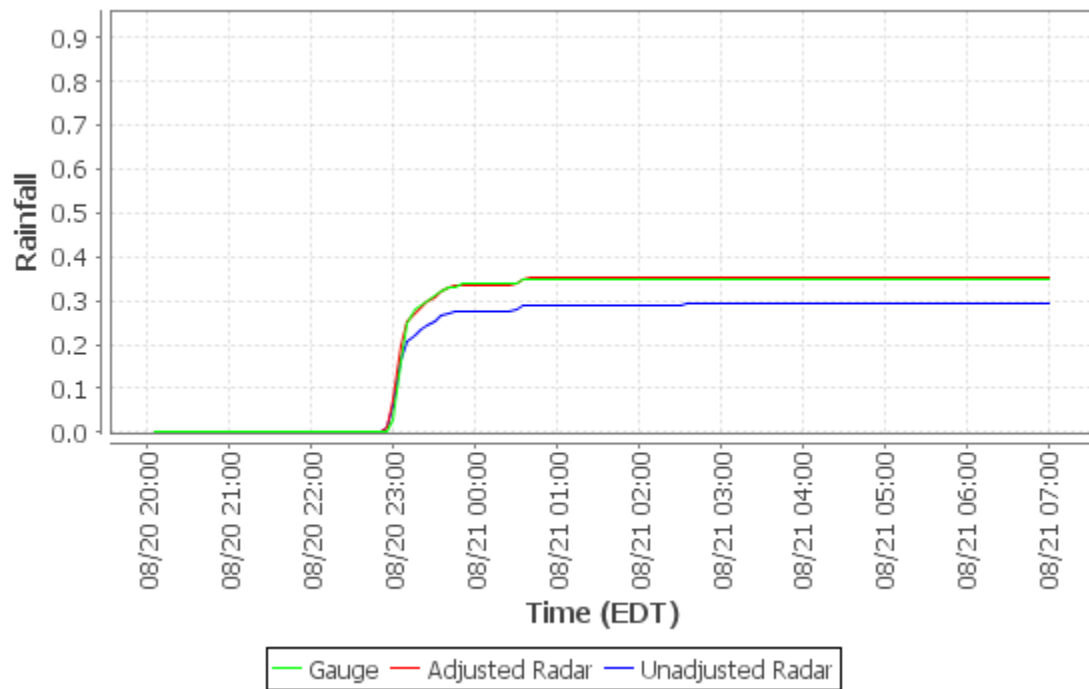
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



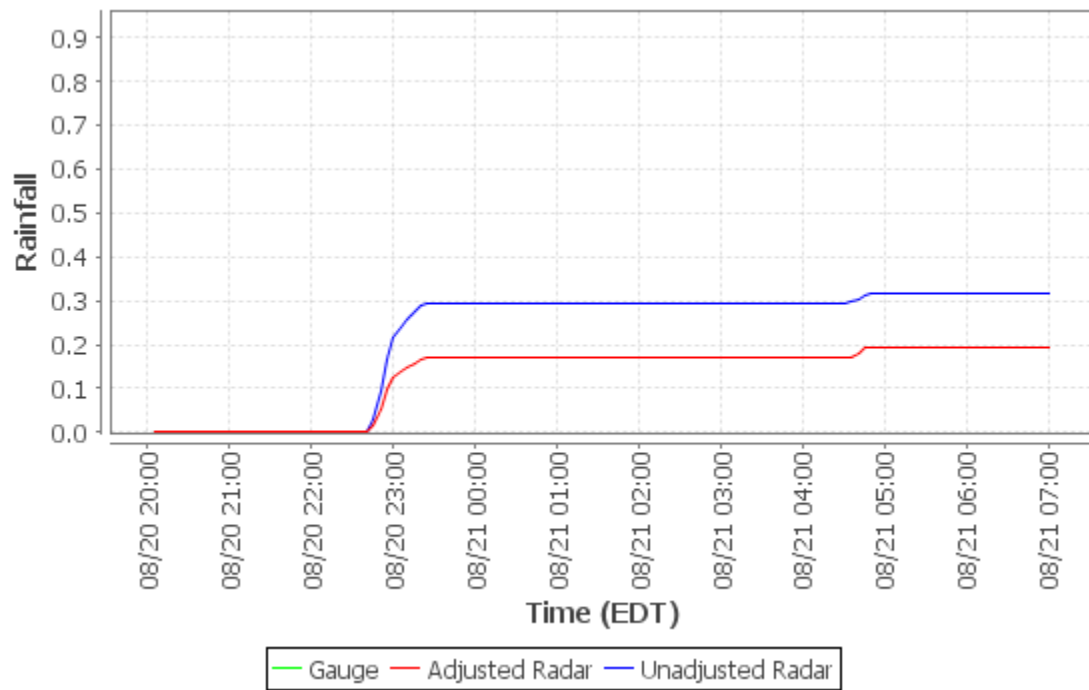
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



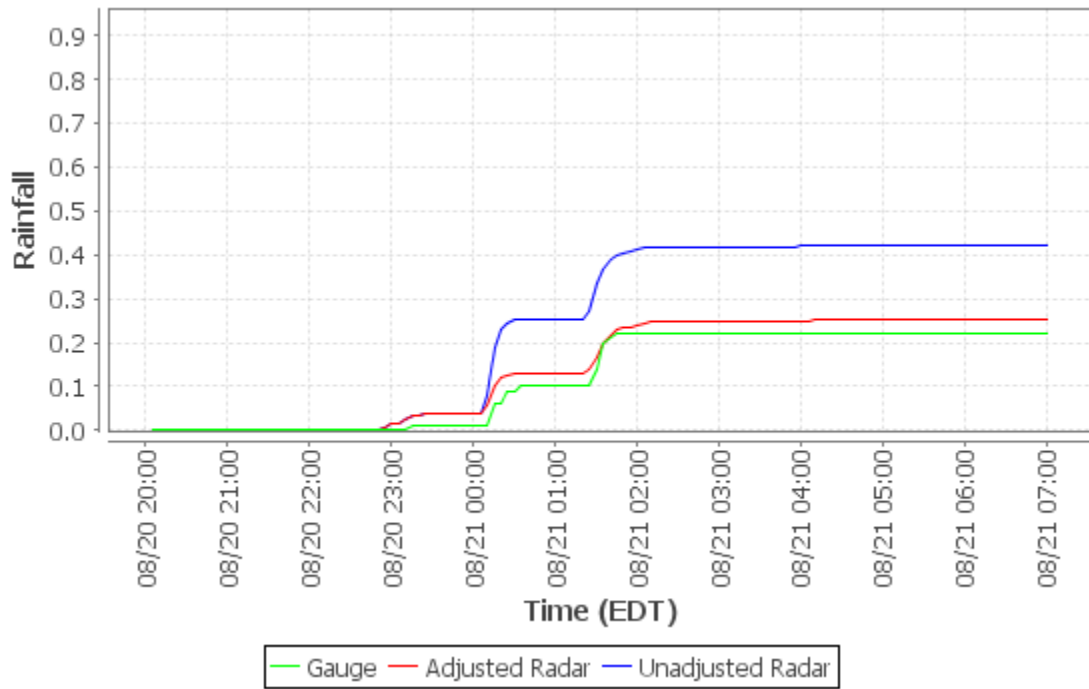
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



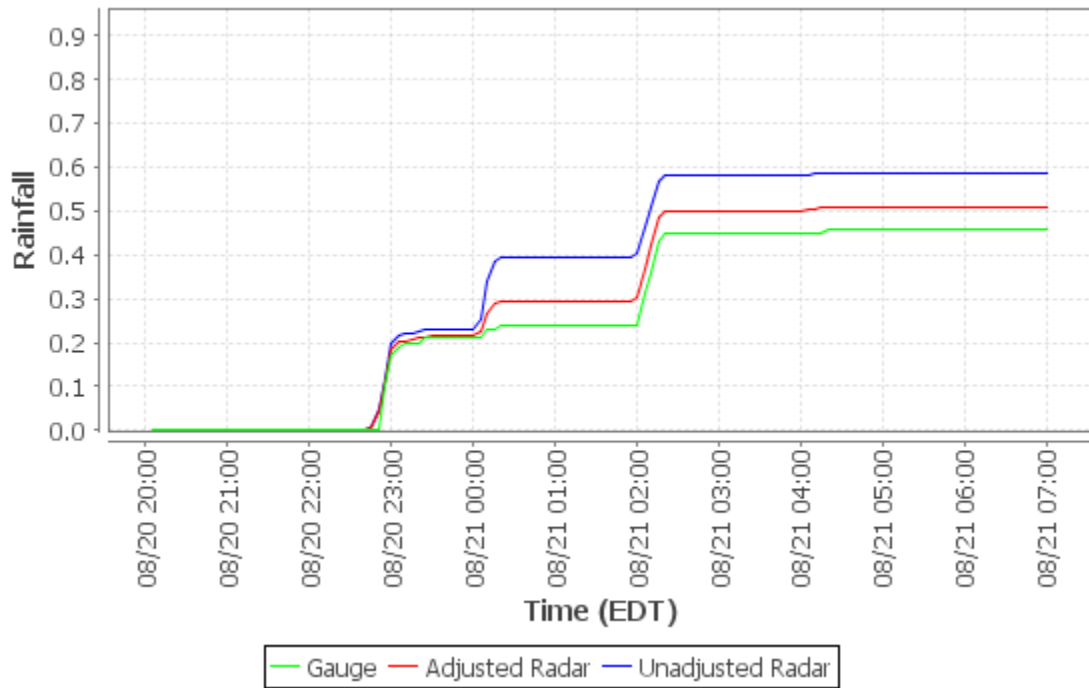
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



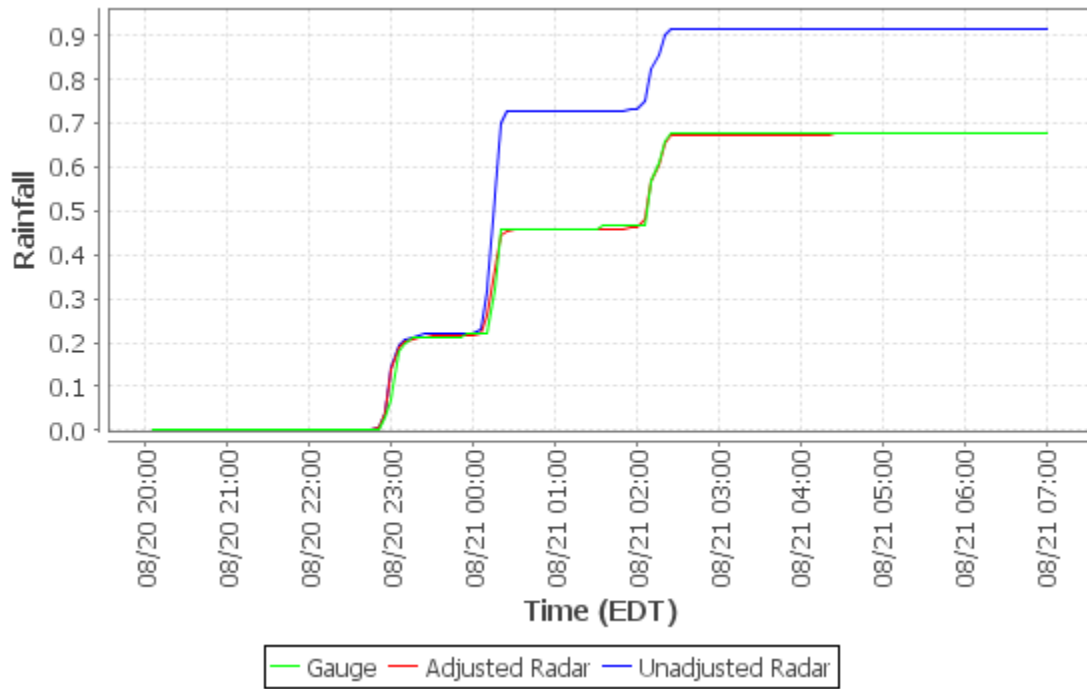
Cumulative Distribution Plot - Upper St. Clair (Loc05)



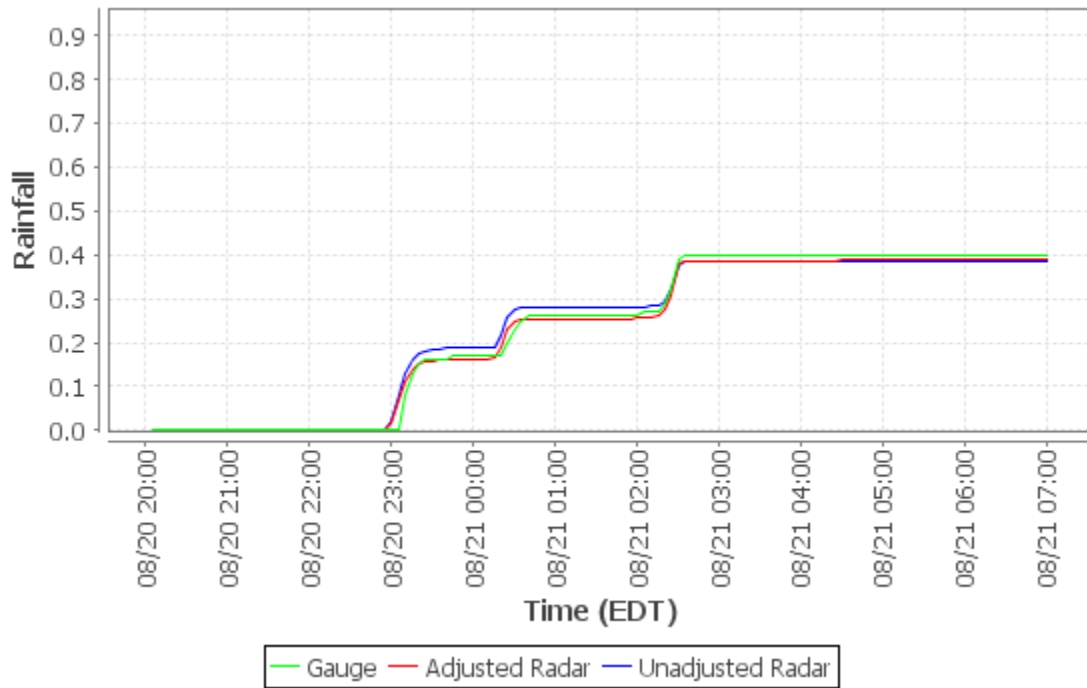
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



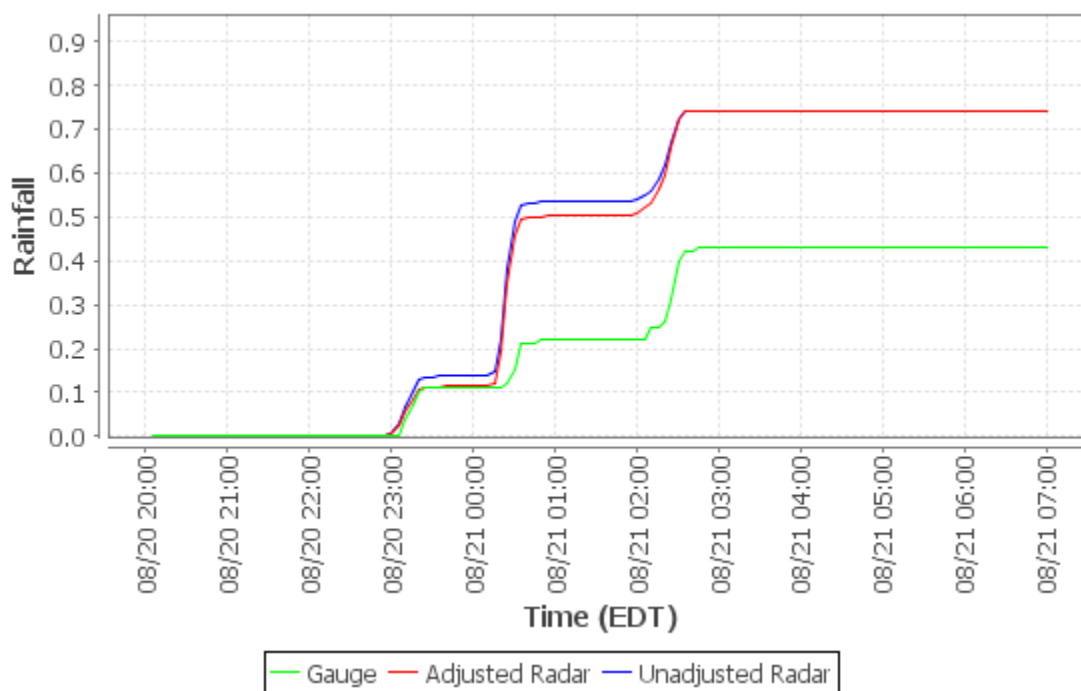
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



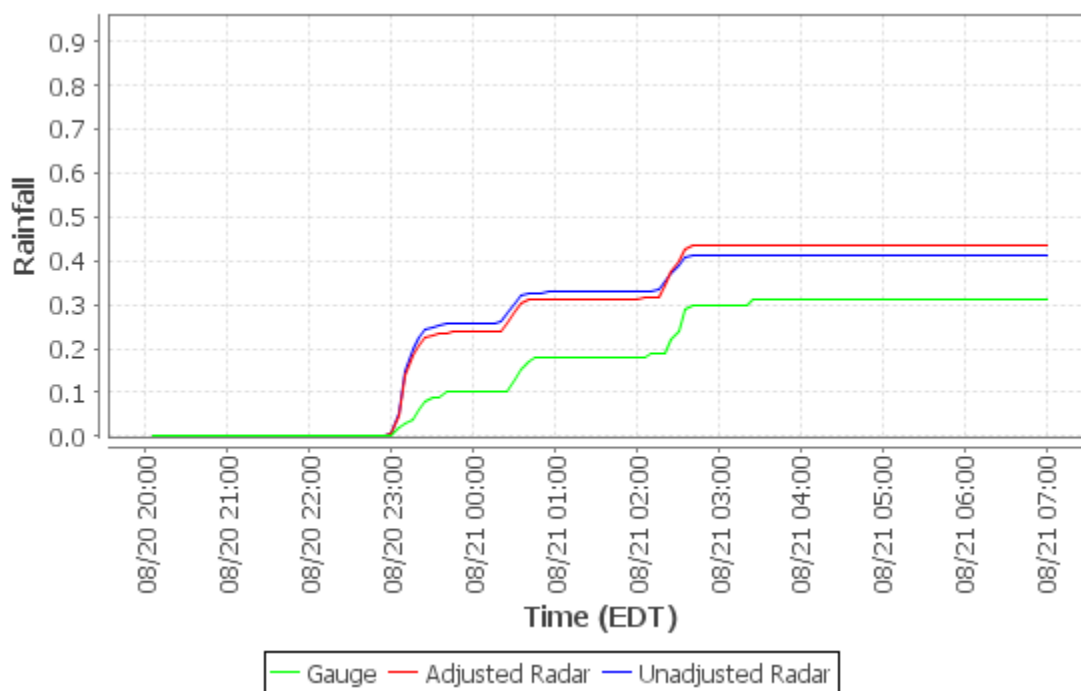
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



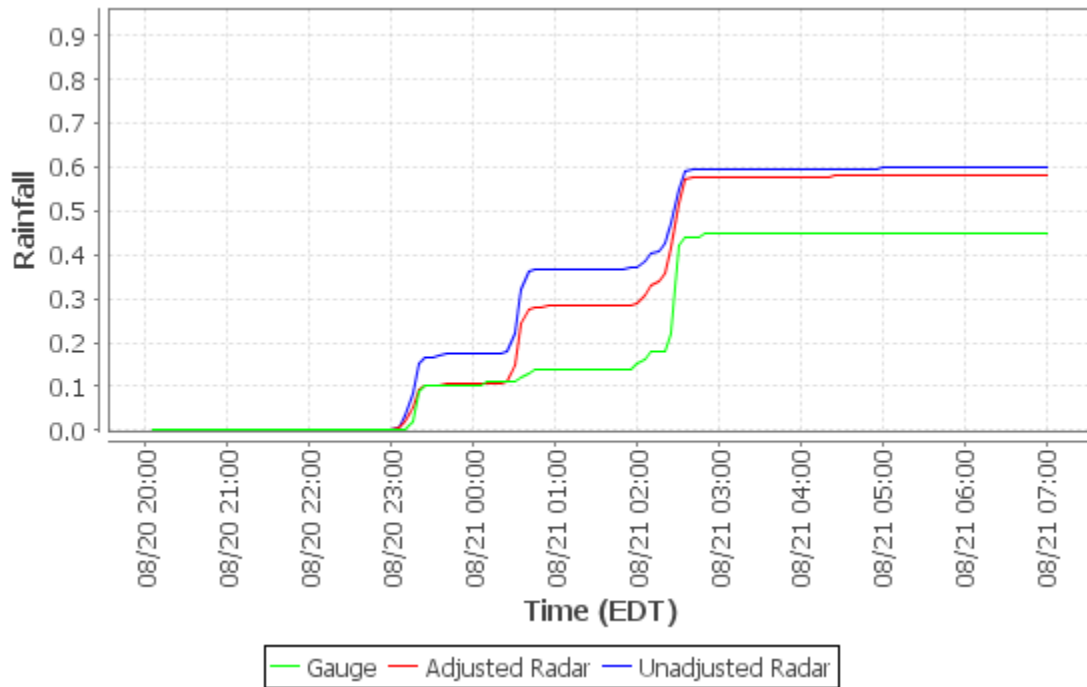
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



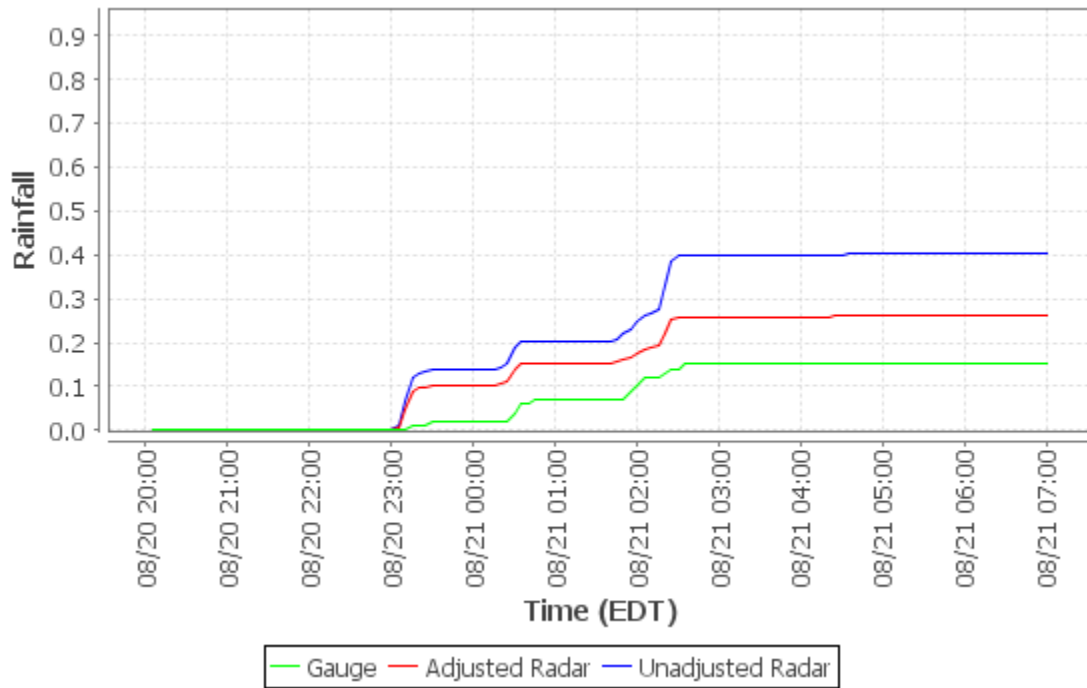
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



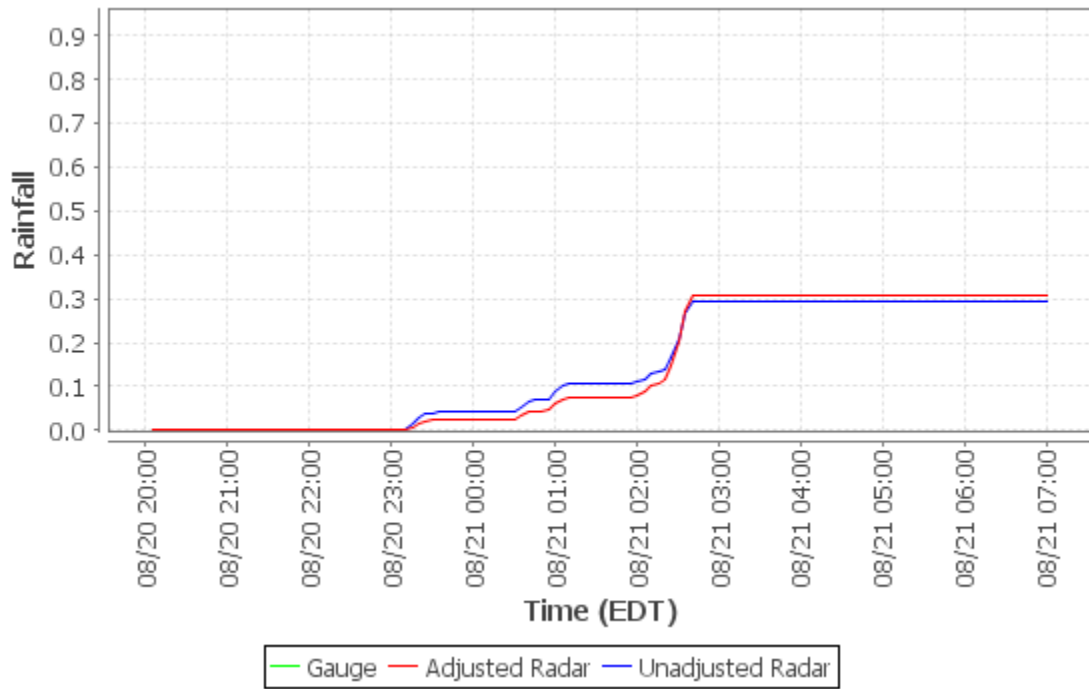
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



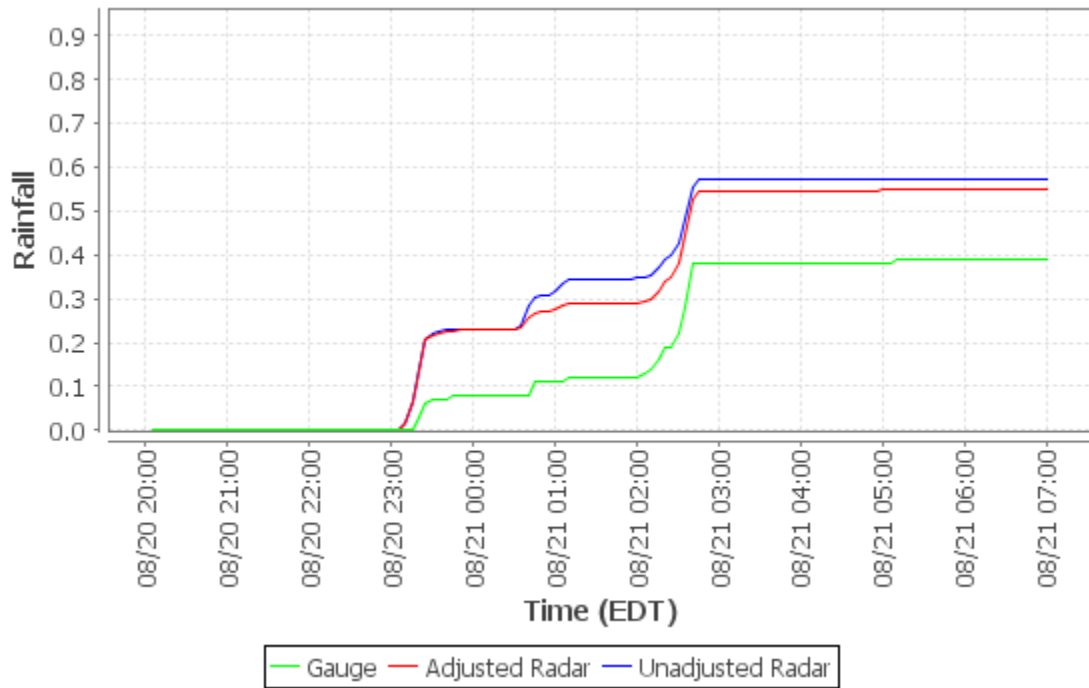
Cumulative Distribution Plot - Baldwin (Loc12)



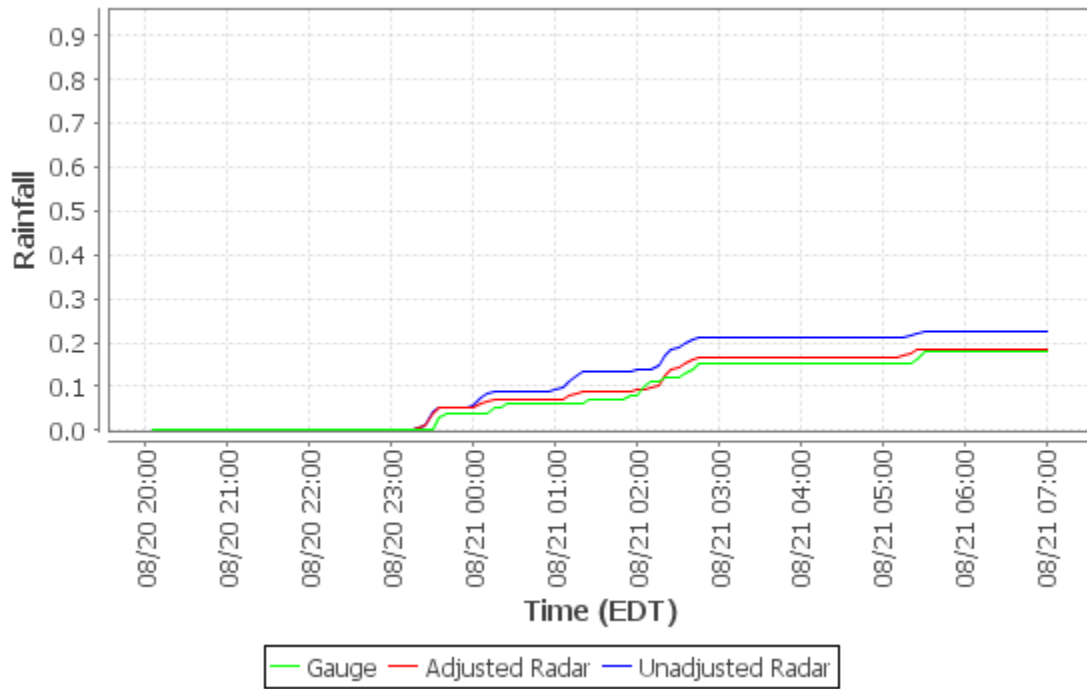
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



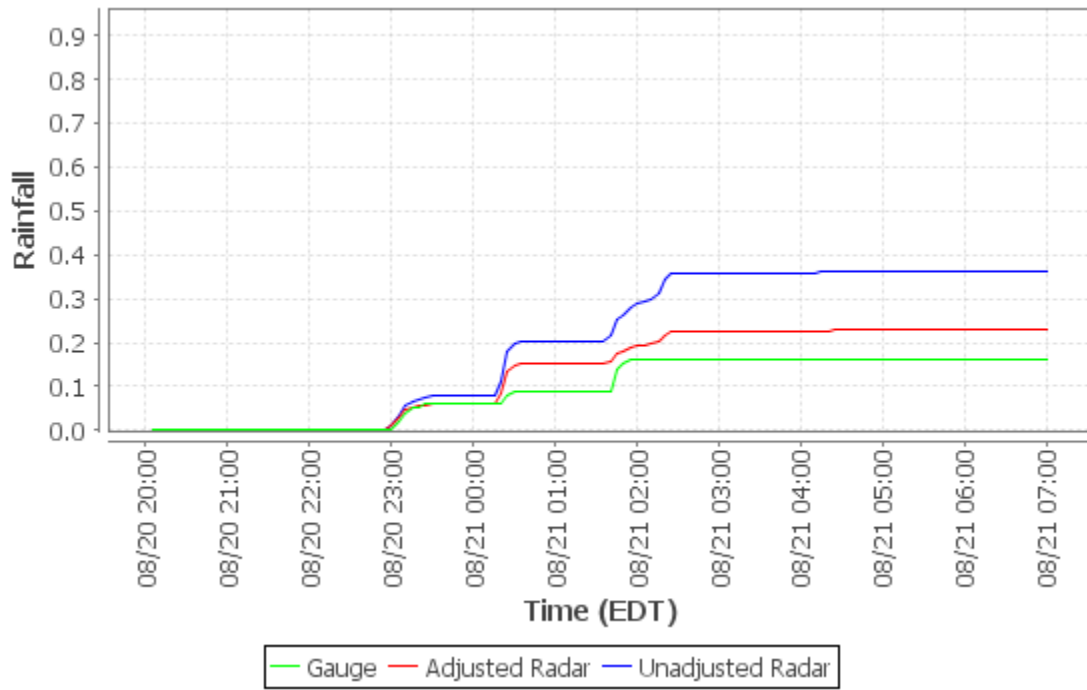
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



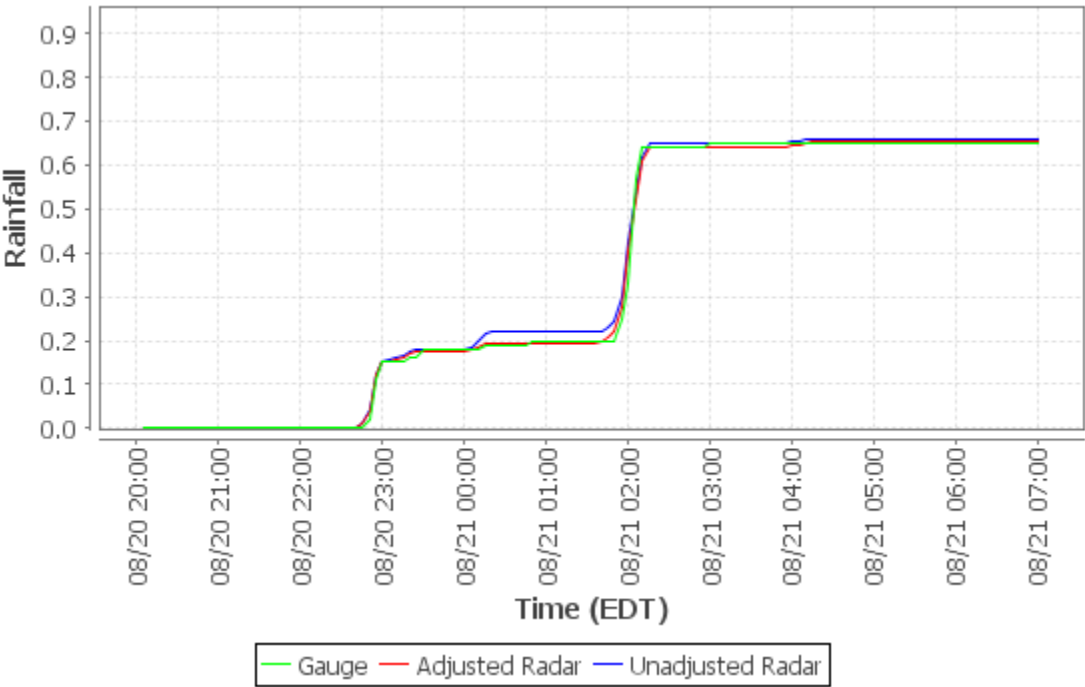
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



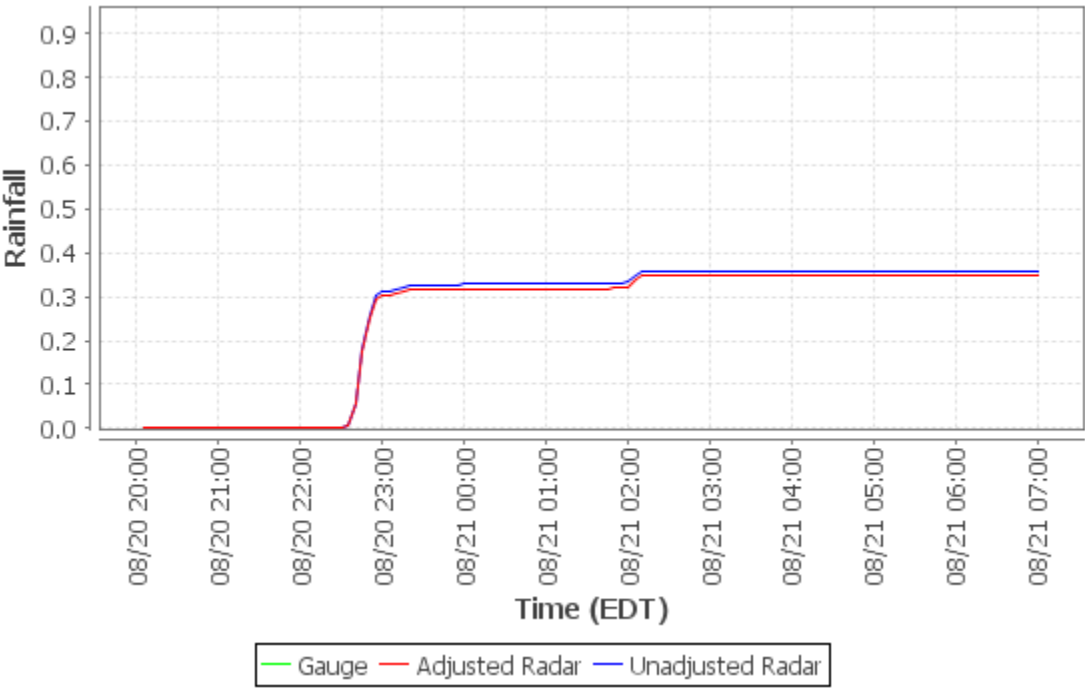
Cumulative Distribution Plot - Castle Shannon (Loc16)



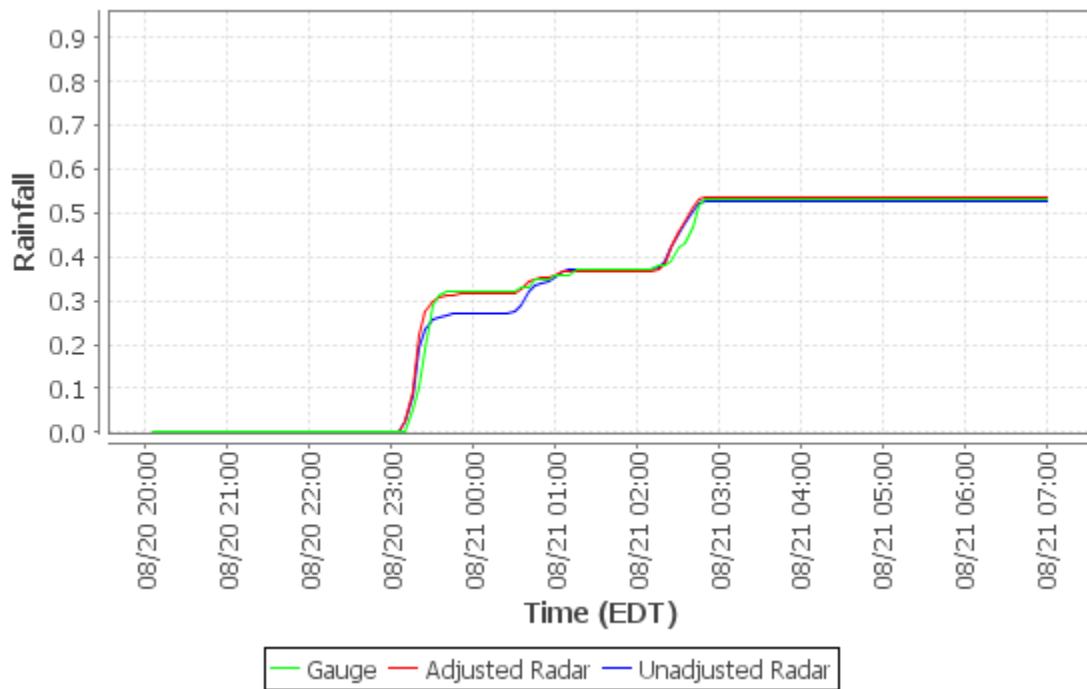
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



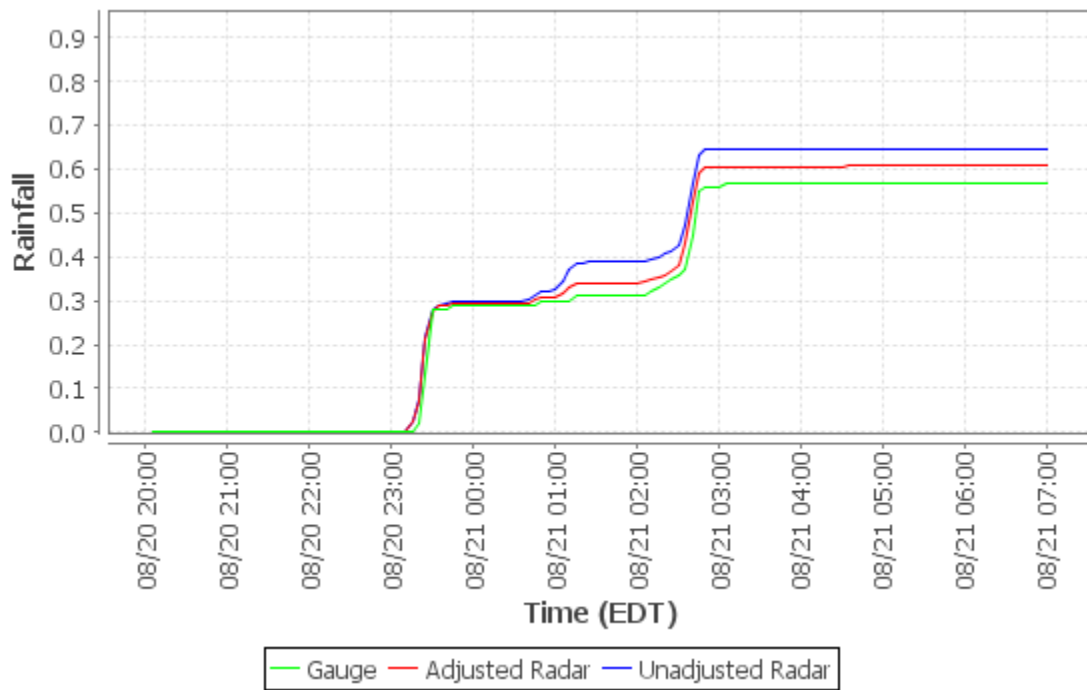
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



