

Radar Rainfall Analysis

July 2019 Summary Report



Prepared for 3 Rivers Wet Weather

August 16, 2019



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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.

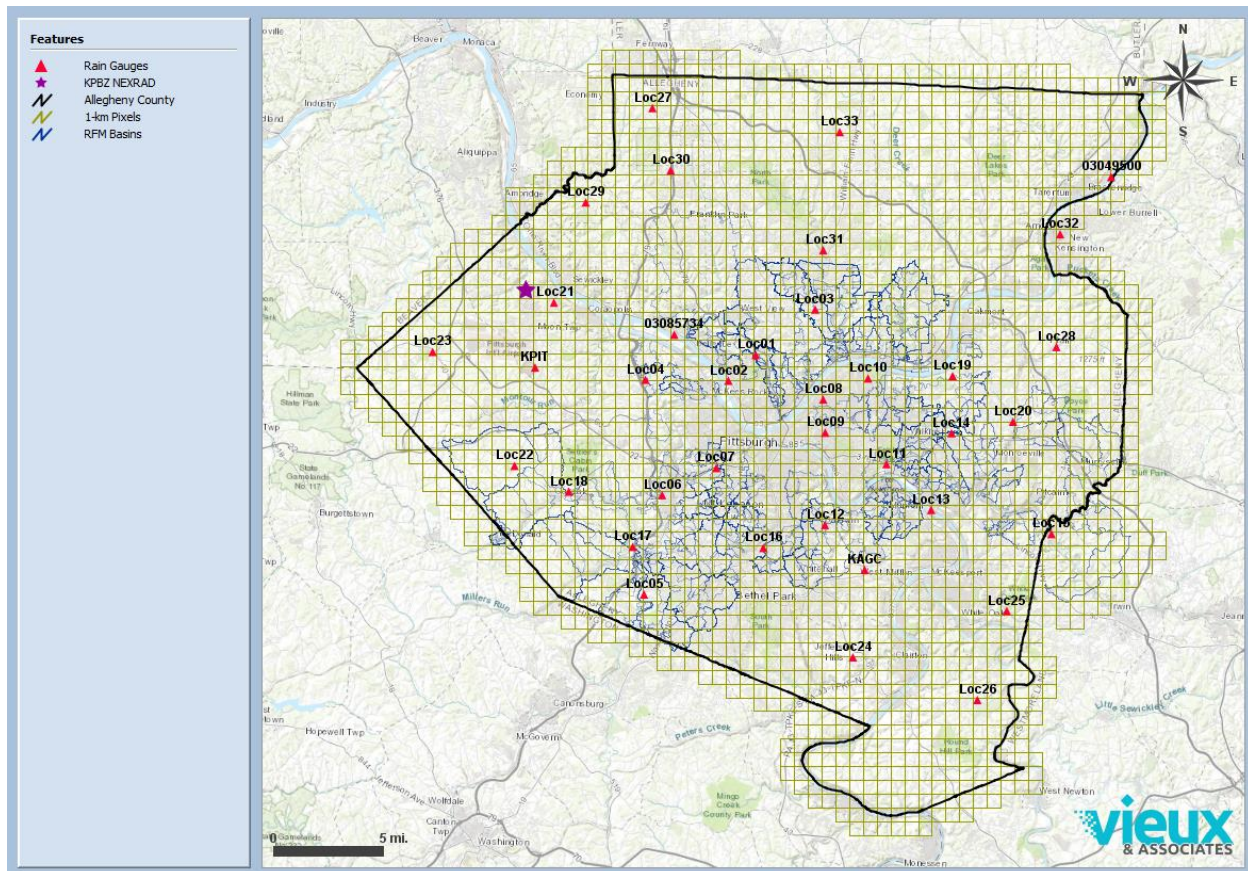


Figure 1. Spatial Distribution of the Rain Gauge Network, KPBZ NEXRAD, RFM Basins and 1-km² Pixels

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 2019-07-01 00:00 EDT to 2019-08-01 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 July 2019 are shown in Figure 2. The rainfall amounts for the 2313 1-km² pixels range from 3.3 to 11.1 inches with a mean of 6.6 inches. The rainfall amounts for the 440 RFM basins range from 3.4 to 10.6 inches with a mean of 6.7 inches. The rainfall amounts for the 871 RFM sheds range from 3.2 to 11.3 inches with a mean of 6.7 inches.

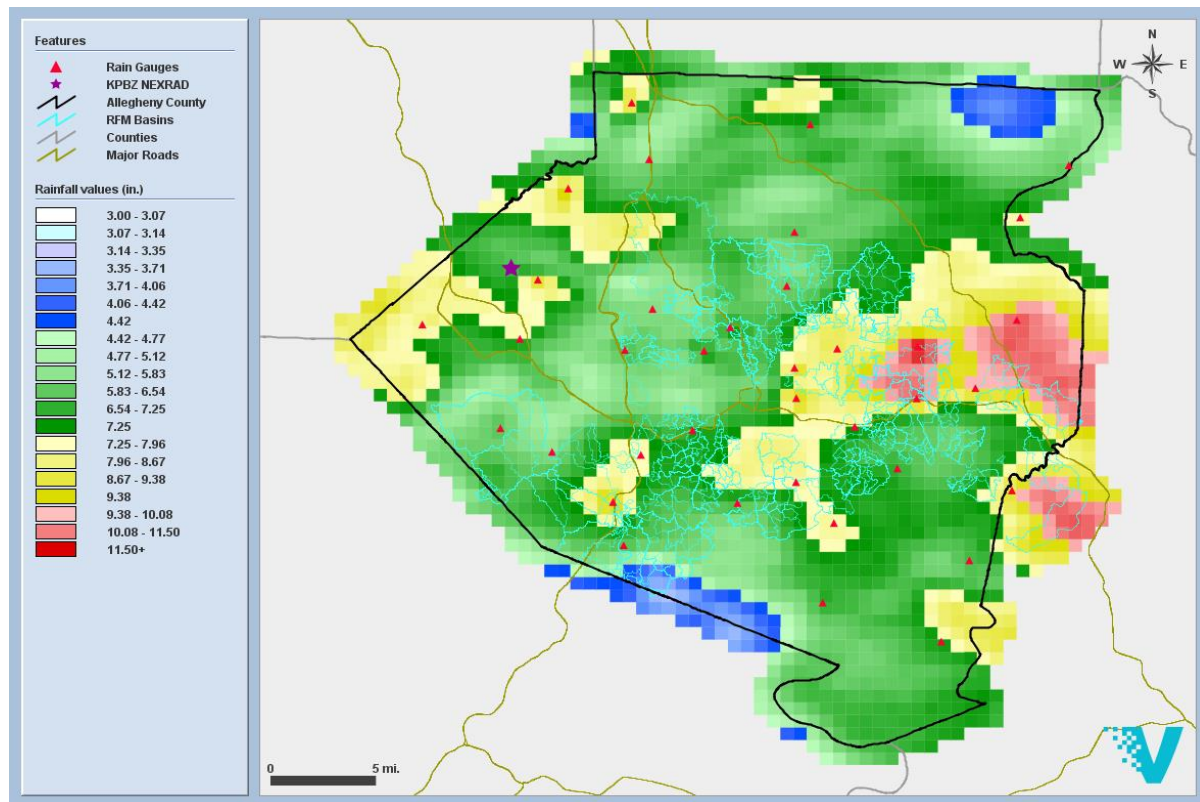


Figure 2. GARR Storm Total for July 2019

GARR was processed continuously at five-minute increments and covers the period from 2019-07-01 00:00 EDT to 2019-08-01 00:00 EDT. Seven rainfall events were identified as having met the storm definition during July 2019. The GARR statistics for each event are listed in Table 2. Five of the events were split into multiple sub-event periods to improve gauge-adjustment of the radar, resulting in a total of twenty 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 event and sub-event periods, the event CAD averaged 2.0%, indicating that the mean GARR agrees with the mean gauge accumulation to within $\pm 1.0\%$.

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 (%)
E1	KPBZ LII	2019-07-02	2019-07-02 11:05	2019-07-03 05:00	28	0.339	0.767	36.5	2.1
E2	KPBZ LII	2019-07-06	2019-07-06 07:05	2019-07-06 21:00	30	0.754	1.261	25.4	4.1
E3a	KPBZ LII	2019-07-07	2019-07-07 03:05	2019-07-07 10:00	20	0.279	1.551	34.2	2.7
E3b	KPBZ LII	2019-07-07	2019-07-07 10:05	2019-07-07 21:00	10	0.192	1.524	36.3	3.9
E4a	KPBZ LII	2019-07-11	2019-07-11 03:05	2019-07-11 07:00	17	0.228	1.166	19.0	1.7
E4b	KPBZ LII	2019-07-11	2019-07-11 07:05	2019-07-11 09:00	28	0.615	1.172	16.1	1.2
E4c	KPBZ LII	2019-07-11	2019-07-11 09:05	2019-07-11 10:00	10	0.160	1.763	43.0	0.9
E4d	KPBZ LII	2019-07-11	2019-07-11 10:05	2019-07-11 22:00	31	1.016	1.524	34.3	1.6
E5a	KPBZ LII	2019-07-17	2019-07-17 08:05	2019-07-17 11:10	4	0.038	1.719	40.1	0.0
E5b	KCCX LIII	2019-07-17	2019-07-17 11:15	2019-07-17 13:45	5	0.040	0.887	21.2	0.0
E5c	KPBZ LII	2019-07-17	2019-07-17 13:50	2019-07-17 17:30	28	0.152	1.308	20.8	2.6
E5d	KPBZ LII	2019-07-17	2019-07-17 17:35	2019-07-18 01:00	14	0.115	0.897	22.4	1.7
E6a	KPBZ LII	2019-07-22	2019-07-21 18:05	2019-07-21 23:00	27	0.500	1.031	19.9	4.7
E6b	KPBZ LII	2019-07-22	2019-07-21 23:05	2019-07-22 05:30	29	0.237	1.283	20.8	3.0
E6c	KPBZ LII	2019-07-22	2019-07-22 05:35	2019-07-22 08:30	7	0.036	1.121	14.9	0.7
E6d	KPBZ LII	2019-07-22	2019-07-22 08:35	2019-07-22 12:00	21	0.106	0.969	18.3	2.2
E6e	KPBZ LII	2019-07-22	2019-07-22 12:05	2019-07-22 14:00	25	0.350	1.356	25.5	1.8

Event #	Source	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E6f	KPBZ LII	2019-07-22	2019-07-22 14:05	2019-07-22 19:00	12	0.071	0.698	61.2	0.8
E7a	KPBZ LII	2019-07-30	2019-07-30 15:05	2019-07-30 19:00	5	0.052	0.765	32.5	1.2
E7b	KPBZ LII	2019-07-30	2019-07-30 19:05	2019-07-31 02:00	27	0.464	0.732	44.5	3.5

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 Shaler Munic Bldg (Loc03) gauge during the 2019-07-11 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.

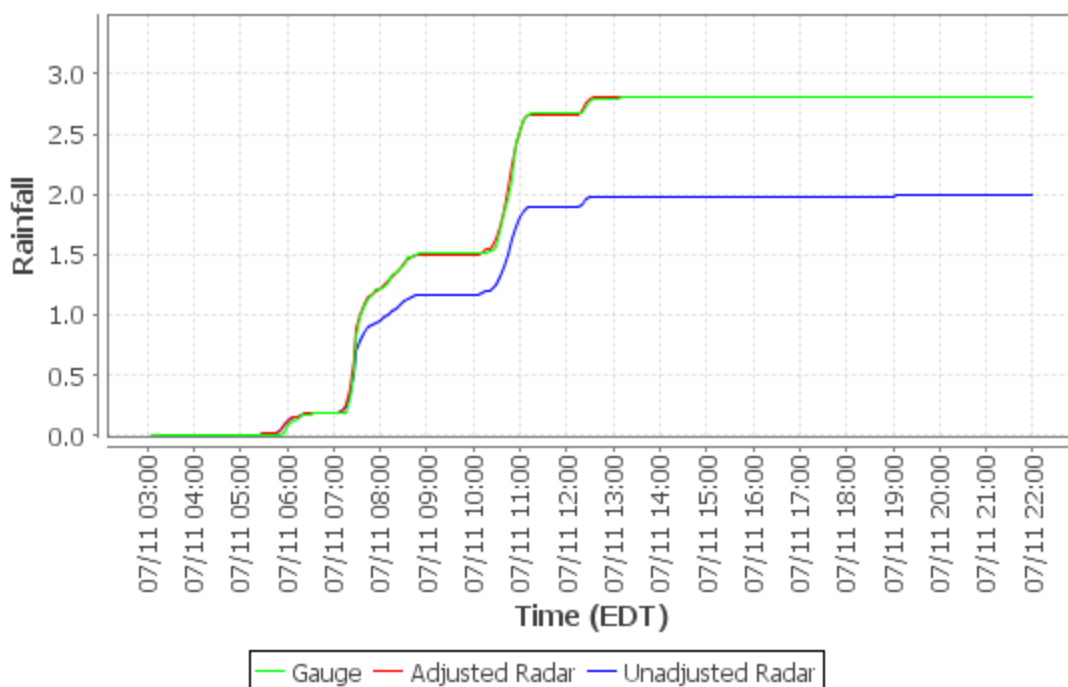


Figure 3. CDP Showing Rain Gauge Versus Unadjusted Radar Versus GARR

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: 2019-07-02

The analysis period was from 2019-07-02 11:00 EDT to 2019-07-03 05:00 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 5 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Table 6 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 4 shows the scatter plot of the RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 5 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.0 - 1.2 inches with a mean of 0.3 inches. The GARR amounts for the 440 RFM basins range from 0.1 - 1.1 inches with a mean of 0.4 inches. The GARR amounts for the 871 RFM sheds range from 0.1 - 1.1 inches with a mean

of 0.4 inches. Table 7 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 (%)
E1	KPBZ LII	2019-07-02	2019-07-02 11:05	2019-07-03 05:00	28	0.339	0.767	36.5	2.1