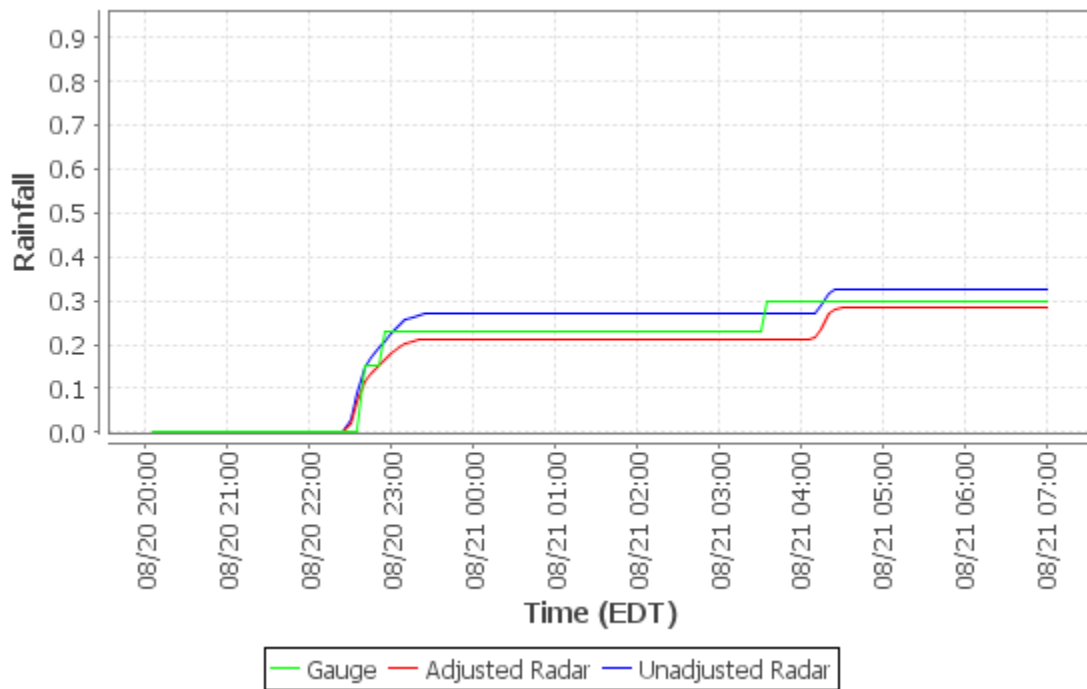
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



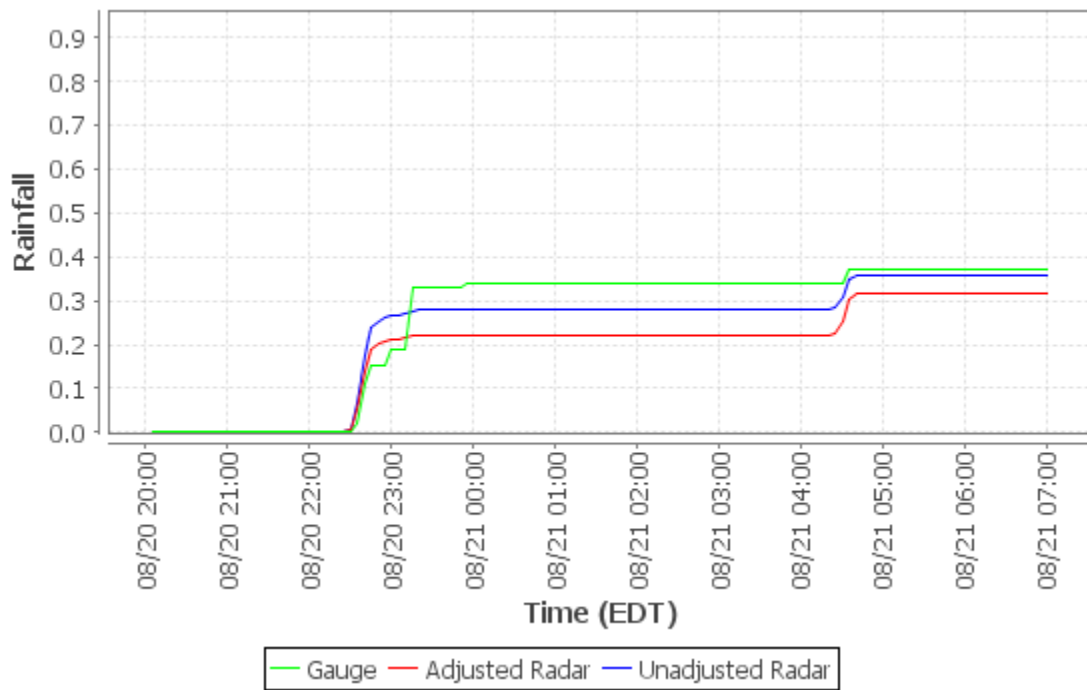
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



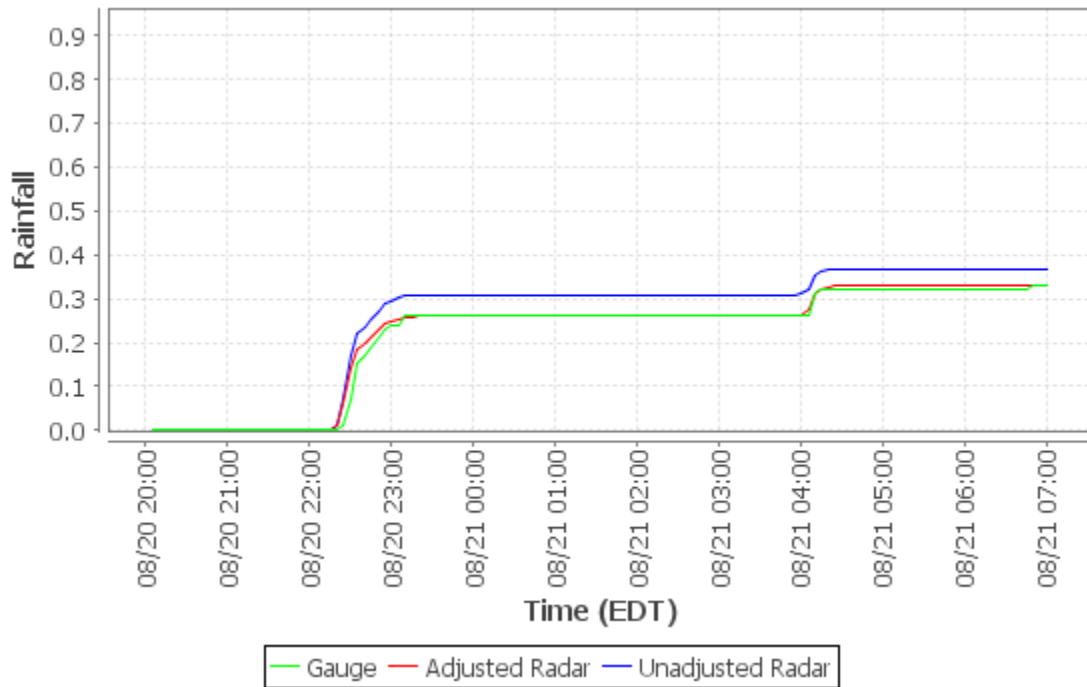
Cumulative Distribution Plot - Moon TWP (Loc21)



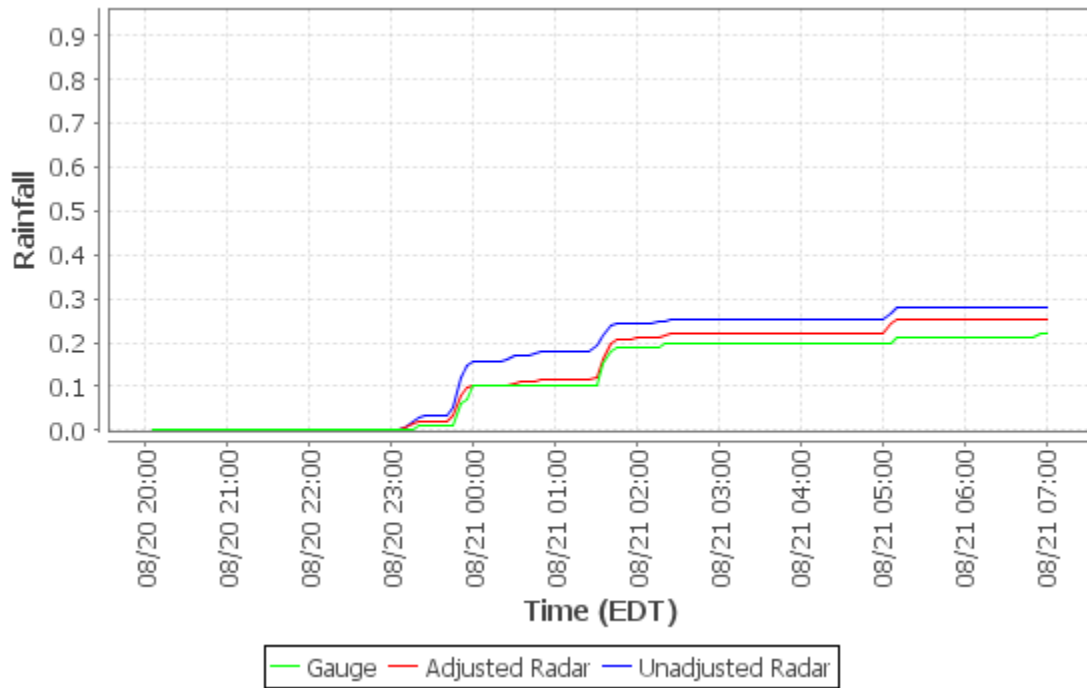
Cumulative Distribution Plot - North Fayette TWP (Loc22)



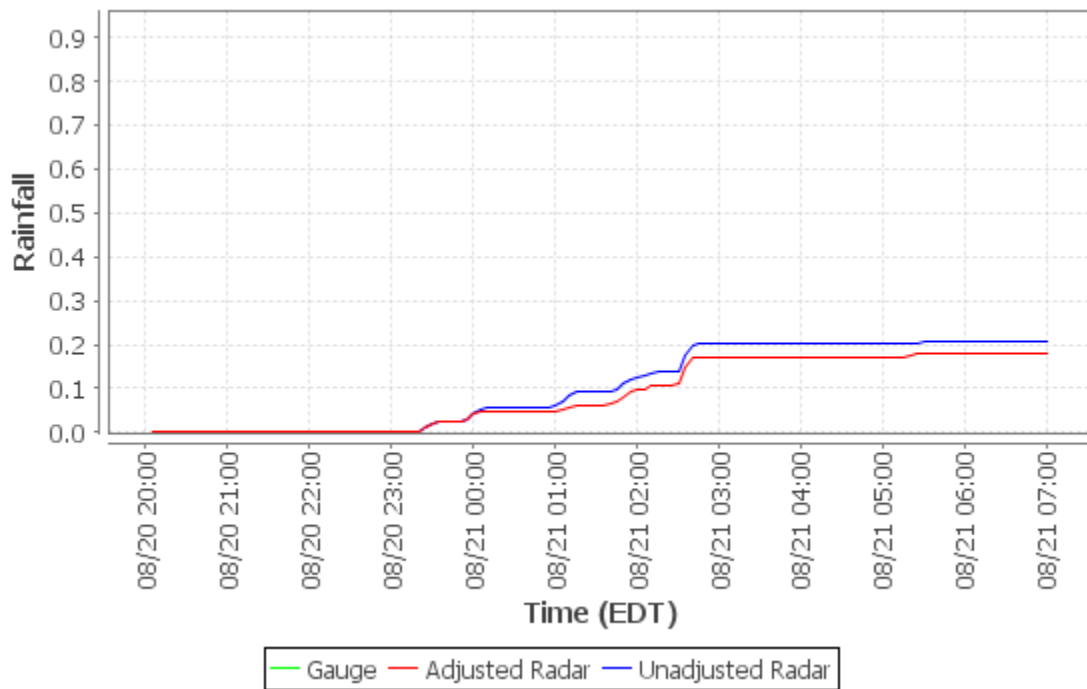
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



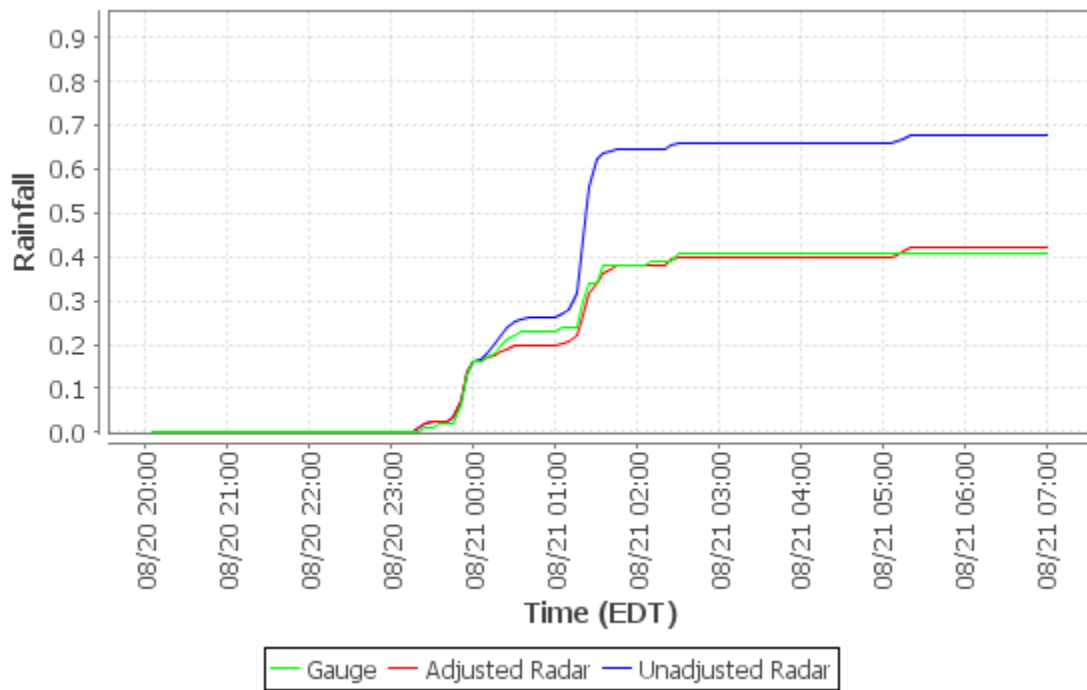
Cumulative Distribution Plot - Jefferson Hills (Loc24)



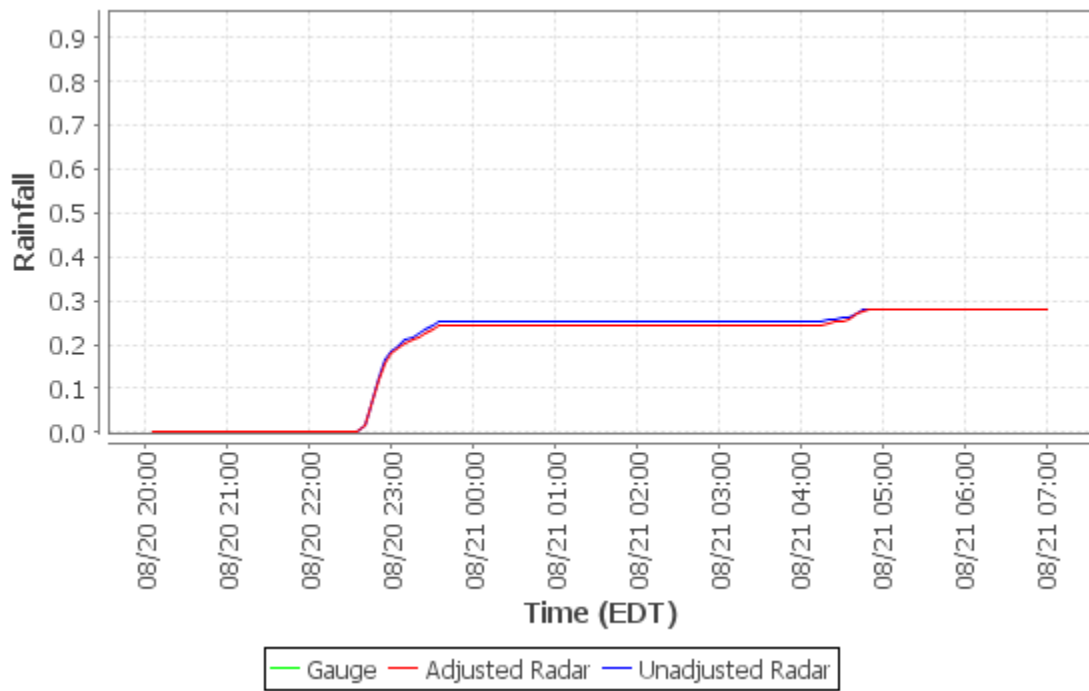
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



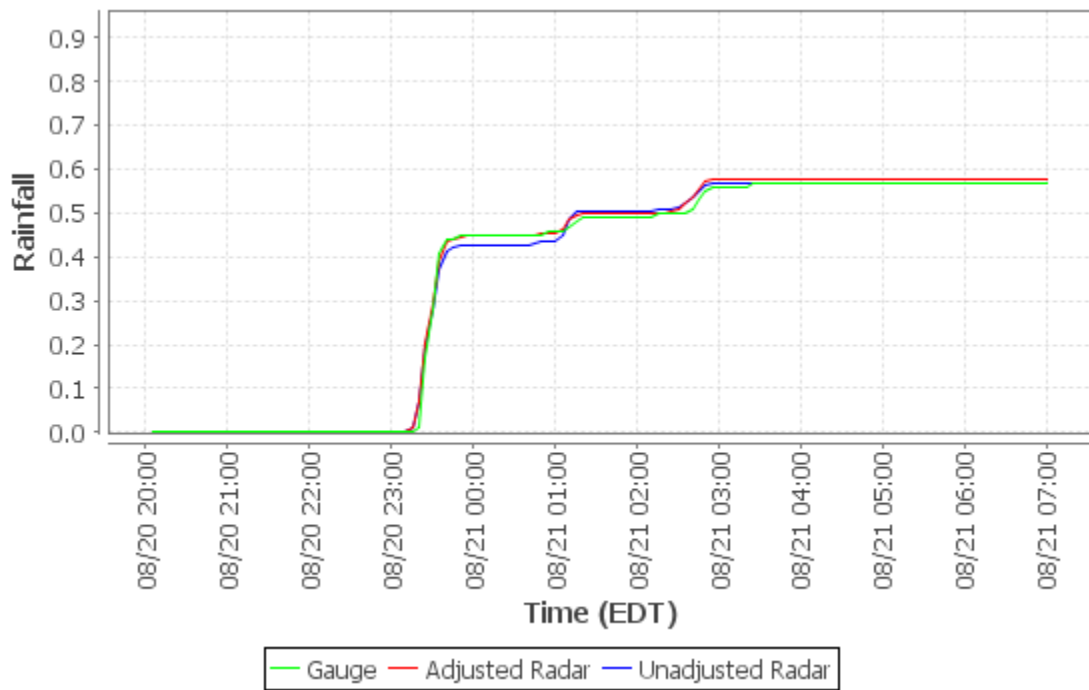
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



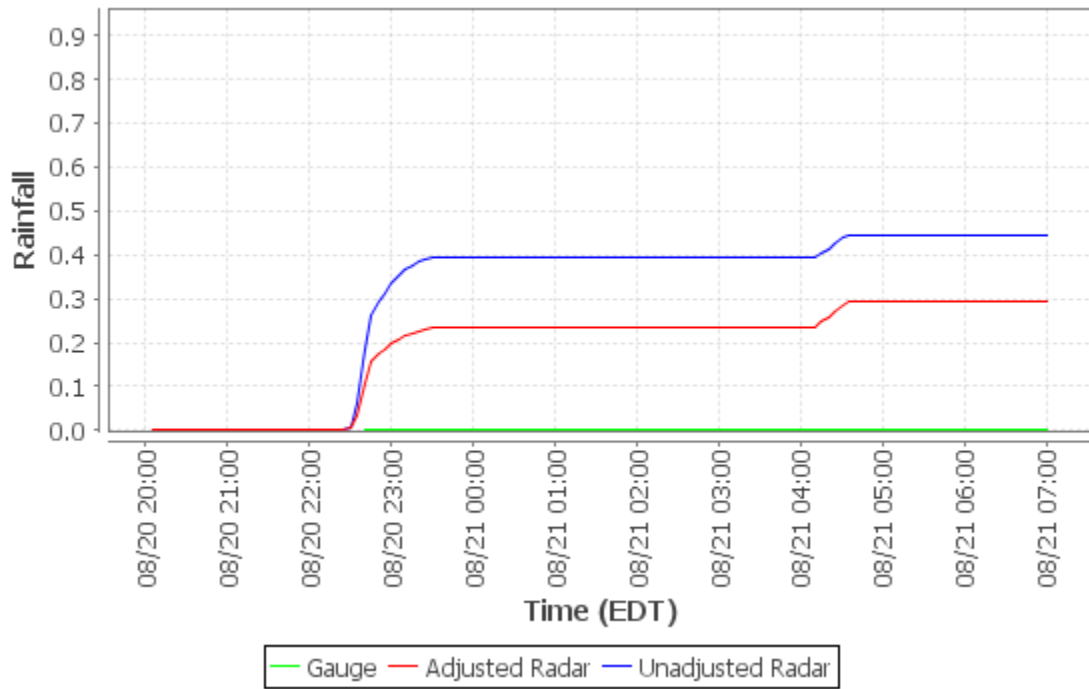
Cumulative Distribution Plot - Marshall TWP (Loc27)



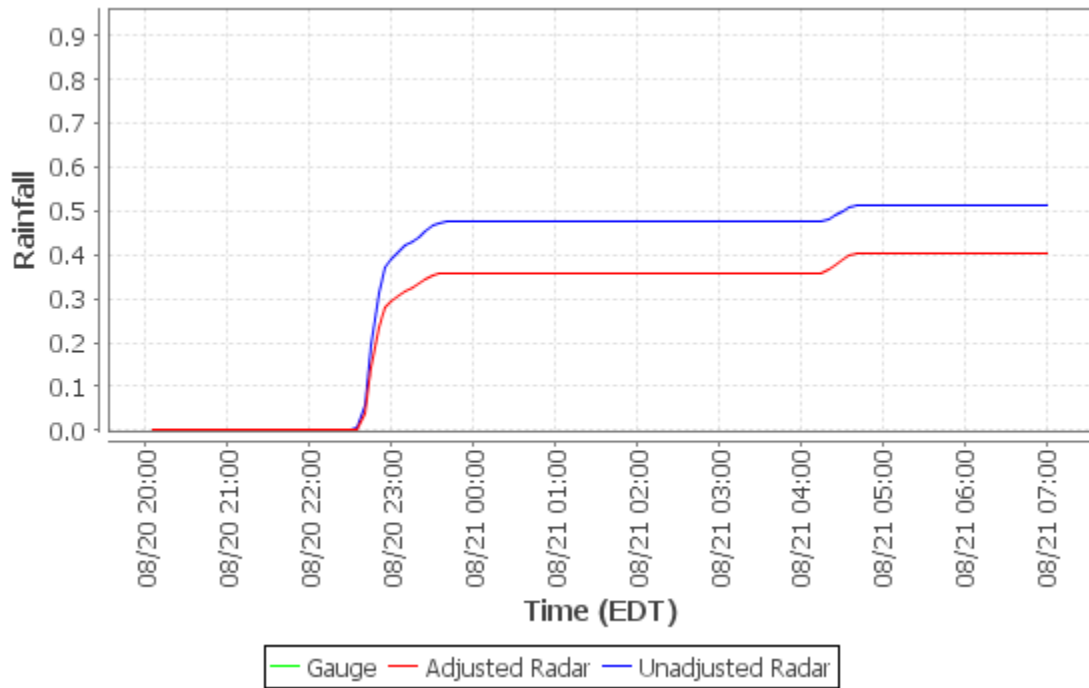
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



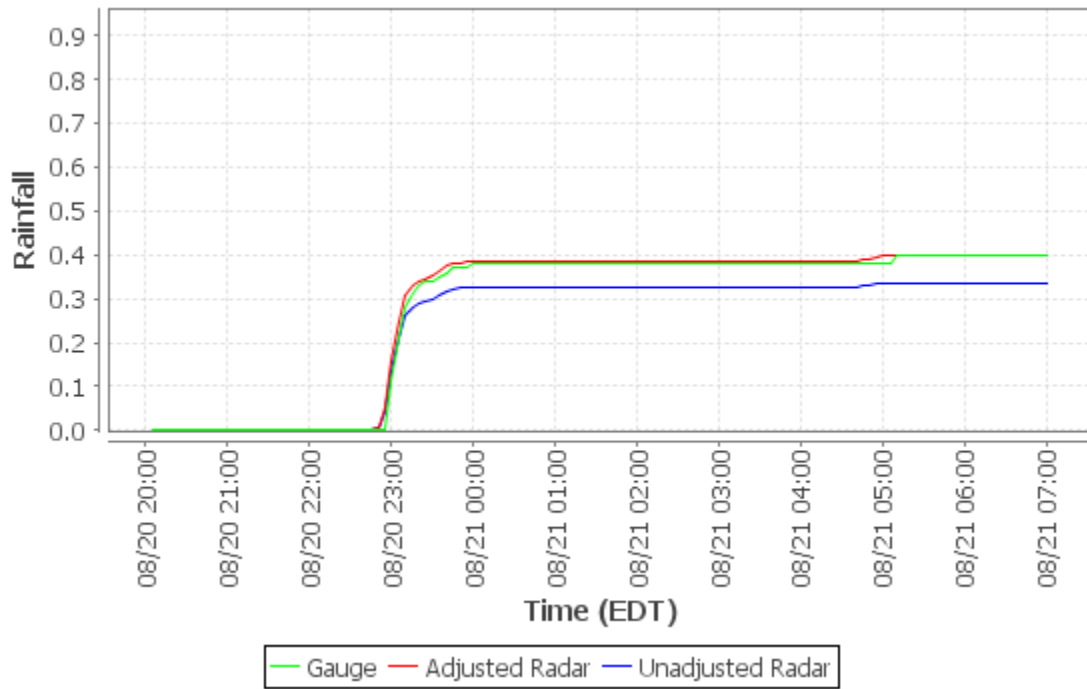
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



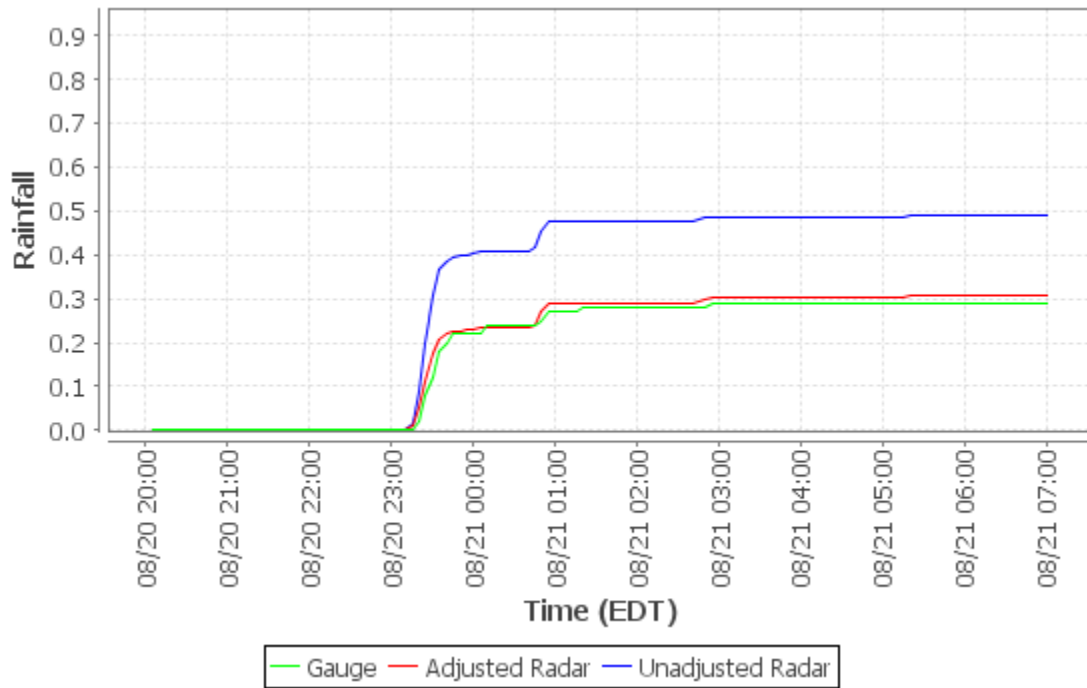
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



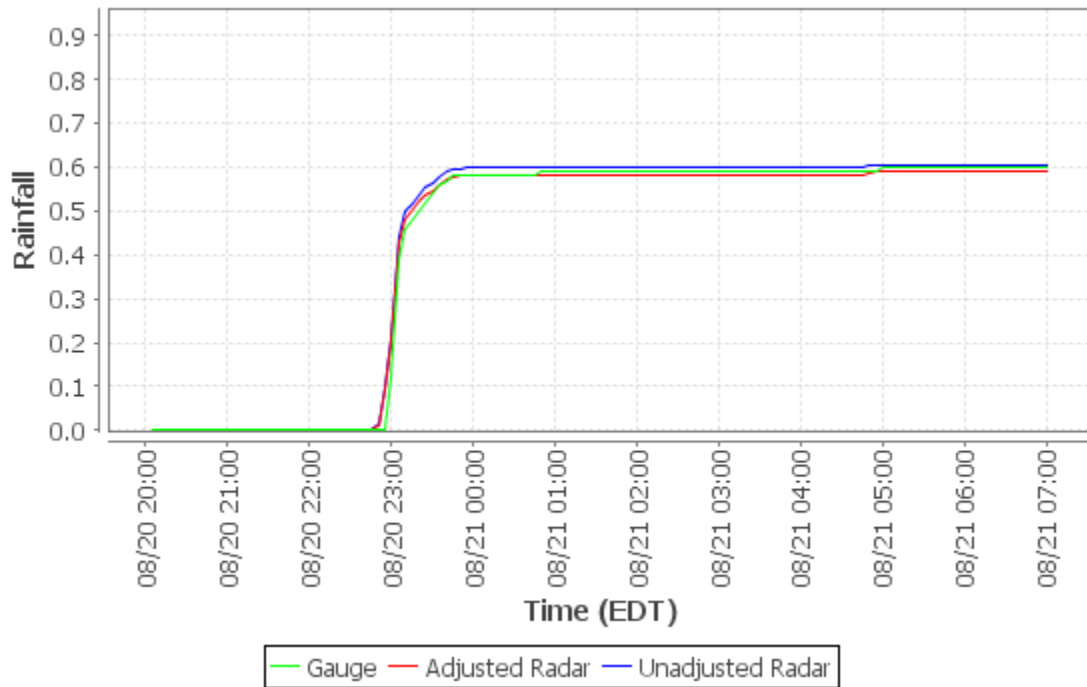
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



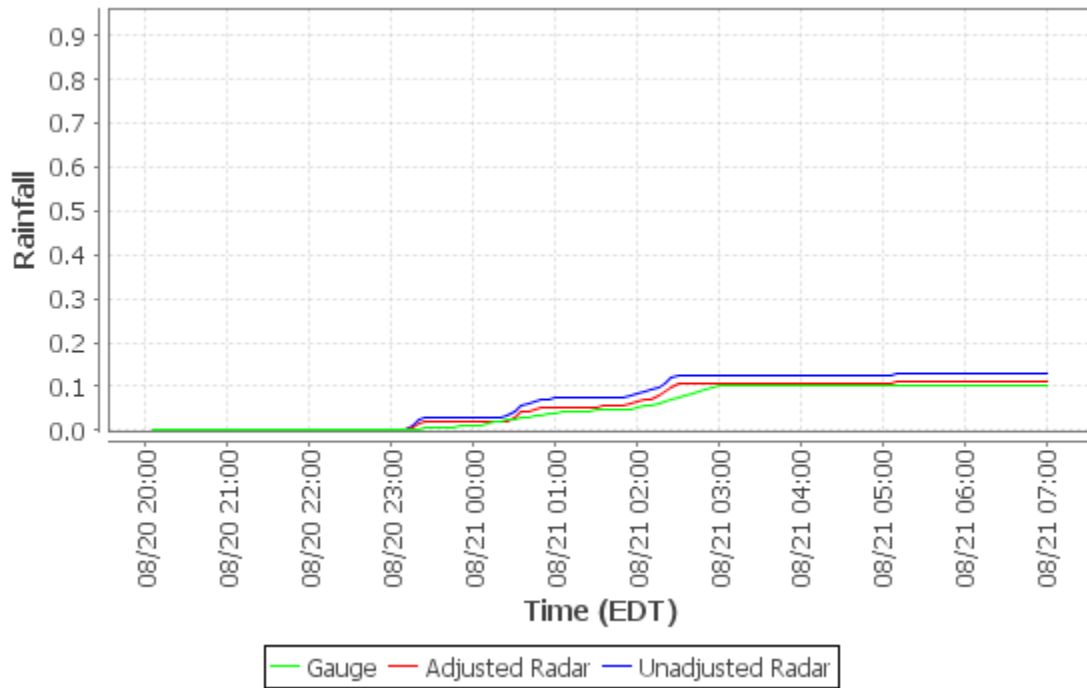
Cumulative Distribution Plot - Arnold (Loc32)



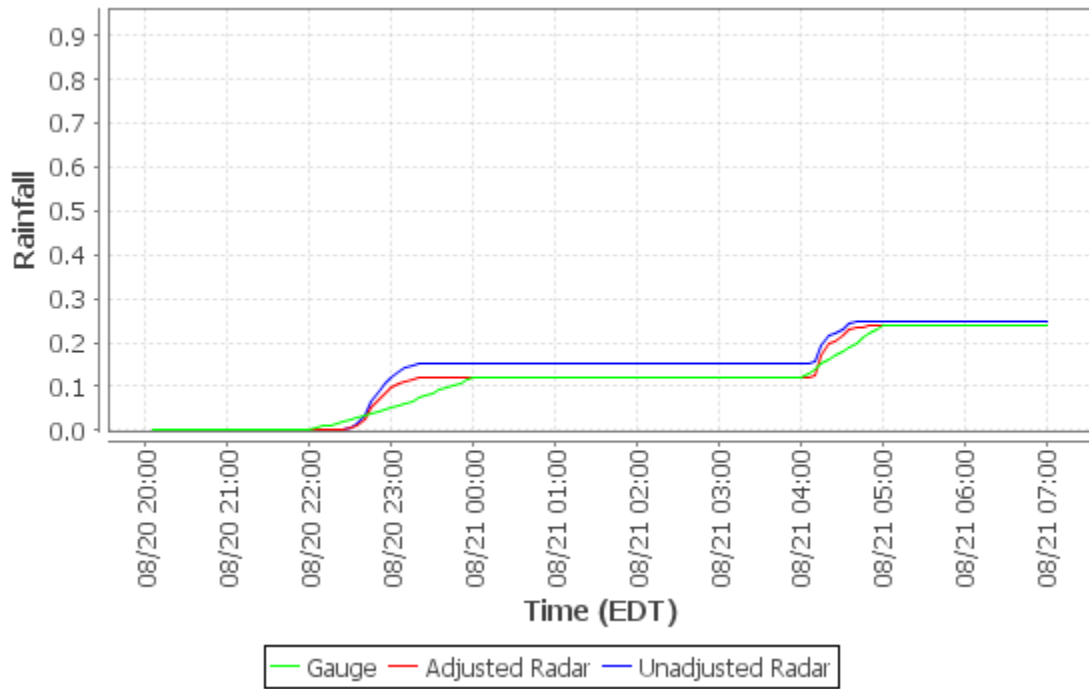
Cumulative Distribution Plot - Richland TWP (Loc33)



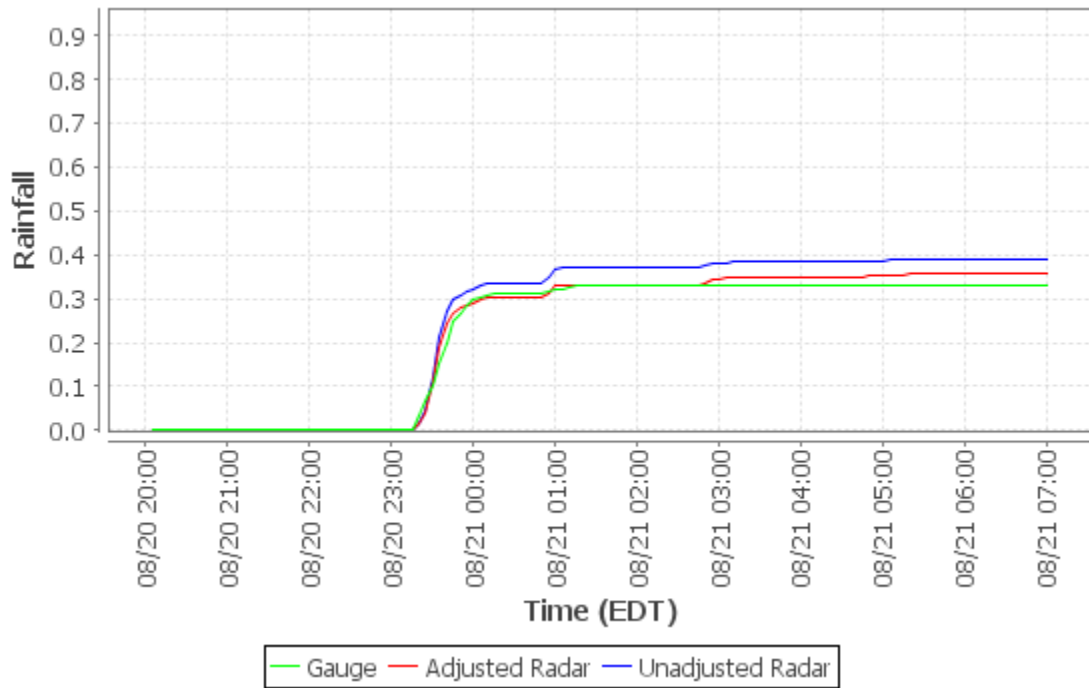
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



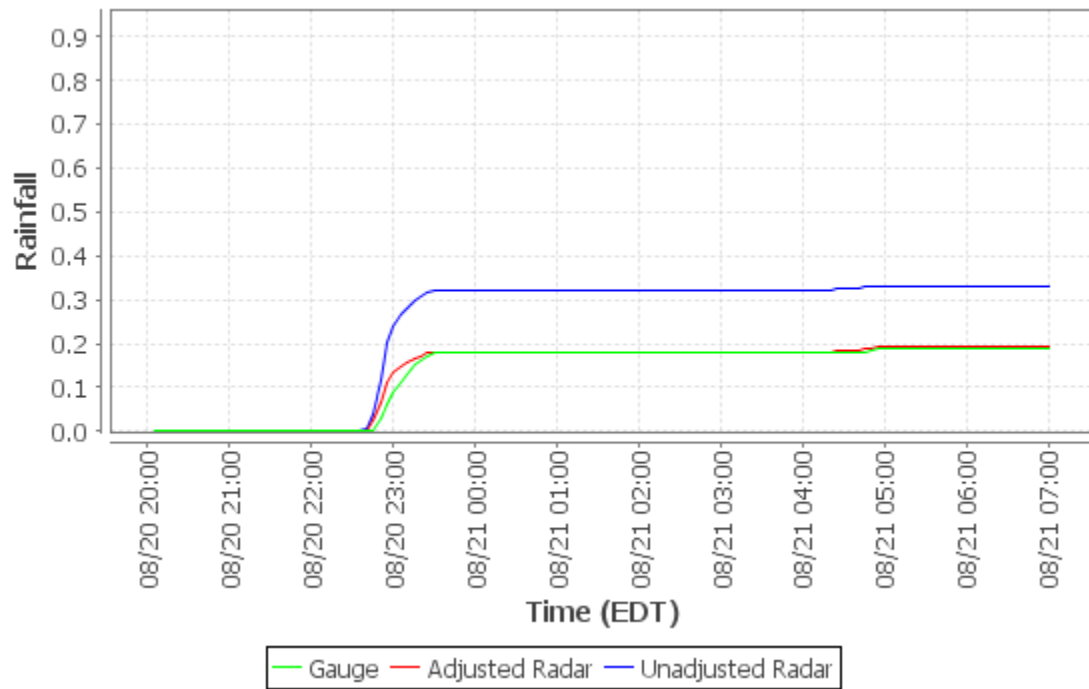
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

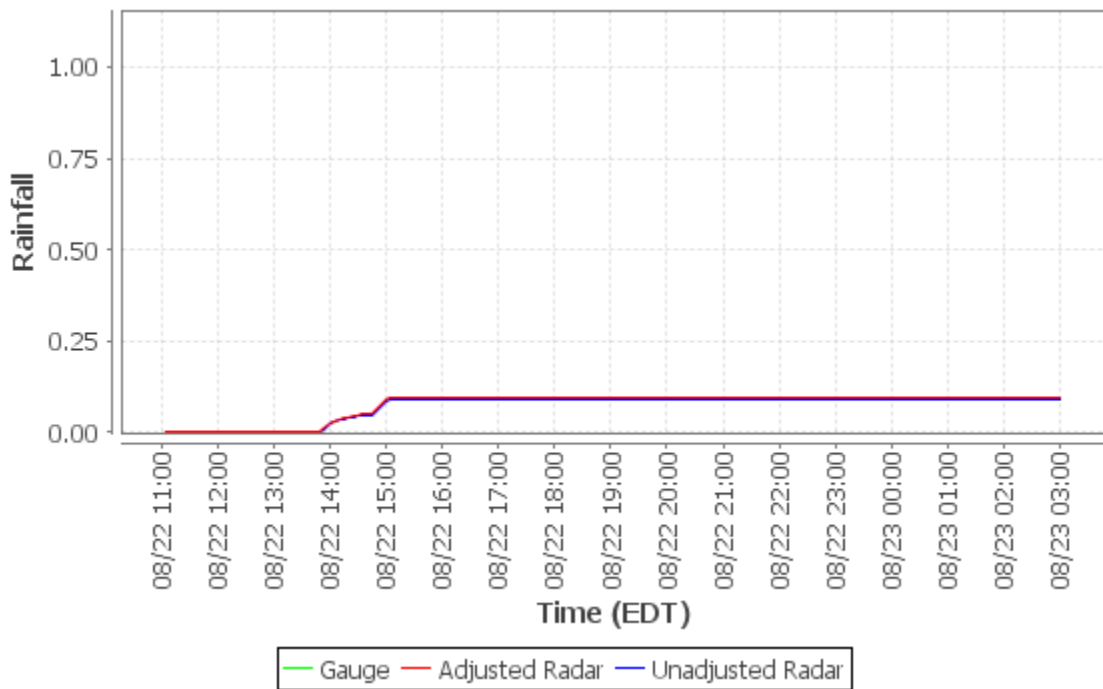


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

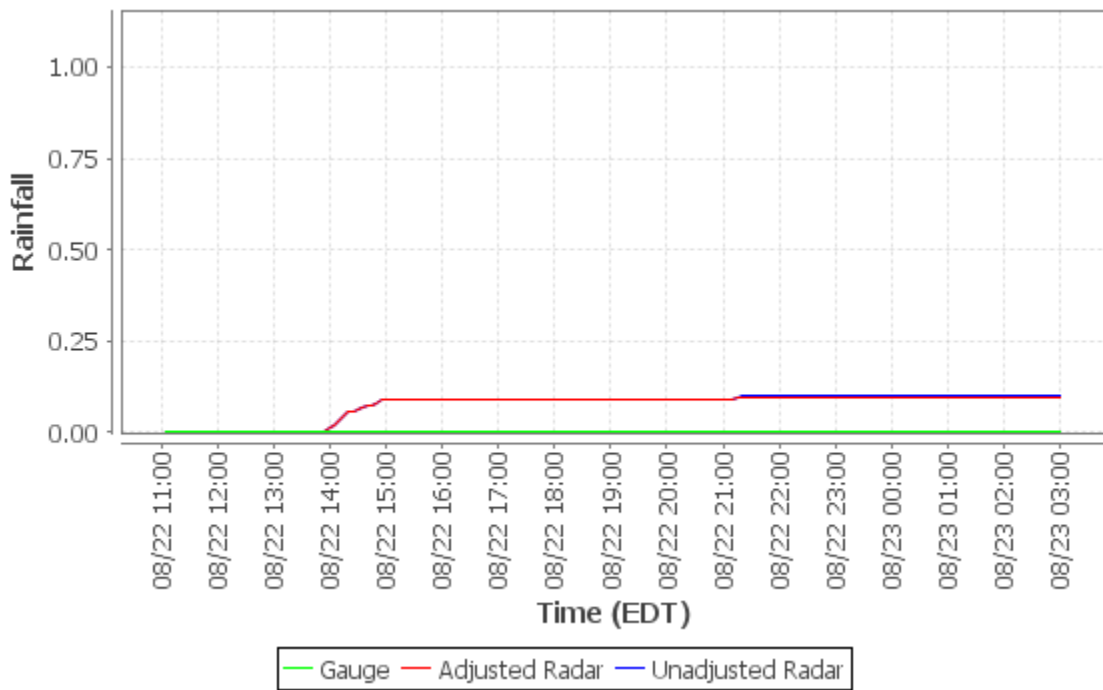


Appendix G - Event 5 (2019-08-22) CDPs

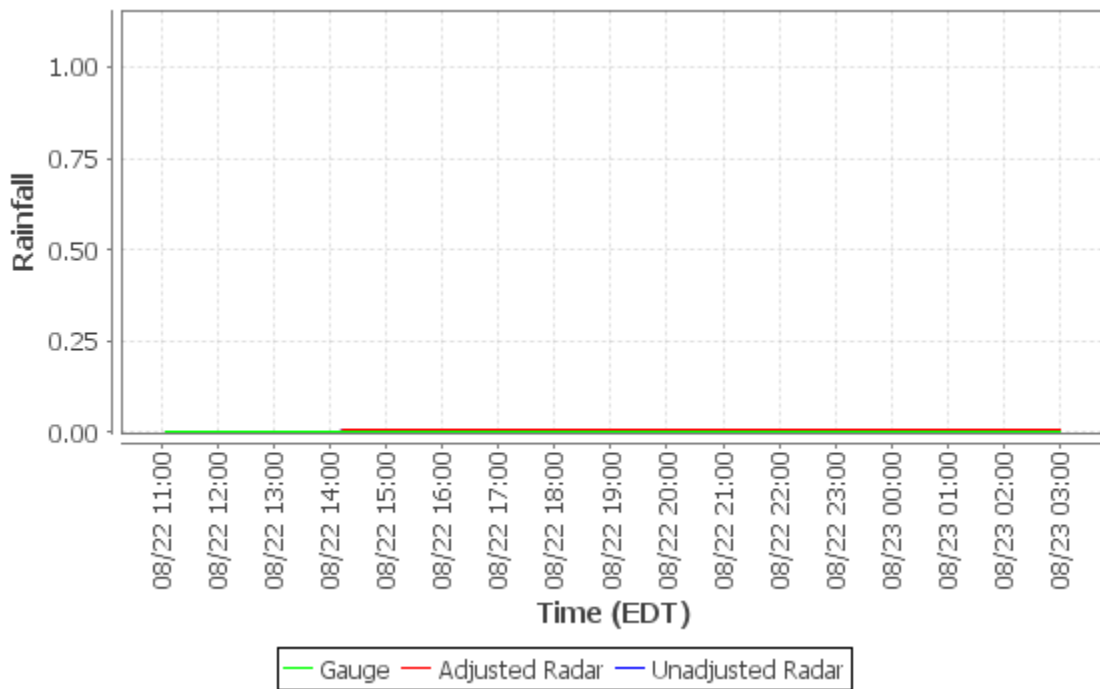
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



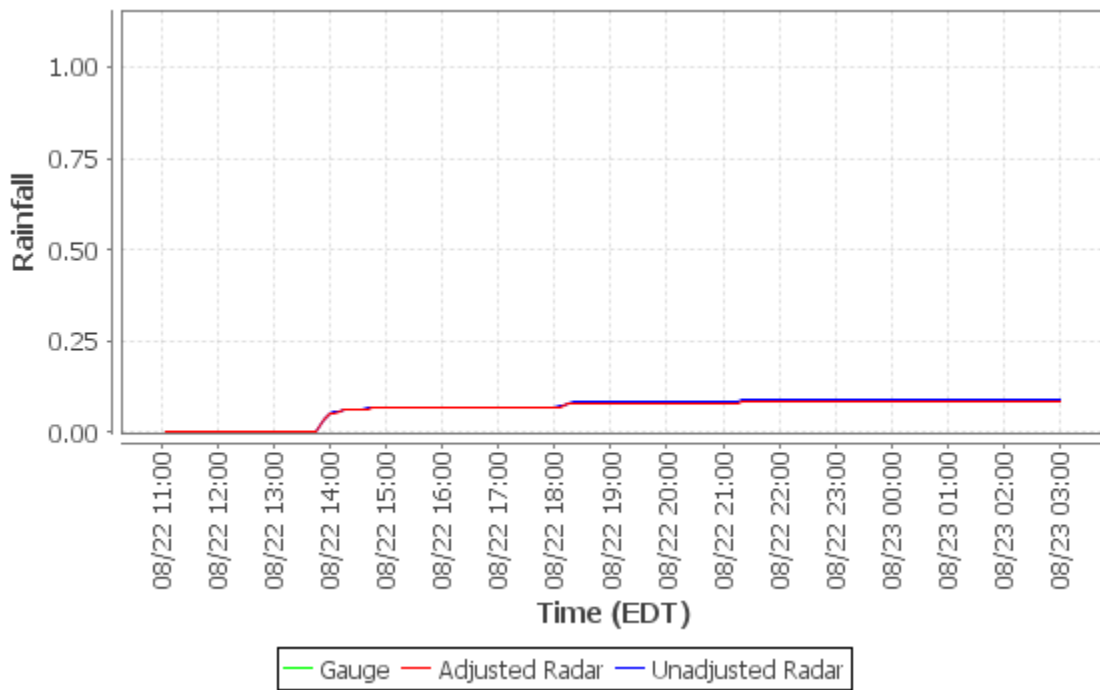
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



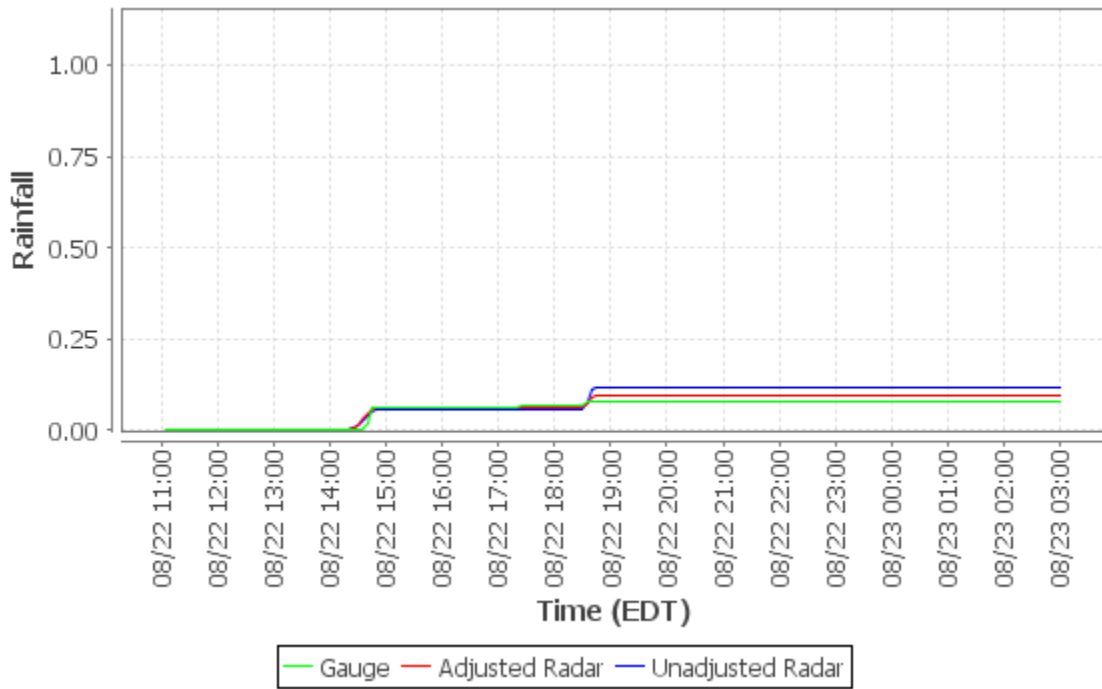
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



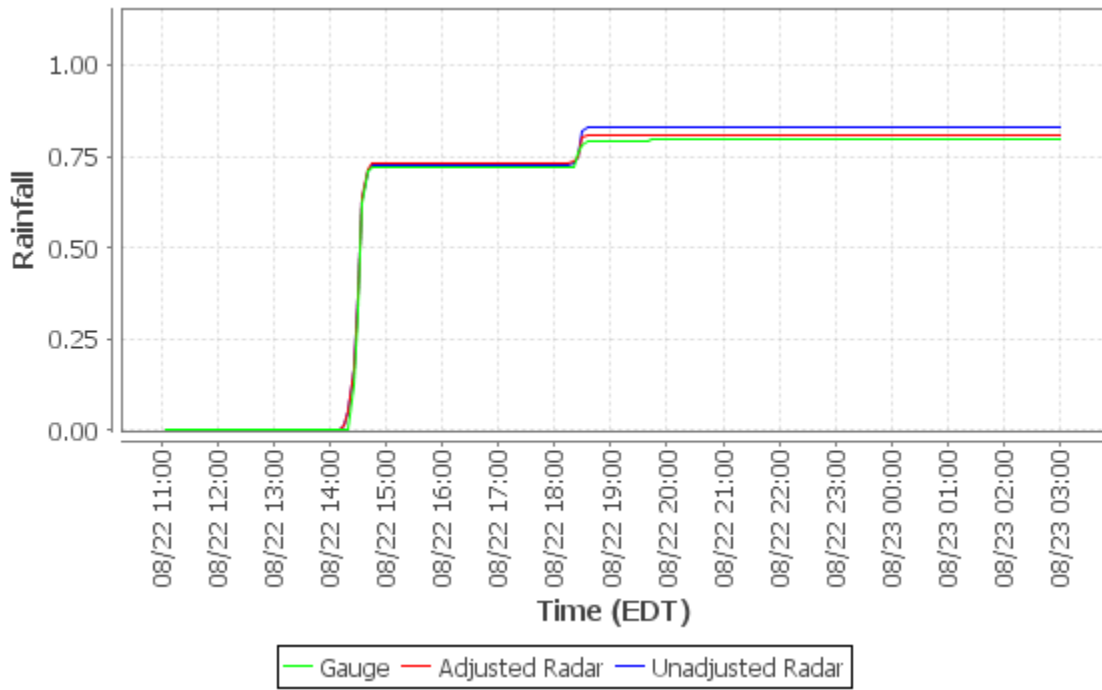
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



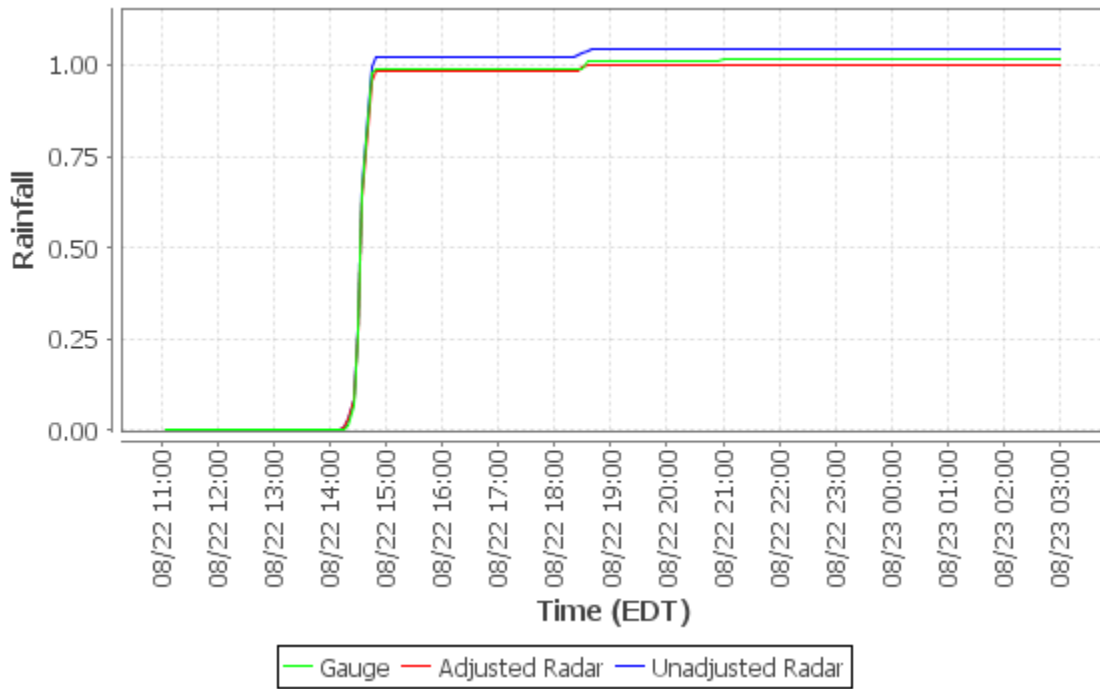
Cumulative Distribution Plot - Upper St. Clair (Loc05)



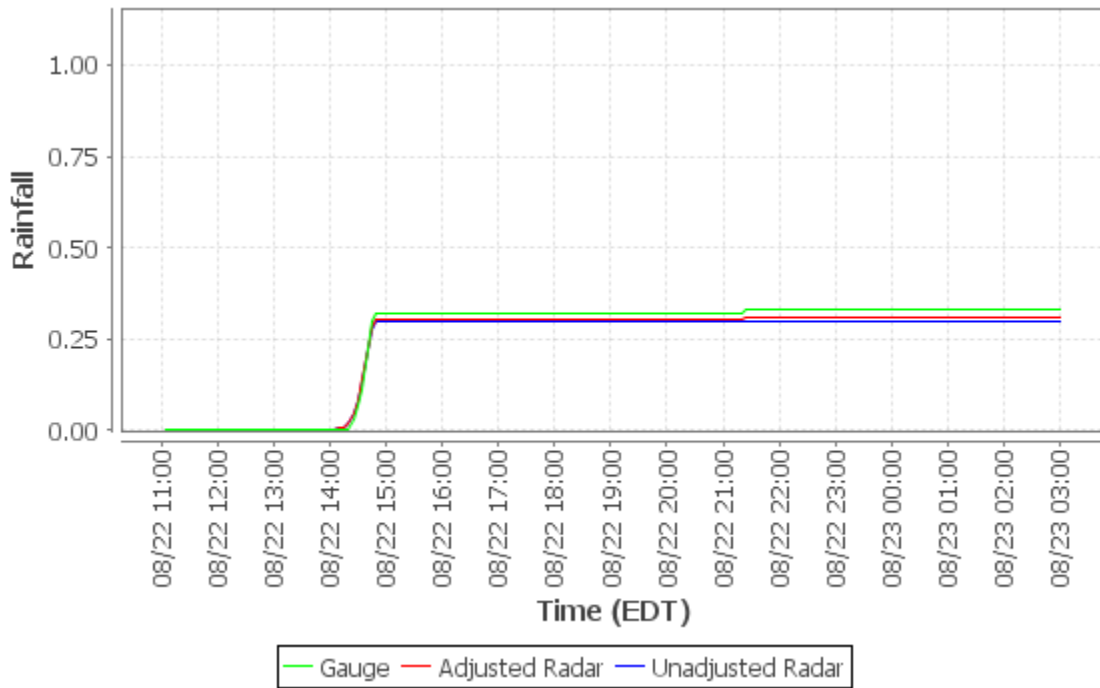
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



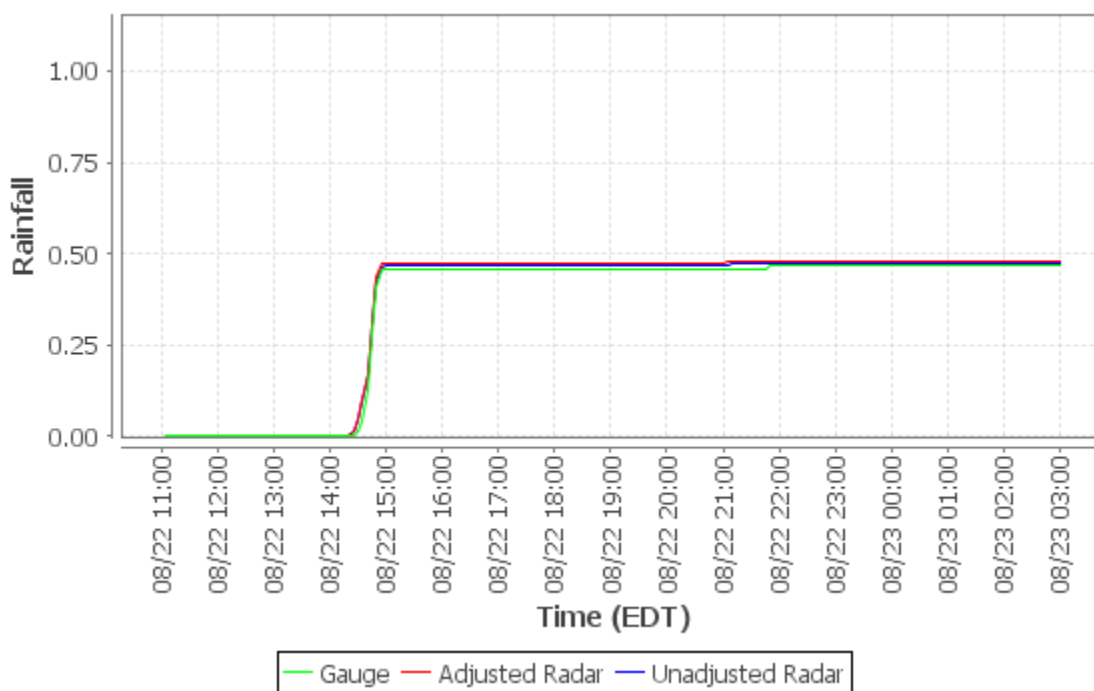
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



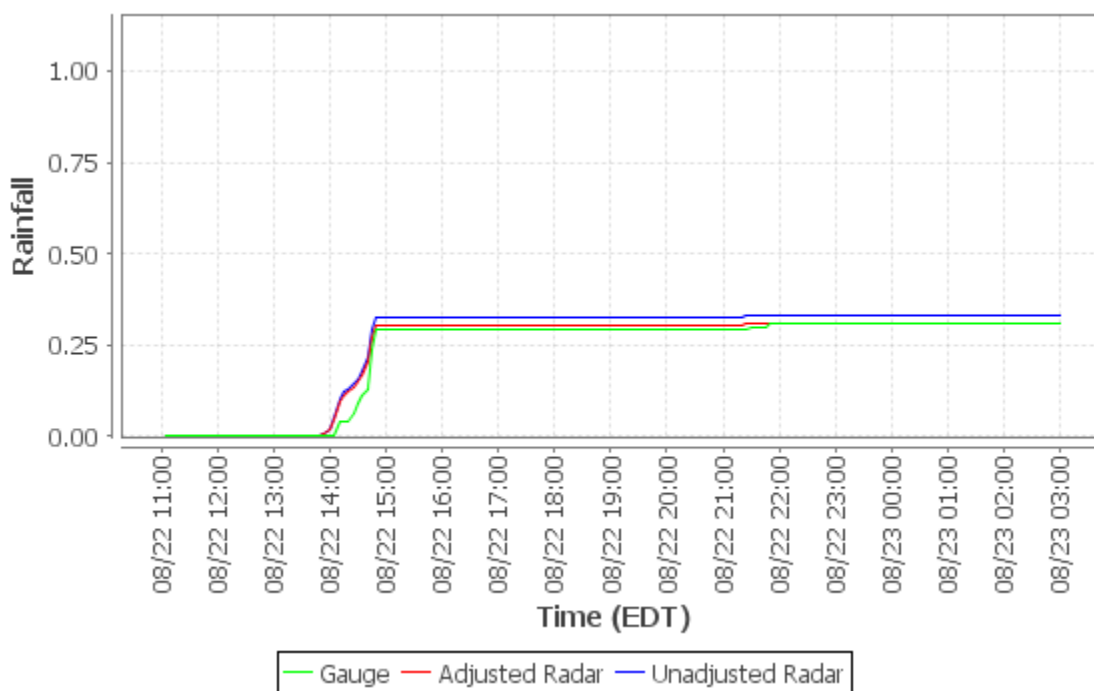
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



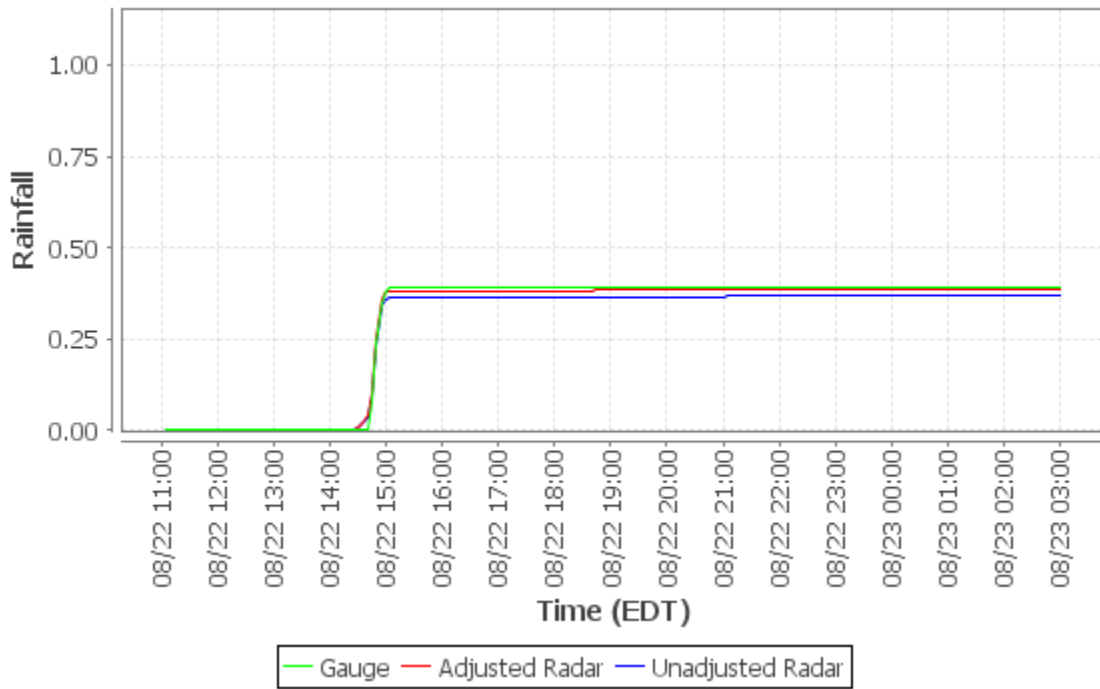
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



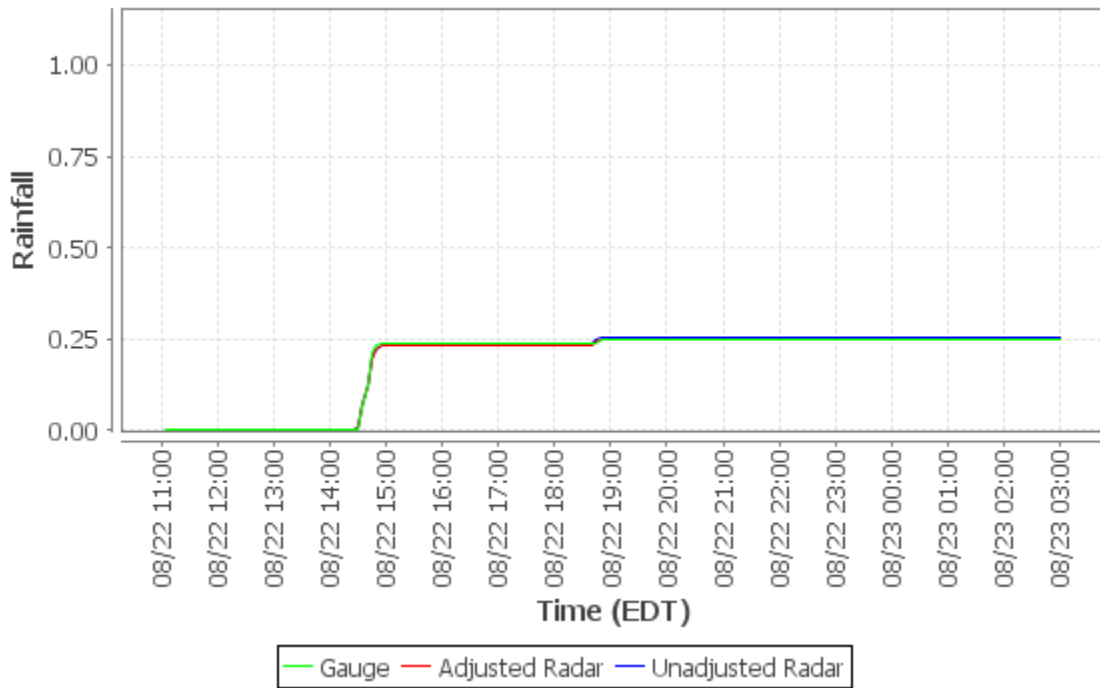
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



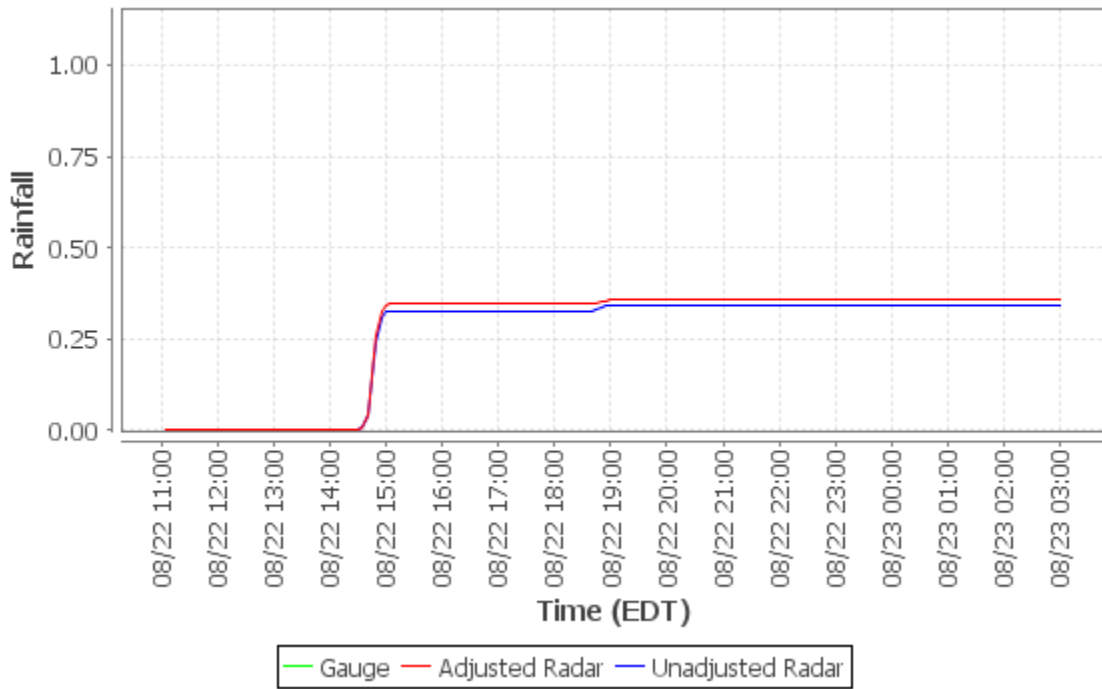
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



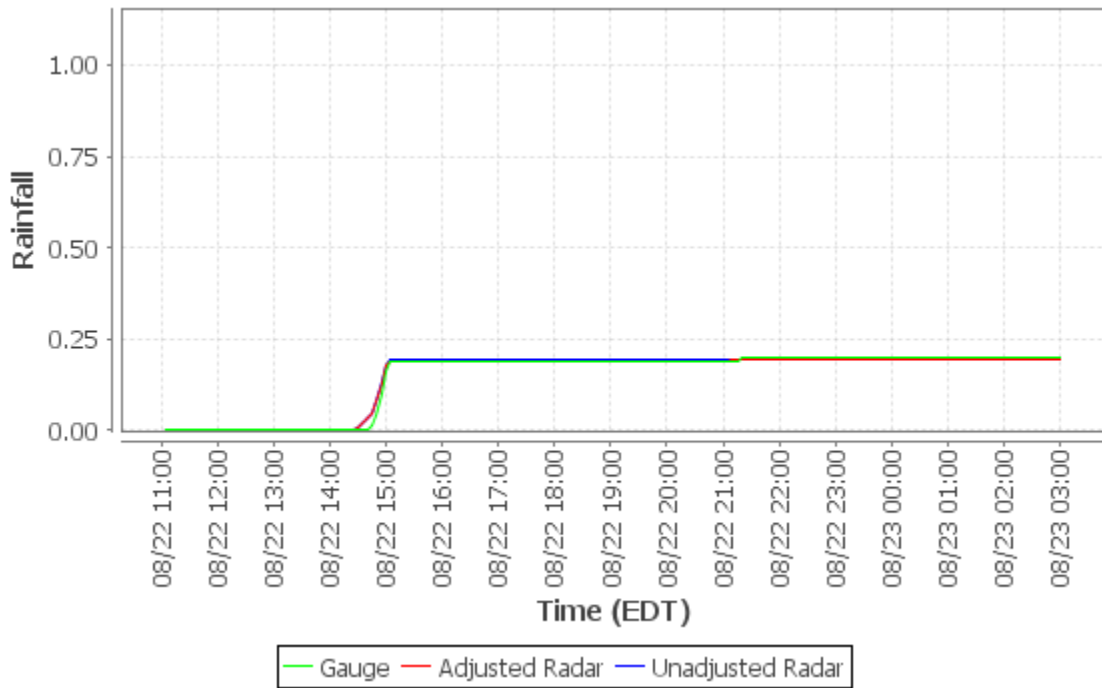
Cumulative Distribution Plot - Baldwin (Loc12)



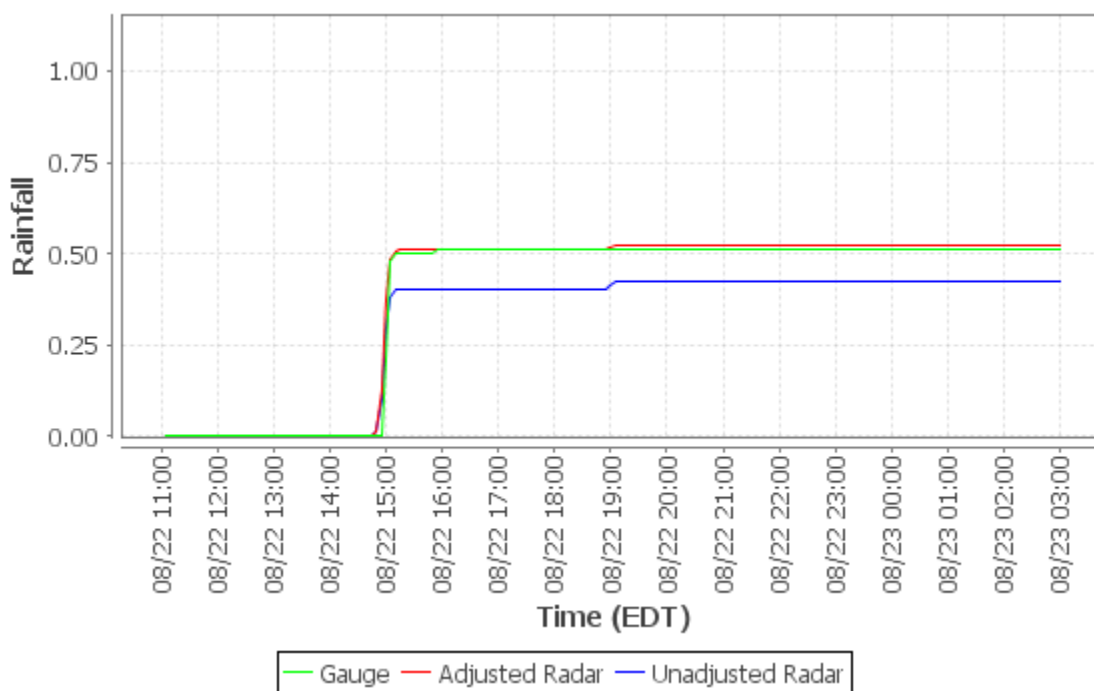
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



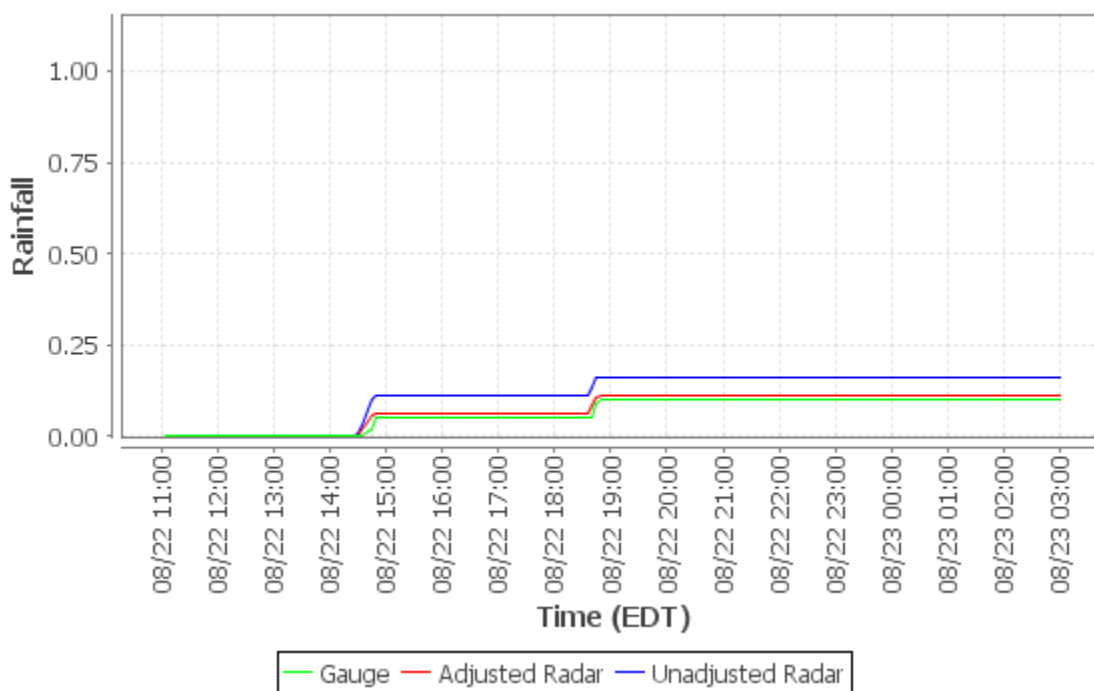
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



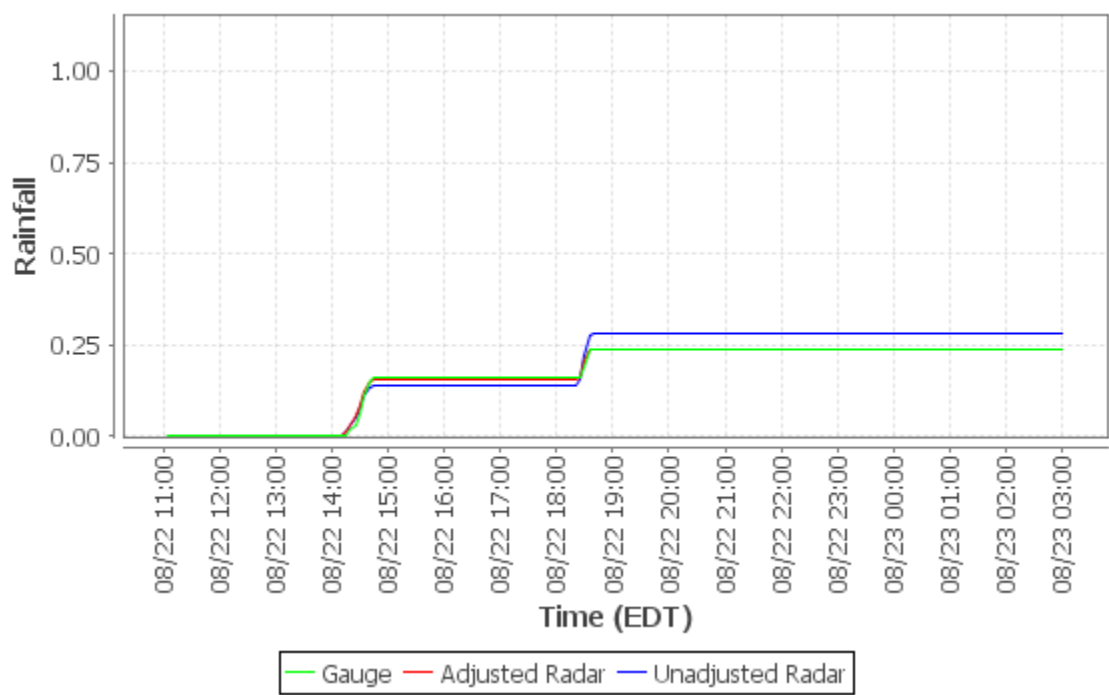
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



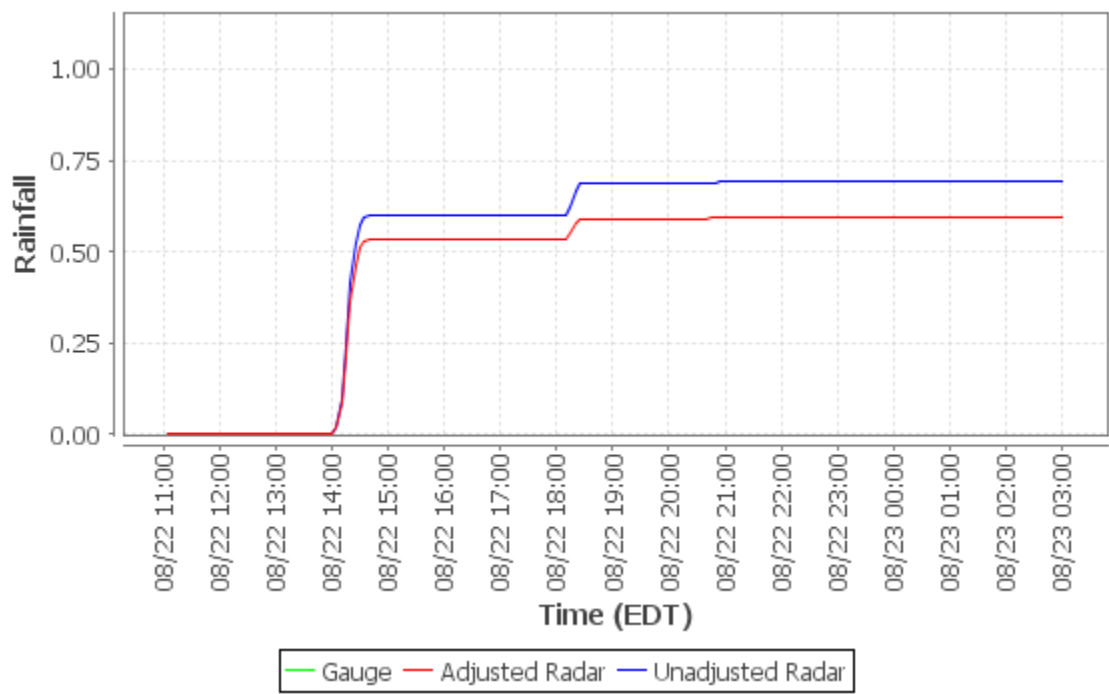
Cumulative Distribution Plot - Castle Shannon (Loc16)



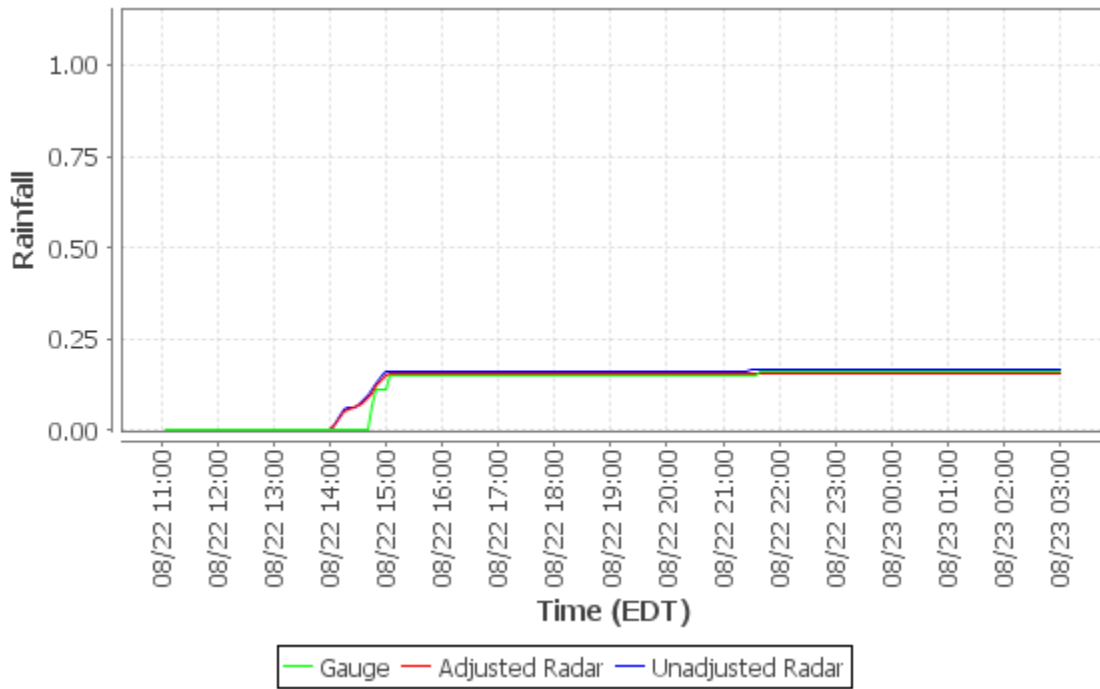
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