Table 6. Summary of Individual RG Pairs for Event 1

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc04	Kennedy Twp PS	0.13	0.21	0.14	-0.01	-7.7	
Loc09	Univ of Pittsburgh	0.55	0.76	0.59	-0.04	-7.3	
Loc16	Castle Shannon	0.16	0.31	0.17	-0.01	-6.3	
Loc19	Sandy Creek Eq Facility	0.17	0.26	0.18	-0.01	-5.9	
Loc27	Marshall TWP	0.23	0.31	0.24	-0.01	-4.3	
Loc12	Baldwin	0.34	0.54	0.35	-0.01	-2.9	
Loc11	M-46 Access Shaft	0.43	0.62	0.44	-0.01	-2.3	
KPIT	Greater Pittsburgh Int'l	0.19	0.26	0.19	0.00	0.0	
Loc02	ALCOSAN WWTP Lab	0.25	0.34	0.25	0.00	0.0	
Loc06	Carnegie Transit Time	0.41	0.53	0.41	0.00	0.0	
Loc07	Greentree Munic Bldg	0.70	0.95	0.70	0.00	0.0	
Loc15	Trafford Maint Bldg	0.43	0.58	0.43	0.00	0.0	
Loc21	Moon TWP	0.18	0.25	0.18	0.00	0.0	
Loc22	North Fayette TWP	0.24	0.28	0.24	0.00	0.0	
Loc23	Clinton Munic Bldg	0.29	0.36	0.29	0.00	0.0	
Loc24	Jefferson Hills	0.39	0.54	0.39	0.00	0.0	
Loc25	White Oak Public Works Bldg	0.30	0.33	0.30	0.00	0.0	
Loc28	Plum Municipal Bldg	0.13	0.25	0.13	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.68	0.78	0.68	0.00	0.0	
Loc30	McCandless Twn Hall	0.20	0.23	0.20	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.14	0.20	0.14	0.00	0.0	
Loc32	Arnold	0.30	0.43	0.30	0.00	0.0	
Loc17	Chartiers Pump Station	1.09	1.24	1.07	0.02	1.8	
Loc03	Shaler Munic Bldg	0.37	0.44	0.36	0.01	2.7	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.36	0.50	0.35	0.01	2.8	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
KAGC	Pittsburgh Allegheny Cty	0.68	0.84	0.65	0.03	4.4	
Loc14	Churchill Munic Bldg	0.21	0.26	0.20	0.01	4.8	
Loc08	AC Health Dept Bldg	0.80	0.92	0.75	0.05	6.3	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.26	---	---	---	---	U
Loc05	Upper St. Clair	0.70	---	---	---	---	C
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	C
Loc33	Richland TWP	0.07	---	---	---	---	OAD

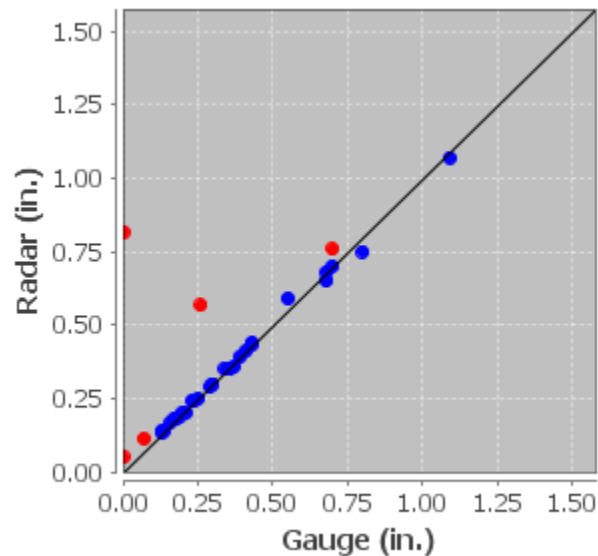


Figure 4. Scatter Plot of RG Pairs for Event 1

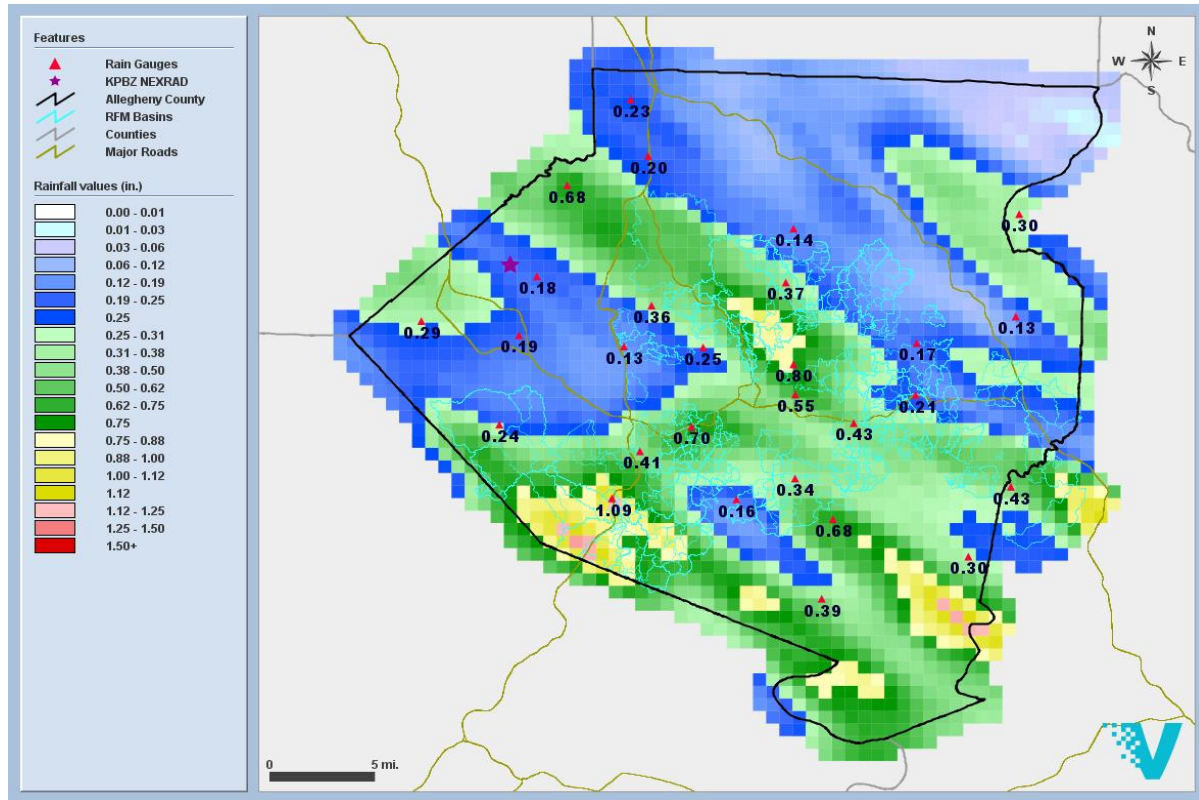


Figure 5. GARR Storm Total for Event 1

Table 7. Depth Duration Frequency Analyses for Event 1

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.751	133150	2019-07-02 19:55	2 yr.
30 minutes	1.063	133150	2019-07-02 20:05	2 yr.
1 hour	1.093	133150	2019-07-02 20:30	1 yr.
2 hour	1.156	133150	2019-07-02 21:30	1 yr.
3 hour	1.170	133150	2019-07-02 22:05	<1 yr.
6 hour	1.194	133150	2019-07-03 00:10	<1 yr.
12 hour	1.194	133150	2019-07-03 00:10	<1 yr.

Event 2: 2019-07-06

The analysis period was from 2019-07-06 07:00 EDT to 2019-07-06 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 8 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Table 9 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 6 shows the scatter plot of the RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 7 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.0 - 2.3 inches with a mean of 0.8 inches. The GARR amounts for the 440 RFM basins range from 0.1 - 2.2 inches with a mean of 0.8 inches. The GARR amounts for the 871 RFM sheds range from 0.1 - 2.4 inches with a mean of 0.9 inches. Table 10 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 8. GARR Statistics for Event 2

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E2	KPBZ LII	2019-07-06	2019-07-06 07:05	2019-07-06 21:00	30	0.754	1.261	25.4	4.1

Table 9. Summary of Individual RG Pairs for Event 2

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	Diff* (in)	Diff* (%)	Flag
Loc14	Churchill Munic Bldg	0.44	0.74	0.51	-0.07	-15.9	
Loc30	McCandless Twn Hall	0.27	0.28	0.30	-0.03	-11.1	
Loc07	Greentree Munic Bldg	1.30	1.30	1.44	-0.14	-10.8	
Loc03	Shaler Munic Bldg	0.11	0.15	0.12	-0.01	-9.1	
Loc04	Kennedy Twp PS	0.45	0.49	0.49	-0.04	-8.9	
Loc08	AC Health Dept Bldg	0.12	0.16	0.13	-0.01	-8.3	
Loc17	Chartiers Pump Station	1.49	1.21	1.56	-0.07	-4.7	
Loc22	North Fayette TWP	0.48	0.77	0.49	-0.01	-2.1	
Loc21	Moon TWP	0.53	0.45	0.54	-0.01	-1.9	
Loc12	Baldwin	1.65	0.98	1.68	-0.03	-1.8	
Loc25	White Oak Public Works Bldg	0.69	0.72	0.70	-0.01	-1.4	
Loc24	Jefferson Hills	0.95	0.63	0.96	-0.01	-1.1	
03049500	Allegheny River at Natrona	0.70	0.61	0.70	0.00	0.0	
Loc11	M-46 Access Shaft	0.79	0.87	0.79	0.00	0.0	
Loc23	Clinton Munic Bldg	1.20	1.00	1.20	0.00	0.0	

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc28	Plum Municipal Bldg	1.44	0.98	1.44	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.14	0.10	0.14	0.00	0.0	
Loc32	Arnold	1.50	1.30	1.50	0.00	0.0	
Loc33	Richland TWP	0.72	0.56	0.72	0.00	0.0	
Loc15	Trafford Maint Bldg	1.24	0.72	1.22	0.02	1.6	
KAGC	Pittsburgh Allegheny Cty	1.32	0.69	1.29	0.03	2.3	
Loc16	Castle Shannon	1.76	0.89	1.71	0.05	2.8	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.33	0.27	0.32	0.01	3.0	
KPIT	Greater Pittsburgh Int'l	0.90	0.63	0.87	0.03	3.3	
Loc02	ALCOSAN WWTP Lab	0.26	0.19	0.25	0.01	3.8	
Loc09	Univ of Pittsburgh	0.41	0.44	0.39	0.02	4.9	
Loc31	Hampton Municipal Bldg	0.59	0.54	0.56	0.03	5.1	
Loc27	Marshall TWP	1.16	0.74	1.10	0.06	5.2	
Loc19	Sandy Creek Eq Facility	0.50	0.50	0.47	0.03	6.0	
Loc06	Carnegie Transit Time	2.09	1.35	1.93	0.16	7.7	
Loc01	PWSA-Montana St.	0.04	---	---	---	---	U
Loc05	Upper St. Clair	0.66	---	---	---	---	C
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	ND	---	---	---	---	ND
Loc26	Elizabeth TWP Municipal Bldg	0.01	---	---	---	---	C

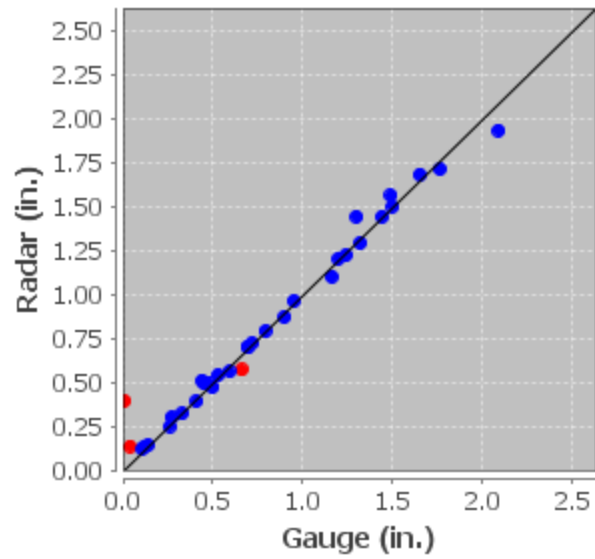


Figure 6. Scatter Plot of RG Pairs for Event 2

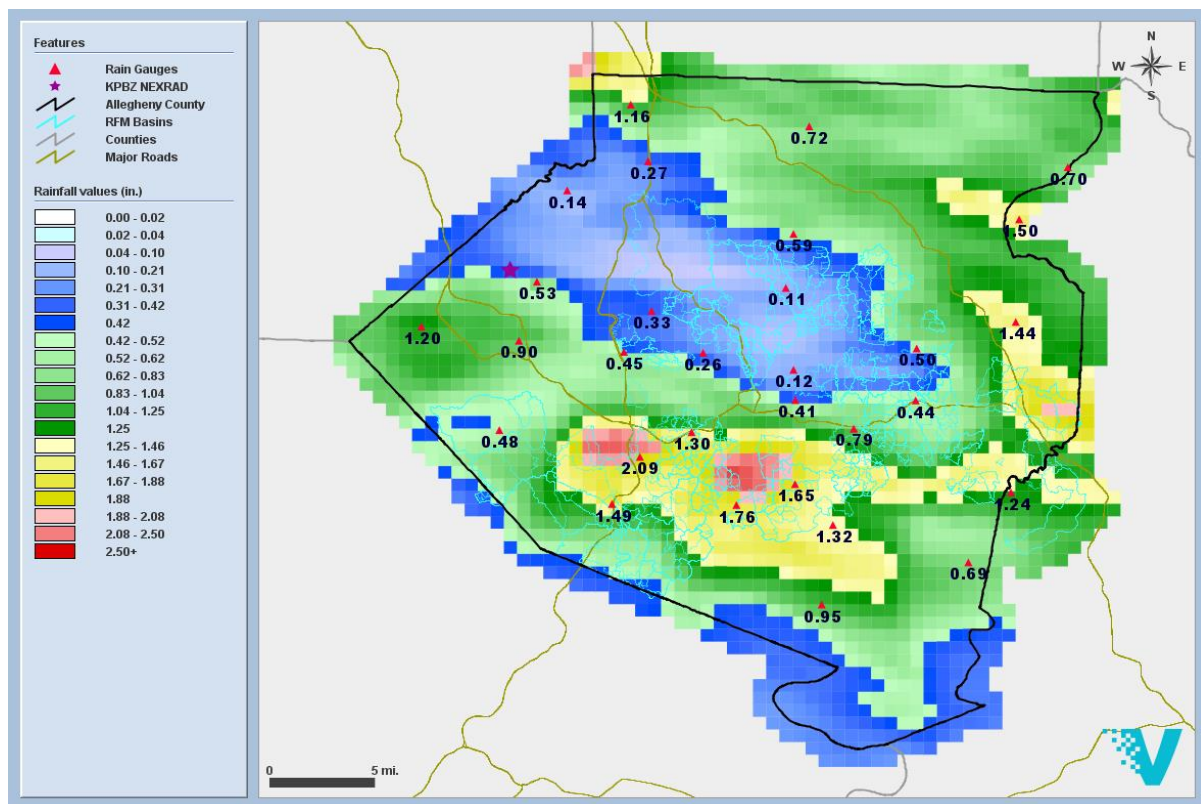


Figure 7. GARR Storm Total for Event 2

Table 10. Depth Duration Frequency Analyses for Event 2

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	1.212	145144	2019-07-06 16:45	25 yr.
30 minutes	1.995	145144	2019-07-06 16:55	100 yr.
1 hour	2.205	145144	2019-07-06 17:20	25 yr.
2 hour	2.281	145144	2019-07-06 17:55	10 yr.
3 hour	2.288	145144	2019-07-06 18:40	10 yr.
6 hour	2.288	145144	2019-07-06 18:40	5 yr.
12 hour	2.288	145144	2019-07-06 19:00	2 yr.

Event 3: 2019-07-07

The analysis period was from 2019-07-07 03:00 EDT to 2019-07-07 21:00 EDT. The event was then split into two sub-event periods at 2019-07-07 10:00 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 11 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 12 - 13 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 8 - 9 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 10 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.0 - 2.5 inches with a mean of 0.5 inches. The GARR amounts for the 440 RFM basins range from 0.0 - 2.4 inches with a mean of 0.4 inches. The GARR amounts for the 871 RFM sheds range from 0.0 - 2.5 inches with a mean of 0.4 inches. Table 14 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 11. GARR Statistics for Event 3

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E3a	KPBZ LII	2019-07-07	2019-07-07 03:05	2019-07-07 10:00	20	0.279	1.551	34.2	2.7
E3b	KPBZ LII	2019-07-07	2019-07-07 10:05	2019-07-07 21:00	10	0.192	1.524	36.3	3.9

Table 12. Summary of Individual RG Pairs for Event 3a

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc09	Univ of Pittsburgh	0.37	0.33	0.40	-0.03	-8.1	
Loc07	Greentree Munic Bldg	0.16	0.12	0.17	-0.01	-6.3	
Loc02	ALCOSAN WWTP Lab	0.53	0.47	0.56	-0.03	-5.7	
Loc19	Sandy Creek Eq Facility	0.29	0.16	0.30	-0.01	-3.4	
Loc03	Shaler Munic Bldg	0.35	0.23	0.36	-0.01	-2.9	
Loc21	Moon TWP	1.05	0.61	1.08	-0.03	-2.9	
Loc04	Kennedy Twp PS	0.40	0.25	0.40	0.00	0.0	
Loc12	Baldwin	0.11	0.10	0.11	0.00	0.0	
Loc15	Trafford Maint Bldg	0.17	0.12	0.17	0.00	0.0	
Loc24	Jefferson Hills	0.27	0.17	0.27	0.00	0.0	
Loc29	Bell Acres Munic Bldg	1.08	0.71	1.08	0.00	0.0	
Loc30	McCandless Twn Hall	0.30	0.23	0.30	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.13	0.07	0.13	0.00	0.0	
Loc25	White Oak Public Works Bldg	1.08	0.58	1.07	0.01	0.9	
KPIT	Greater Pittsburgh Int'l	0.53	0.25	0.52	0.01	1.9	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.50	0.30	0.49	0.01	2.0	
Loc11	M-46 Access Shaft	0.40	0.24	0.39	0.01	2.5	
Loc08	AC Health Dept Bldg	0.76	0.58	0.73	0.03	3.9	
Loc14	Churchill Munic Bldg	0.22	0.11	0.21	0.01	4.5	
Loc06	Carnegie Transit Time	0.15	0.09	0.14	0.01	6.7	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.22	---	---	---	---	U
Loc01	PWSA-Montana St.	0.22	---	---	---	---	U
Loc05	Upper St. Clair	0.04	---	---	---	---	C
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc16	Castle Shannon	0.01	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.01	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	ND	---	---	---	---	ND
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.01	---	---	---	---	MSTT
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	C
Loc27	Marshall TWP	0.03	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.05	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc32	Arnold	0.01	---	---	---	---	MSTT
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

Table 13. Summary of Individual RG Pairs for Event 3b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc30	McCandless Twn Hall	0.09	0.08	0.11	-0.02	-22.2	
Loc06	Carnegie Transit Time	0.11	0.10	0.12	-0.01	-9.1	
Loc02	ALCOSAN WWTP Lab	0.24	0.18	0.24	0.00	0.0	
Loc08	AC Health Dept Bldg	0.05	0.07	0.05	0.00	0.0	
Loc16	Castle Shannon	0.11	0.07	0.11	0.00	0.0	
Loc21	Moon TWP	0.50	0.24	0.50	0.00	0.0	
Loc22	North Fayette TWP	0.92	0.62	0.92	0.00	0.0	
Loc17	Chartiers Pump Station	2.09	1.46	2.01	0.08	3.8	
Loc29	Bell Acres Munic Bldg	0.25	0.07	0.24	0.01	4.0	
Loc27	Marshall TWP	0.14	0.06	0.13	0.01	7.1	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.02	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.03	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.04	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.04	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.07	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.98	---	---	---	---	C
Loc07	Greentree Munic Bldg	0.04	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.02	---	---	---	---	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	0.01	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.03	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.00	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc20	Gascola Eq Facility	ND	---	---	---	---	ND
Loc23	Clinton Munic Bldg	0.06	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.02	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.01	---	---	---	---	MSTT
Loc26	Elizabeth TWP Municipal Bldg	0.01	---	---	---	---	C
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

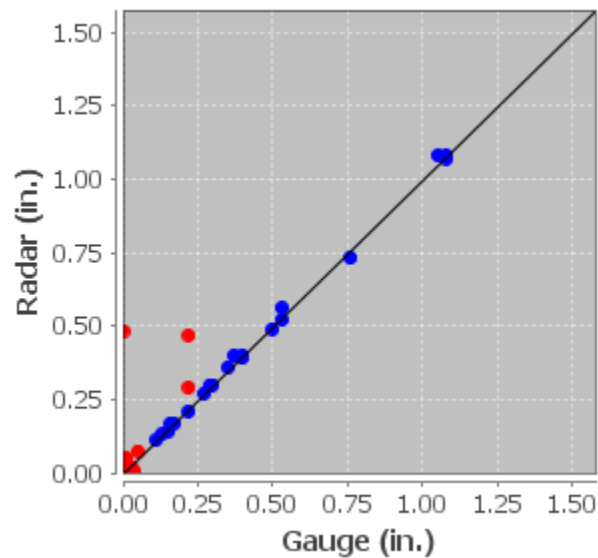


Figure 8. Scatter Plot of RG Pairs for Event 3a

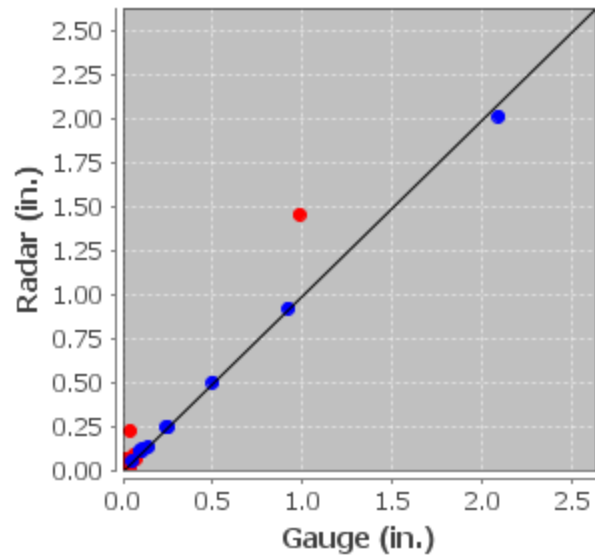


Figure 9. Scatter Plot of RG Pairs for Event 3b

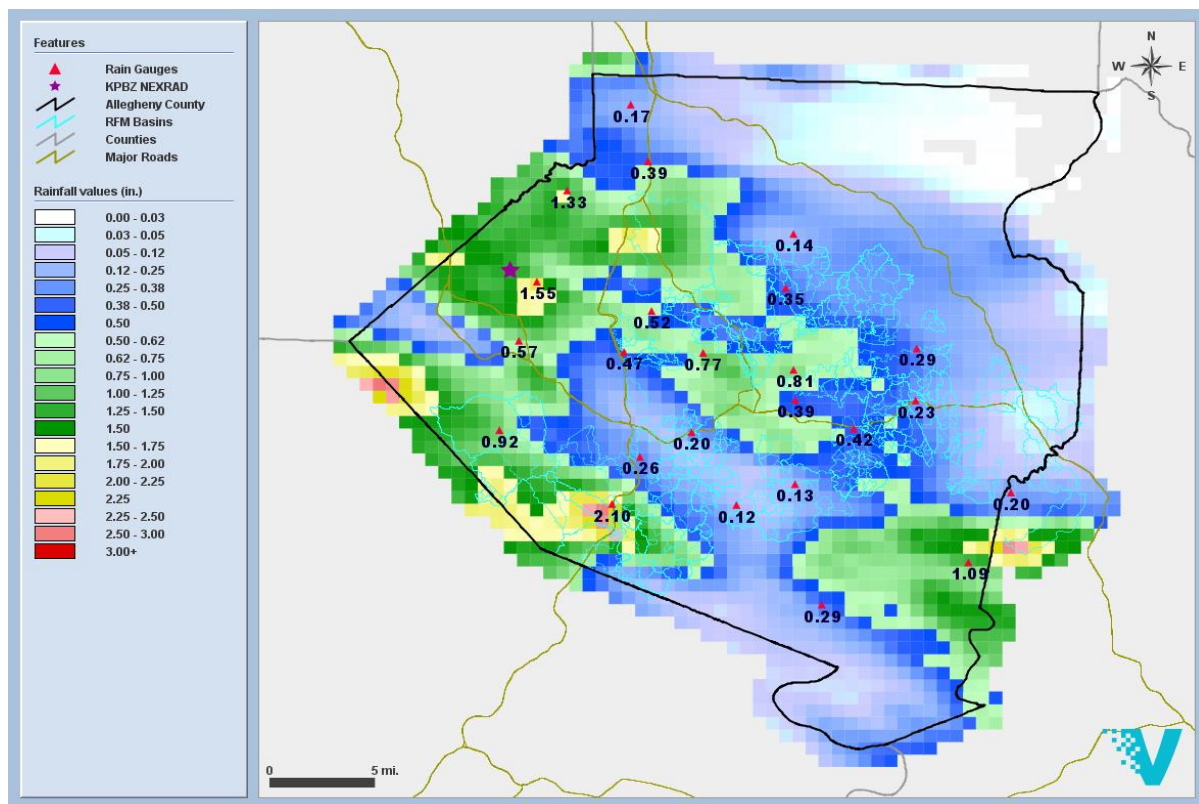


Figure 10. GARR Storm Total for Event 3

Table 14. Depth Duration Frequency Analyses for Event 3

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	1.182	165150	2019-07-07 08:30	25 yr.
30 minutes	1.881	166150	2019-07-07 08:35	50 yr.
1 hour	2.414	166150	2019-07-07 08:55	50 yr.
2 hour	2.504	118137	2019-07-07 14:40	25 yr.
3 hour	2.504	118137	2019-07-07 14:40	25 yr.
6 hour	2.535	118137	2019-07-07 18:30	10 yr.
12 hour	2.535	118137	2019-07-07 18:30	5 yr.