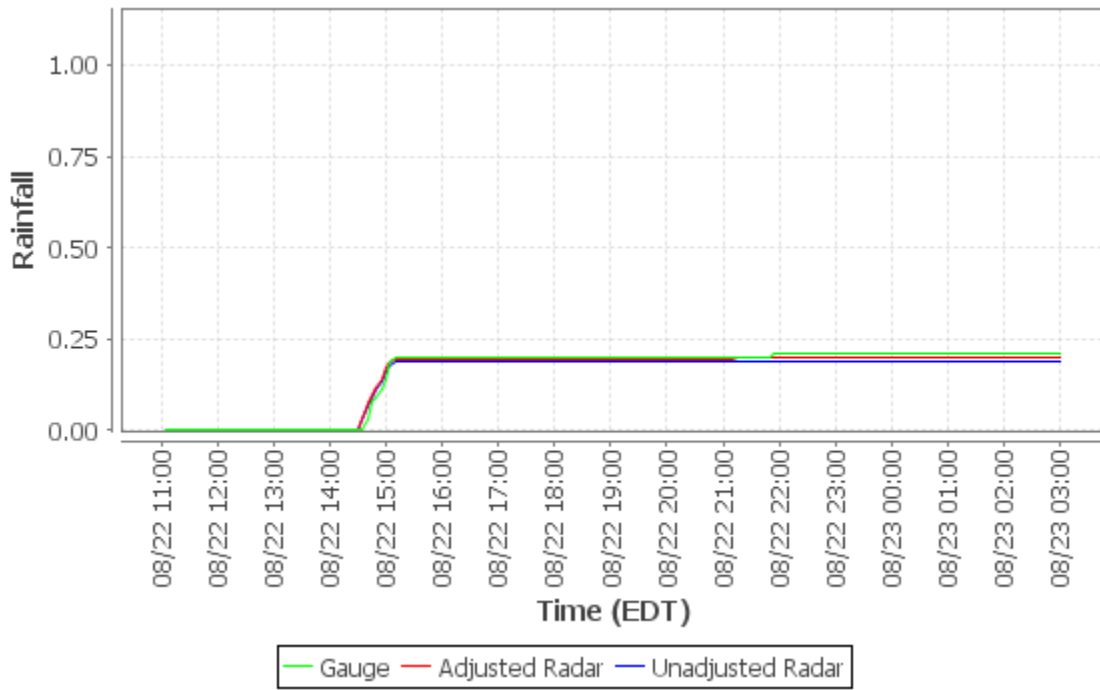
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



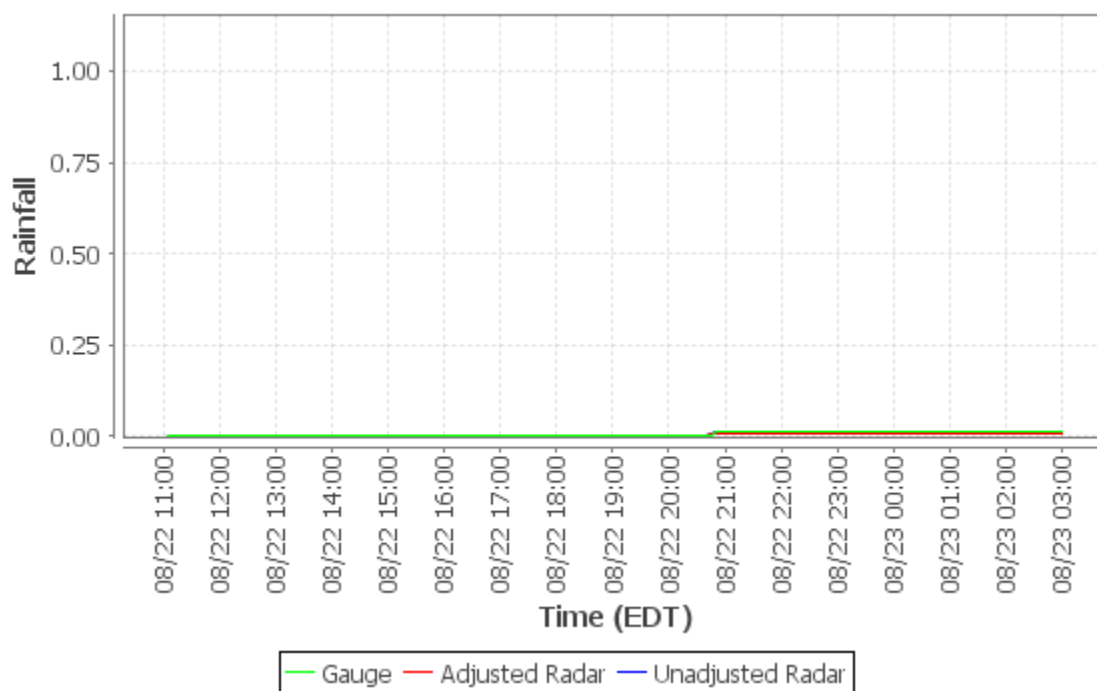
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



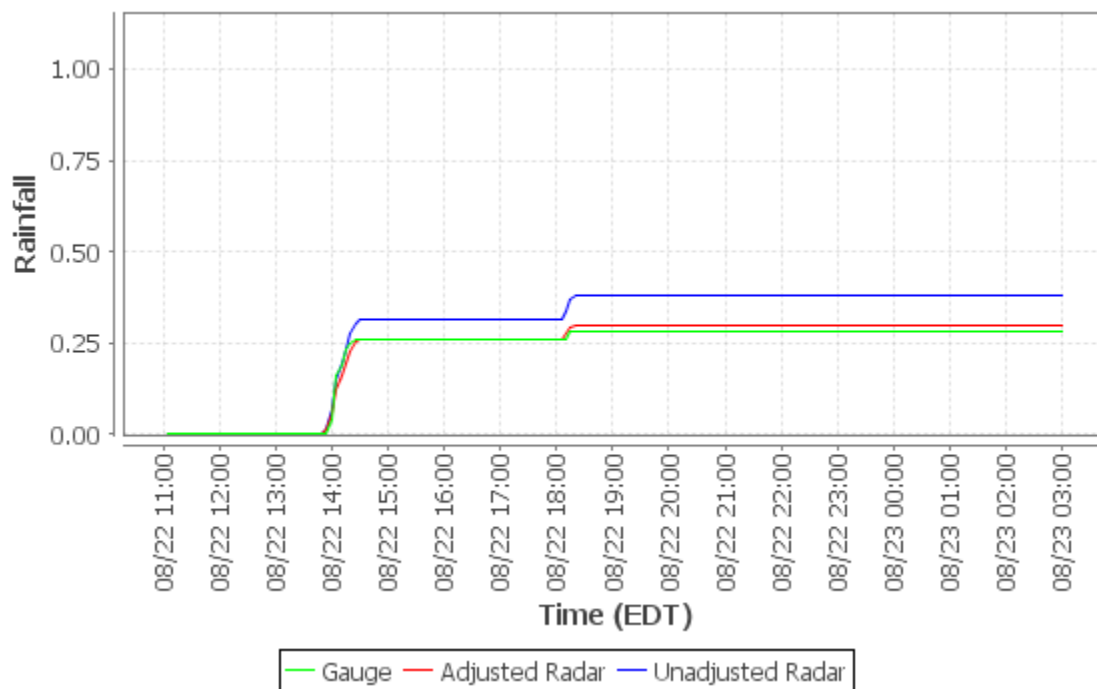
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



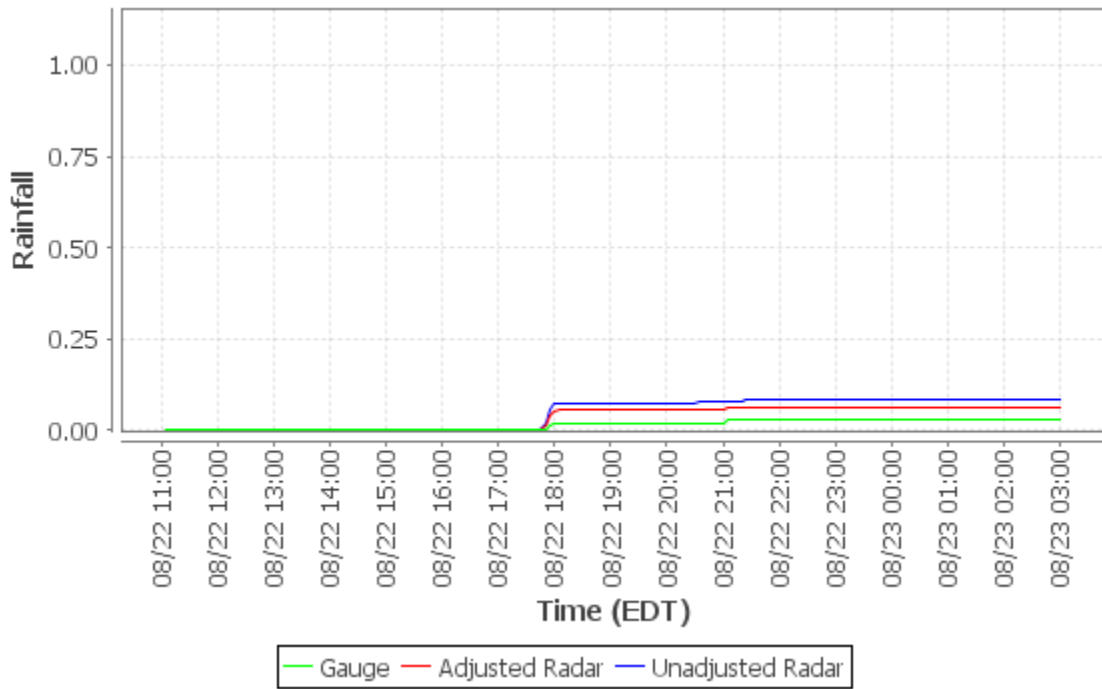
Cumulative Distribution Plot - Moon TWP (Loc21)



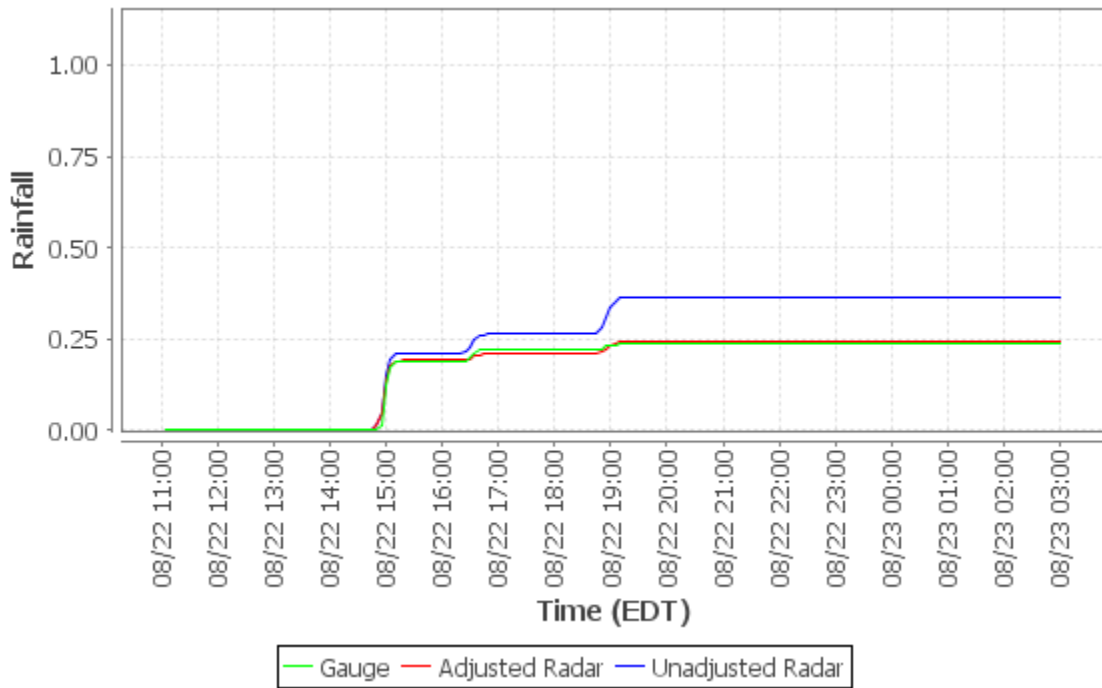
Cumulative Distribution Plot - North Fayette TWP (Loc22)



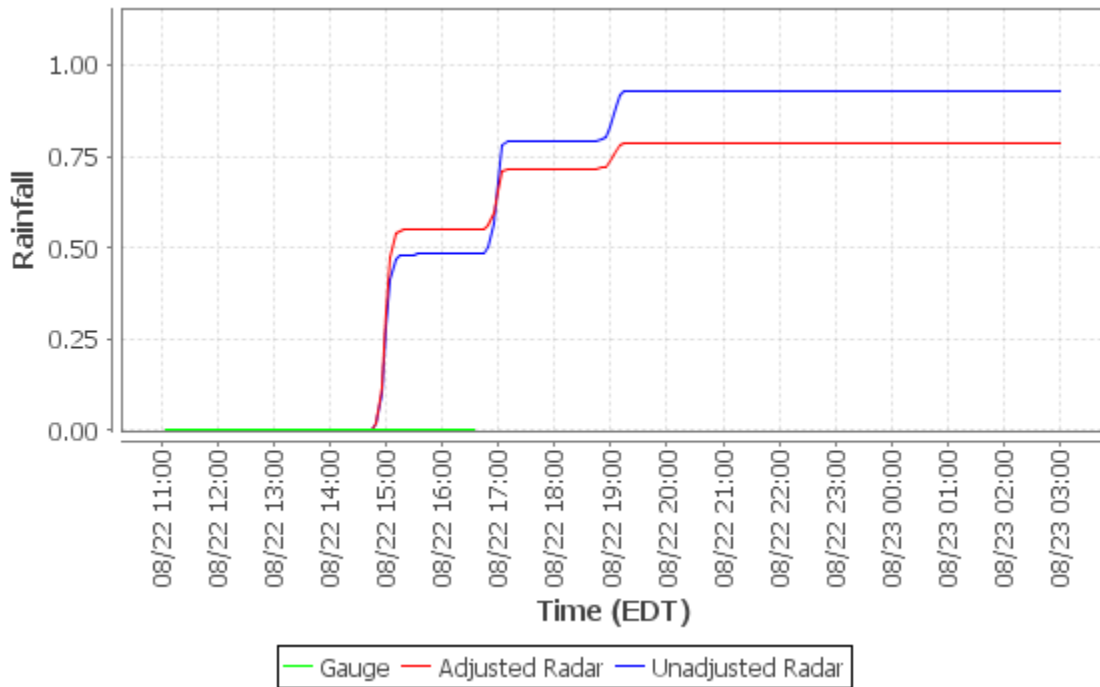
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



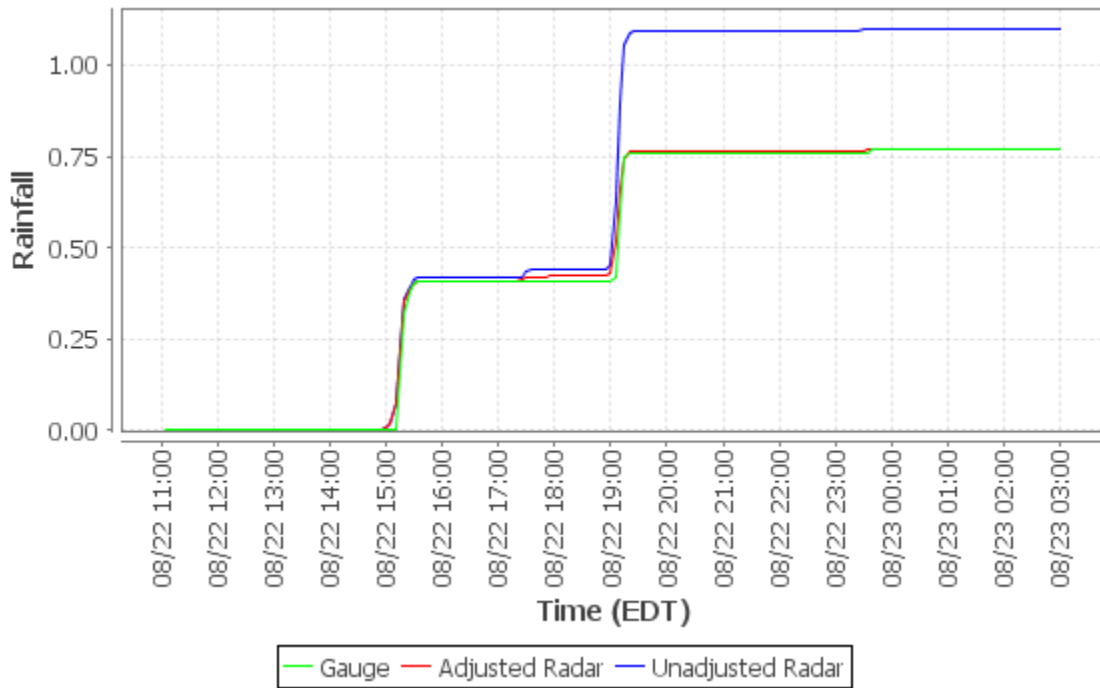
Cumulative Distribution Plot - Jefferson Hills (Loc24)



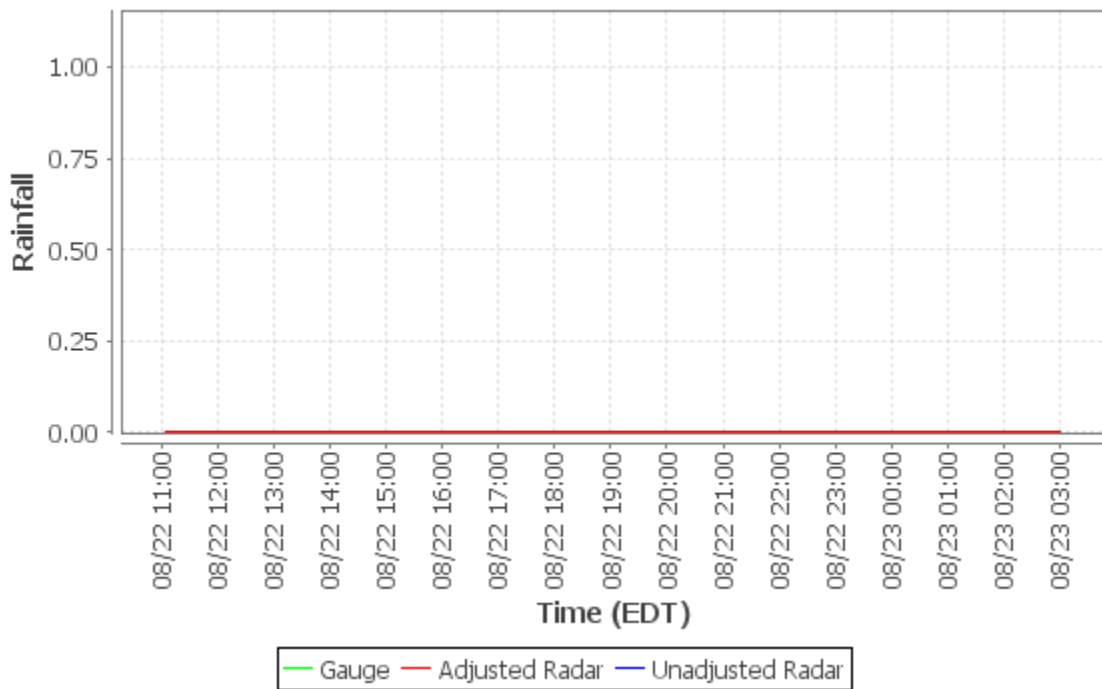
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



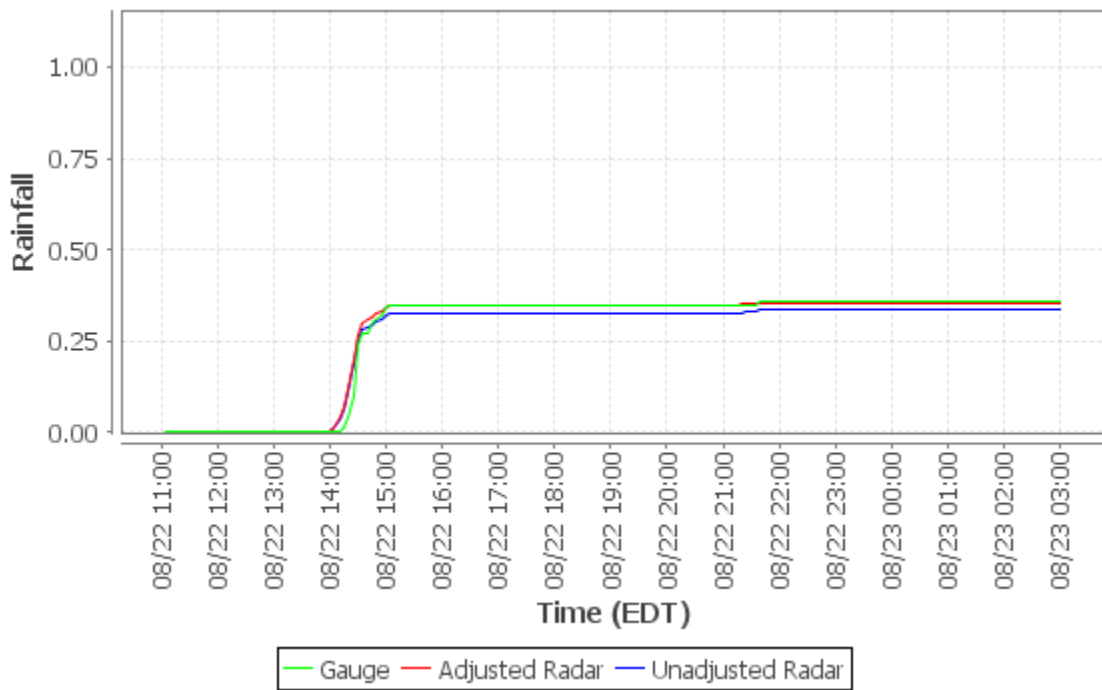
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



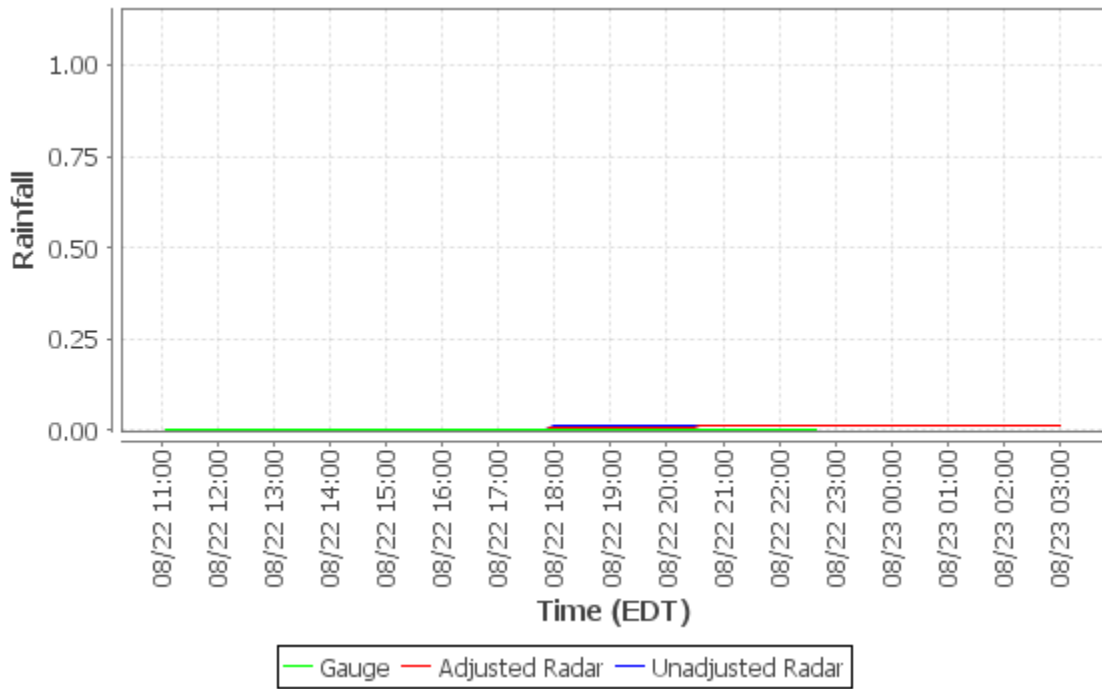
Cumulative Distribution Plot - Marshall TWP (Loc27)



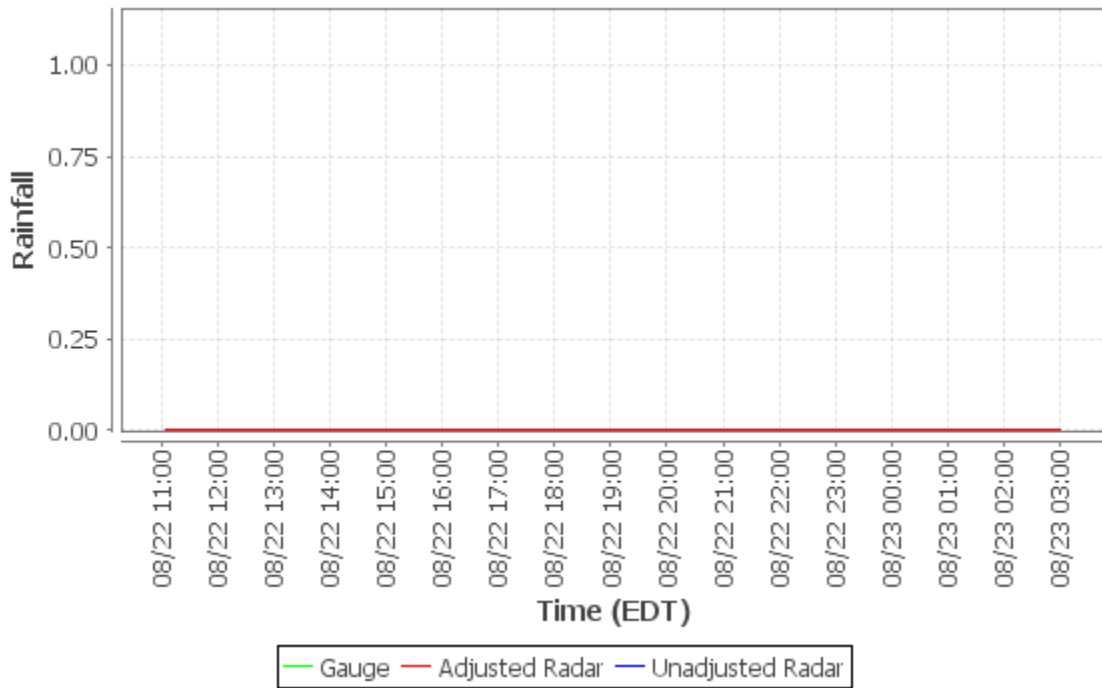
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



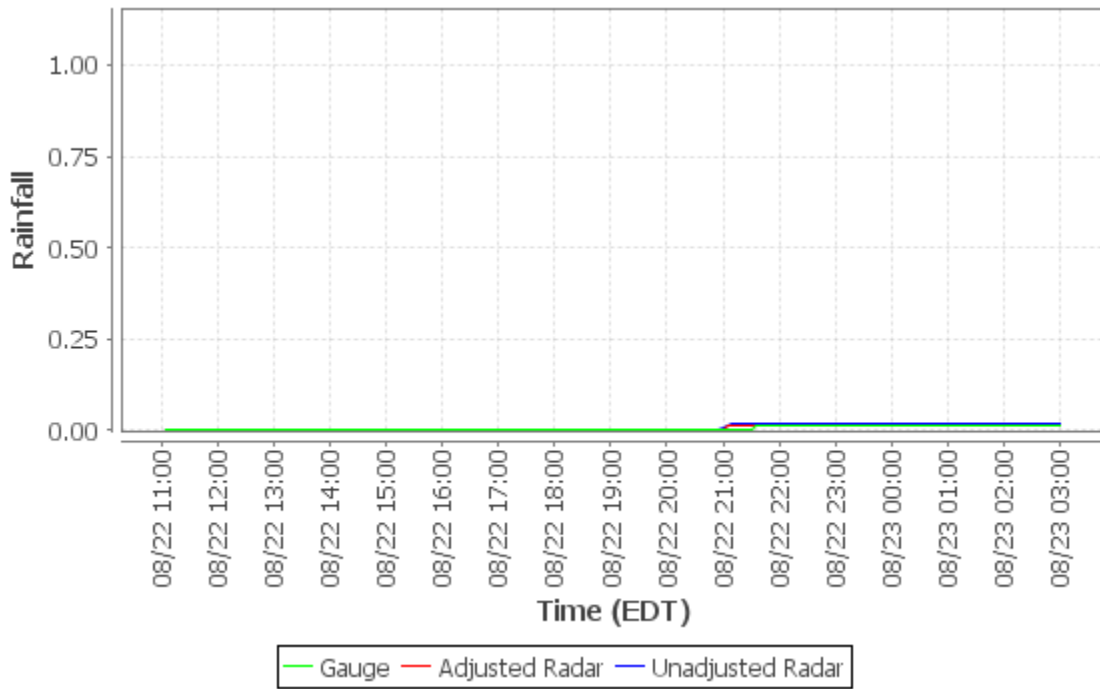
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



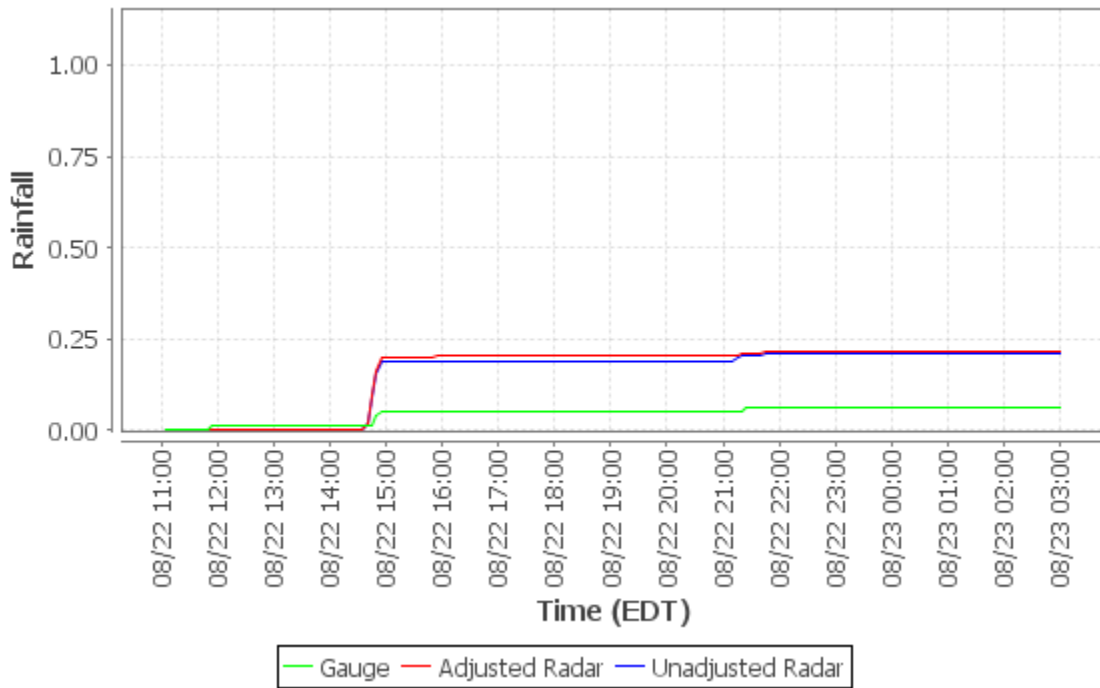
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



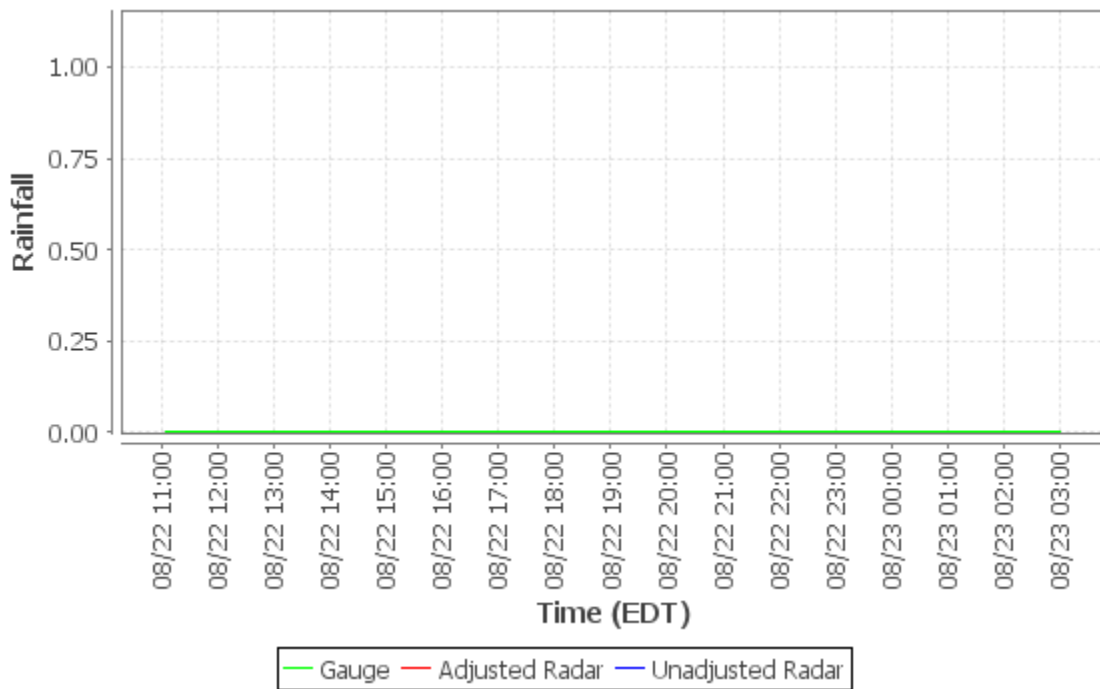
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



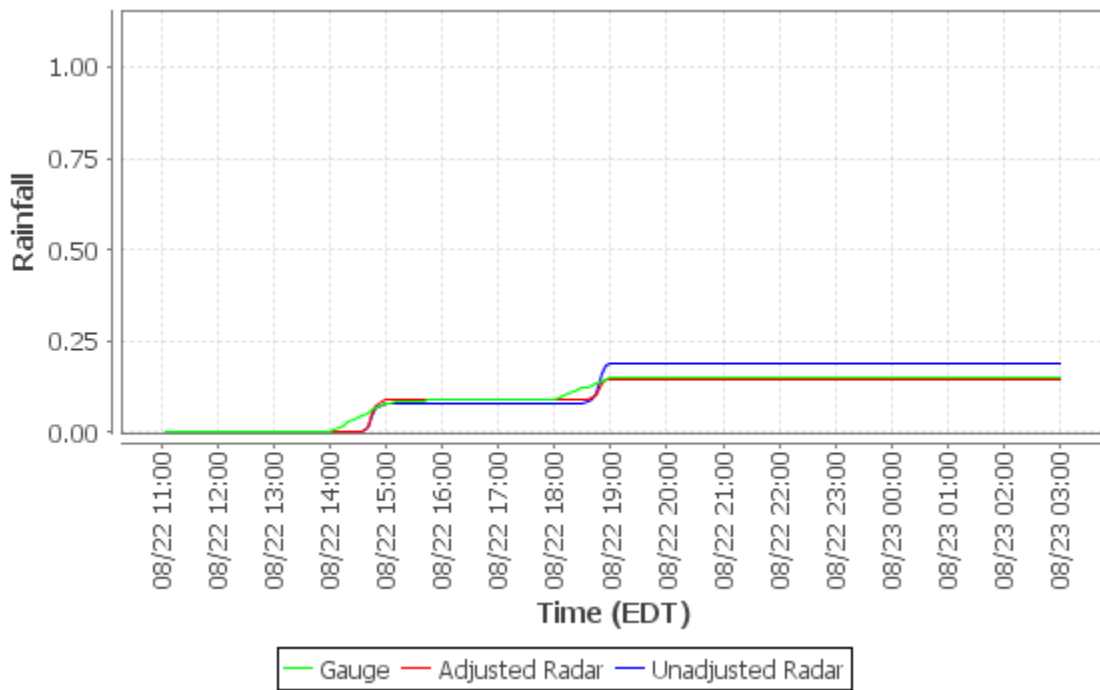
Cumulative Distribution Plot - Arnold (Loc32)



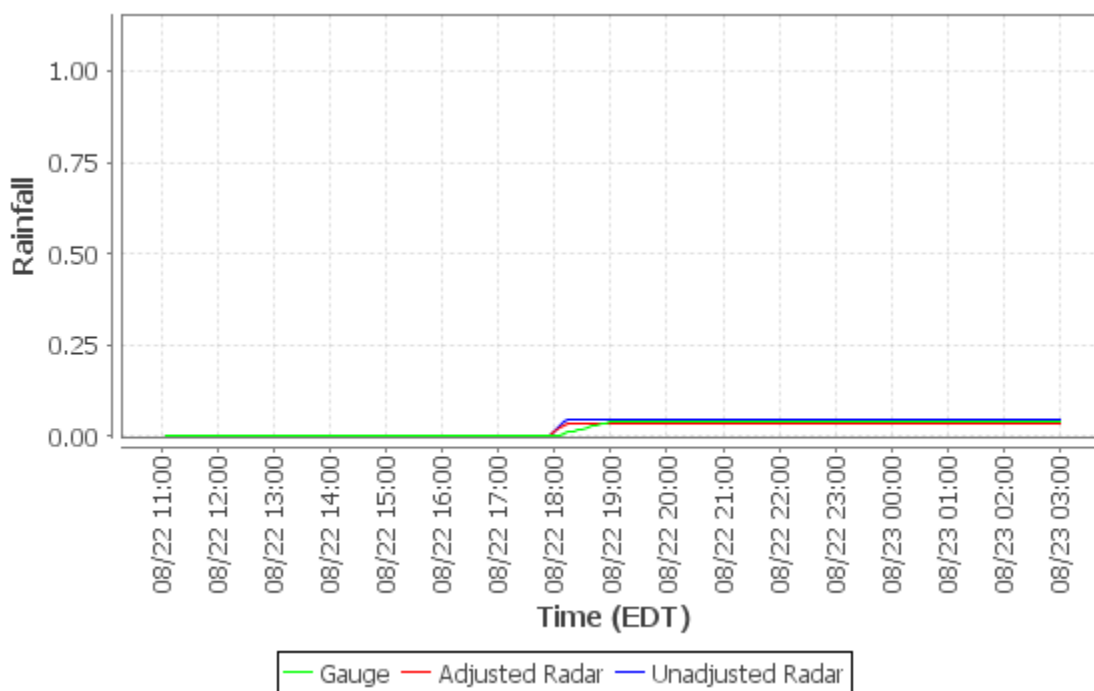
Cumulative Distribution Plot - Richland TWP (Loc33)



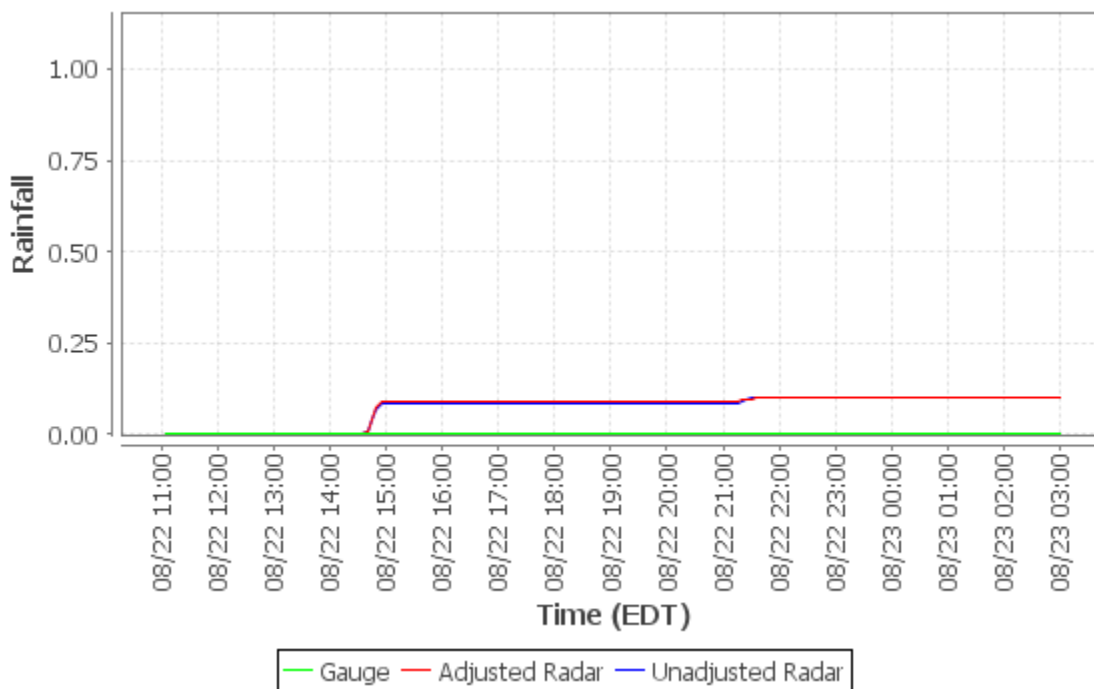
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



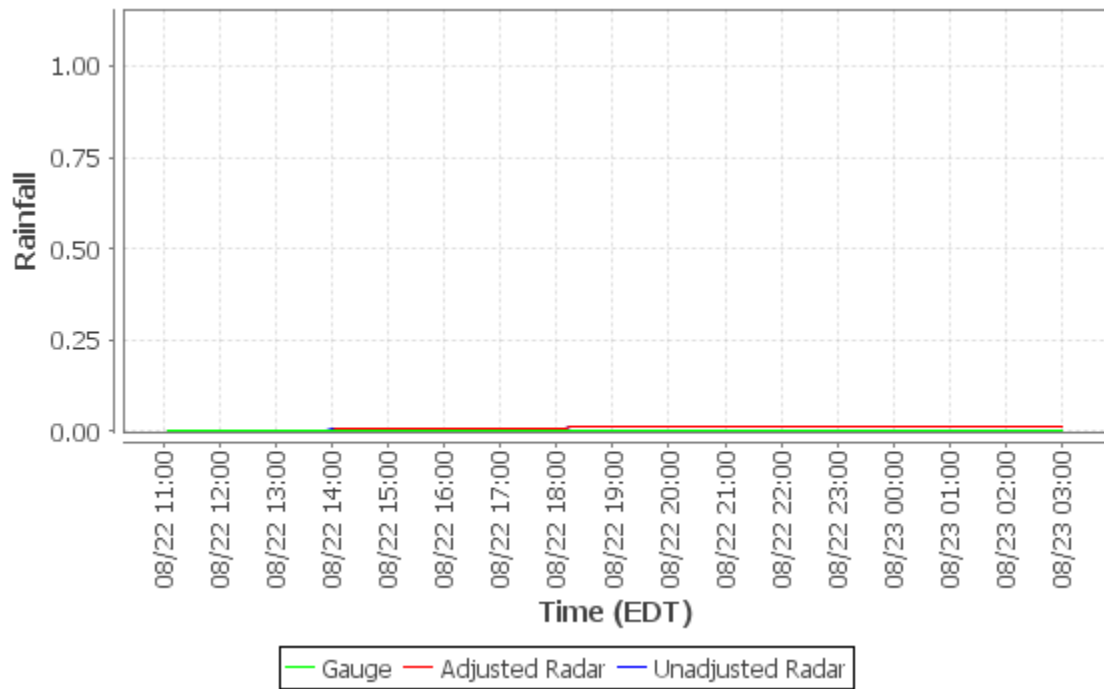
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