Event 4: 2019-07-11

The analysis period was from 2019-07-11 03:00 EDT to 2019-07-11 22:00 EDT. The event was then split into four sub-event periods at 2019-07-11 07:00 EDT, 2019-07-11 09:00 EDT and 2019-07-11 10:00 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 15 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 16 - 19 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 11 - 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 0.6 - 3.5 inches with a mean of 2.0 inches. The GARR amounts for the 440 RFM basins range from 0.7 - 3.3 inches with a mean of 2.1 inches. The GARR amounts for the 871 RFM sheds range from 0.7 - 3.3 inches with a mean of 2.1 inches. Table 20 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 15. 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	2019-07-11	2019-07-11 03:05	2019-07-11 07:00	17	0.228	1.166	19.0	1.7
E4b	KPBZ LII	2019-07-11	2019-07-11 07:05	2019-07-11 09:00	28	0.615	1.172	16.1	1.2

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E4c	KPBZ LII	2019-07-11	2019-07-11 09:05	2019-07-11 10:00	10	0.160	1.763	43.0	0.9
E4d	KPBZ LII	2019-07-11	2019-07-11 10:05	2019-07-11 22:00	31	1.016	1.524	34.3	1.6

Table 16. Summary of Individual RG Pairs for Event 4a

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc03	Shaler Munic Bldg	0.19	0.20	0.20	-0.01	-5.3	
03049500	Allegheny River at Natrona	0.85	0.68	0.85	0.00	0.0	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.08	0.08	0.08	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.06	0.06	0.06	0.00	0.0	
Loc02	ALCOSAN WWTP Lab	0.21	0.24	0.21	0.00	0.0	
Loc04	Kennedy Twp PS	0.21	0.23	0.21	0.00	0.0	
Loc08	AC Health Dept Bldg	0.31	0.37	0.31	0.00	0.0	
Loc09	Univ of Pittsburgh	0.24	0.29	0.24	0.00	0.0	
Loc14	Churchill Munic Bldg	0.24	0.24	0.24	0.00	0.0	
Loc21	Moon TWP	0.05	0.08	0.05	0.00	0.0	
Loc28	Plum Municipal Bldg	0.76	0.53	0.76	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.74	0.54	0.74	0.00	0.0	
Loc30	McCandless Twn Hall	0.37	0.29	0.37	0.00	0.0	
Loc32	Arnold	0.81	0.61	0.81	0.00	0.0	
Loc33	Richland TWP	0.51	0.33	0.51	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.71	0.68	0.70	0.01	1.4	
Loc31	Hampton Municipal Bldg	0.31	0.26	0.30	0.01	3.2	
KAGC	Pittsburgh Allegheny Cty	0.00	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.38	---	---	---	---	O
Loc05	Upper St. Clair	0.00	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.02	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.01	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc11	M-46 Access Shaft	0.03	---	---	---	---	MSTT
Loc12	Baldwin	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc15	Trafford Maint Bldg	0.03	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc16	Castle Shannon	0.00	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	ND	---	---	---	---	ND
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.01	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	MSTT
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc27	Marshall TWP	0.05	---	---	---	---	MSTT

Table 17. Summary of Individual RG Pairs for Event 4b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc08	AC Health Dept Bldg	1.13	1.14	1.20	-0.07	-6.2	
Loc02	ALCOSAN WWTP Lab	1.36	1.14	1.39	-0.03	-2.2	
Loc04	Kennedy Twp PS	0.96	0.71	0.98	-0.02	-2.1	
Loc19	Sandy Creek Eq Facility	1.15	1.04	1.17	-0.02	-1.7	
Loc25	White Oak Public Works Bldg	0.74	0.75	0.75	-0.01	-1.4	
Loc31	Hampton Municipal Bldg	0.91	0.69	0.92	-0.01	-1.1	
KAGC	Pittsburgh Allegheny Cty	0.57	0.60	0.57	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.85	0.63	0.85	0.00	0.0	
Loc01	PWSA-Montana St.	1.30	1.07	1.30	0.00	0.0	
Loc11	M-46 Access Shaft	0.61	0.56	0.61	0.00	0.0	
Loc12	Baldwin	0.73	0.75	0.73	0.00	0.0	
Loc16	Castle Shannon	0.67	0.68	0.67	0.00	0.0	
Loc17	Chartiers Pump Station	0.70	0.75	0.70	0.00	0.0	
Loc22	North Fayette TWP	0.51	0.54	0.51	0.00	0.0	
Loc23	Clinton Munic Bldg	0.69	0.48	0.69	0.00	0.0	
Loc24	Jefferson Hills	0.30	0.30	0.30	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	1.46	1.37	1.46	0.00	0.0	
Loc28	Plum Municipal Bldg	1.08	0.83	1.08	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.42	0.40	0.42	0.00	0.0	
Loc30	McCandless Twn Hall	0.36	0.31	0.36	0.00	0.0	
Loc32	Arnold	0.34	0.19	0.34	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc33	Richland TWP	0.31	0.18	0.31	0.00	0.0	
Loc07	Greentree Munic Bldg	1.32	1.09	1.31	0.01	0.8	
Loc15	Trafford Maint Bldg	0.73	0.55	0.72	0.01	1.4	
Loc03	Shaler Munic Bldg	1.33	0.97	1.31	0.02	1.5	
Loc14	Churchill Munic Bldg	1.48	1.22	1.45	0.03	2.0	
Loc09	Univ of Pittsburgh	1.37	1.23	1.32	0.05	3.6	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	1.11	0.72	1.06	0.05	4.5	
03049500	Allegheny River at Natrona	0.86	---	---	---	---	OMFB
Loc05	Upper St. Clair	0.21	---	---	---	---	C
Loc06	Carnegie Transit Time	0.13	---	---	---	---	C
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	ND	---	---	---	---	ND
Loc21	Moon TWP	0.77	---	---	---	---	O
Loc27	Marshall TWP	0.06	---	---	---	---	MSTT

Table 18. Summary of Individual RG Pairs for Event 4c

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc25	White Oak Public Works Bldg	0.36	0.25	0.37	-0.01	-2.8	
Loc11	M-46 Access Shaft	0.17	0.10	0.17	0.00	0.0	
Loc14	Churchill Munic Bldg	0.10	0.05	0.10	0.00	0.0	
Loc15	Trafford Maint Bldg	0.55	0.31	0.55	0.00	0.0	
Loc24	Jefferson Hills	0.24	0.14	0.24	0.00	0.0	
Loc27	Marshall TWP	0.74	0.49	0.74	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.74	0.50	0.74	0.00	0.0	
Loc33	Richland TWP	0.10	0.06	0.10	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.68	0.26	0.67	0.01	1.5	
KAGC	Pittsburgh Allegheny Cty	0.45	0.17	0.44	0.01	2.2	
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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc01	PWSA-Montana St.	0.02	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.01	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.00	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.23	---	---	---	---	C
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	0.00	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc12	Baldwin	0.12	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc16	Castle Shannon	0.03	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.01	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	ND	---	---	---	---	ND
Loc21	Moon TWP	0.00	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.01	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.04	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.03	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.11	---	---	---	---	U
Loc31	Hampton Municipal Bldg	0.00	---	---	---	---	MSTT
Loc32	Arnold	0.01	---	---	---	---	MSTT

Table 19. Summary of Individual RG Pairs for Event 4d

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc02	ALCOSAN WWTP Lab	1.03	0.81	1.12	-0.09	-8.7	
KAGC	Pittsburgh Allegheny Cty	0.94	0.74	0.98	-0.04	-4.3	
03049500	Allegheny River at Natrona	0.70	0.49	0.72	-0.02	-2.9	
Loc30	McCandless Twn Hall	1.32	0.71	1.35	-0.03	-2.3	
KPIT	Greater Pittsburgh Int'l	1.41	0.96	1.44	-0.03	-2.1	
Loc19	Sandy Creek Eq Facility	1.41	1.16	1.44	-0.03	-2.1	
Loc08	AC Health Dept Bldg	1.03	0.78	1.05	-0.02	-1.9	

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc03	Shaler Munic Bldg	1.29	0.82	1.31	-0.02	-1.6	
Loc11	M-46 Access Shaft	0.97	0.74	0.98	-0.01	-1.0	
Loc07	Greentree Munic Bldg	0.73	0.49	0.73	0.00	0.0	
Loc15	Trafford Maint Bldg	1.36	1.01	1.36	0.00	0.0	
Loc17	Chartiers Pump Station	0.90	0.59	0.90	0.00	0.0	
Loc22	North Fayette TWP	0.36	0.24	0.36	0.00	0.0	
Loc23	Clinton Munic Bldg	1.27	0.60	1.27	0.00	0.0	
Loc24	Jefferson Hills	0.91	0.68	0.91	0.00	0.0	
Loc25	White Oak Public Works Bldg	0.86	0.67	0.86	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	1.11	0.74	1.11	0.00	0.0	
Loc28	Plum Municipal Bldg	1.36	0.96	1.36	0.00	0.0	
Loc29	Bell Acres Munic Bldg	1.29	0.68	1.29	0.00	0.0	
Loc33	Richland TWP	1.23	0.64	1.23	0.00	0.0	
Loc09	Univ of Pittsburgh	1.47	1.08	1.46	0.01	0.7	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	1.21	0.77	1.20	0.01	0.8	
Loc16	Castle Shannon	0.97	0.59	0.96	0.01	1.0	
Loc27	Marshall TWP	0.66	0.29	0.65	0.01	1.5	
Loc04	Kennedy Twp PS	1.29	0.81	1.27	0.02	1.6	
Loc21	Moon TWP	1.27	0.75	1.25	0.02	1.6	
Loc14	Churchill Munic Bldg	1.12	0.82	1.10	0.02	1.8	
Loc32	Arnold	1.05	0.57	1.03	0.02	1.9	
Loc31	Hampton Municipal Bldg	1.41	0.78	1.38	0.03	2.1	
Loc12	Baldwin	1.06	0.66	1.02	0.04	3.8	
Loc01	PWSA-Montana St.	1.63	1.08	1.55	0.08	4.9	
Loc05	Upper St. Clair	0.64	---	---	---	---	C
Loc06	Carnegie Transit Time	0.11	---	---	---	---	C
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	ND	---	---	---	---	ND