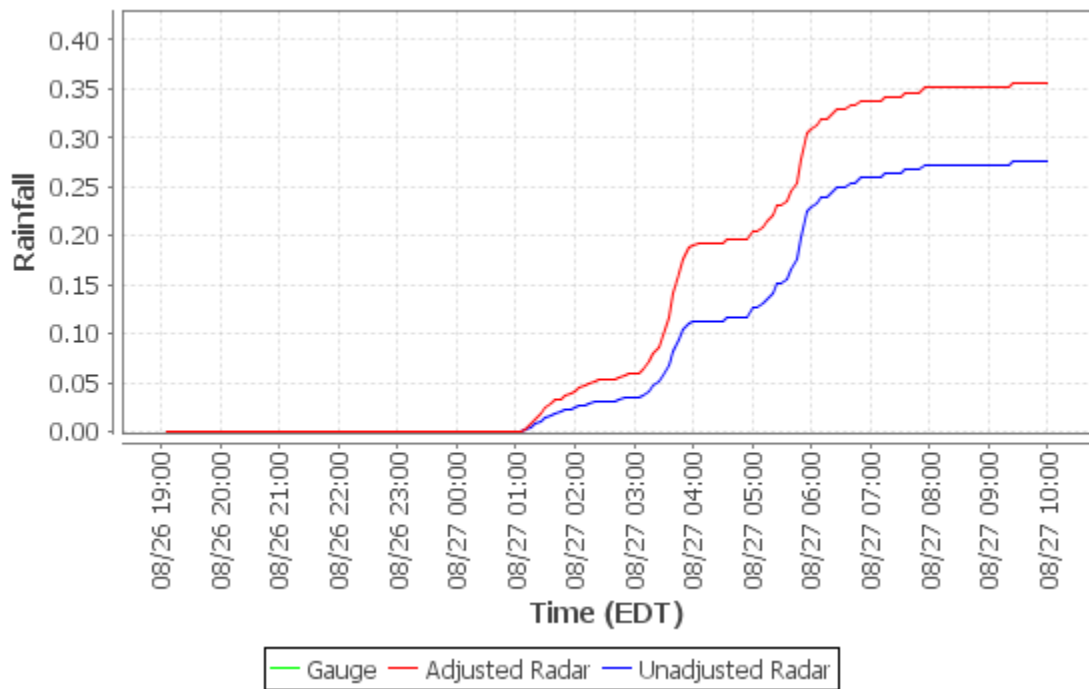


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

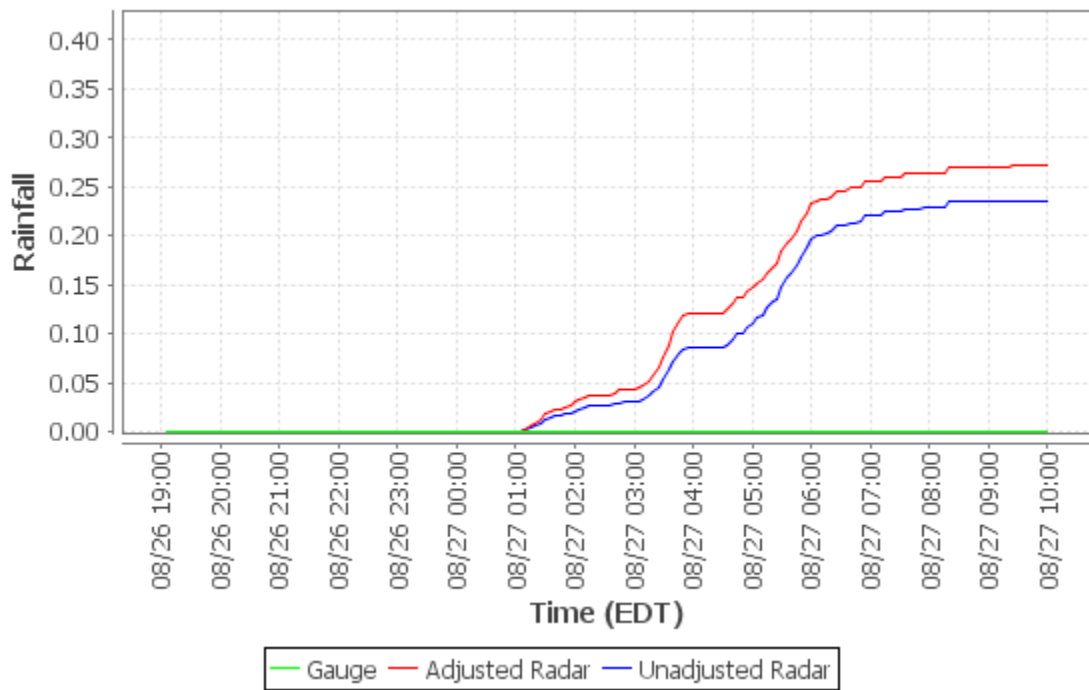


Appendix H - Event 6 (2019-08-27) CDPs

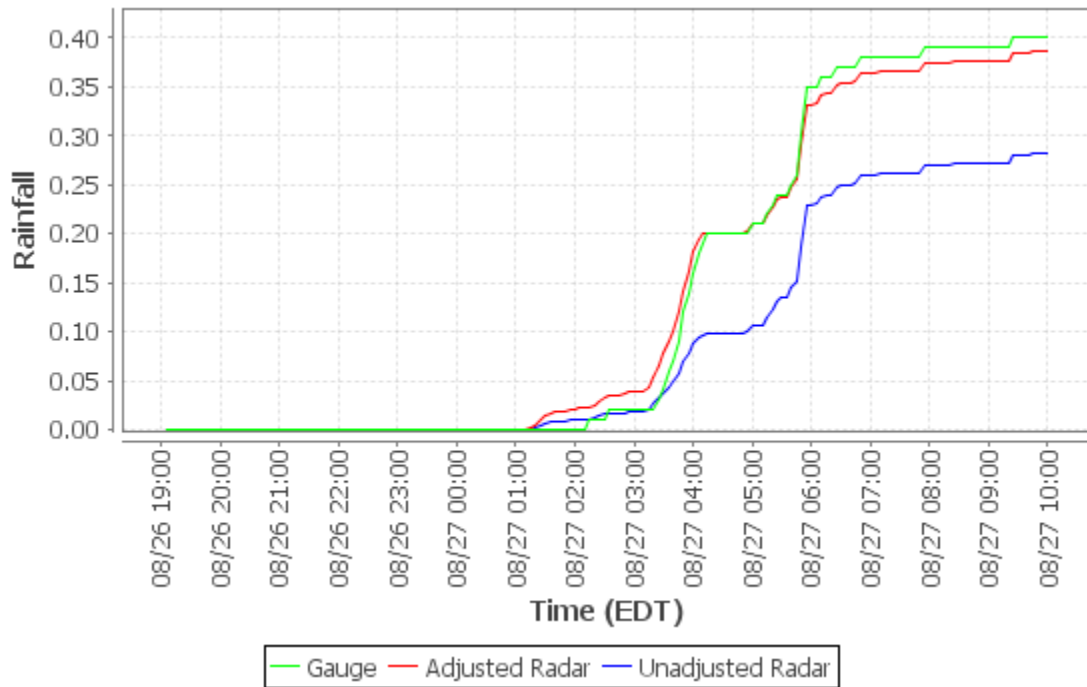
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



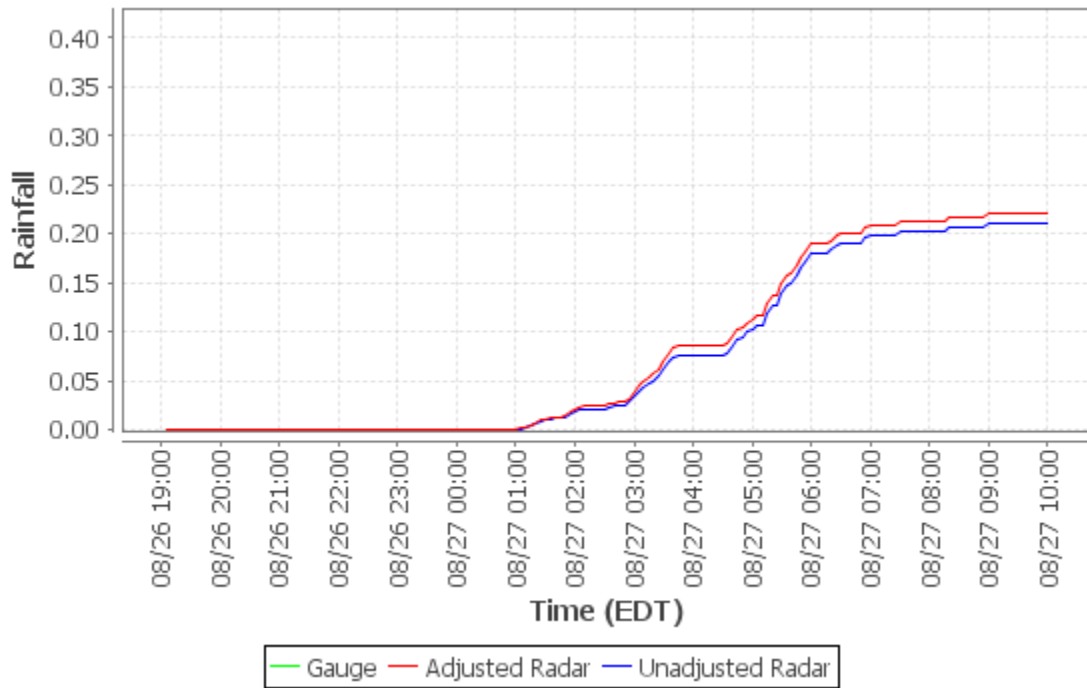
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



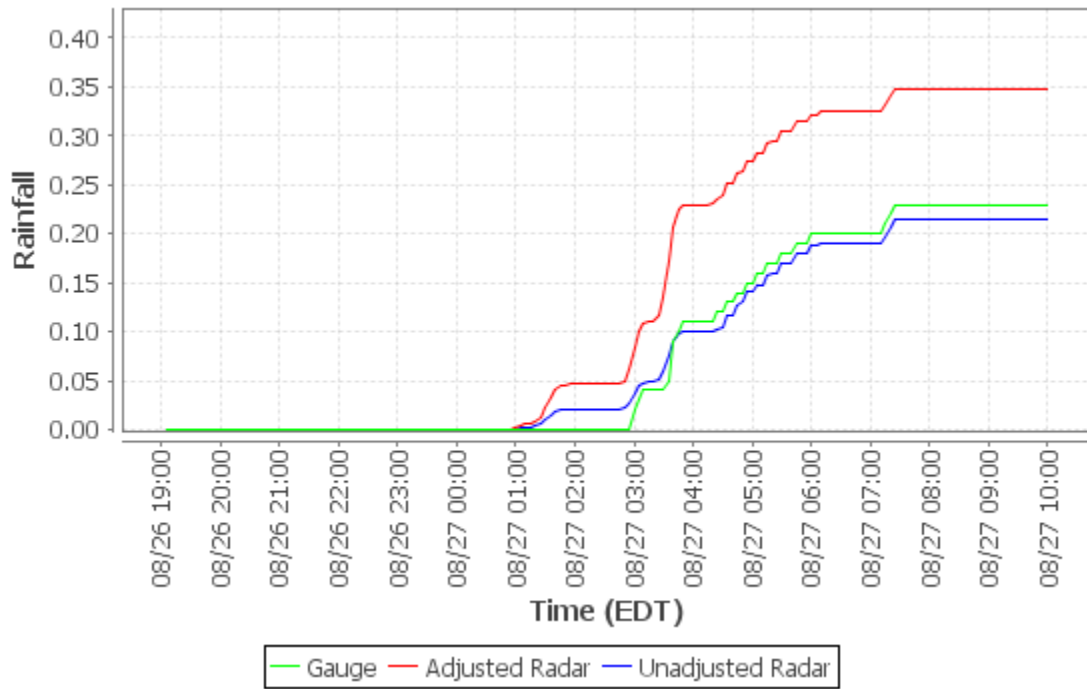
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



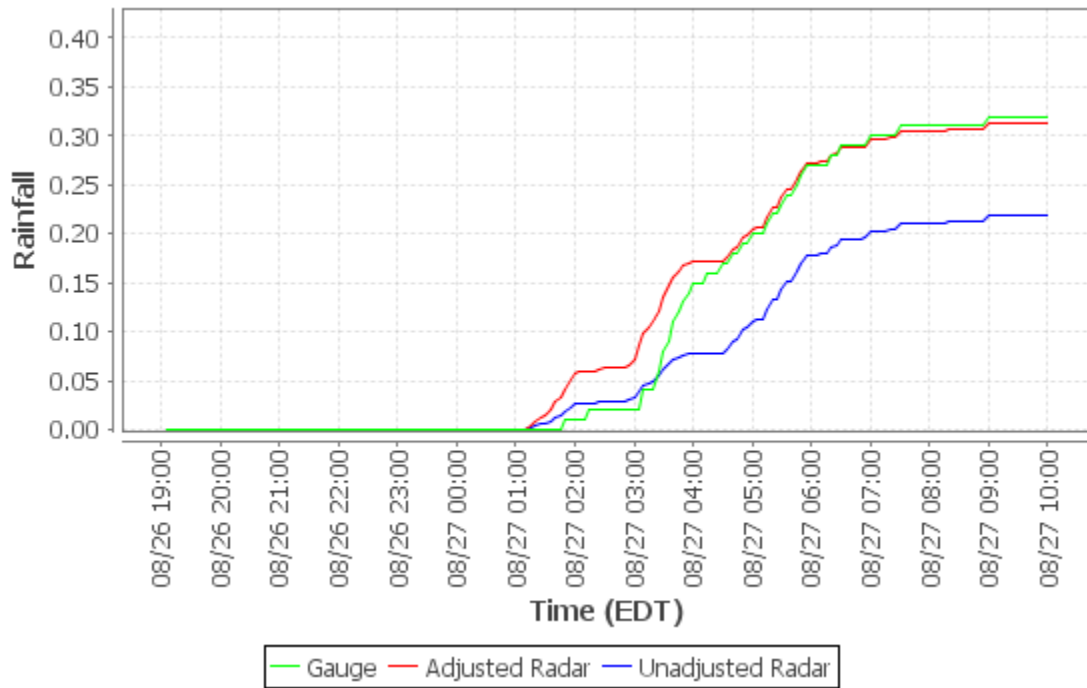
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



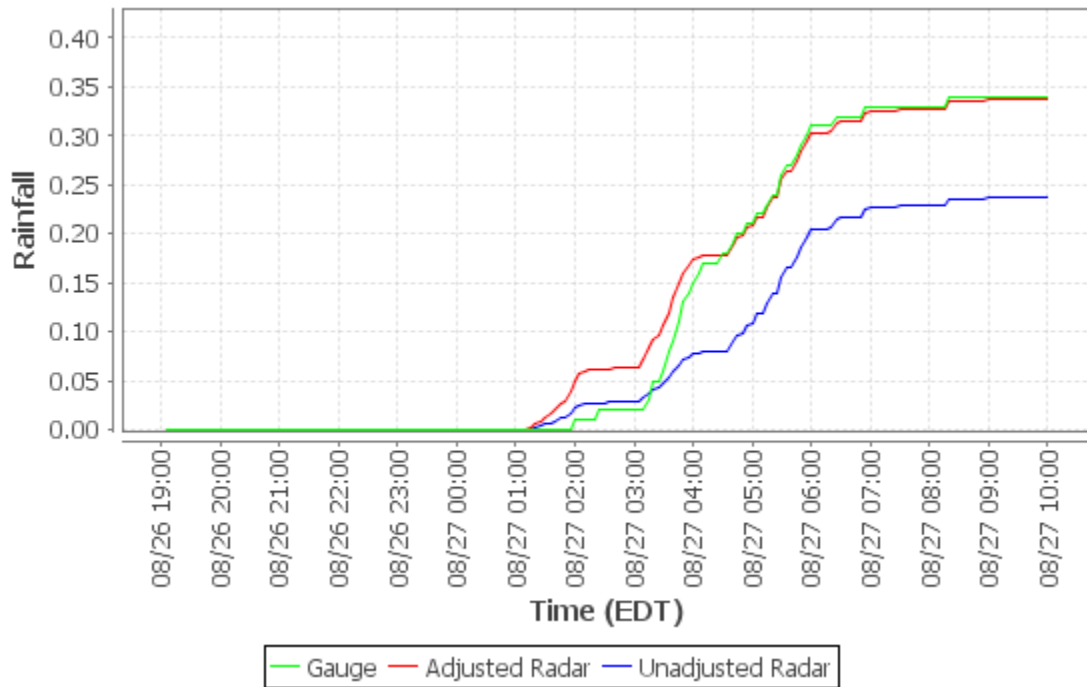
Cumulative Distribution Plot - Upper St. Clair (Loc05)



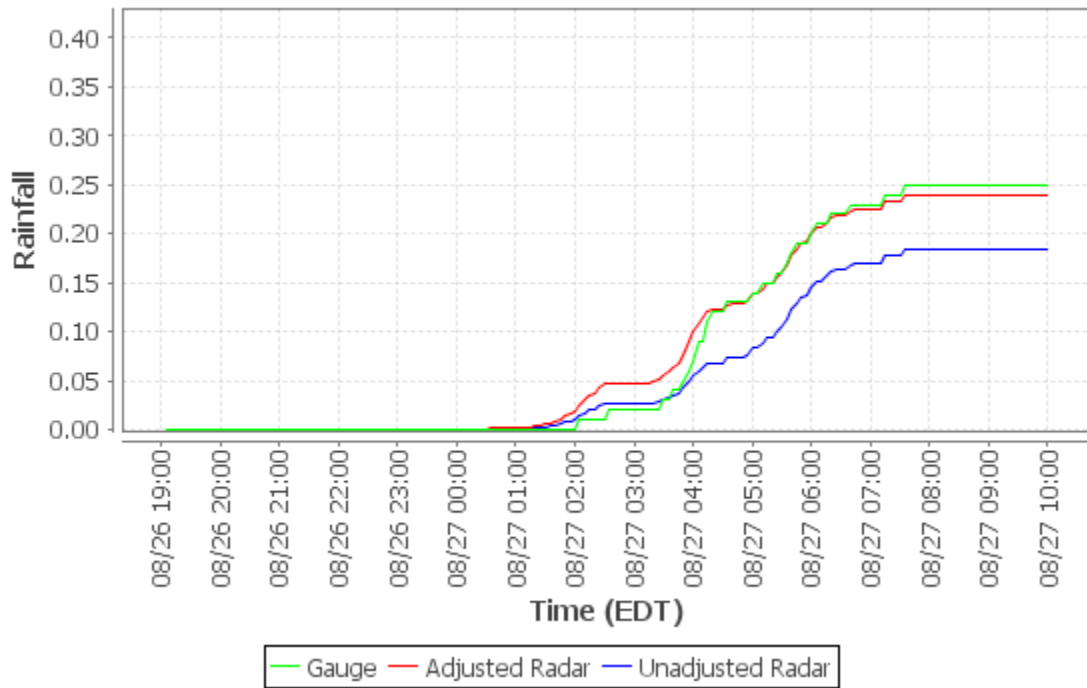
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



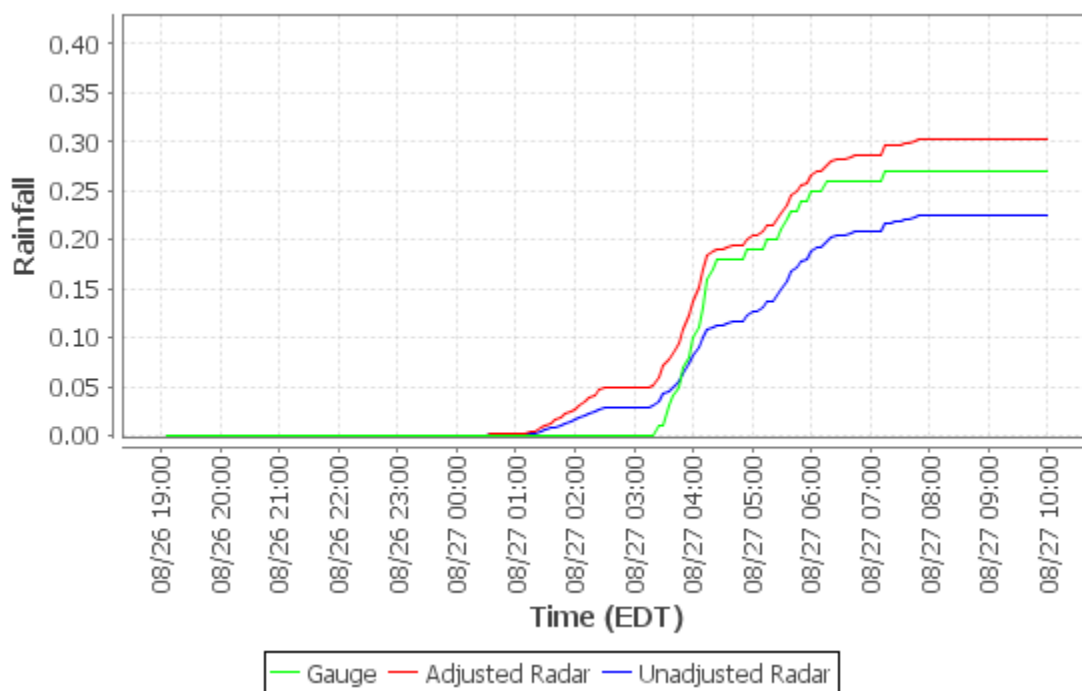
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



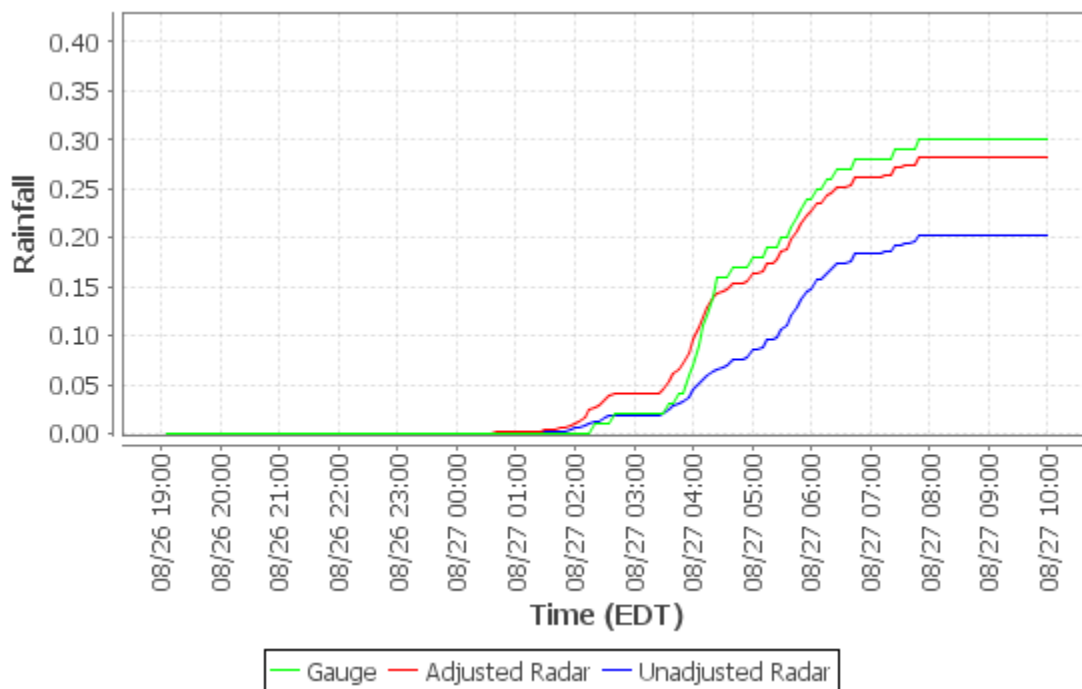
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



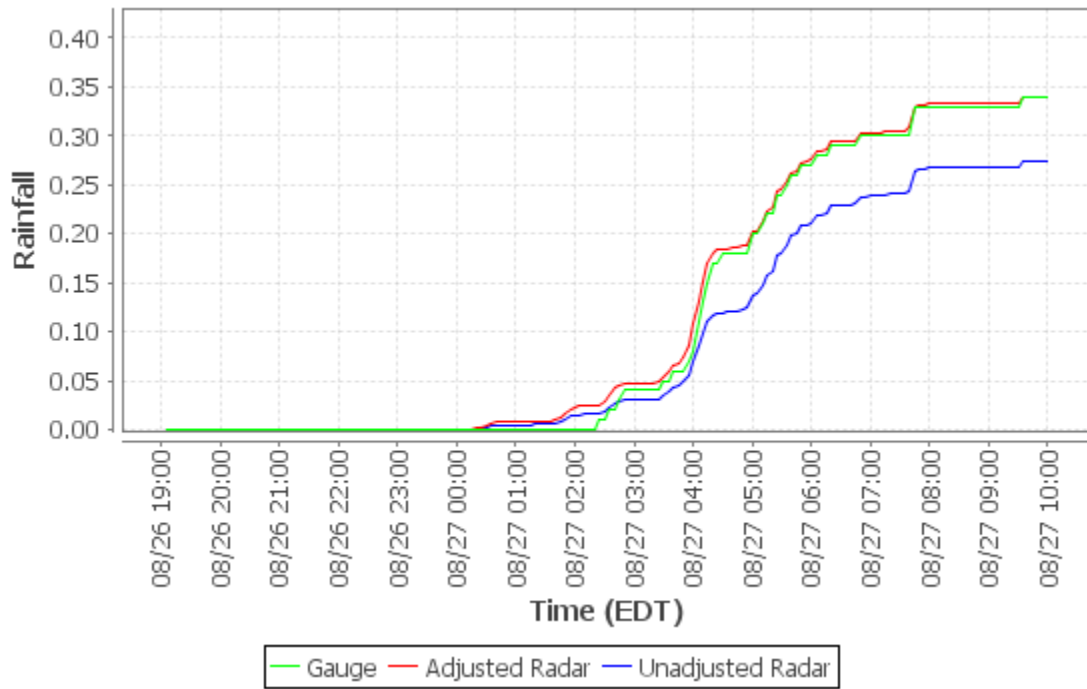
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



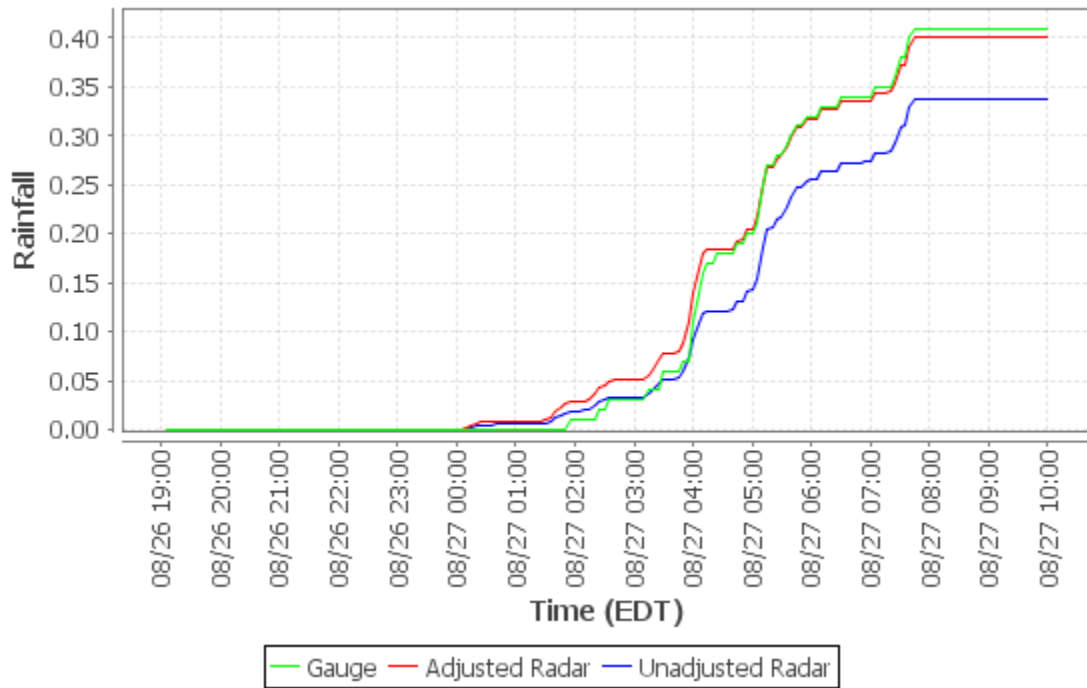
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



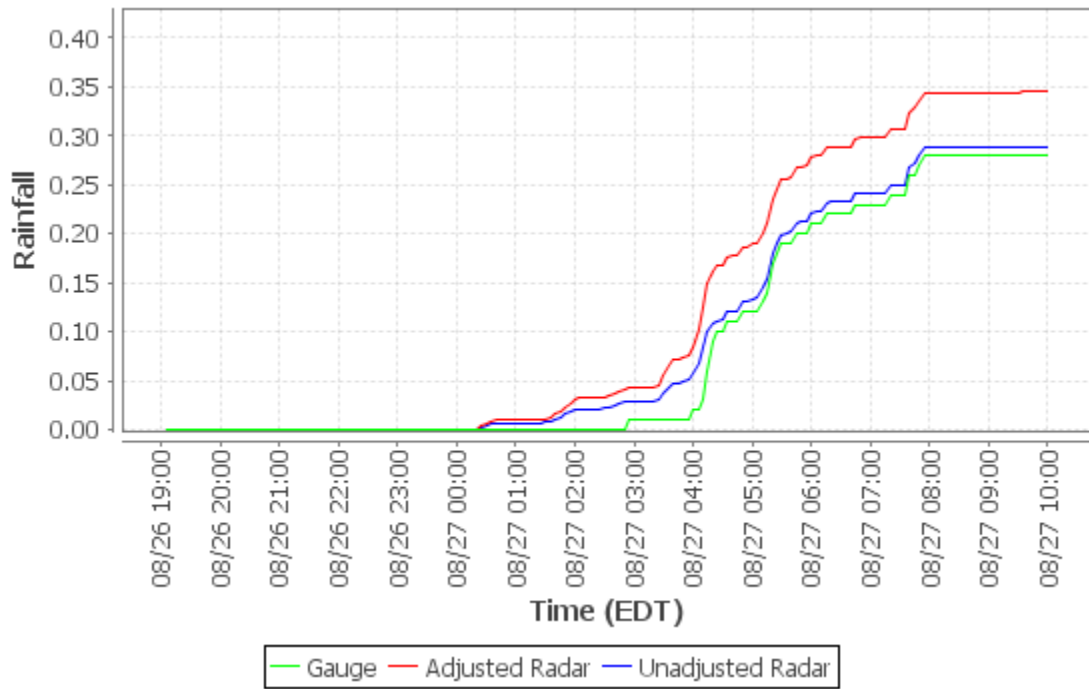
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



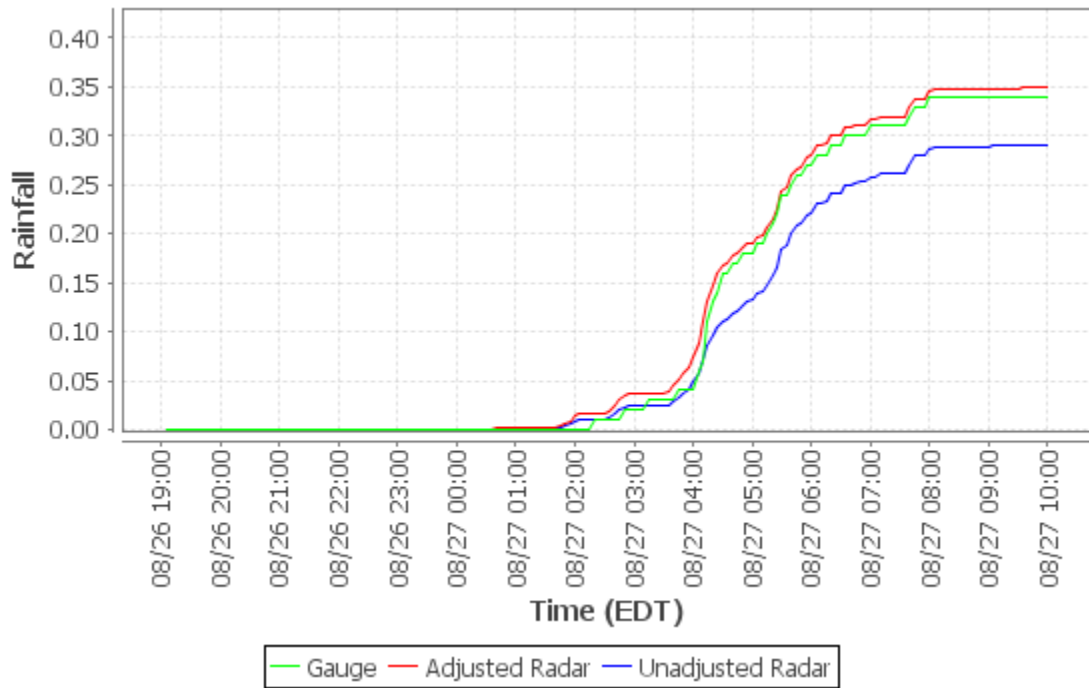
Cumulative Distribution Plot - Baldwin (Loc12)



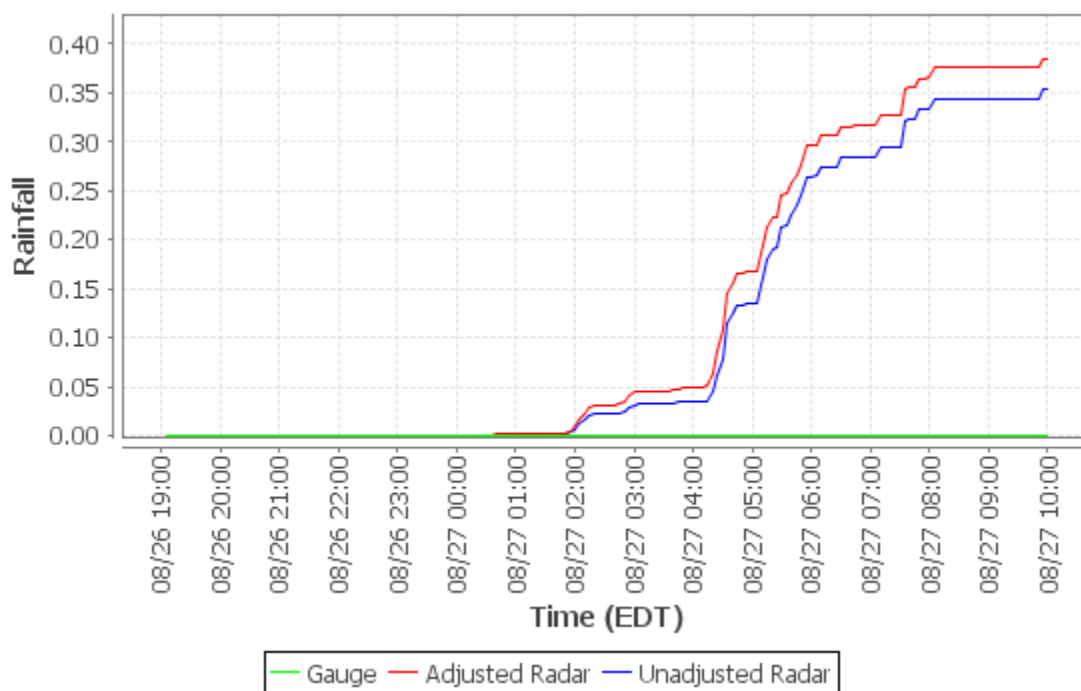
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



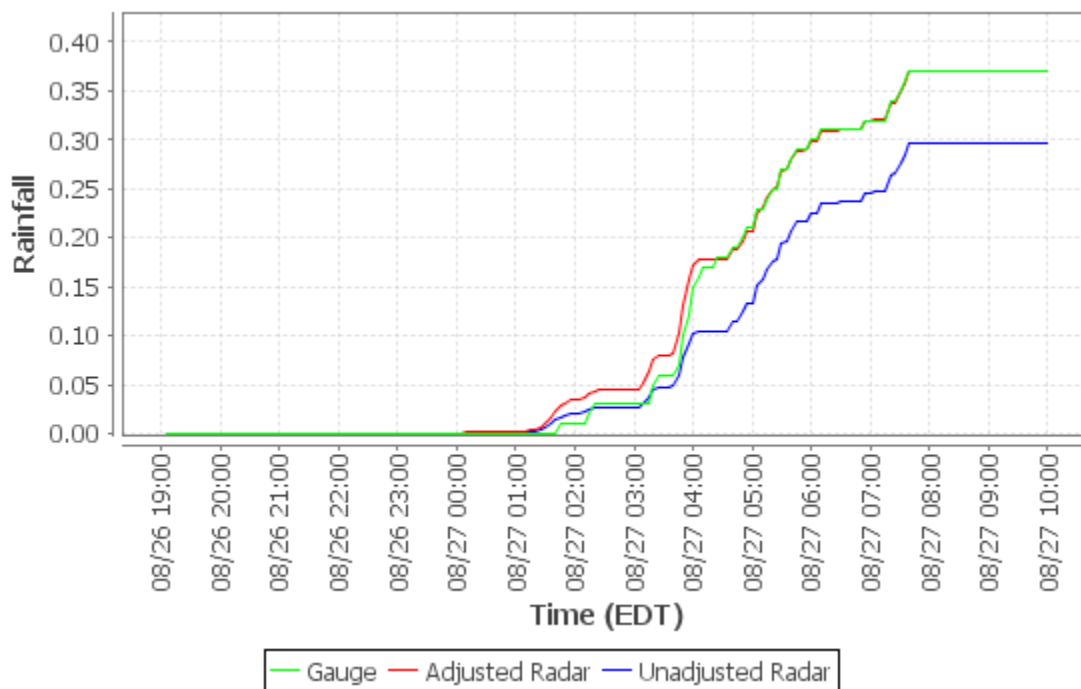
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



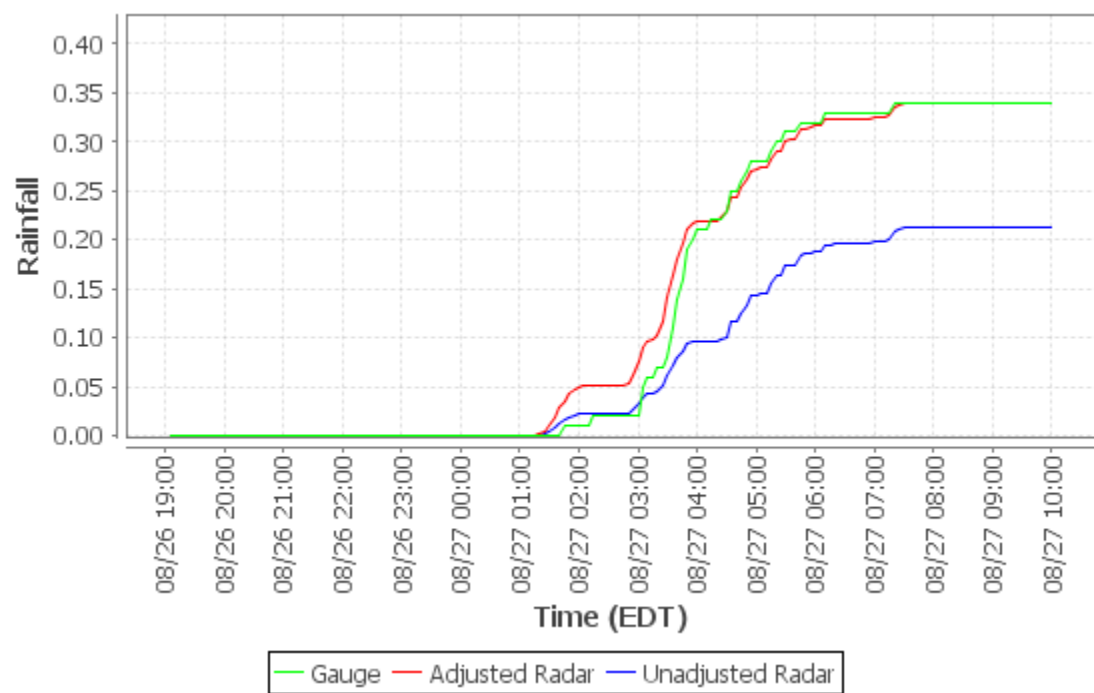
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



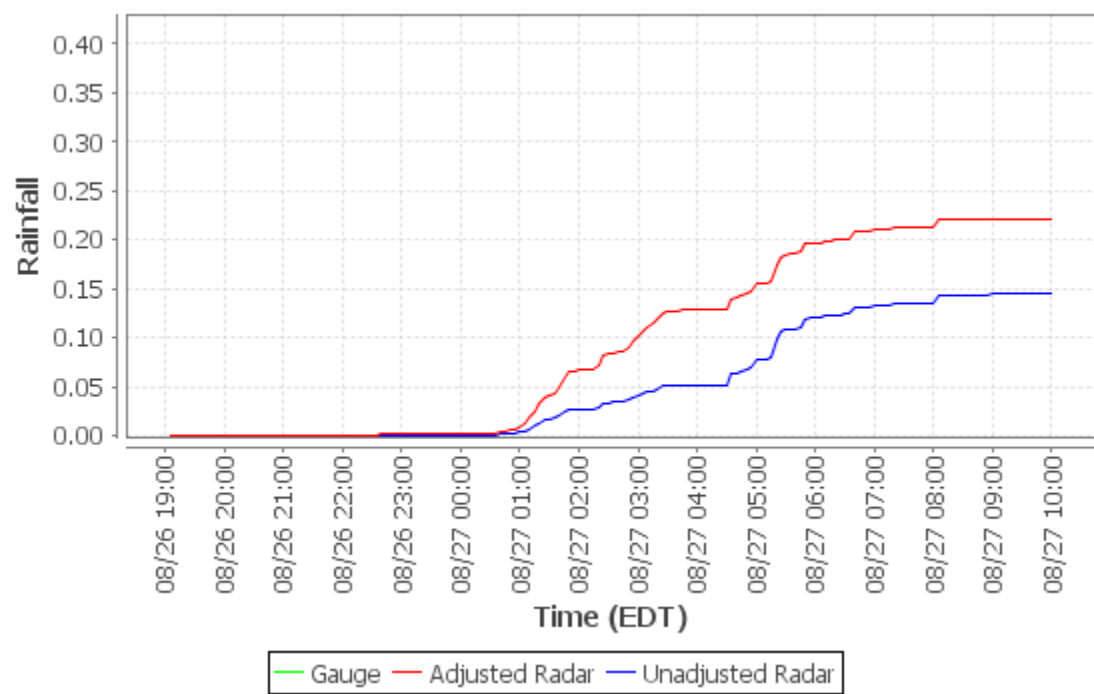
Cumulative Distribution Plot - Castle Shannon (Loc16)