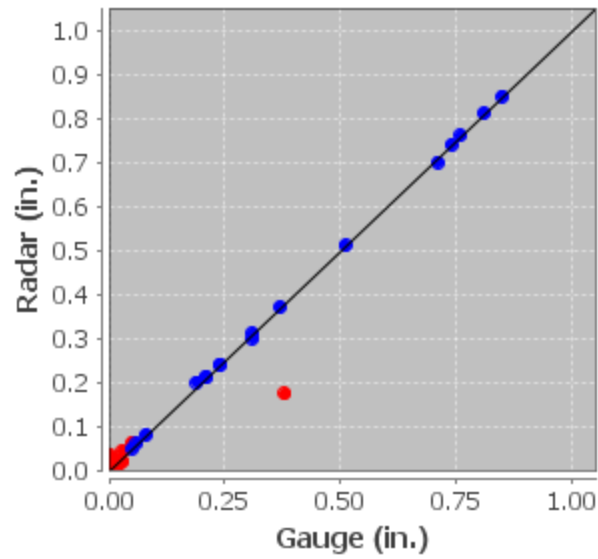


Figure 11. Scatter Plot of RG Pairs for Event 4a

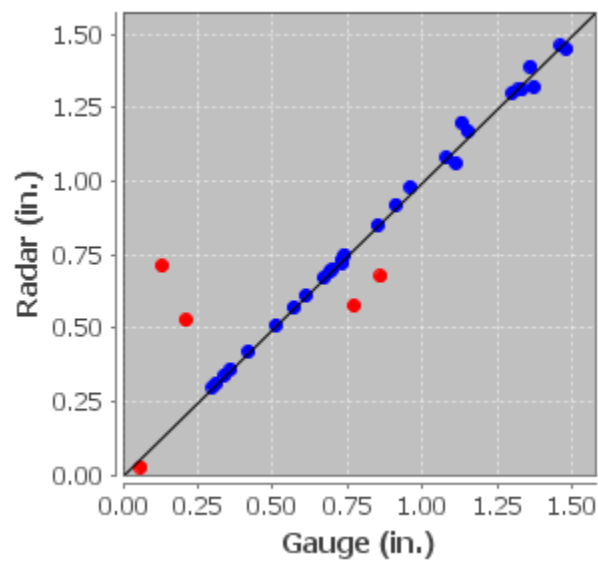


Figure 12. Scatter Plot of RG Pairs for Event 4b

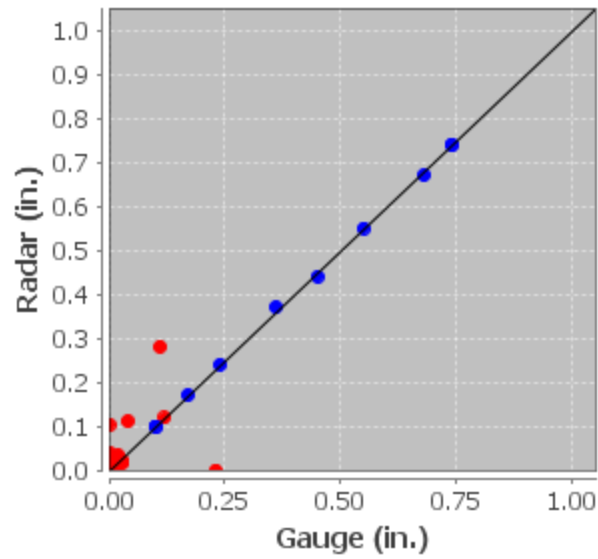


Figure 13. Scatter Plot of RG Pairs for Event 4c

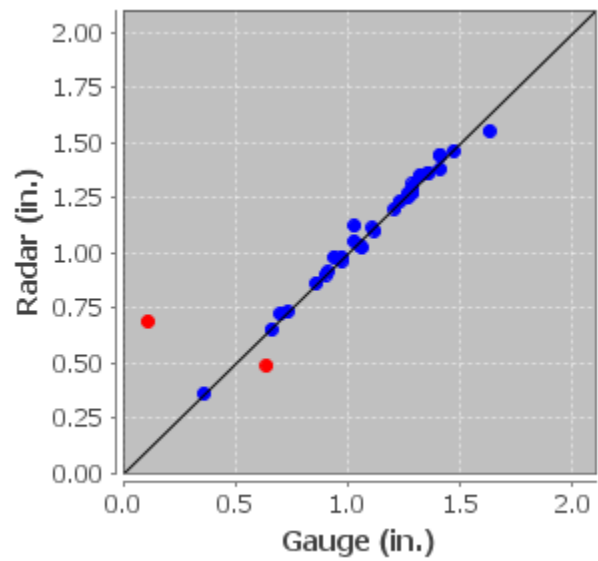


Figure 14. Scatter Plot of RG Pairs for Event 4d

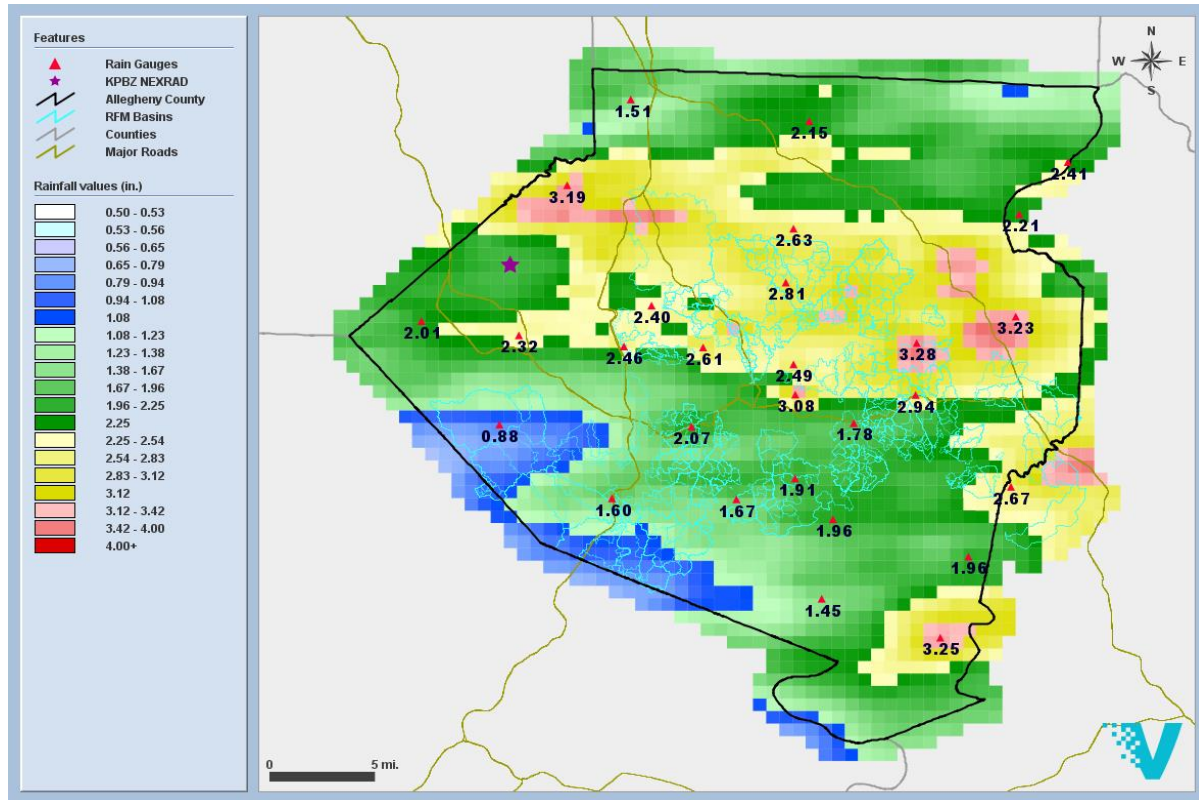


Figure 15. GARR Storm Total for Event 4

Table 20. Depth Duration Frequency Analyses for Event 4

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.952	121128	2019-07-11 10:25	5 yr.
30 minutes	1.306	121128	2019-07-11 10:30	5 yr.
1 hour	1.864	161158	2019-07-11 09:10	10 yr.
2 hour	2.234	161158	2019-07-11 09:55	10 yr.
3 hour	2.640	172144	2019-07-11 12:00	25 yr.
6 hour	3.463	165133	2019-07-11 11:45	50 yr.
12 hour	3.503	165133	2019-07-11 15:00	25 yr.

Event 5: 2019-07-17

The analysis period was from 2019-07-17 08:00 EDT to 2019-07-18 01:00 EDT. The event was then split into four sub-event periods at 2019-07-17 11:10 EDT, 2019-07-17 13:45 EDT and 2019-07-17 17:30 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 21 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 22 - 25 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 16 - 19 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 20 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.1 - 1.8 inches with a mean of 0.3 inches. The GARR amounts for the 440 RFM basins range from 0.1 - 0.6 inches with a mean of 0.2 inches. The GARR amounts for the 871 RFM sheds range from 0.1 - 0.6 inches with a mean of 0.2 inches. Table 26 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 21. 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	2019-07-17	2019-07-17 08:05	2019-07-17 11:10	4	0.038	1.719	40.1	0.0
E5b	KCCX LIII	2019-07-17	2019-07-17 11:15	2019-07-17 13:45	5	0.040	0.887	21.2	0.0
E5c	KPBZ LII	2019-07-17	2019-07-17 13:50	2019-07-17 17:30	28	0.152	1.308	20.8	2.6
E5d	KPBZ LII	2019-07-17	2019-07-17 17:35	2019-07-18 01:00	14	0.115	0.897	22.4	1.7

Table 22. Summary of Individual RG Pairs for Event 5a

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	Diff^* (in)	Diff^* (%)	Flag
Loc21	Moon TWP	0.31	0.17	0.31	0.00	0.0	
Loc23	Clinton Munic Bldg	0.10	0.07	0.10	0.00	0.0	
Loc27	Marshall TWP	0.12	0.07	0.12	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.12	0.07	0.12	0.00	0.0	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.02	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.00	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.07	---	---	---	---	U

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc01	PWSA-Montana St.	0.00	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.01	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.03	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.01	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	MSTT
Loc07	Greentree Munic Bldg	0.01	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.00	---	---	---	---	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	0.03	---	---	---	---	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	0.04	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	MSTT
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.00	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.07	---	---	---	---	U
Loc31	Hampton Municipal Bldg	0.00	---	---	---	---	MSTT
Loc32	Arnold	0.00	---	---	---	---	MSTT
Loc33	Richland TWP	0.01	---	---	---	---	MSTT

Table 23. Summary of Individual RG Pairs for Event 5b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc19	Sandy Creek Eq Facility	0.13	0.14	0.13	0.00	0.0	
Loc21	Moon TWP	0.07	0.06	0.07	0.00	0.0	
Loc30	McCandless Twn Hall	0.05	0.08	0.05	0.00	0.0	
Loc32	Arnold	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
Loc33	Richland TWP	0.21	0.24	0.21	0.00	0.0	
03049500	Allegheny River at Natrona	0.02	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.02	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.03	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.20	---	---	---	---	O
Loc01	PWSA-Montana St.	0.00	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.01	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.03	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.02	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.01	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.01	---	---	---	---	C
Loc07	Greentree Munic Bldg	0.01	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.01	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.00	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc11	M-46 Access Shaft	0.04	---	---	---	---	MSTT
Loc12	Baldwin	0.03	---	---	---	---	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	0.03	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.01	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	0.02	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.01	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.01	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.01	---	---	---	---	MSTT
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc27	Marshall TWP	0.02	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.02	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.01	---	---	---	---	MSTT
Loc31	Hampton Municipal Bldg	0.04	---	---	---	---	MSTT

Table 24. Summary of Individual RG Pairs for Event 5c

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc01	PWSA-Montana St.	0.05	0.06	0.06	-0.01	-20.0	
Loc11	M-46 Access Shaft	0.14	0.15	0.15	-0.01	-7.1	
Loc20	Gascola Eq Facility	0.17	0.19	0.18	-0.01	-5.9	
Loc21	Moon TWP	0.56	0.39	0.59	-0.03	-5.4	
Loc19	Sandy Creek Eq Facility	0.27	0.28	0.28	-0.01	-3.7	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.13	0.11	0.13	0.00	0.0	
KAGC	Pittsburgh Allegheny Cty	0.06	0.06	0.06	0.00	0.0	
Loc03	Shaler Munic Bldg	0.11	0.08	0.11	0.00	0.0	
Loc04	Kennedy Twp PS	0.09	0.07	0.09	0.00	0.0	
Loc05	Upper St. Clair	0.09	0.07	0.09	0.00	0.0	
Loc07	Greentree Munic Bldg	0.05	0.05	0.05	0.00	0.0	
Loc08	AC Health Dept Bldg	0.05	0.05	0.05	0.00	0.0	
Loc09	Univ of Pittsburgh	0.07	0.06	0.07	0.00	0.0	
Loc15	Trafford Maint Bldg	0.05	0.06	0.05	0.00	0.0	
Loc16	Castle Shannon	0.08	0.09	0.08	0.00	0.0	
Loc17	Chartiers Pump Station	0.08	0.06	0.08	0.00	0.0	
Loc22	North Fayette TWP	0.12	0.05	0.12	0.00	0.0	
Loc23	Clinton Munic Bldg	0.41	0.27	0.41	0.00	0.0	
Loc24	Jefferson Hills	0.09	0.10	0.09	0.00	0.0	
Loc27	Marshall TWP	0.42	0.26	0.42	0.00	0.0	
Loc28	Plum Municipal Bldg	0.28	0.26	0.28	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.28	0.16	0.28	0.00	0.0	
Loc32	Arnold	0.08	0.07	0.08	0.00	0.0	
Loc33	Richland TWP	0.27	0.17	0.27	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.39	0.19	0.38	0.01	2.6	
Loc31	Hampton Municipal Bldg	0.21	0.13	0.20	0.01	4.8	
Loc14	Churchill Munic Bldg	0.19	0.16	0.18	0.01	5.3	
Loc02	ALCOSAN WWTP Lab	0.06	0.05	0.05	0.01	16.7	
03049500	Allegheny River at Natrona	0.01	---	---	---	---	U
Loc06	Carnegie Transit Time	0.01	---	---	---	---	C
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc12	Baldwin	0.03	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc25	White Oak Public Works Bldg	0.04	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc26	Elizabeth TWP Municipal Bldg	0.03	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.29	---	---	---	---	U

Table 25. Summary of Individual RG Pairs for Event 5d

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc27	Marshall TWP	0.26	0.35	0.27	-0.01	-3.8	
KPIT	Greater Pittsburgh Int'l	0.13	0.12	0.13	0.00	0.0	
Loc03	Shaler Munic Bldg	0.06	0.09	0.06	0.00	0.0	
Loc04	Kennedy Twp PS	0.18	0.27	0.18	0.00	0.0	
Loc07	Greentree Munic Bldg	0.08	0.07	0.08	0.00	0.0	
Loc15	Trafford Maint Bldg	0.06	0.09	0.06	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.09	0.07	0.09	0.00	0.0	
Loc21	Moon TWP	0.12	0.09	0.12	0.00	0.0	
Loc23	Clinton Munic Bldg	0.10	0.12	0.10	0.00	0.0	
Loc24	Jefferson Hills	0.08	0.07	0.08	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.26	0.29	0.26	0.00	0.0	
Loc30	McCandless Twn Hall	0.06	0.06	0.06	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.05	0.06	0.05	0.00	0.0	
Loc33	Richland TWP	0.11	0.09	0.11	0.00	0.0	
03049500	Allegheny River at Natrona	0.00	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.05	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.02	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.06	---	---	---	---	OAD
Loc02	ALCOSAN WWTP Lab	0.05	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.07	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.01	---	---	---	---	C
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	0.01	---	---	---	---	MSTT
Loc12	Baldwin	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.03	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc16	Castle Shannon	0.00	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.02	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	0.03	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.02	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.03	---	---	---	---	MSTT
Loc26	Elizabeth TWP Municipal Bldg	0.07	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.01	---	---	---	---	MSTT
Loc32	Arnold	0.01	---	---	---	---	MSTT

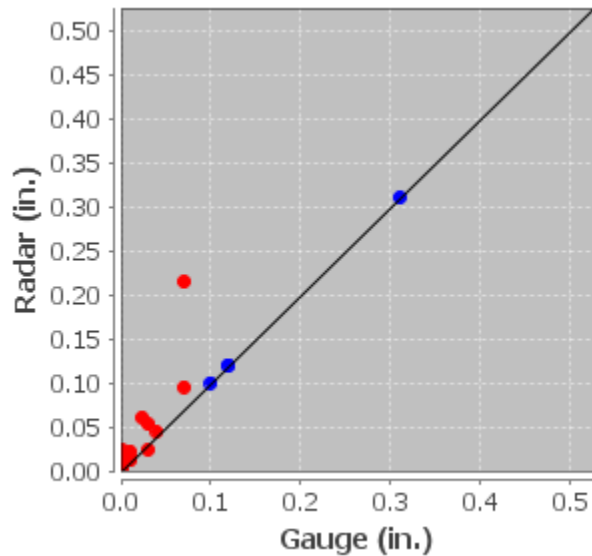


Figure 16. Scatter Plot of RG Pairs for Event 5a

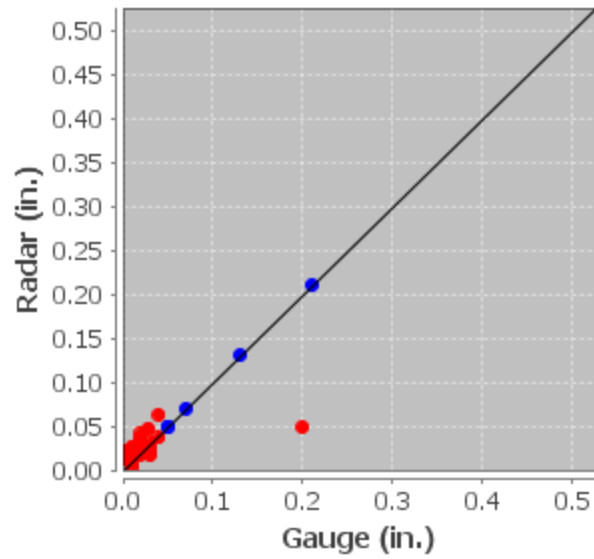


Figure 17. Scatter Plot of RG Pairs for Event 5b

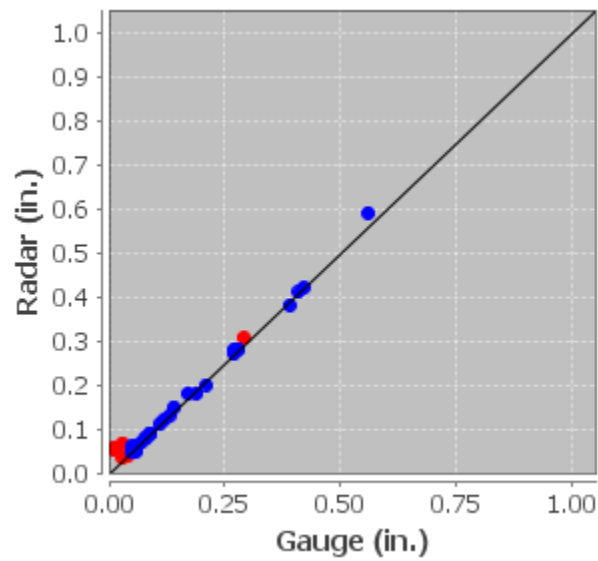


Figure 18. Scatter Plot of RG Pairs for Event 5c

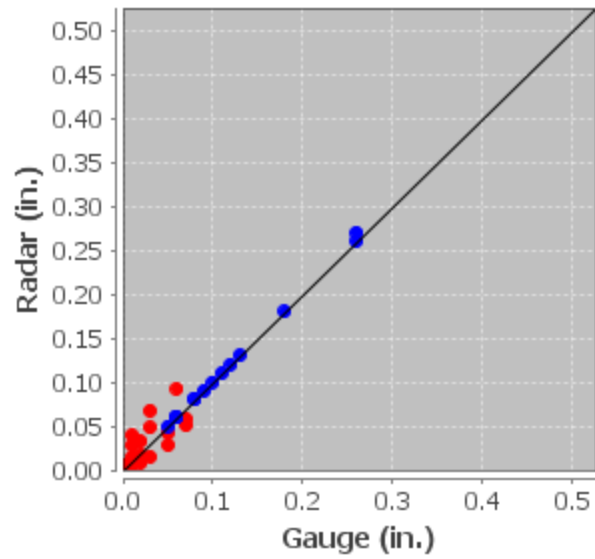


Figure 19. Scatter Plot of RG Pairs for Event 5d

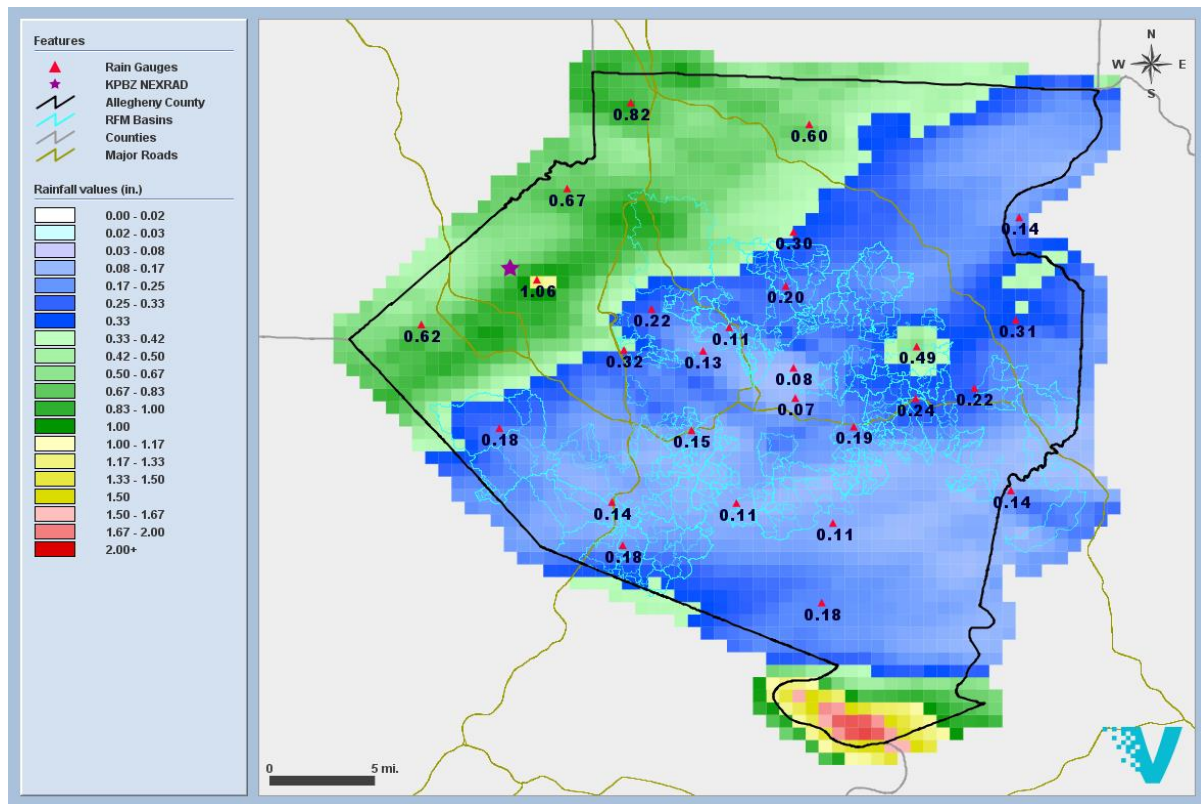


Figure 20. GARR Storm Total for Event 5

Table 26. Depth Duration Frequency Analyses for Event 5

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.723	151162	2019-07-17 21:55	2 yr.
30 minutes	0.893	154165	2019-07-17 22:40	1 yr.
1 hour	1.346	154164	2019-07-17 22:40	2 yr.
2 hour	1.414	154164	2019-07-17 22:35	2 yr.
3 hour	1.488	155165	2019-07-17 22:55	2 yr.
6 hour	1.679	155165	2019-07-17 22:55	1 yr.
12 hour	1.814	155165	2019-07-17 22:55	1 yr.

Event 6: 2019-07-22

The analysis period was from 2019-07-21 18:00 EDT to 2019-07-22 19:00 EDT. The event was then split into six sub-event periods at 2019-07-21 23:00 EDT, 2019-07-22 05:30 EDT, 2019-07-22 08:30 EDT, 2019-07-22 12:00 EDT and 2019-07-22 14:00 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 27 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 28 - 33 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 21 - 26 show the scatter plots 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 0.2 - 5.5 inches with a mean of 1.3 inches. The GARR amounts for the 440 RFM basins range from 0.4 - 4.9 inches with a mean of 1.4 inches. The GARR amounts for the 871 RFM sheds range from 0.3 - 4.9 inches with a mean of 1.4 inches. Table 34 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 27. 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	2019-07-22	2019-07-21 18:05	2019-07-21 23:00	27	0.500	1.031	19.9	4.7
E6b	KPBZ LII	2019-07-22	2019-07-21 23:05	2019-07-22 05:30	29	0.237	1.283	20.8	3.0
E6c	KPBZ LII	2019-07-22	2019-07-22 05:35	2019-07-22 08:30	7	0.036	1.121	14.9	0.7
E6d	KPBZ LII	2019-07-22	2019-07-22 08:35	2019-07-22 12:00	21	0.106	0.969	18.3	2.2
E6e	KPBZ LII	2019-07-22	2019-07-22 12:05	2019-07-22 14:00	25	0.350	1.356	25.5	1.8
E6f	KPBZ LII	2019-07-22	2019-07-22 14:05	2019-07-22 19:00	12	0.071	0.698	61.2	0.8