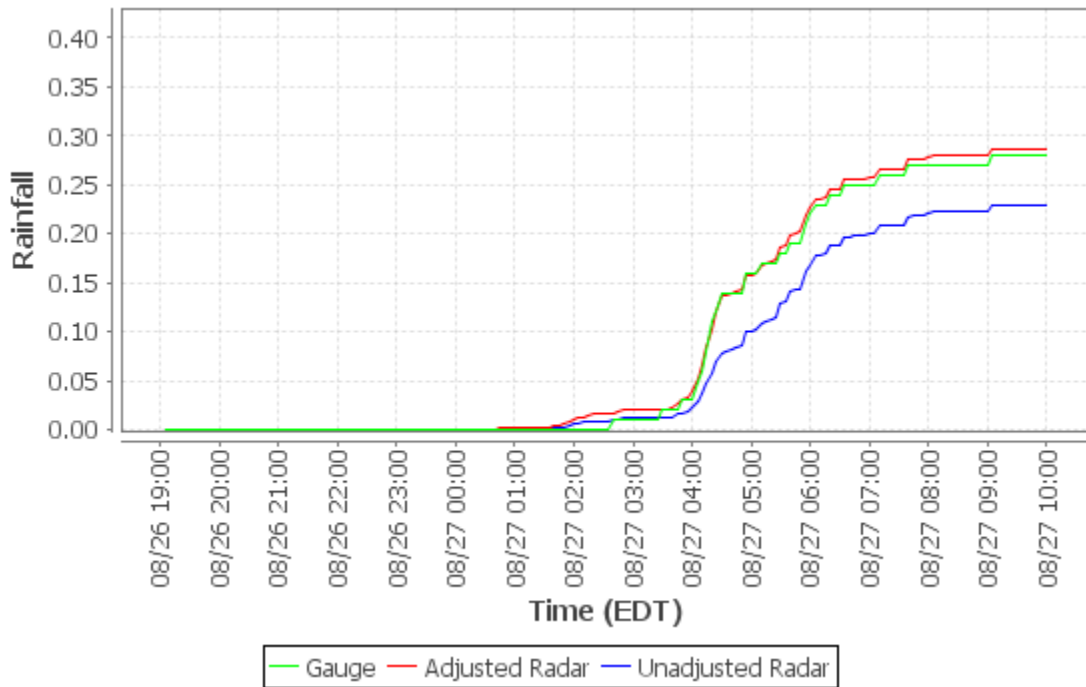
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



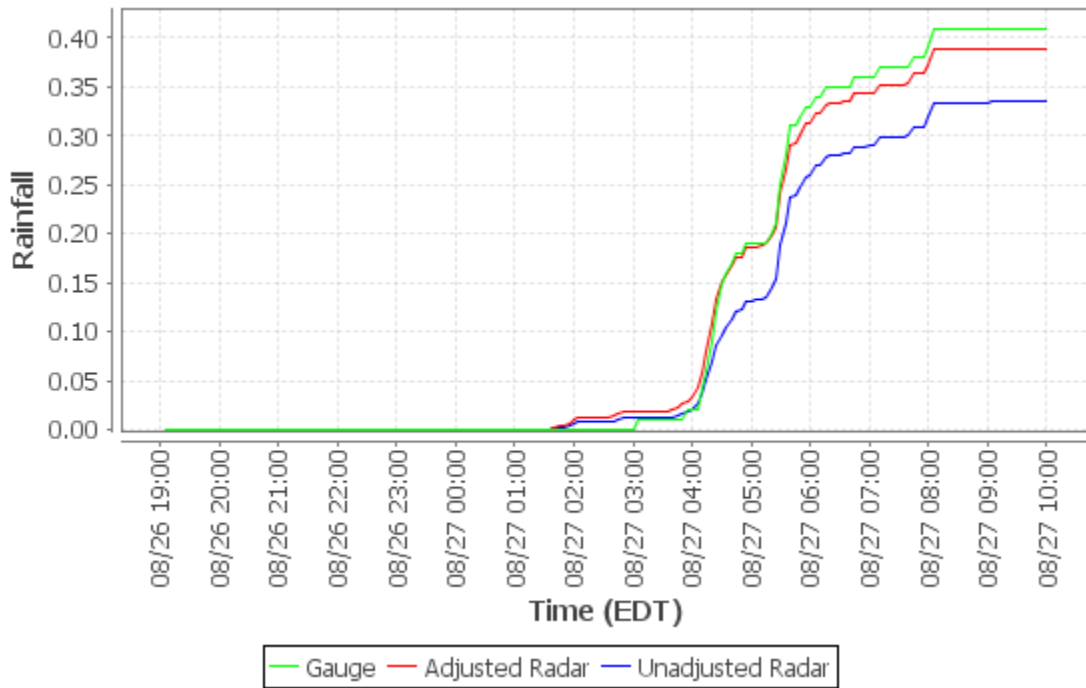
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



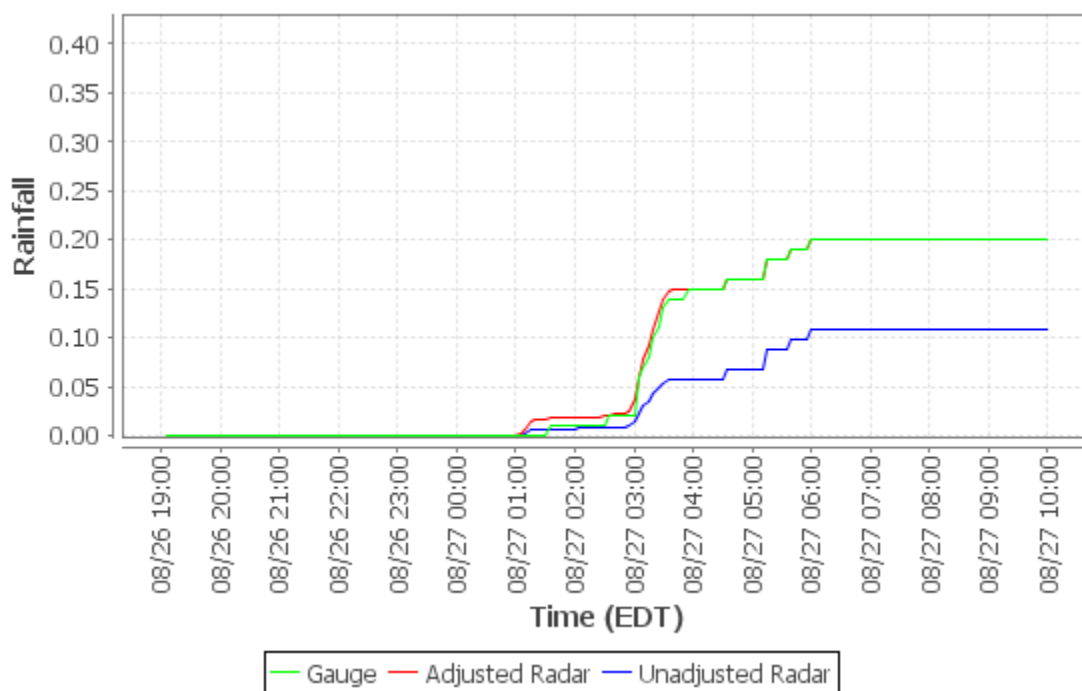
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



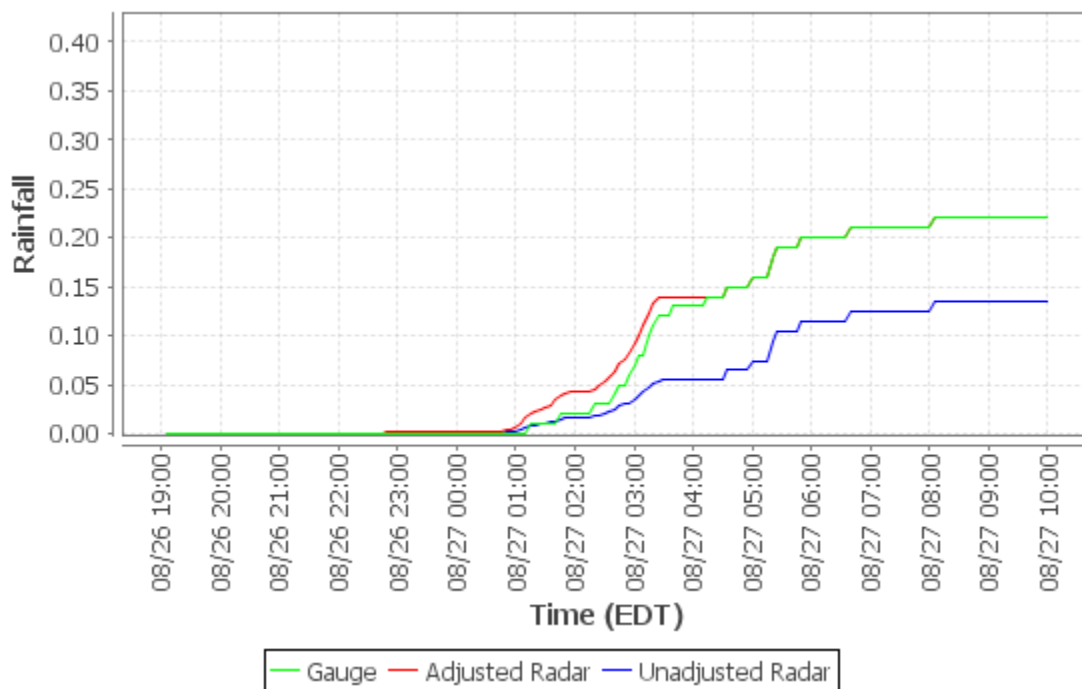
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



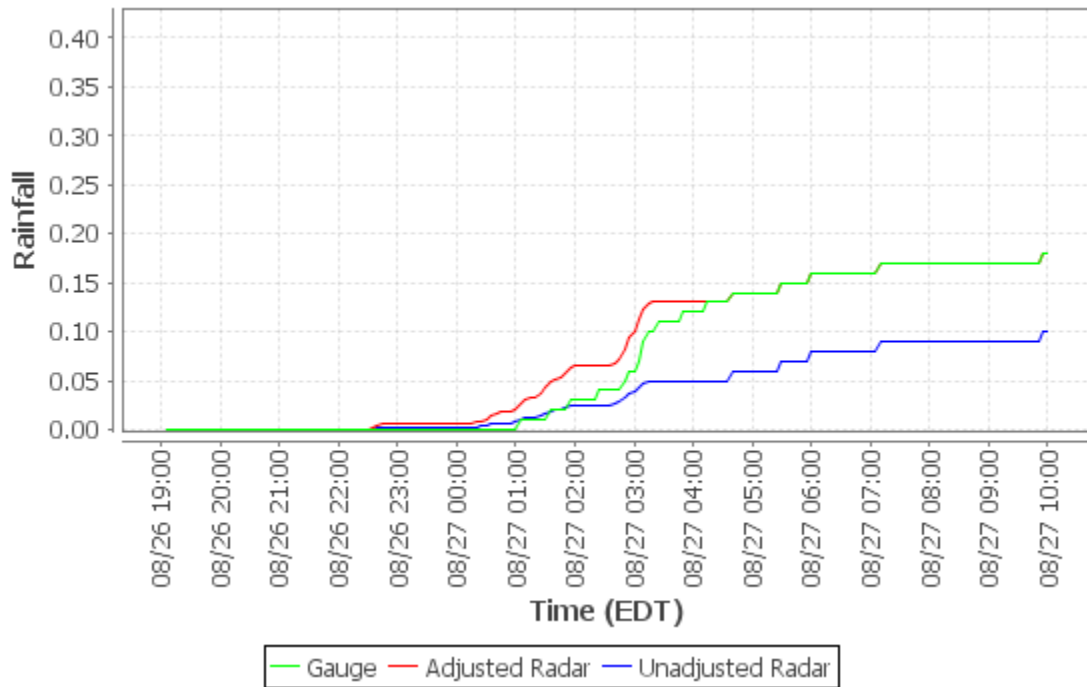
Cumulative Distribution Plot - Moon TWP (Loc21)



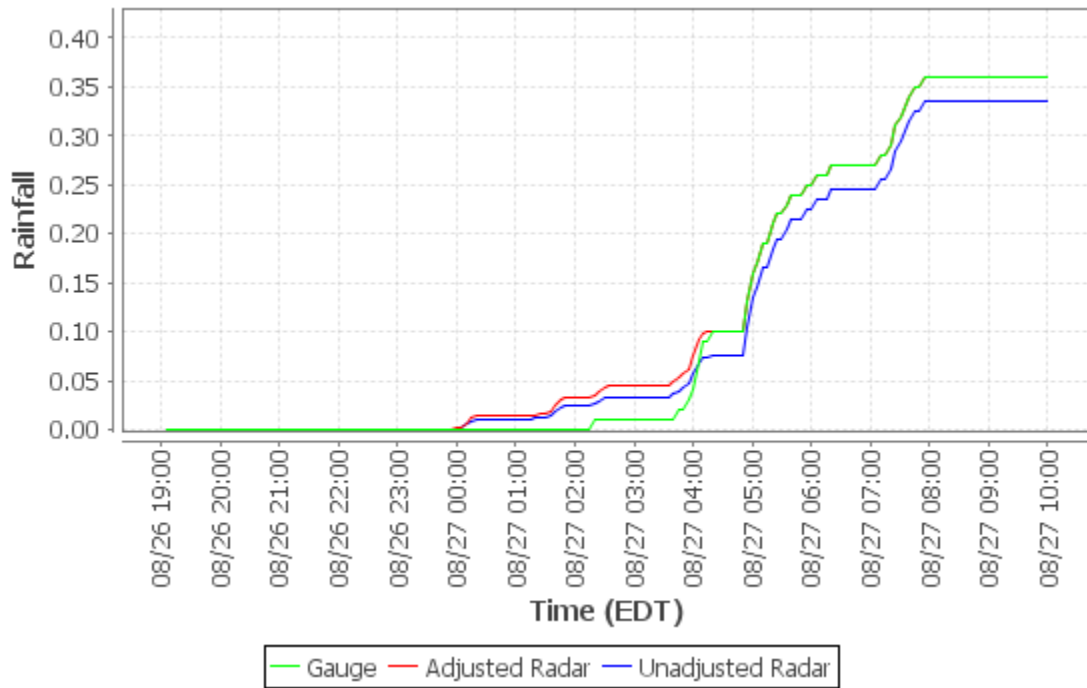
Cumulative Distribution Plot - North Fayette TWP (Loc22)



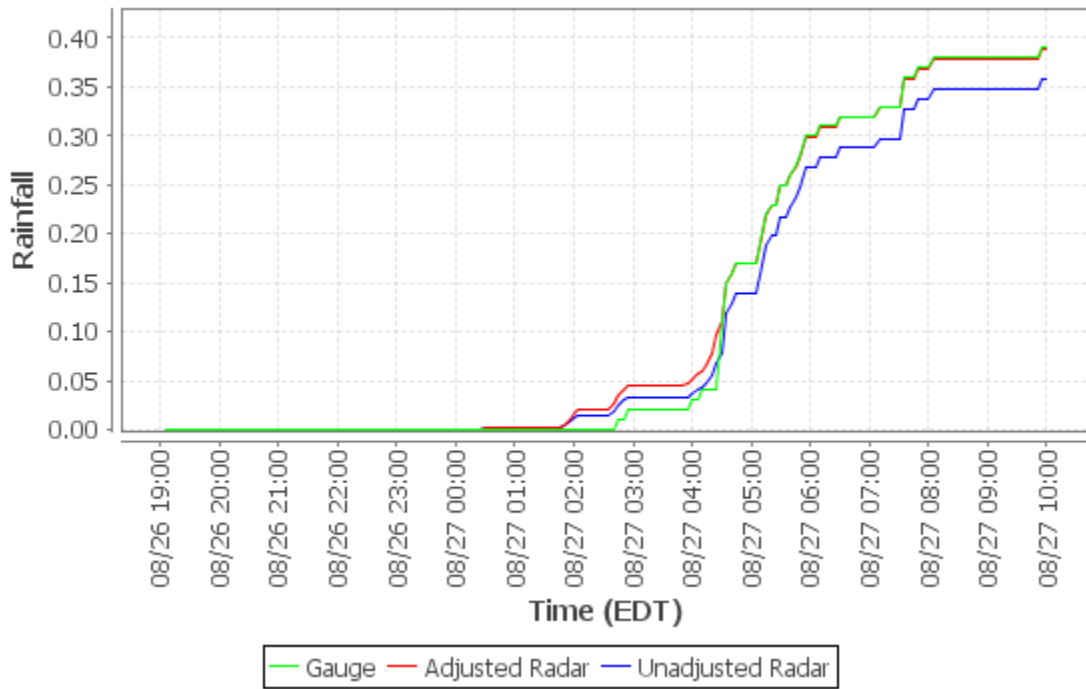
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



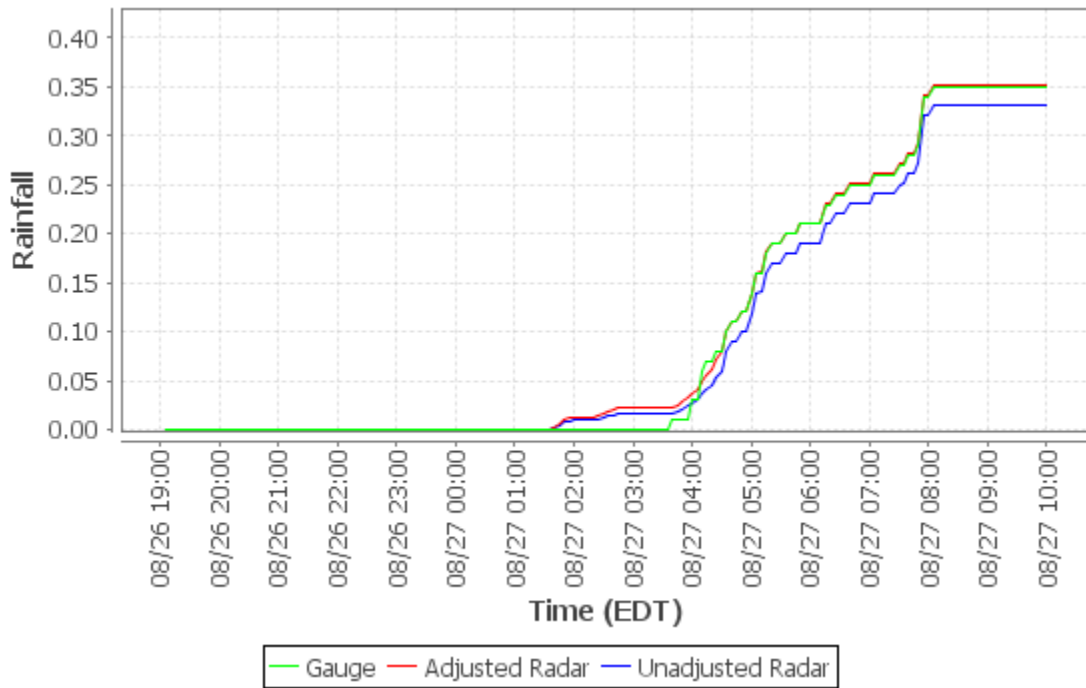
Cumulative Distribution Plot - Jefferson Hills (Loc24)



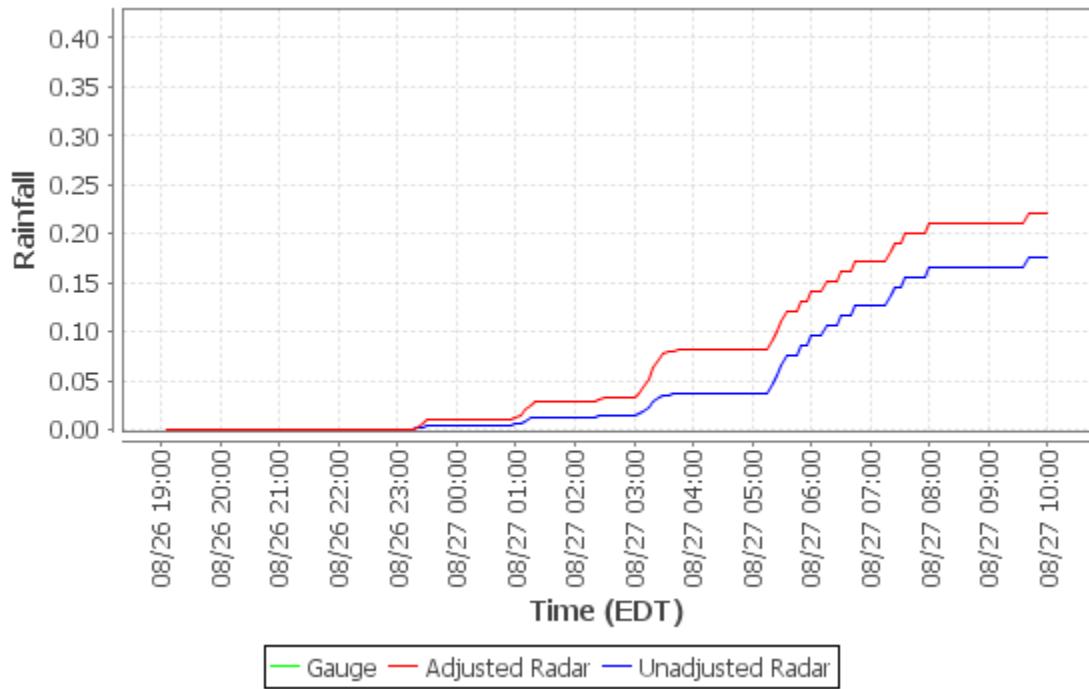
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



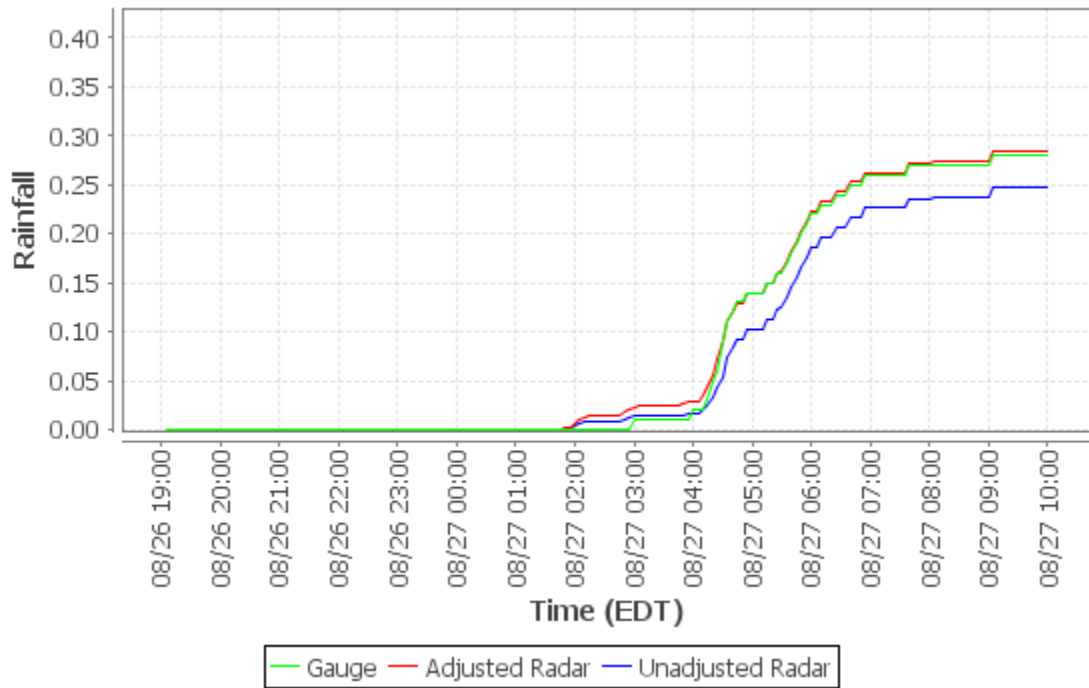
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



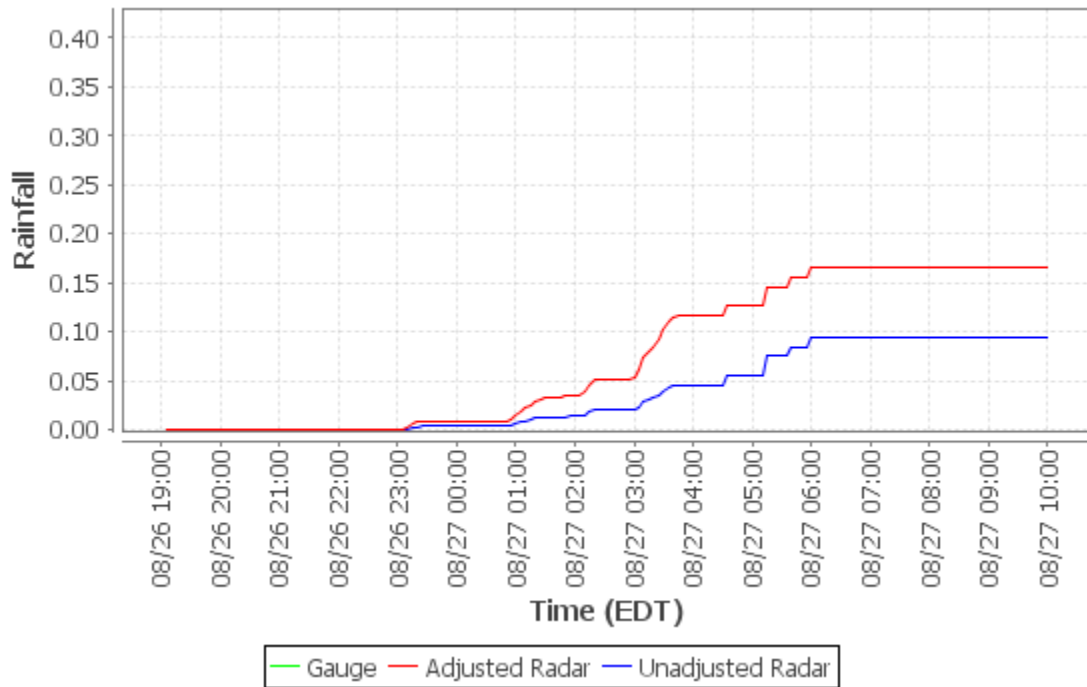
Cumulative Distribution Plot - Marshall TWP (Loc27)



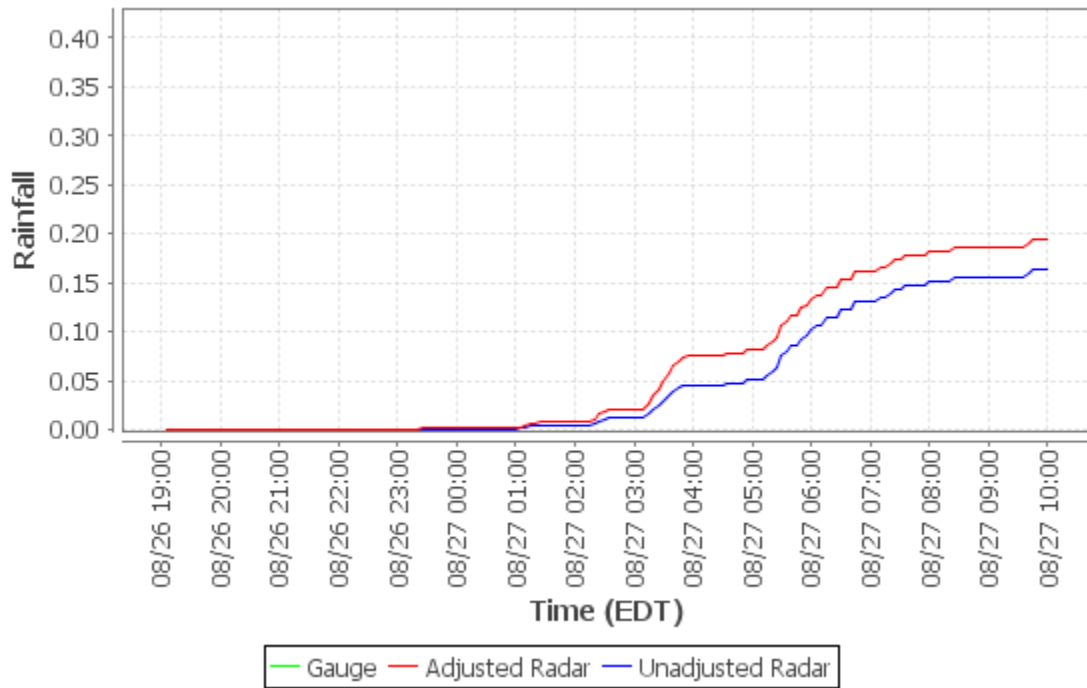
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



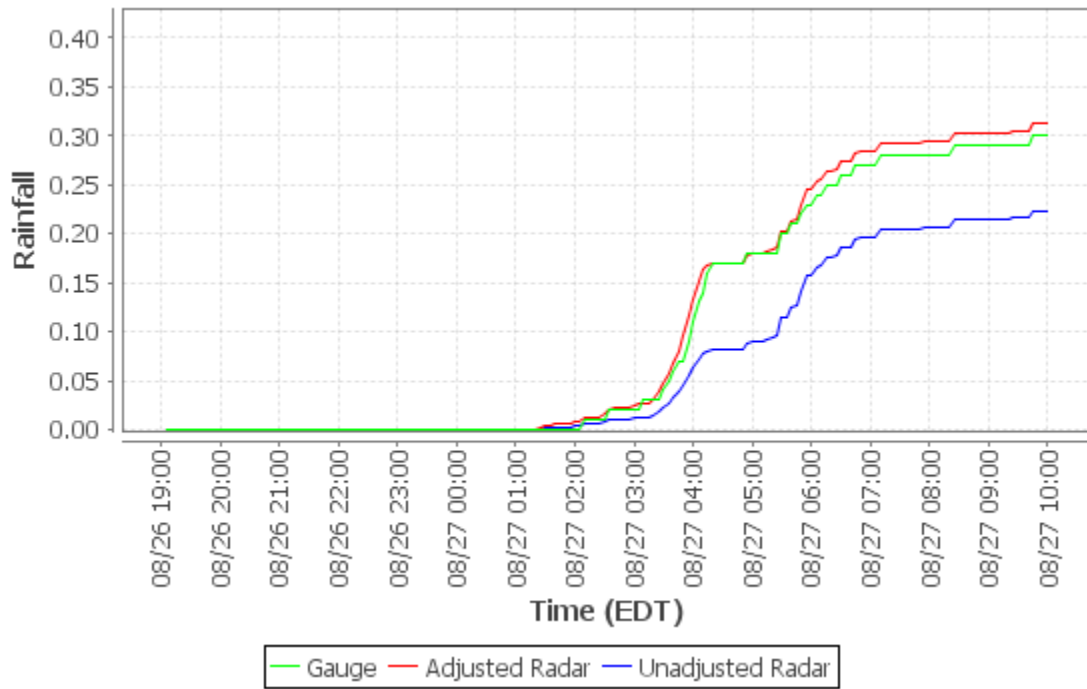
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



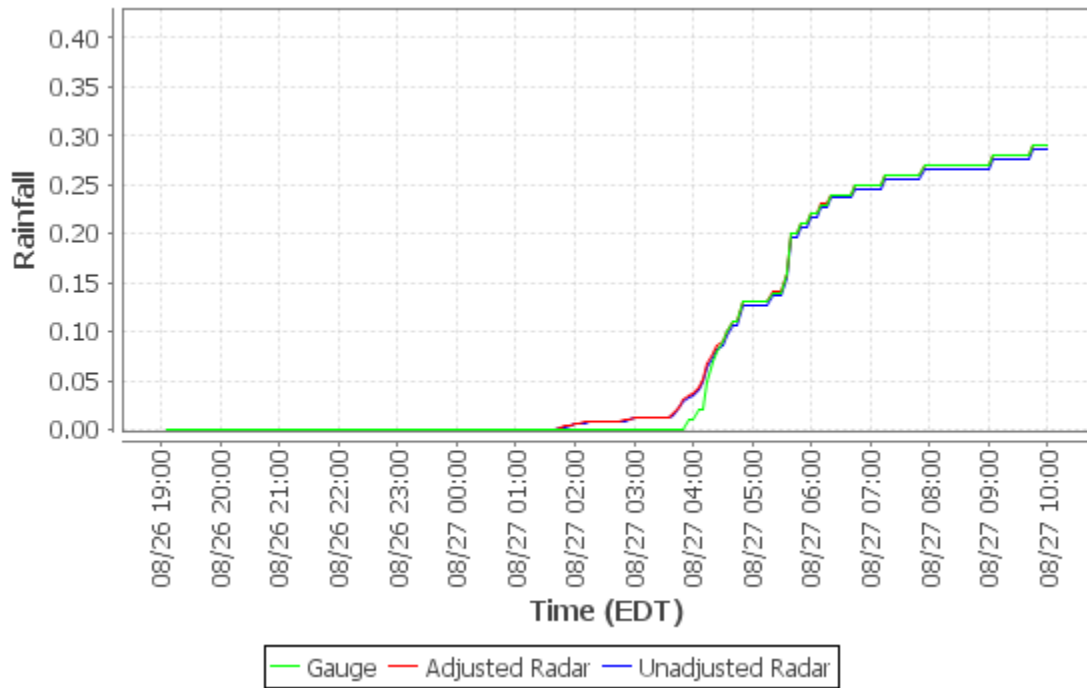
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



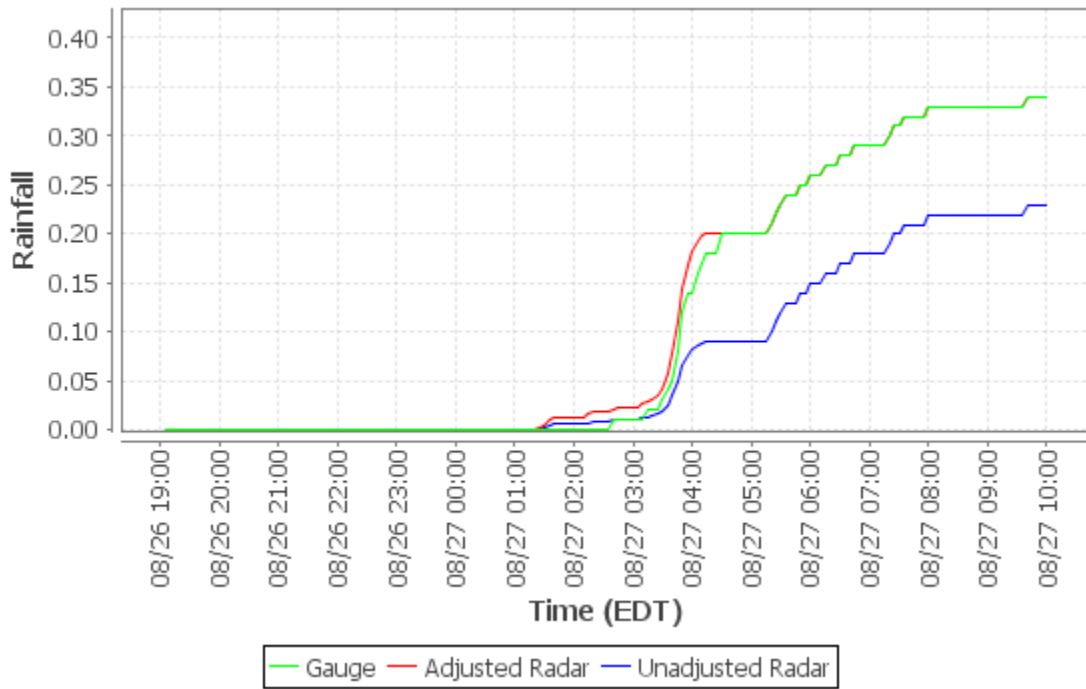
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



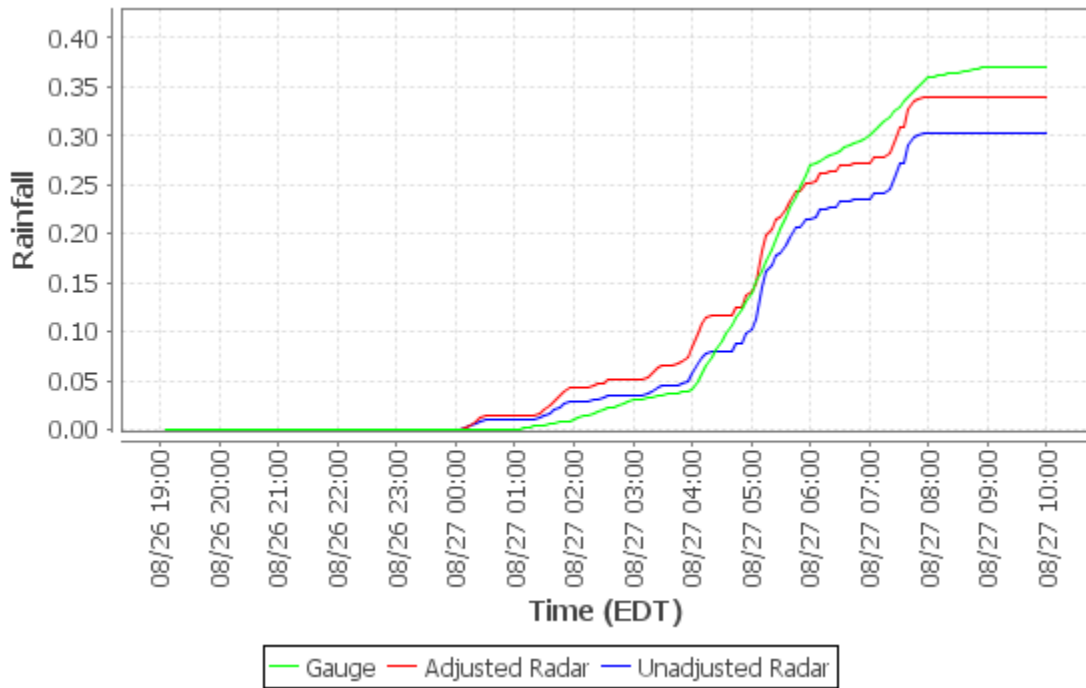
Cumulative Distribution Plot - Arnold (Loc32)



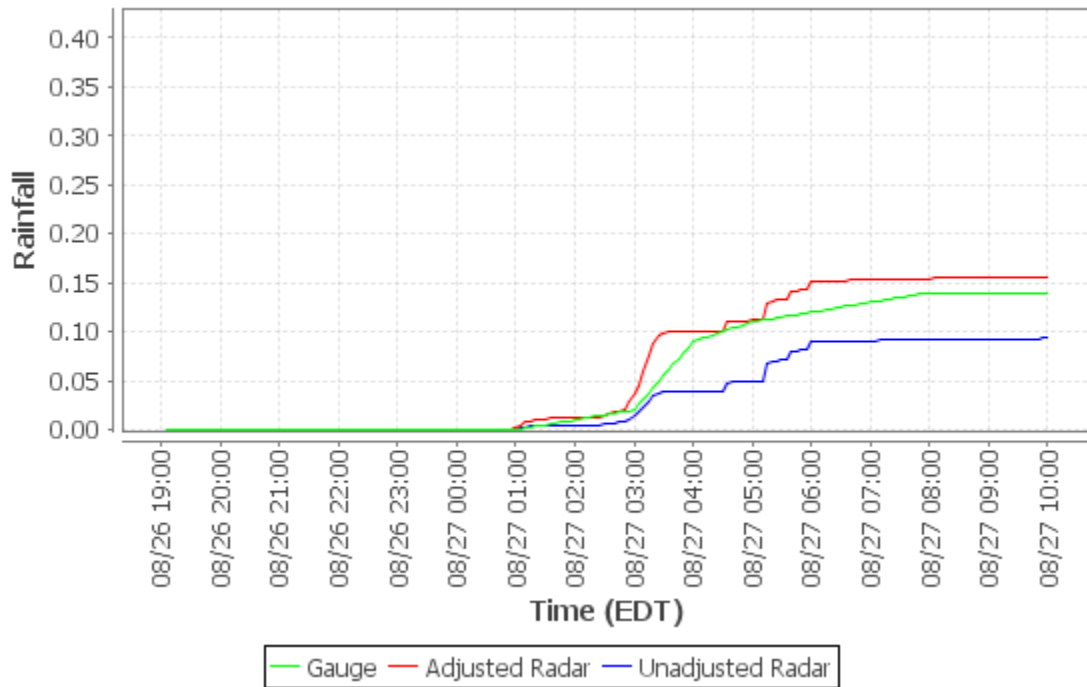
Cumulative Distribution Plot - Richland TWP (Loc33)



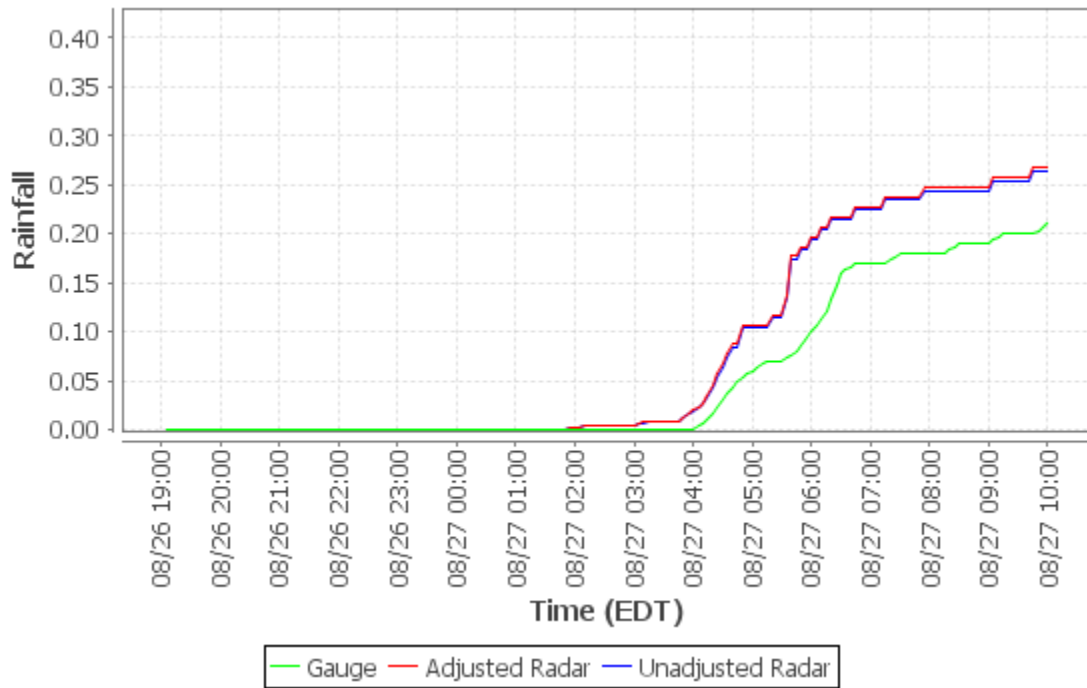
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



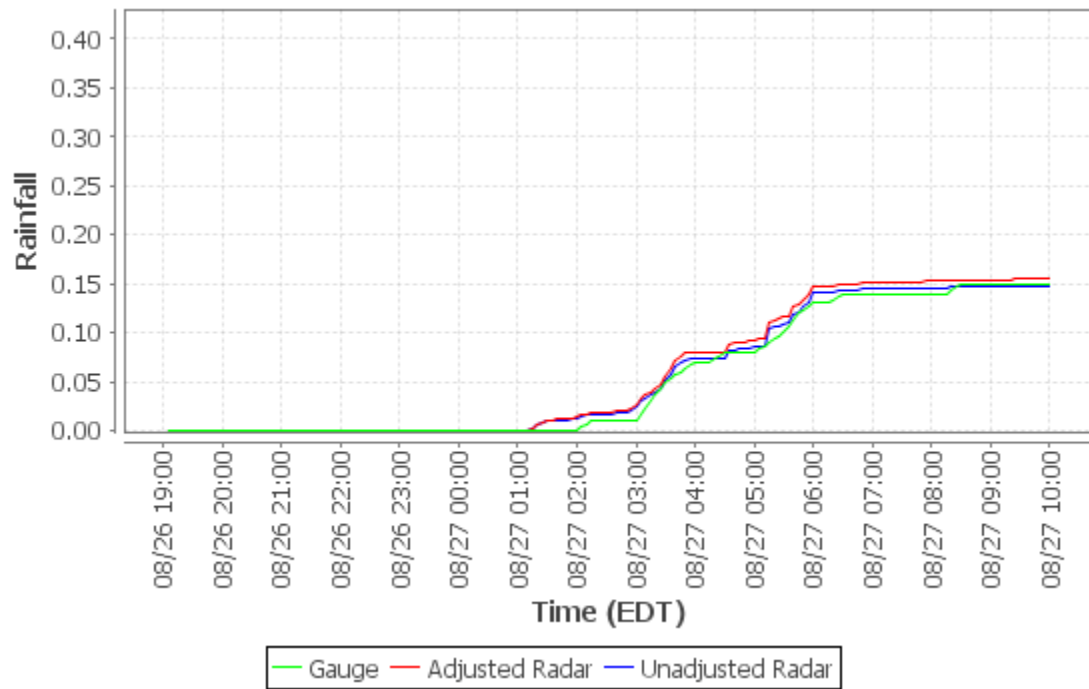
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