Table 28. Summary of Individual RG Pairs for Event 6a

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc04	Kennedy Twp PS	0.18	0.25	0.22	-0.04	-22.2	
Loc09	Univ of Pittsburgh	0.30	0.47	0.35	-0.05	-16.7	
Loc31	Hampton Municipal Bldg	0.14	0.14	0.16	-0.02	-14.3	
Loc02	ALCOSAN WWTP Lab	0.20	0.23	0.22	-0.02	-10.0	
Loc16	Castle Shannon	0.32	0.55	0.35	-0.03	-9.4	
Loc12	Baldwin	0.73	0.78	0.75	-0.02	-2.7	
Loc32	Arnold	0.80	1.12	0.82	-0.02	-2.5	
Loc20	Gascola Eq Facility	2.23	2.28	2.27	-0.04	-1.8	
Loc24	Jefferson Hills	1.16	0.94	1.17	-0.01	-0.9	
Loc14	Churchill Munic Bldg	2.56	2.70	2.58	-0.02	-0.8	
KPIT	Greater Pittsburgh Int'l	0.32	0.26	0.32	0.00	0.0	
Loc01	PWSA-Montana St.	0.15	0.15	0.15	0.00	0.0	
Loc07	Greentree Munic Bldg	0.21	0.18	0.21	0.00	0.0	
Loc15	Trafford Maint Bldg	0.32	0.30	0.32	0.00	0.0	
Loc21	Moon TWP	0.26	0.22	0.26	0.00	0.0	
Loc22	North Fayette TWP	0.30	0.29	0.30	0.00	0.0	
Loc23	Clinton Munic Bldg	0.92	0.82	0.92	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.63	0.55	0.63	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.08	0.06	0.08	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc11	M-46 Access Shaft	1.08	1.27	1.07	0.01	0.9	
Loc28	Plum Municipal Bldg	2.72	1.74	2.68	0.04	1.5	
Loc19	Sandy Creek Eq Facility	1.79	1.74	1.76	0.03	1.7	
03049500	Allegheny River at Natrona	0.32	0.34	0.31	0.01	3.1	
KAGC	Pittsburgh Allegheny Cty	0.52	0.36	0.49	0.03	5.8	
Loc03	Shaler Munic Bldg	0.12	0.07	0.11	0.01	8.3	
Loc08	AC Health Dept Bldg	0.46	0.51	0.42	0.04	8.7	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.37	0.27	0.32	0.05	13.5	
Loc05	Upper St. Clair	0.03	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	C
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc17	Chartiers Pump Station	0.00	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	Z
Loc27	Marshall TWP	0.02	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.00	---	---	---	---	MSTT
Loc33	Richland TWP	0.03	---	---	---	---	MSTT

Table 29. Summary of Individual RG Pairs for Event 6b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc09	Univ of Pittsburgh	0.39	0.35	0.46	-0.07	-17.9	
Loc14	Churchill Munic Bldg	0.09	0.10	0.10	-0.01	-11.1	
Loc02	ALCOSAN WWTP Lab	0.30	0.31	0.32	-0.02	-6.7	
Loc01	PWSA-Montana St.	0.29	0.29	0.30	-0.01	-3.4	
Loc27	Marshall TWP	1.02	0.75	1.04	-0.02	-2.0	
Loc03	Shaler Munic Bldg	0.19	0.17	0.19	0.00	0.0	
Loc04	Kennedy Twp PS	0.42	0.28	0.42	0.00	0.0	
Loc05	Upper St. Clair	0.07	0.06	0.07	0.00	0.0	
Loc07	Greentree Munic Bldg	0.08	0.08	0.08	0.00	0.0	
Loc15	Trafford Maint Bldg	0.08	0.07	0.08	0.00	0.0	
Loc16	Castle Shannon	0.09	0.08	0.09	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc17	Chartiers Pump Station	0.07	0.07	0.07	0.00	0.0	
Loc19	Sandy Creek Eq Facility	0.15	0.14	0.15	0.00	0.0	
Loc21	Moon TWP	0.17	0.09	0.17	0.00	0.0	
Loc22	North Fayette TWP	0.38	0.39	0.38	0.00	0.0	
Loc23	Clinton Munic Bldg	0.28	0.21	0.28	0.00	0.0	
Loc24	Jefferson Hills	0.12	0.06	0.12	0.00	0.0	
Loc25	White Oak Public Works Bldg	0.20	0.16	0.20	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.22	0.16	0.22	0.00	0.0	
Loc28	Plum Municipal Bldg	0.18	0.19	0.18	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.63	0.48	0.63	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.29	0.29	0.29	0.00	0.0	
Loc32	Arnold	0.11	0.07	0.11	0.00	0.0	
Loc33	Richland TWP	0.52	0.32	0.52	0.00	0.0	
Loc30	McCandless Twn Hall	0.47	0.31	0.46	0.01	2.1	
KPIT	Greater Pittsburgh Int'l	0.36	0.18	0.35	0.01	2.8	
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.35	0.23	0.34	0.01	2.9	
Loc11	M-46 Access Shaft	0.10	0.06	0.09	0.01	10.0	
Loc08	AC Health Dept Bldg	0.29	0.18	0.25	0.04	13.8	
03049500	Allegheny River at Natrona	0.05	---	---	---	---	U
KAGC	Pittsburgh Allegheny Cty	0.00	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.01	---	---	---	---	C
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc12	Baldwin	0.04	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc20	Gascola Eq Facility	0.04	---	---	---	---	MSTT

Table 30. Summary of Individual RG Pairs for Event 6c

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	0.06	0.05	0.06	0.00	0.0	
Loc14	Churchill Munic Bldg	0.05	0.05	0.05	0.00	0.0	
Loc20	Gascola Eq Facility	0.06	0.07	0.06	0.00	0.0	

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc28	Plum Municipal Bldg	0.06	0.06	0.06	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.13	0.14	0.13	0.00	0.0	
Loc30	McCandless Twn Hall	0.19	0.13	0.19	0.00	0.0	
Loc33	Richland TWP	0.11	0.08	0.11	0.00	0.0	
03049500	Allegheny River at Natrona	0.02	---	---	---	---	U
KAGC	Pittsburgh Allegheny Cty	0.01	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.03	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.03	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.01	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.03	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.04	---	---	---	---	MSTT
Loc05	Upper St. Clair	0.01	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	C
Loc07	Greentree Munic Bldg	0.01	---	---	---	---	MSTT
Loc08	AC Health Dept Bldg	0.01	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.01	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc11	M-46 Access Shaft	0.01	---	---	---	---	MSTT
Loc12	Baldwin	0.00	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc15	Trafford Maint Bldg	0.02	---	---	---	---	MSTT
Loc16	Castle Shannon	0.00	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.04	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.01	---	---	---	---	MSTT
Loc21	Moon TWP	0.00	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.03	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.01	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.00	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	MSTT
Loc26	Elizabeth TWP Municipal Bldg	0.01	---	---	---	---	MSTT
Loc27	Marshall TWP	0.03	---	---	---	---	MSTT
Loc31	Hampton Municipal Bldg	0.04	---	---	---	---	MSTT
Loc32	Arnold	0.04	---	---	---	---	MSTT

Table 31. Summary of Individual RG Pairs for Event 6d

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
Loc17	Chartiers Pump Station	0.06	0.08	0.07	-0.01	-16.7	
Loc30	McCandless Twn Hall	0.15	0.21	0.16	-0.01	-6.7	
Loc01	PWSA-Montana St.	0.21	0.20	0.21	0.00	0.0	
Loc02	ALCOSAN WWTP Lab	0.16	0.15	0.16	0.00	0.0	
Loc03	Shaler Munic Bldg	0.12	0.10	0.12	0.00	0.0	
Loc04	Kennedy Twp PS	0.10	0.09	0.10	0.00	0.0	
Loc08	AC Health Dept Bldg	0.06	0.07	0.06	0.00	0.0	
Loc11	M-46 Access Shaft	0.05	0.07	0.05	0.00	0.0	
Loc12	Baldwin	0.05	0.06	0.05	0.00	0.0	
Loc14	Churchill Munic Bldg	0.05	0.06	0.05	0.00	0.0	
Loc16	Castle Shannon	0.06	0.06	0.06	0.00	0.0	
Loc21	Moon TWP	0.17	0.16	0.17	0.00	0.0	
Loc22	North Fayette TWP	0.43	0.39	0.43	0.00	0.0	
Loc23	Clinton Munic Bldg	0.10	0.08	0.10	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.12	0.16	0.12	0.00	0.0	
Loc28	Plum Municipal Bldg	0.05	0.06	0.05	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.18	0.18	0.18	0.00	0.0	
Loc32	Arnold	0.08	0.13	0.08	0.00	0.0	
Loc33	Richland TWP	0.10	0.11	0.10	0.00	0.0	
Loc27	Marshall TWP	0.39	0.37	0.37	0.02	5.1	
Loc05	Upper St. Clair	0.13	0.11	0.12	0.01	7.7	
03049500	Allegheny River at Natrona	0.08	---	---	---	---	U
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.03	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.03	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.04	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	C
Loc07	Greentree Munic Bldg	0.03	---	---	---	---	MSTT
Loc09	Univ of Pittsburgh	0.03	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc15	Trafford Maint Bldg	0.03	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.04	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.04	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.02	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc25	White Oak Public Works Bldg	0.01	---	---	---	---	MSTT
Loc31	Hampton Municipal Bldg	0.03	---	---	---	---	MSTT

Table 32. Summary of Individual RG Pairs for Event 6e

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	0.14	0.17	-0.01	-6.3	
Loc12	Baldwin	0.59	0.48	0.62	-0.03	-5.1	
Loc09	Univ of Pittsburgh	1.22	0.97	1.28	-0.06	-4.9	
Loc17	Chartiers Pump Station	0.71	0.50	0.73	-0.02	-2.8	
Loc11	M-46 Access Shaft	1.29	1.07	1.32	-0.03	-2.3	
Loc20	Gascola Eq Facility	1.30	0.97	1.31	-0.01	-0.8	
Loc28	Plum Municipal Bldg	1.35	1.12	1.36	-0.01	-0.7	
KAGC	Pittsburgh Allegheny Cty	0.28	0.21	0.28	0.00	0.0	
KPIT	Greater Pittsburgh Int'l	0.17	0.10	0.17	0.00	0.0	
Loc03	Shaler Munic Bldg	0.48	0.37	0.48	0.00	0.0	
Loc07	Greentree Munic Bldg	0.92	0.58	0.92	0.00	0.0	
Loc15	Trafford Maint Bldg	0.52	0.47	0.52	0.00	0.0	
Loc21	Moon TWP	0.64	0.41	0.64	0.00	0.0	
Loc22	North Fayette TWP	0.79	0.54	0.79	0.00	0.0	
Loc23	Clinton Munic Bldg	0.51	0.37	0.51	0.00	0.0	
Loc24	Jefferson Hills	0.09	0.08	0.09	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.07	0.06	0.07	0.00	0.0	
Loc32	Arnold	0.28	0.24	0.28	0.00	0.0	
Loc19	Sandy Creek Eq Facility	1.07	0.74	1.06	0.01	0.9	
Loc14	Churchill Munic Bldg	1.45	1.03	1.43	0.02	1.4	
Loc02	ALCOSAN WWTP Lab	0.67	0.48	0.66	0.01	1.5	
Loc04	Kennedy Twp PS	0.59	0.45	0.58	0.01	1.7	
Loc05	Upper St. Clair	0.48	0.30	0.47	0.01	2.1	
Loc16	Castle Shannon	0.63	0.36	0.61	0.02	3.2	
Loc08	AC Health Dept Bldg	0.91	0.63	0.86	0.05	5.5	
03049500	Allegheny River at Natrona	0.10	---	---	---	---	U
Loc01	PWSA-Montana St.	0.74	---	---	---	---	O
Loc06	Carnegie Transit Time	0.00	---	---	---	---	C

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	Z
Loc27	Marshall TWP	0.05	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.05	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.10	---	---	---	---	O
Loc31	Hampton Municipal Bldg	0.06	---	---	---	---	OAD
Loc33	Richland TWP	0.02	---	---	---	---	MSTT

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc05	Upper St. Clair	0.11	0.05	0.11	0.00	0.0	
Loc07	Greentree Munic Bldg	0.06	0.07	0.06	0.00	0.0	
Loc09	Univ of Pittsburgh	0.06	0.10	0.06	0.00	0.0	
Loc12	Baldwin	0.06	0.10	0.06	0.00	0.0	
Loc16	Castle Shannon	0.05	0.10	0.05	0.00	0.0	
Loc21	Moon TWP	0.09	0.05	0.09	0.00	0.0	
Loc24	Jefferson Hills	0.05	0.16	0.05	0.00	0.0	
Loc26	Elizabeth TWP Municipal Bldg	0.28	0.63	0.28	0.00	0.0	
Loc28	Plum Municipal Bldg	0.08	0.05	0.08	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.06	0.06	0.06	0.00	0.0	
Loc30	McCandless Twn Hall	0.08	0.06	0.08	0.00	0.0	
Loc33	Richland TWP	0.06	0.06	0.06	0.00	0.0	
03049500	Allegheny River at Natrona	0.05	---	---	---	---	MSTT
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.02	---	---	---	---	MSTT
KAGC	Pittsburgh Allegheny Cty	0.02	---	---	---	---	MSTT
KPIT	Greater Pittsburgh Int'l	0.02	---	---	---	---	MSTT
Loc01	PWSA-Montana St.	0.03	---	---	---	---	MSTT
Loc02	ALCOSAN WWTP Lab	0.05	---	---	---	---	MSTT
Loc03	Shaler Munic Bldg	0.00	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.03	---	---	---	---	MSTT
Loc06	Carnegie Transit Time	0.00	---	---	---	---	C