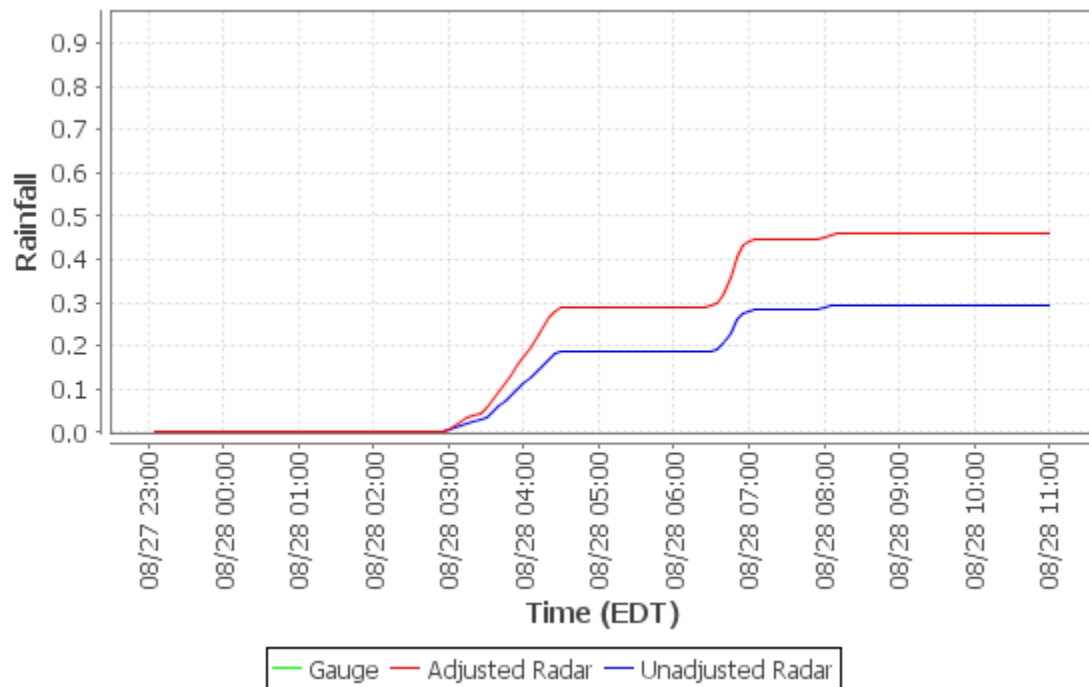


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

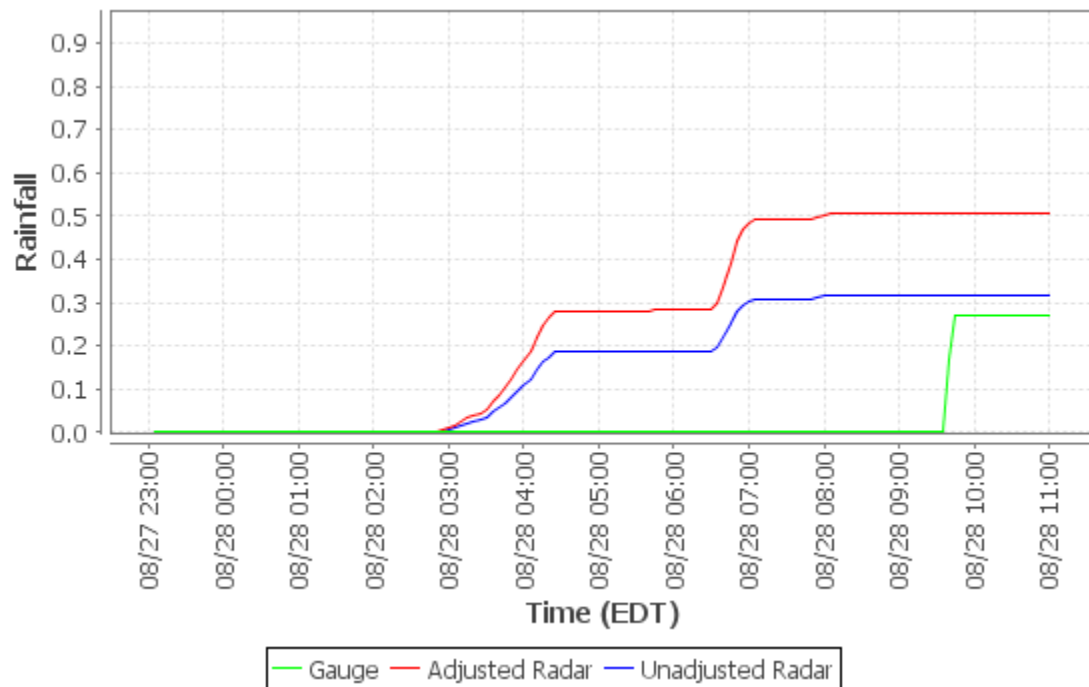


Appendix I - Event 7 (2019-08-28) CDPs

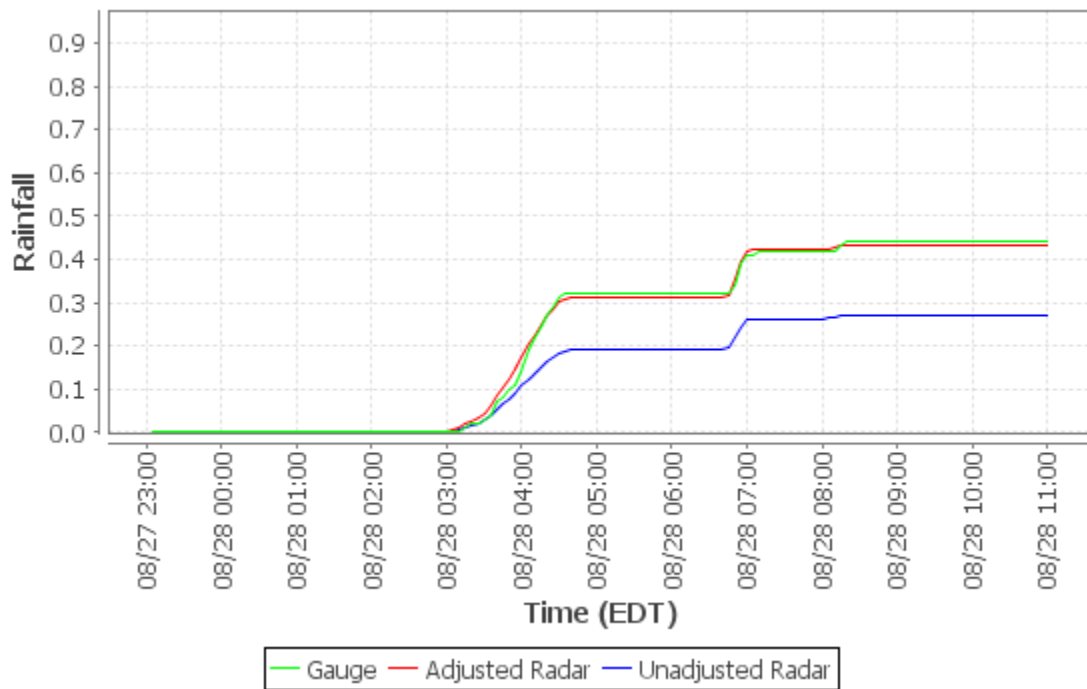
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



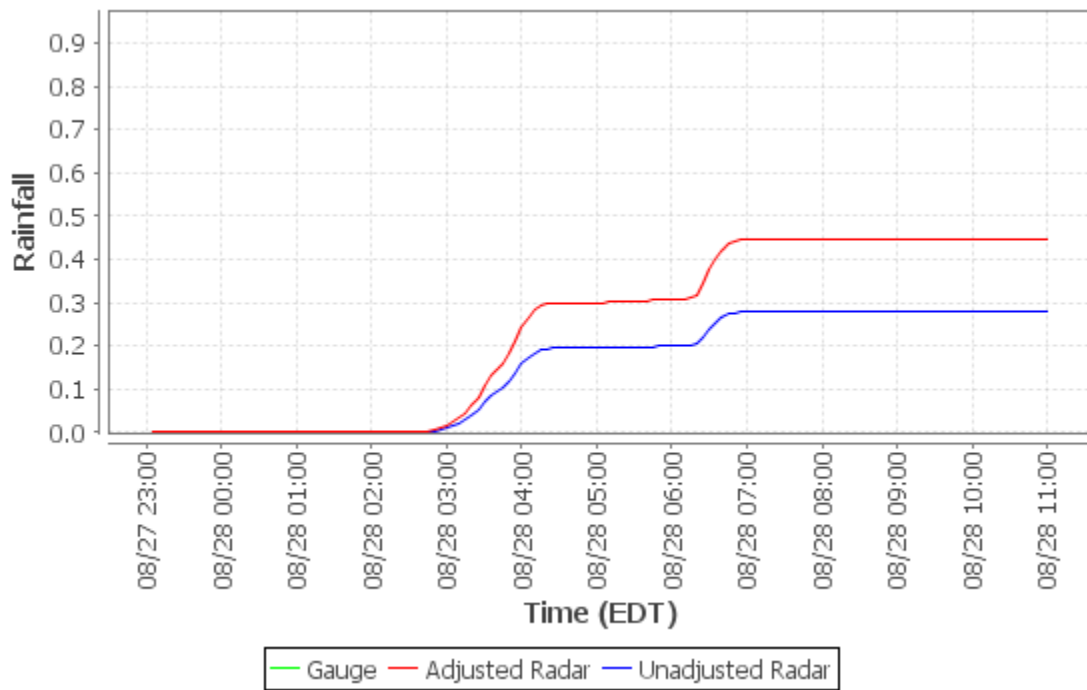
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



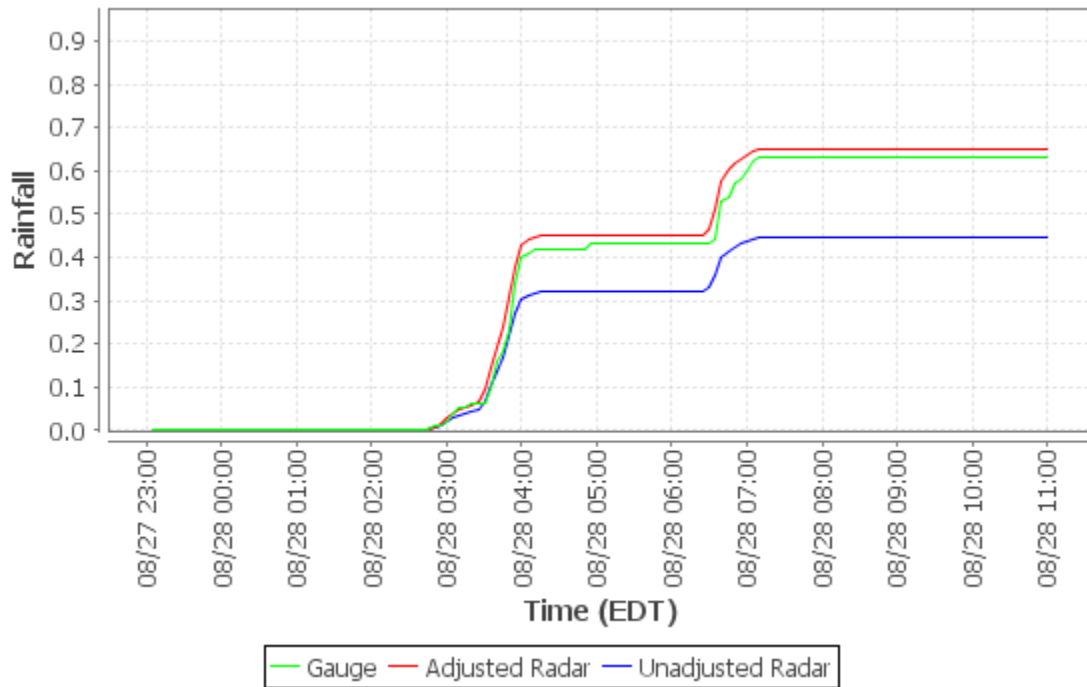
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



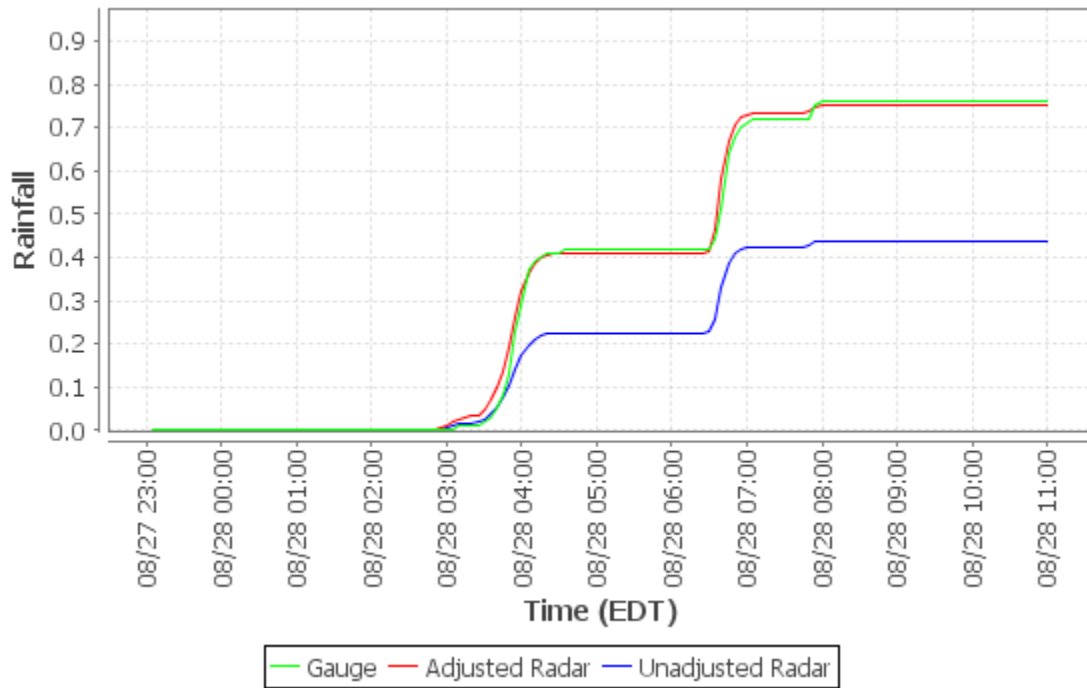
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



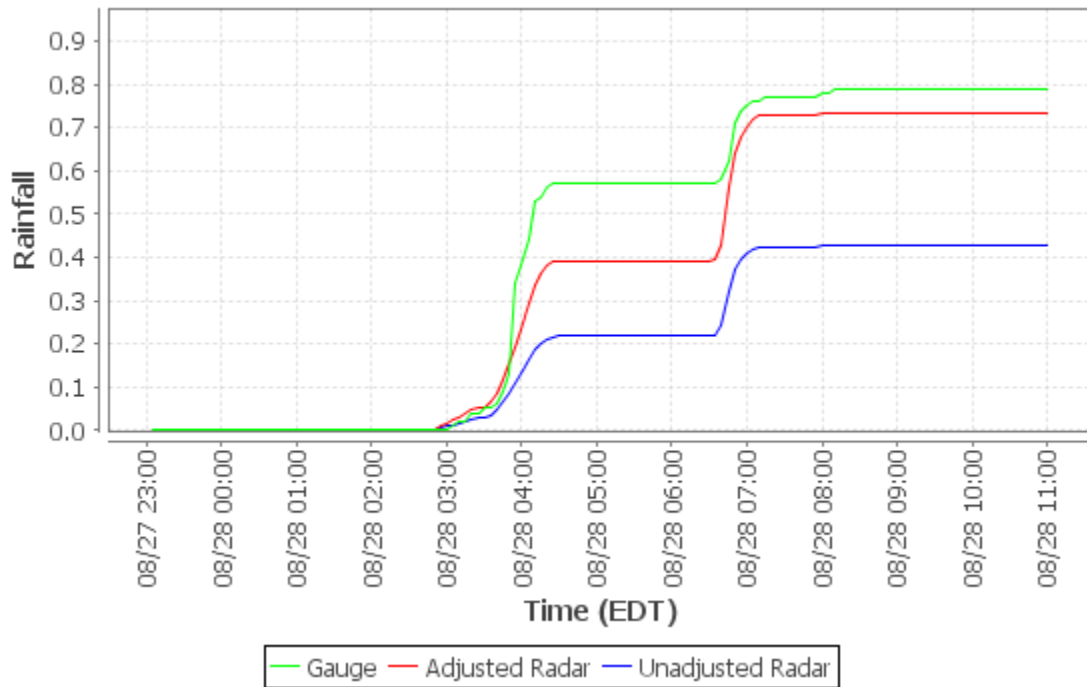
Cumulative Distribution Plot - Upper St. Clair (Loc05)



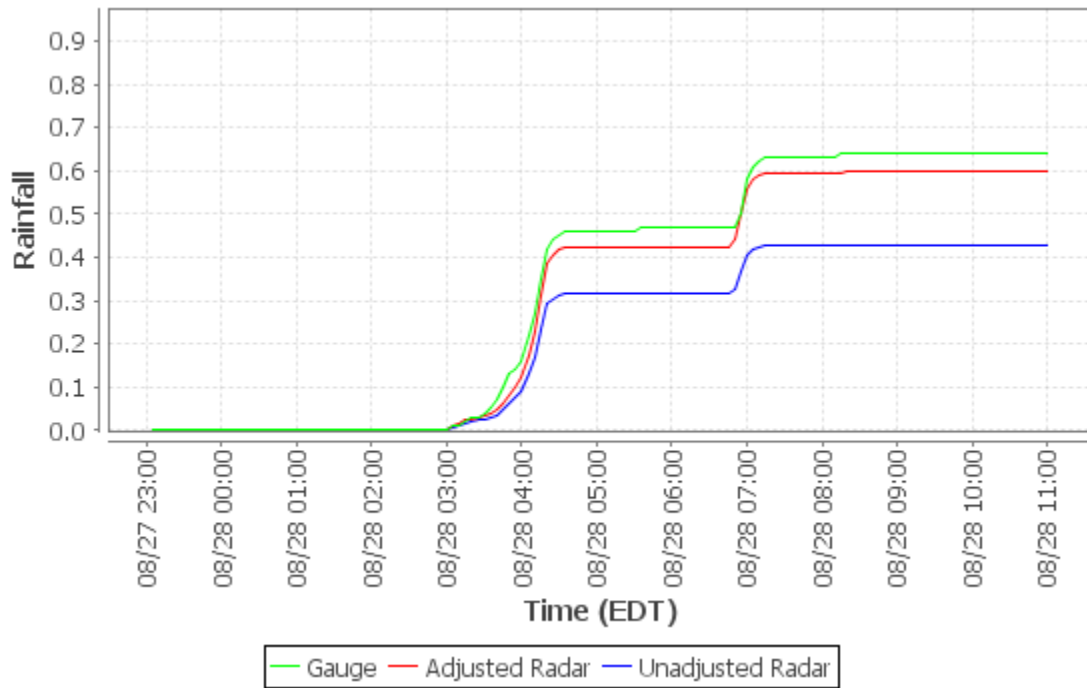
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



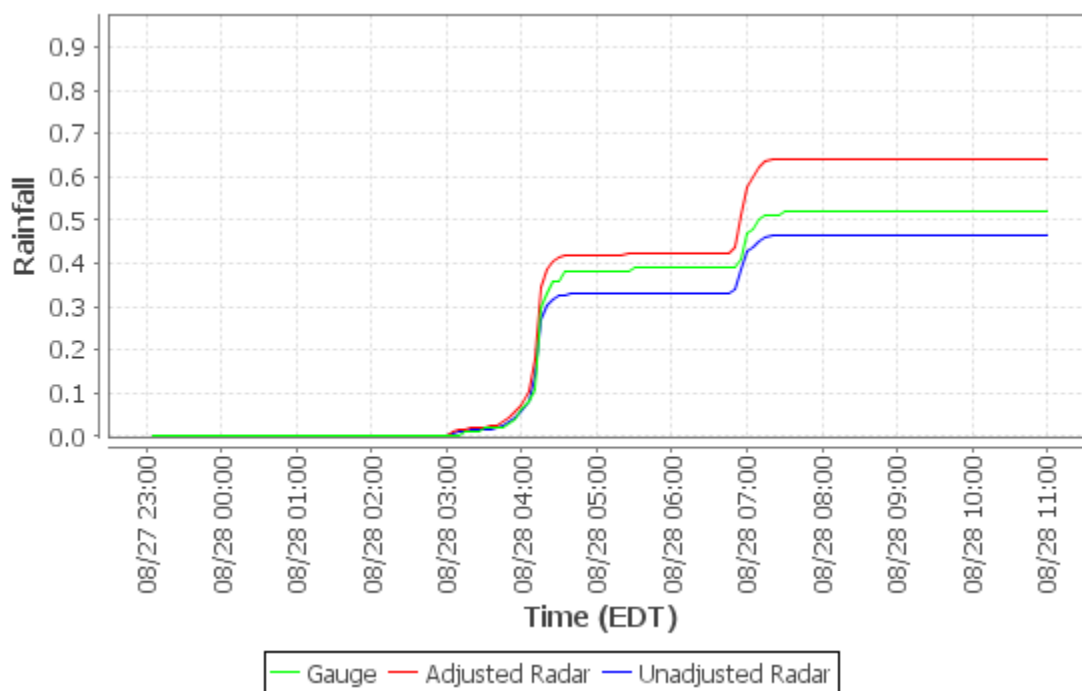
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



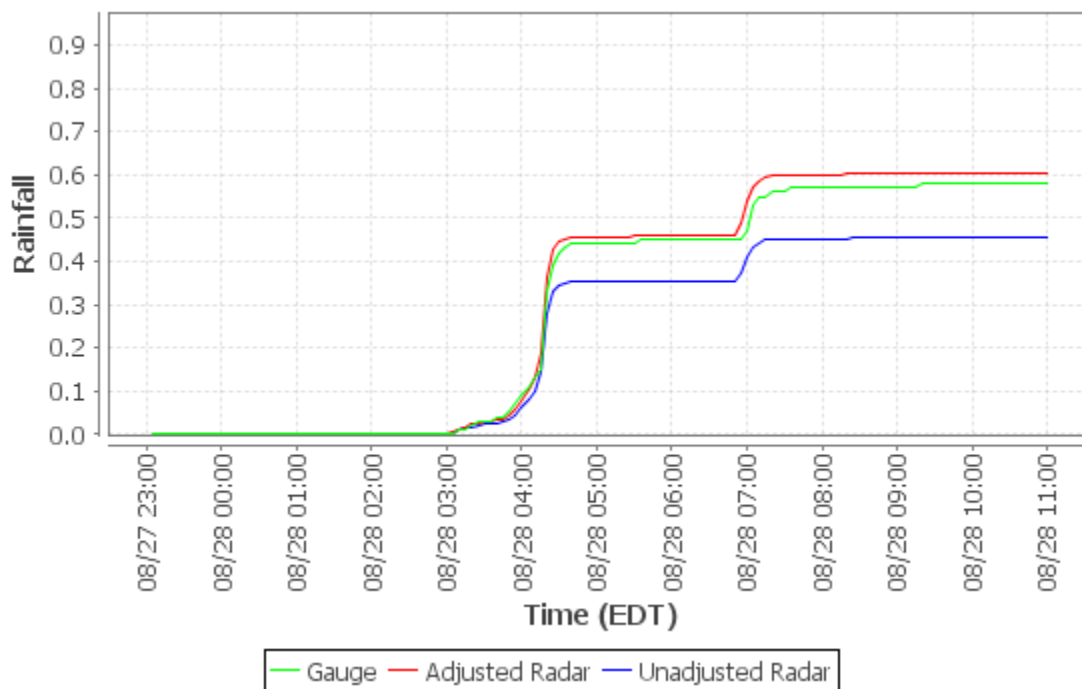
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



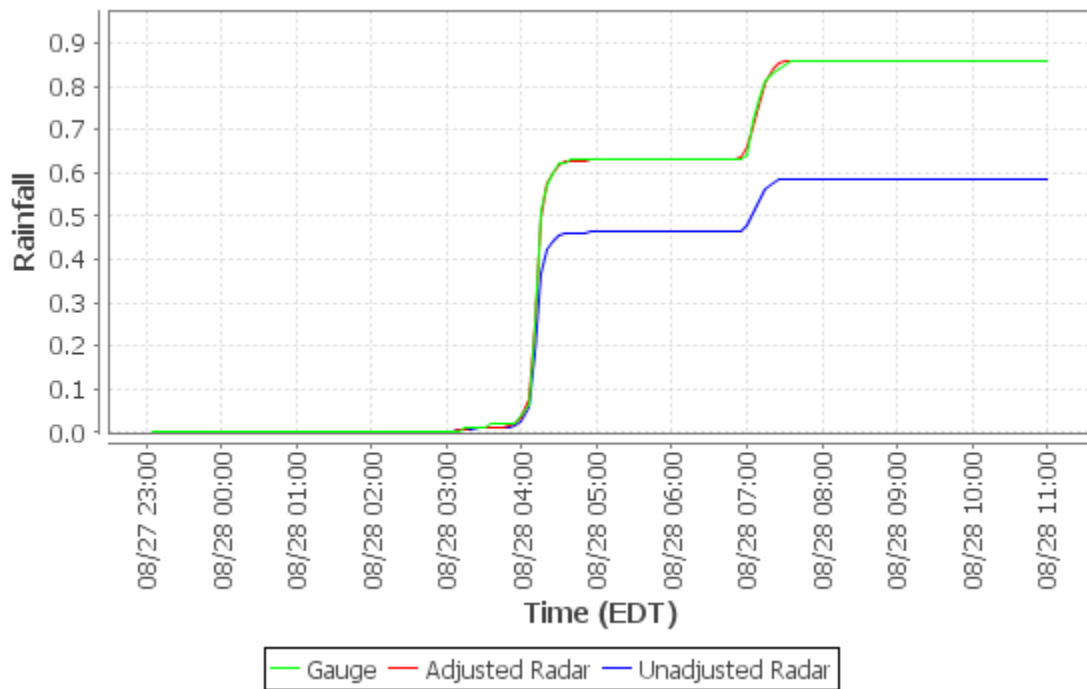
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



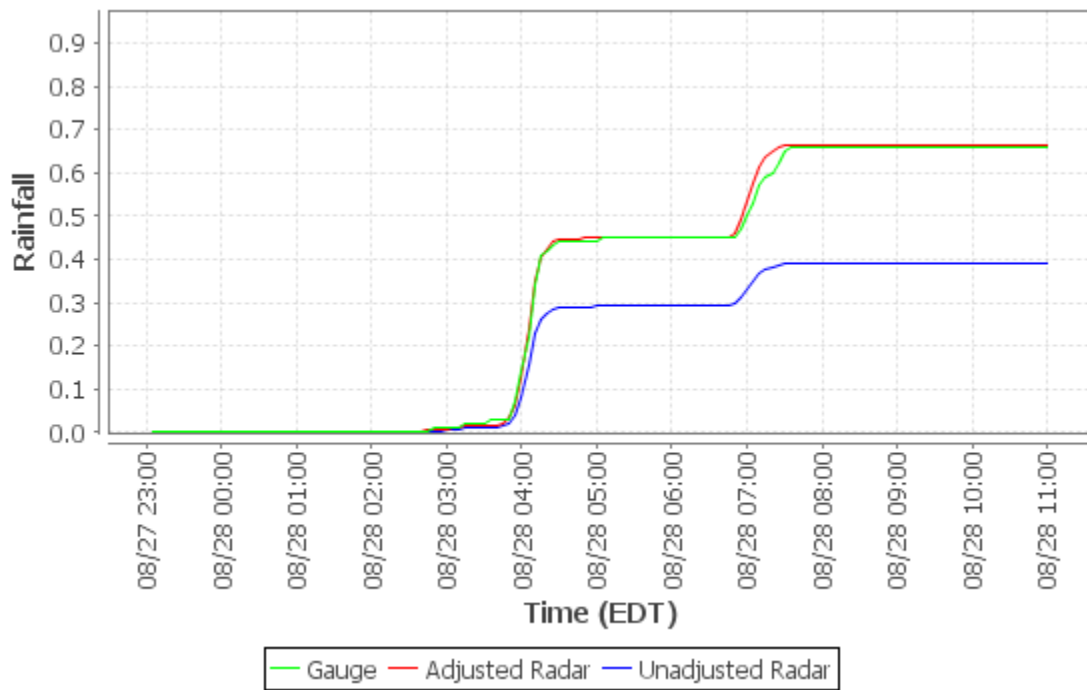
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



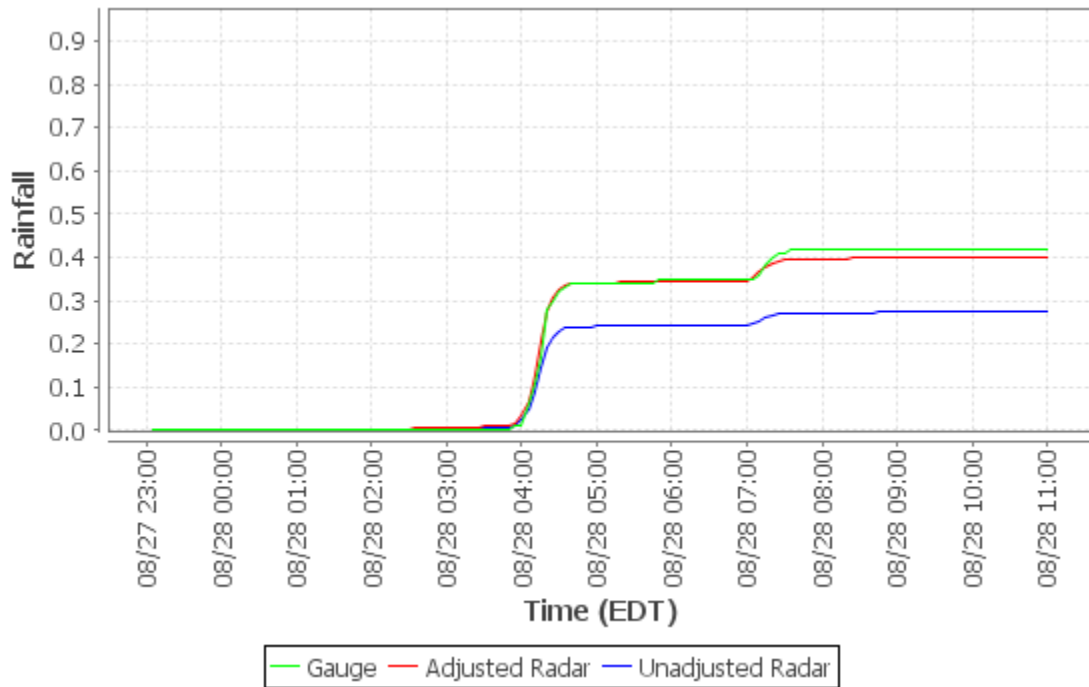
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



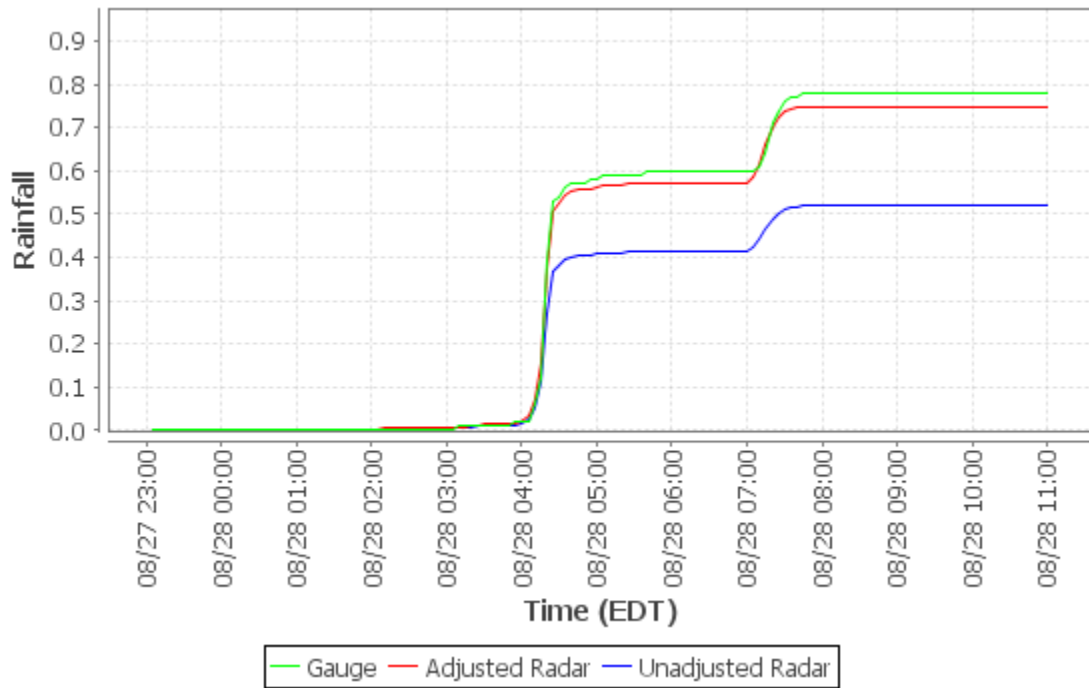
Cumulative Distribution Plot - Baldwin (Loc12)



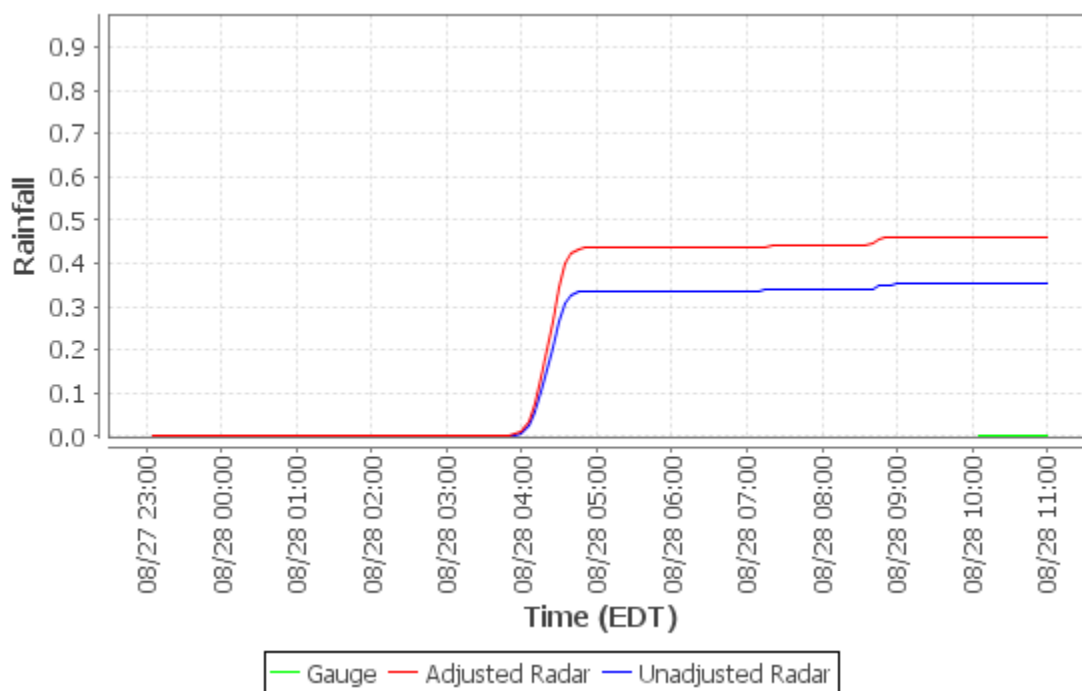
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



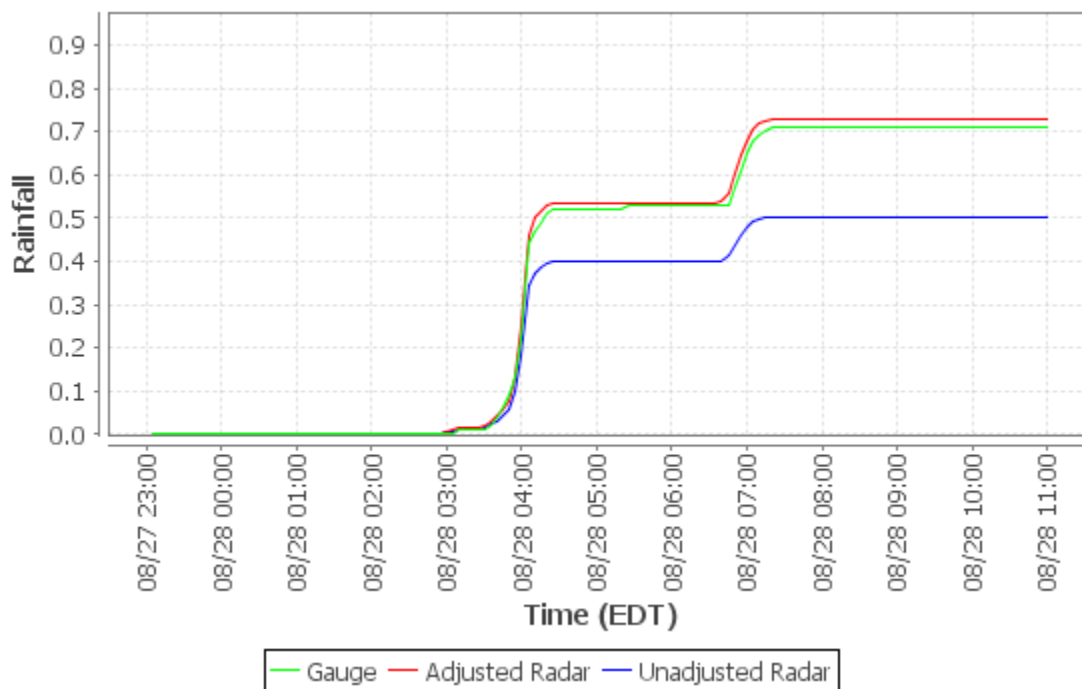
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



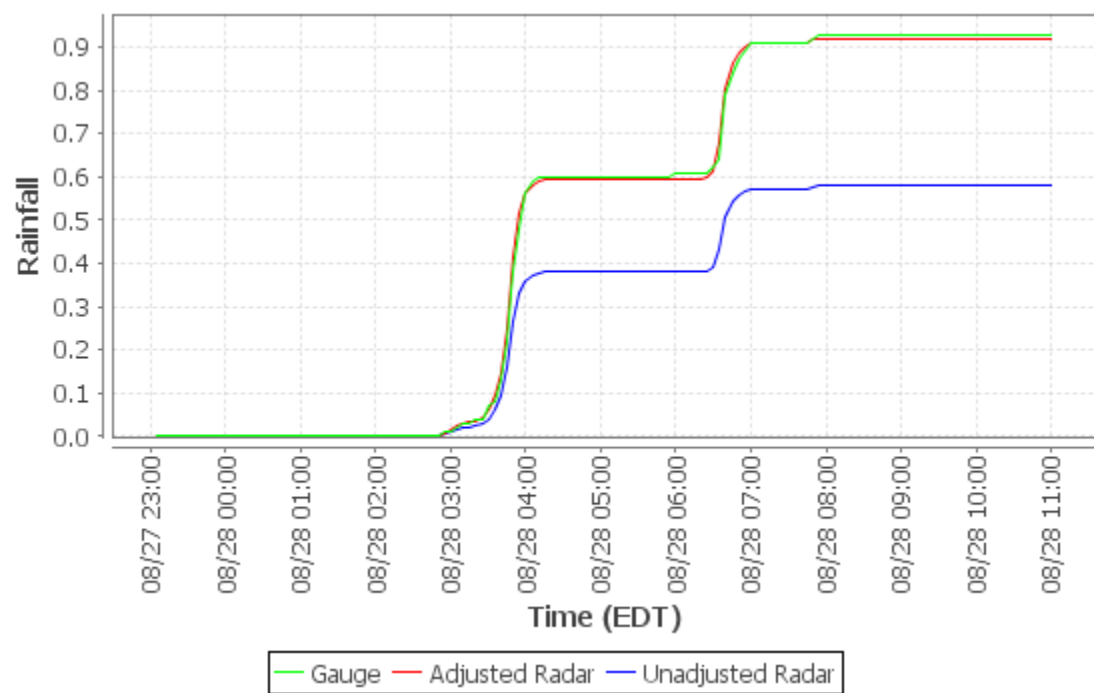
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



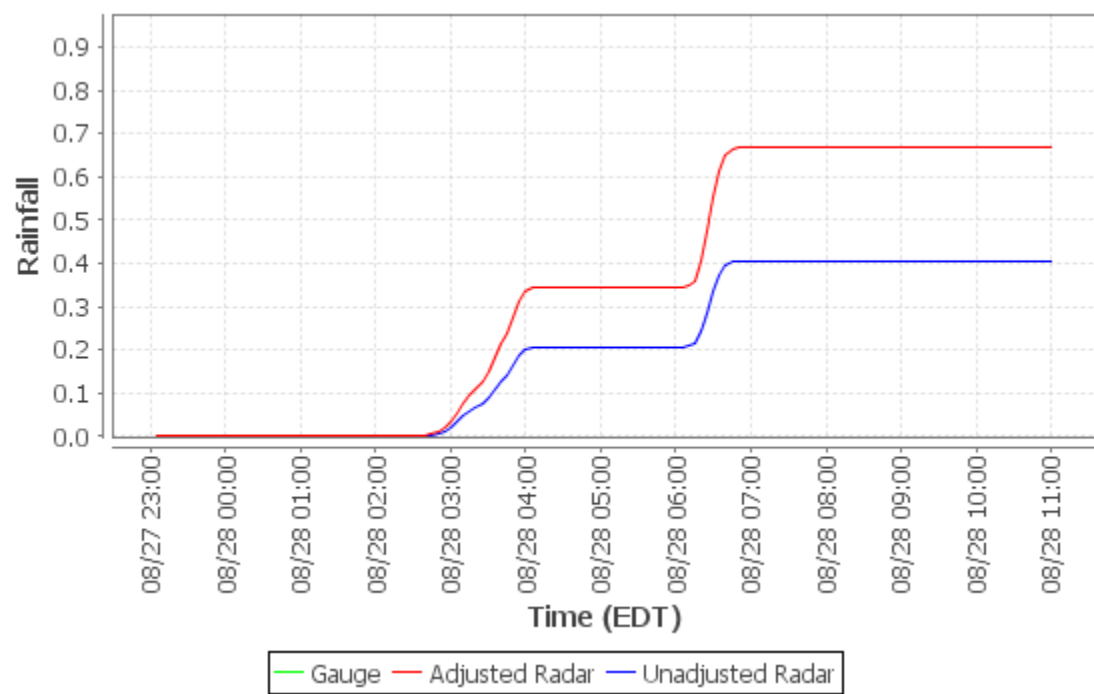
Cumulative Distribution Plot - Castle Shannon (Loc16)



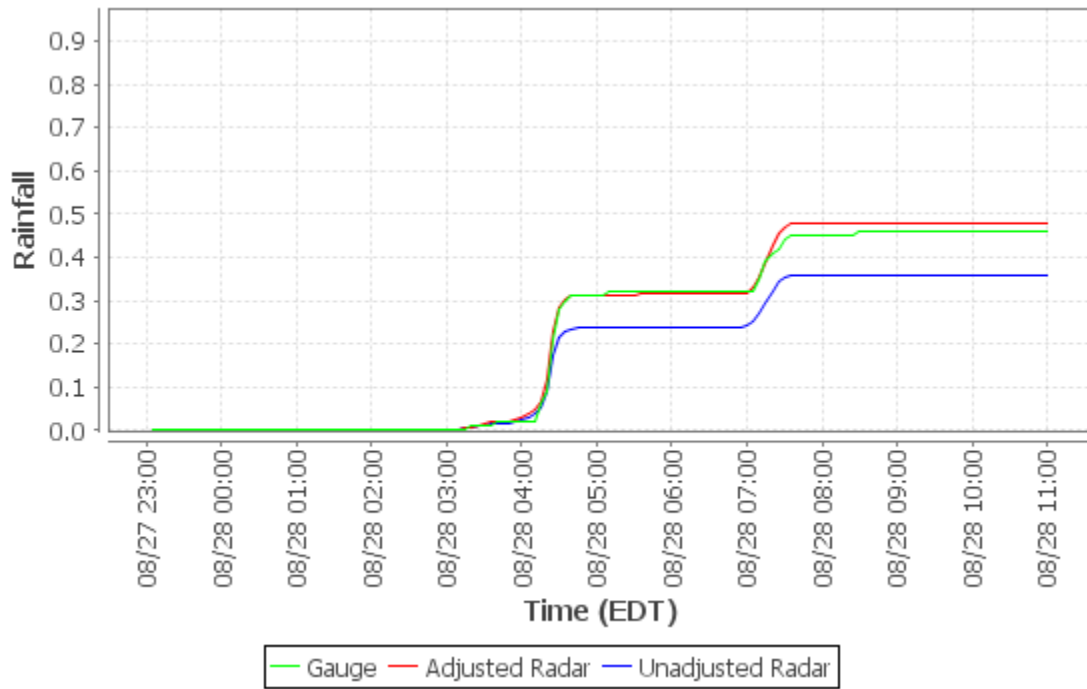
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



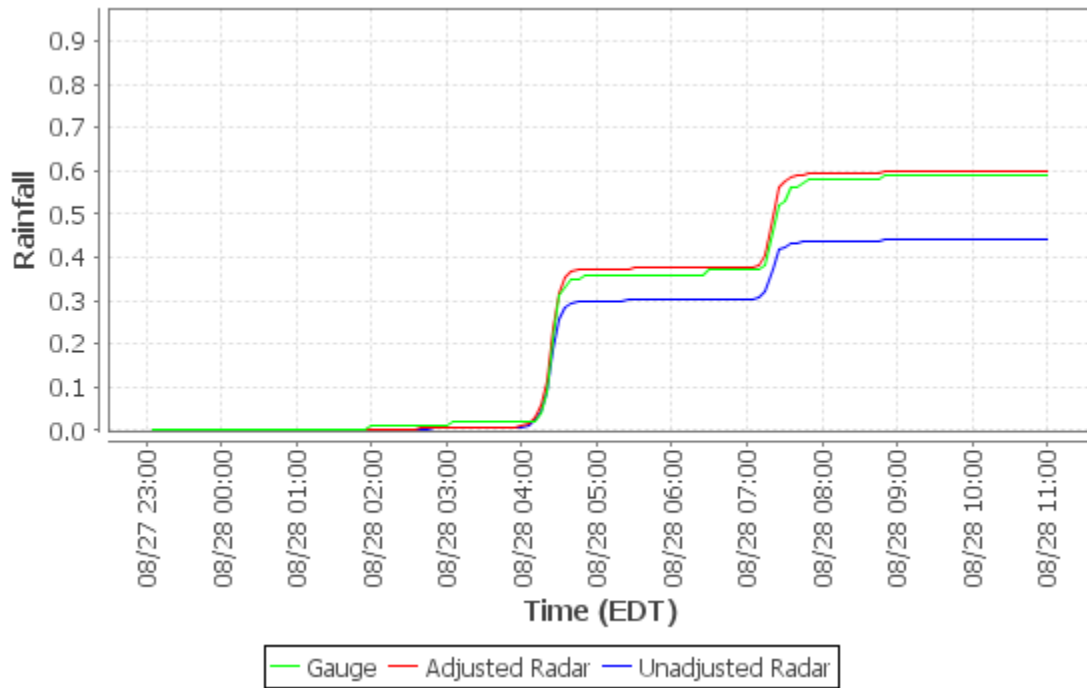
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



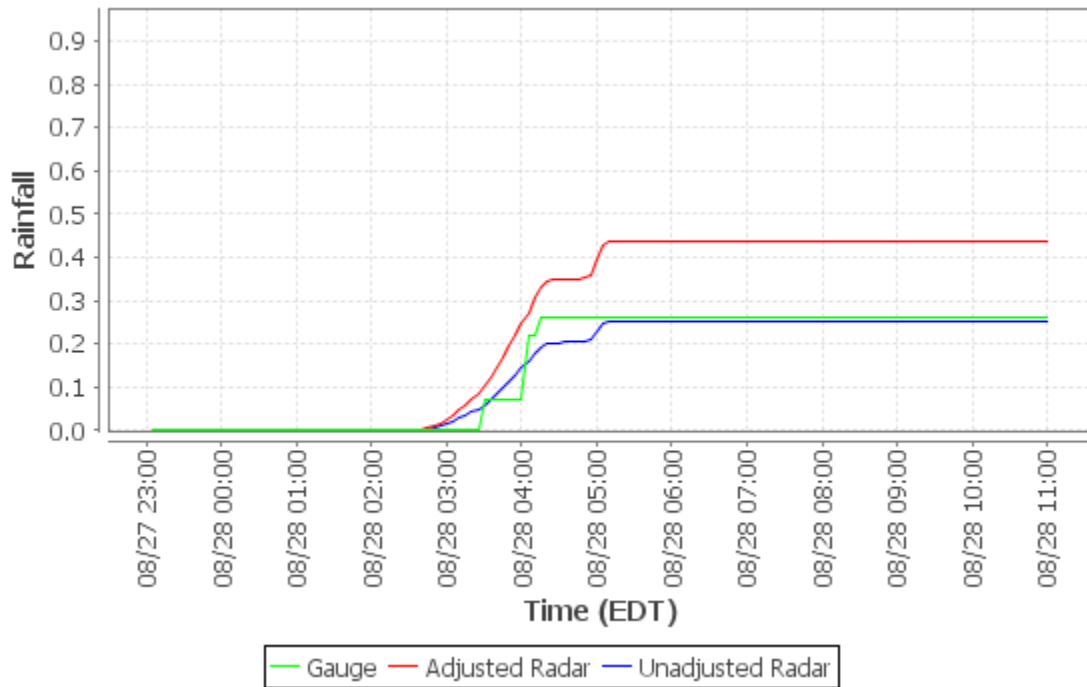
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



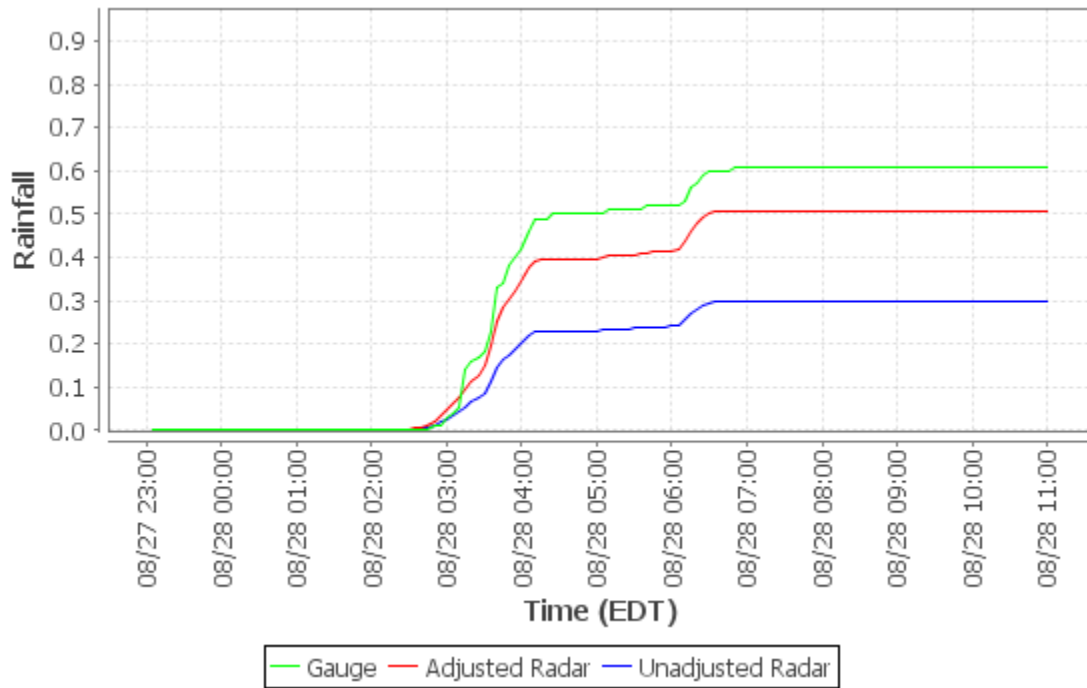
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



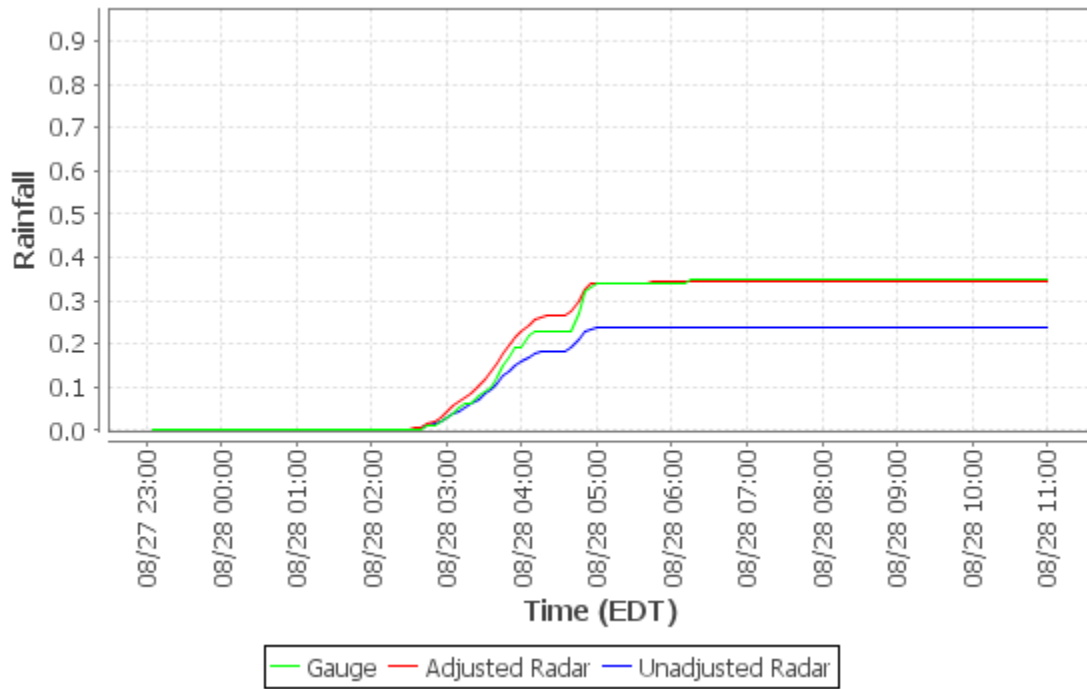
Cumulative Distribution Plot - Moon TWP (Loc21)



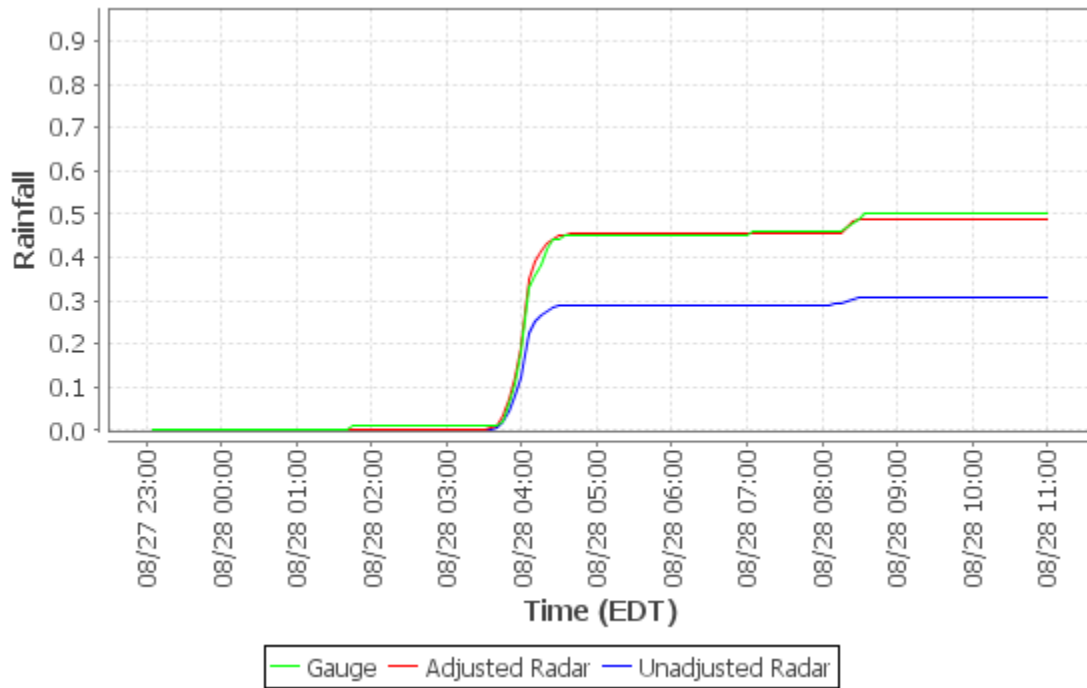
Cumulative Distribution Plot - North Fayette TWP (Loc22)



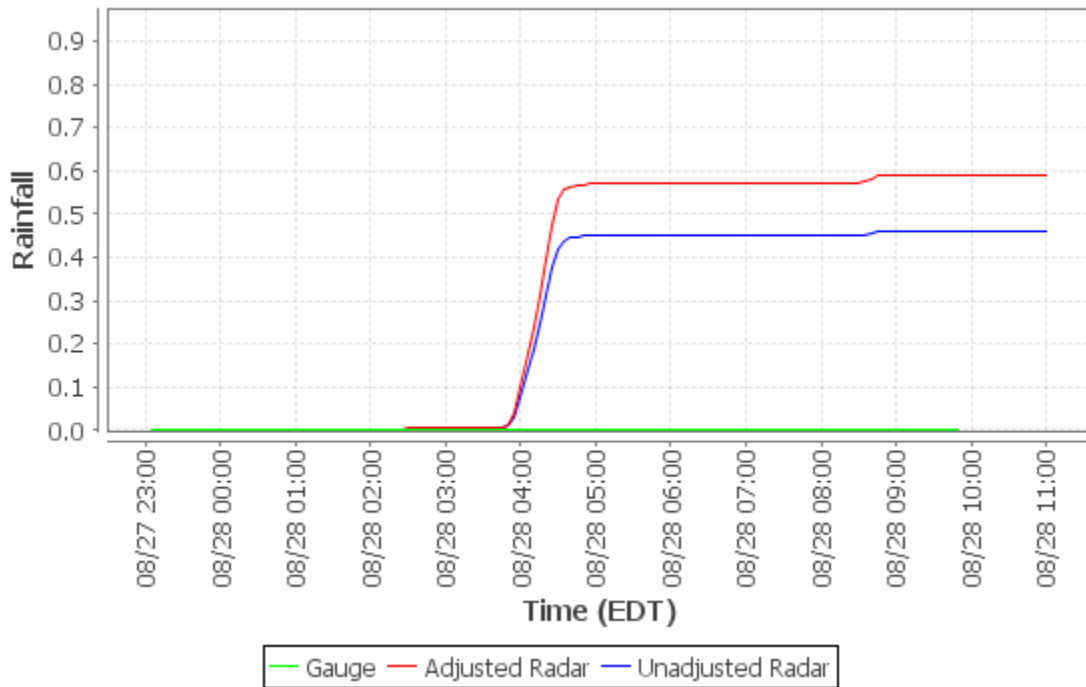
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



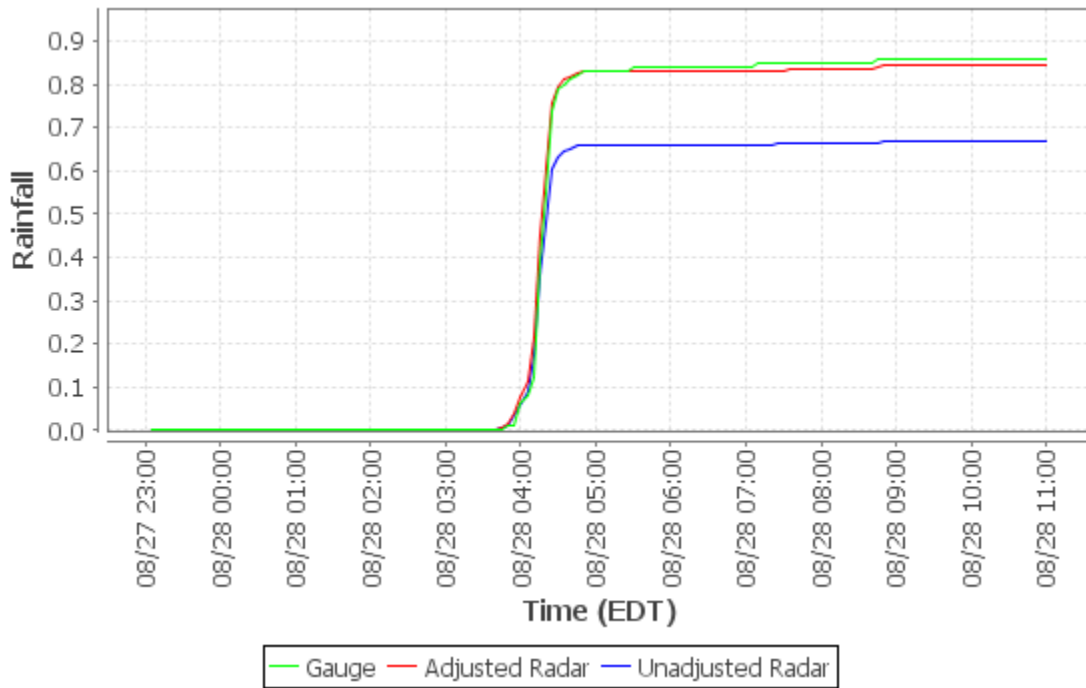
Cumulative Distribution Plot - Jefferson Hills (Loc24)



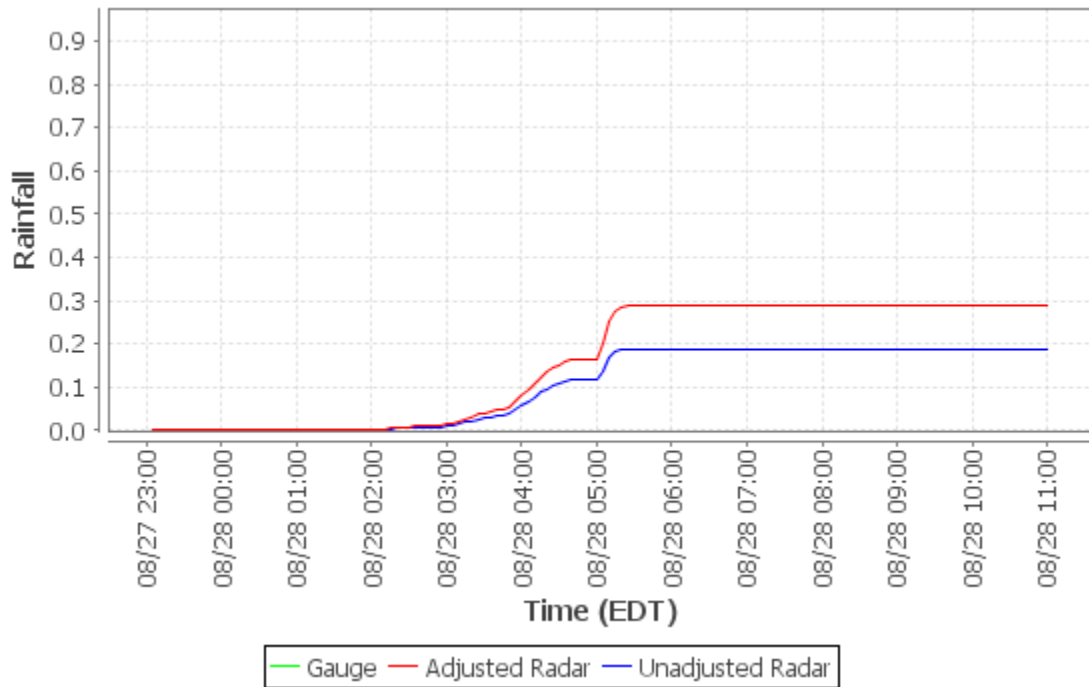
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



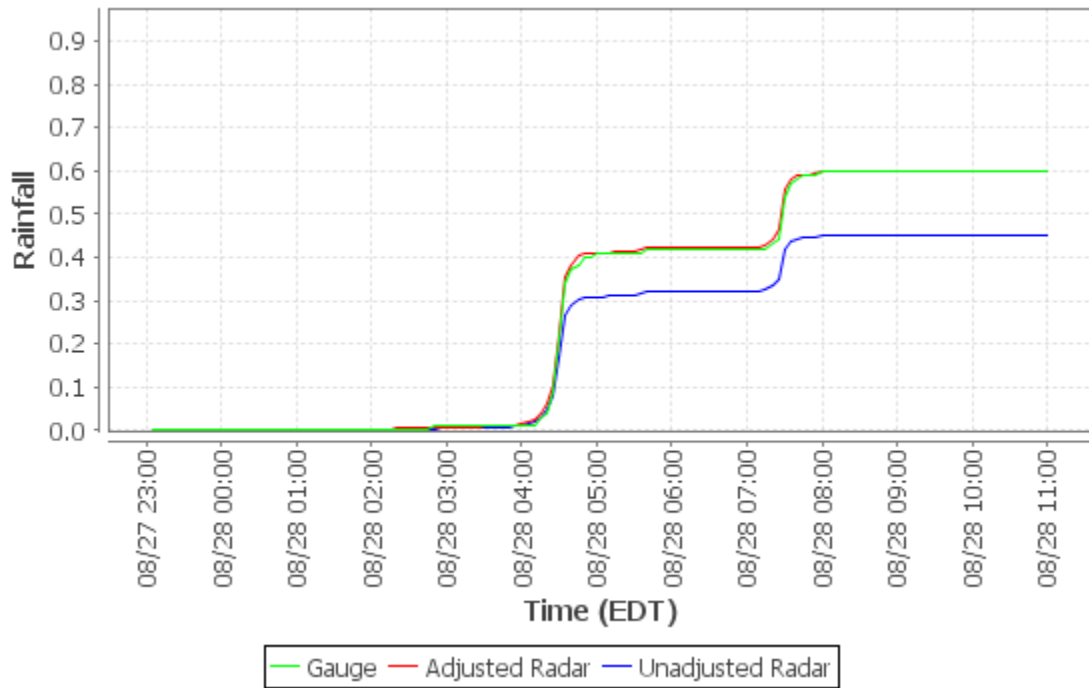
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



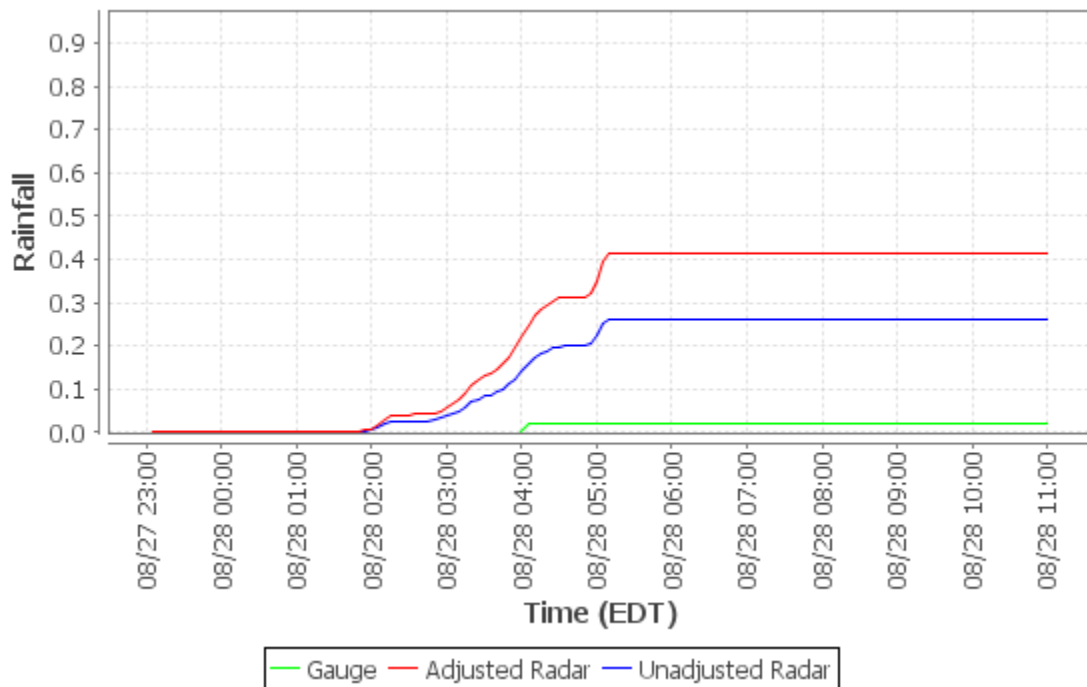
Cumulative Distribution Plot - Marshall TWP (Loc27)



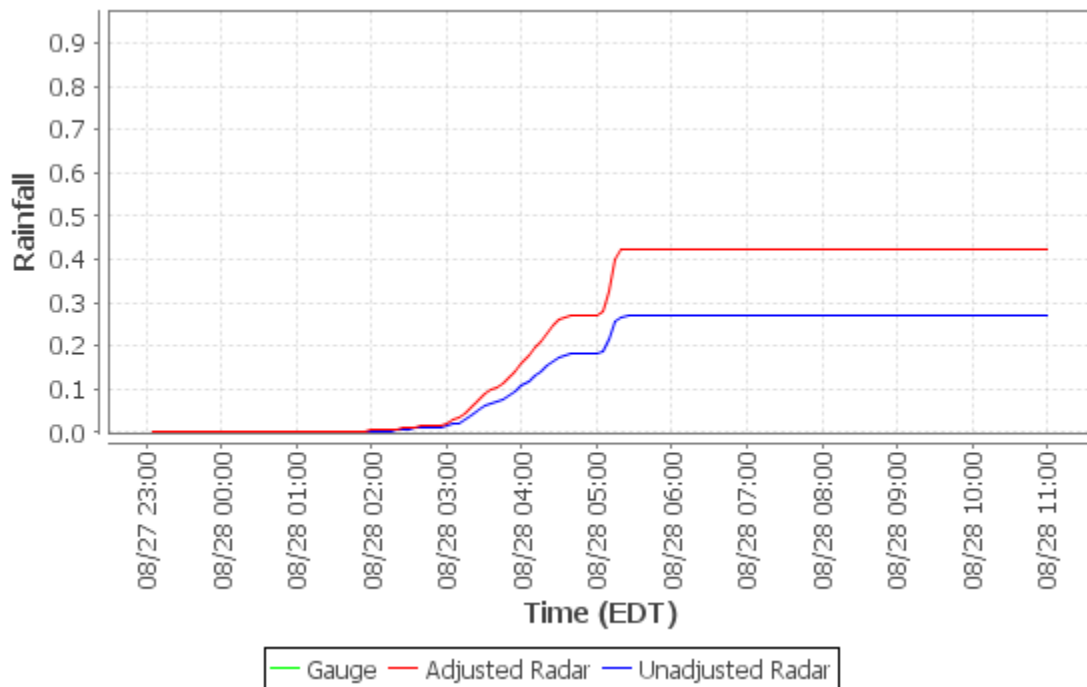
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



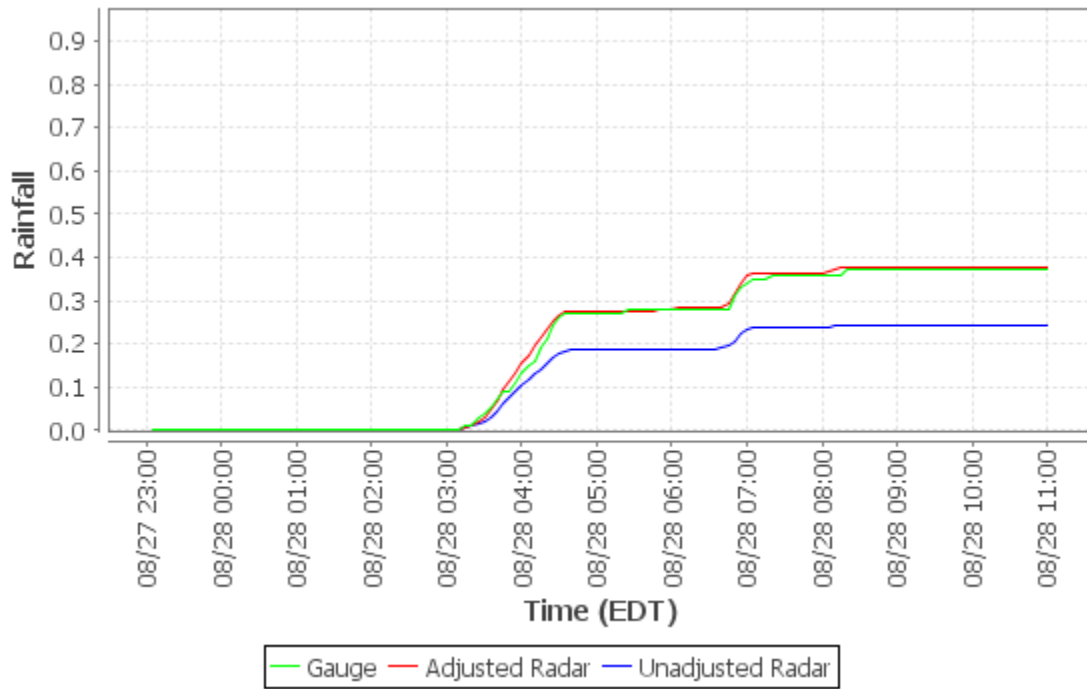
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



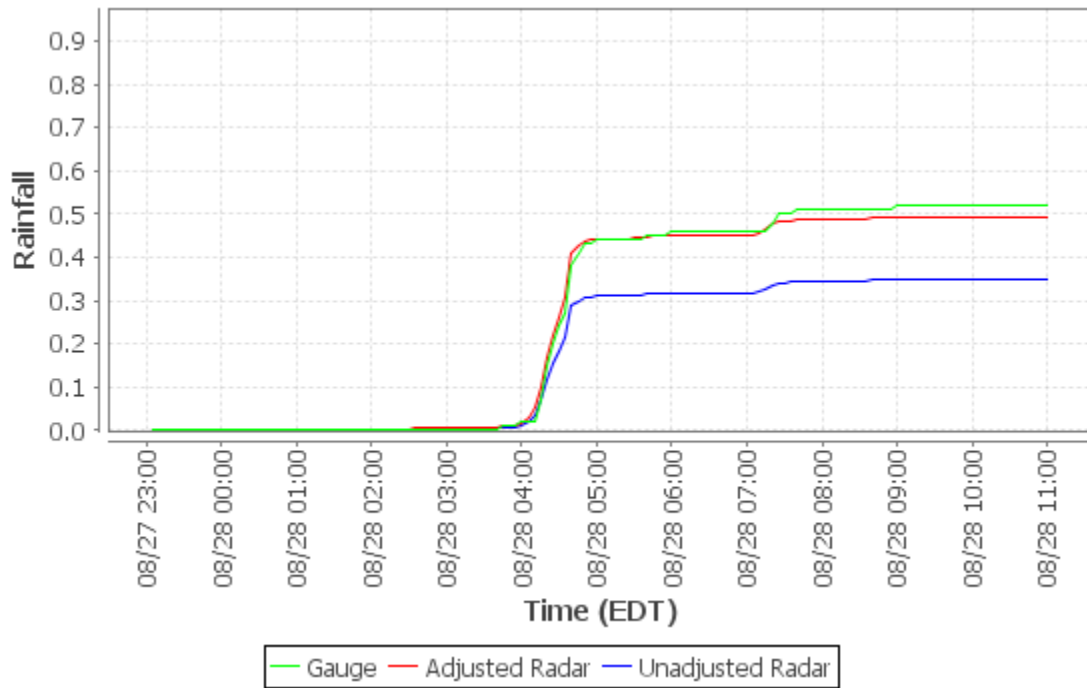
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



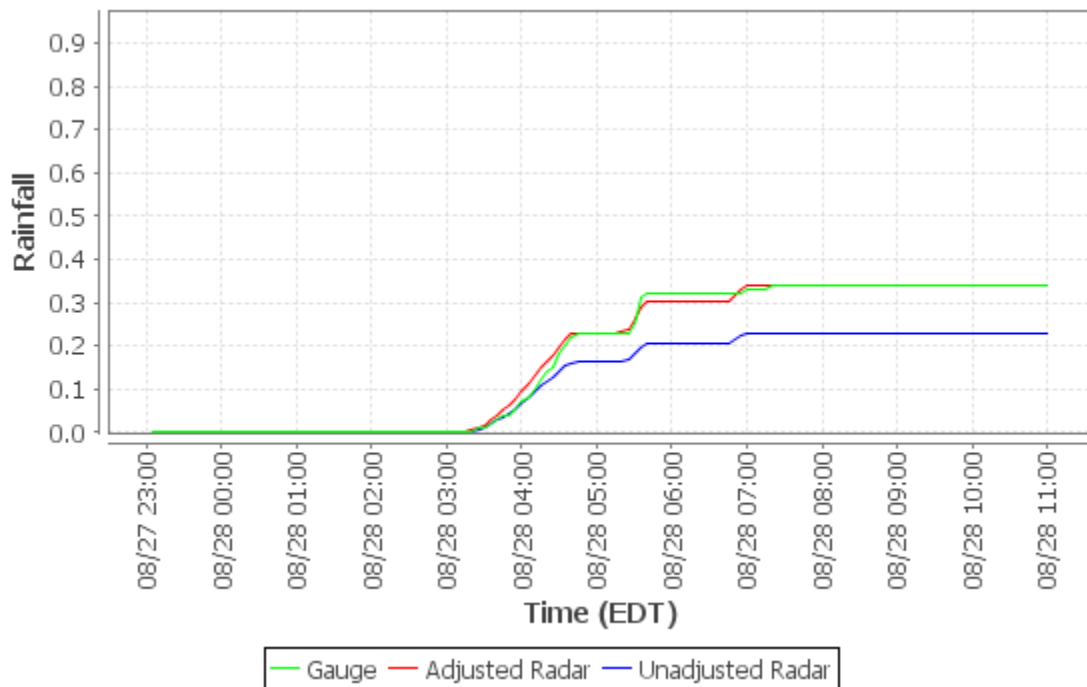
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



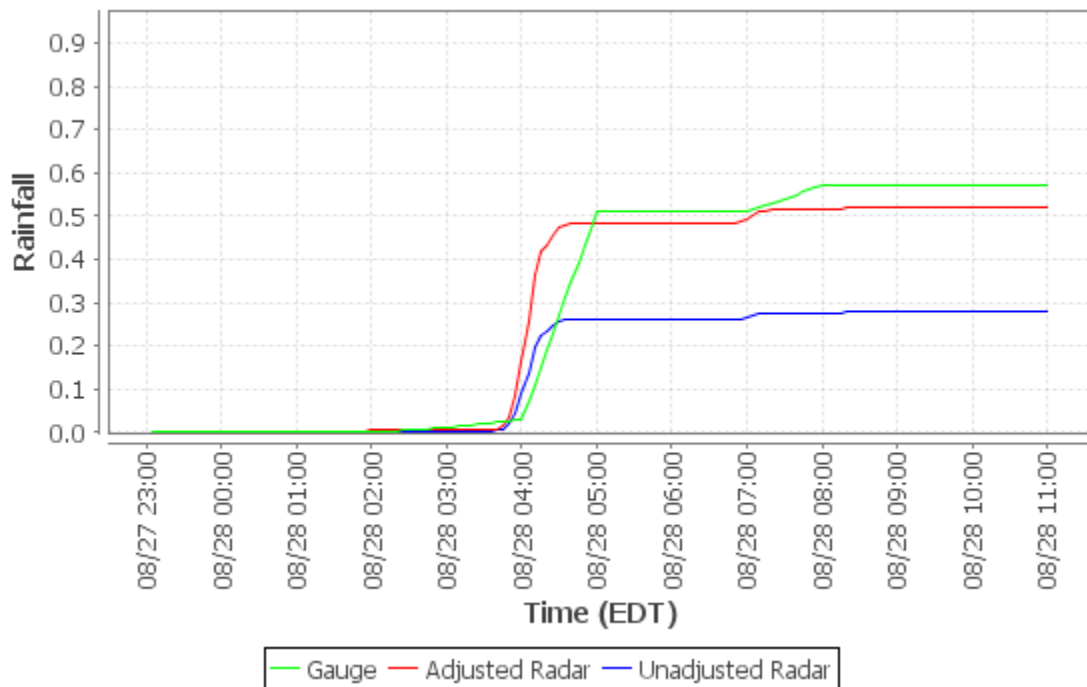
Cumulative Distribution Plot - Arnold (Loc32)



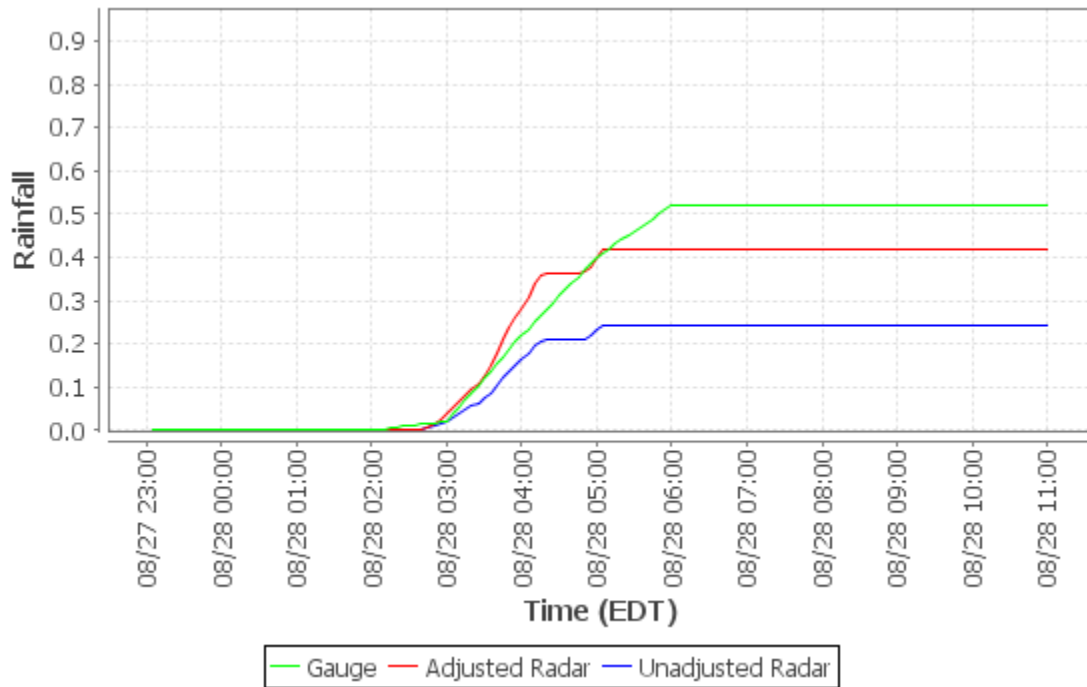
Cumulative Distribution Plot - Richland TWP (Loc33)



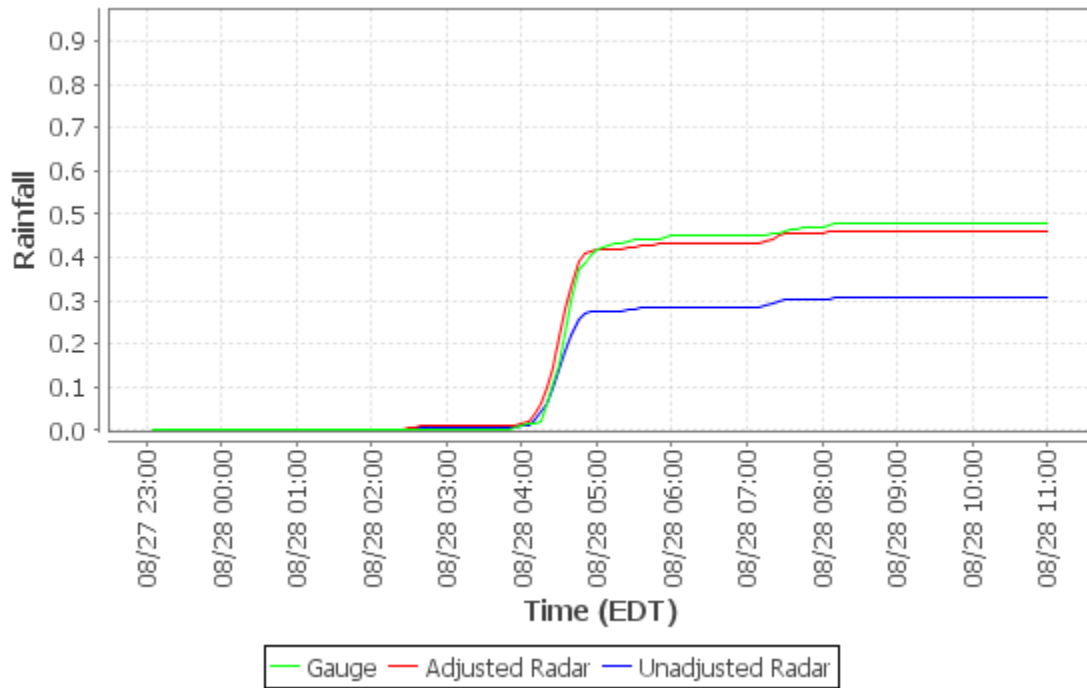
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)



**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