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
Loc08	AC Health Dept Bldg	0.03	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc11	M-46 Access Shaft	0.04	---	---	---	---	MSTT
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.03	---	---	---	---	MSTT
Loc15	Trafford Maint Bldg	0.03	---	---	---	---	MSTT
Loc17	Chartiers Pump Station	0.02	---	---	---	---	MSTT
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc19	Sandy Creek Eq Facility	0.03	---	---	---	---	MSTT
Loc20	Gascola Eq Facility	0.02	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.03	---	---	---	---	MSTT
Loc25	White Oak Public Works Bldg	0.00	---	---	---	---	Z
Loc27	Marshall TWP	0.03	---	---	---	---	MSTT
Loc31	Hampton Municipal Bldg	0.03	---	---	---	---	MSTT
Loc32	Arnold	0.03	---	---	---	---	MSTT

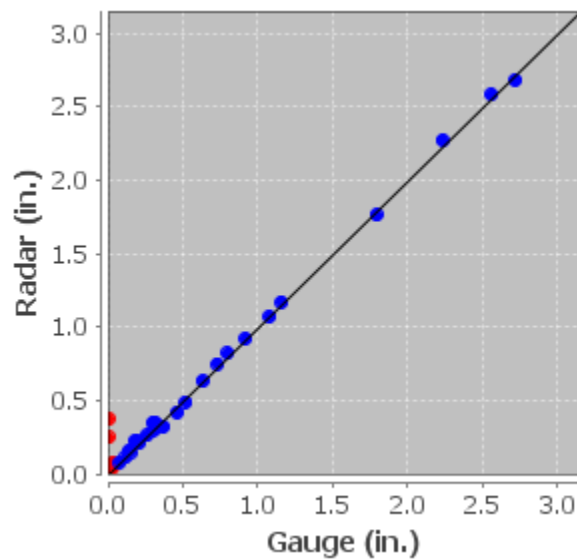


Figure 21. Scatter Plot of RG Pairs for Event 6a

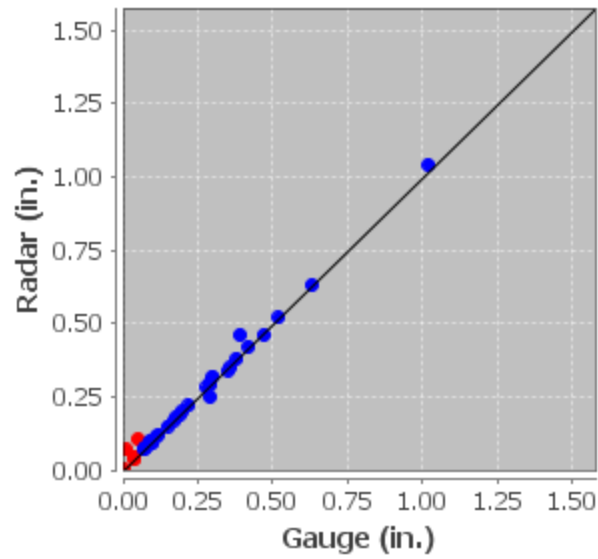


Figure 22. Scatter Plot of RG Pairs for Event 6b

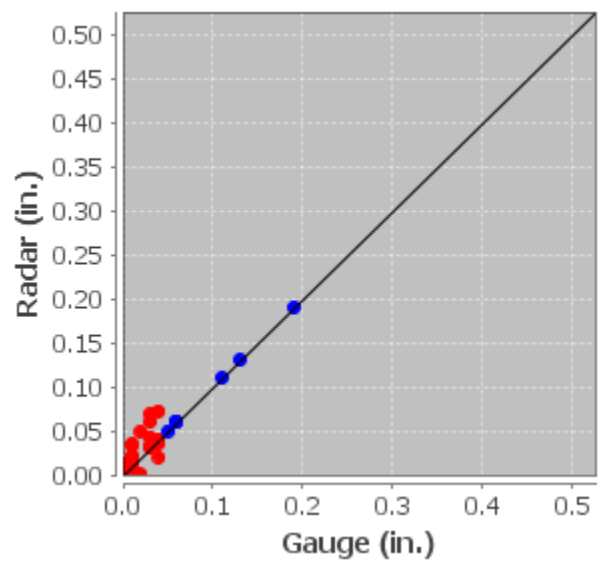


Figure 23. Scatter Plot of RG Pairs for Event 6c

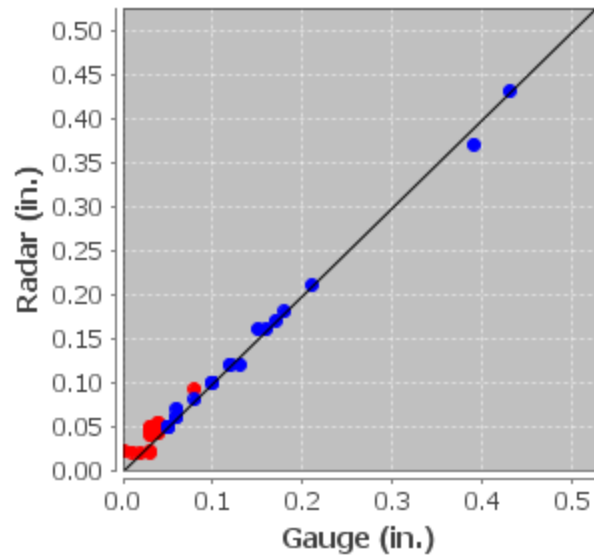


Figure 24. Scatter Plot of RG Pairs for Event 6d

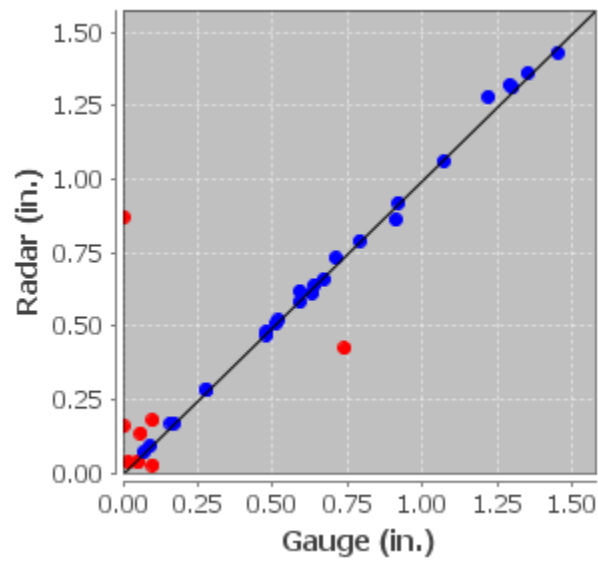


Figure 25. Scatter Plot of RG Pairs for Event 6e

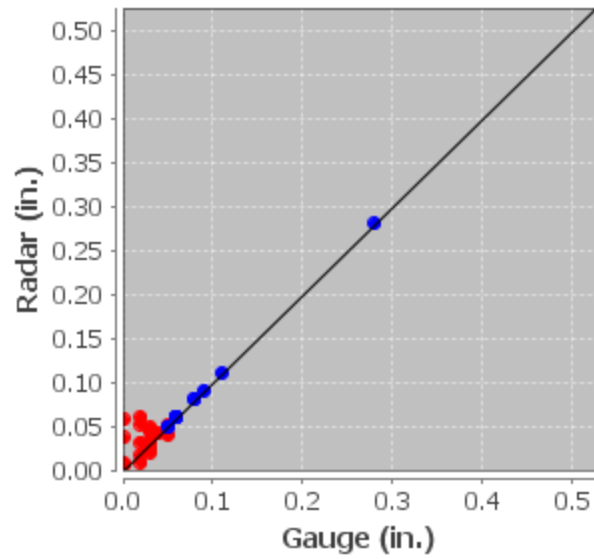


Figure 26. Scatter Plot of RG Pairs for Event 6f

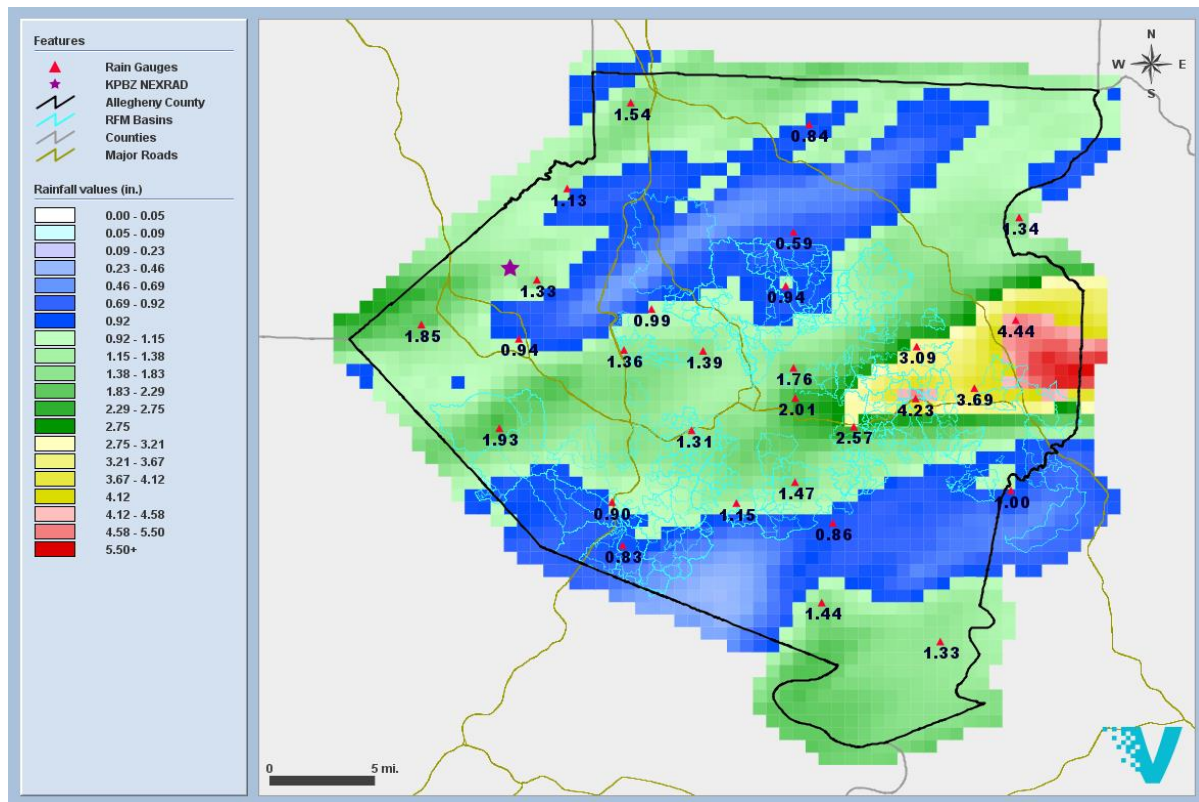


Figure 27. GARR Storm Total for Event 6

Table 34. Depth Duration Frequency Analyses for Event 6

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	1.232	158138	2019-07-21 22:05	50 yr.
30 minutes	2.290	171137	2019-07-21 21:40	200 yr.
1 hour	3.866	171137	2019-07-21 21:55	1000 yr.
2 hour	4.535	171137	2019-07-21 22:45	1000 yr.
3 hour	4.535	171137	2019-07-21 22:45	1000 yr.
6 hour	4.535	171137	2019-07-22 00:00	200 yr.
12 hour	4.707	172136	2019-07-22 08:15	100 yr.
24 hour	5.456	172136	2019-07-22 18:00	200 yr.

Event 7: 2019-07-30

The analysis period was from 2019-07-30 15:00 EDT to 2019-07-31 02:00 EDT. The event was then split into two sub-event periods at 2019-07-30 19:00 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 35 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 36 - 37 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 0.0 - 2.6 inches with a mean of 0.5 inches. The GARR amounts for the 440 RFM basins range from 0.0 - 2.0 inches with a mean of 0.6 inches. The GARR amounts for the 871 RFM sheds range from 0.0 - 2.5 inches with a mean of 0.5 inches. Table 38 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 35. 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	2019-07-30	2019-07-30 15:05	2019-07-30 19:00	5	0.052	0.765	32.5	1.2

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (37)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E7b	KPBZ LII	2019-07-30	2019-07-30 19:05	2019-07-31 02:00	27	0.464	0.732	44.5	3.5

Table 36. Summary of Individual RG Pairs for Event 7a

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
KAGC	Pittsburgh Allegheny Cty	0.26	0.34	0.26	0.00	0.0	
Loc11	M-46 Access Shaft	0.12	0.11	0.12	0.00	0.0	
Loc12	Baldwin	0.20	0.28	0.20	0.00	0.0	
Loc15	Trafford Maint Bldg	0.76	0.94	0.76	0.00	0.0	
Loc16	Castle Shannon	0.30	0.47	0.30	0.00	0.0	
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.	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
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc14	Churchill Munic Bldg	0.01	---	---	---	---	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	0.00	---	---	---	---	MSTT
Loc22	North Fayette TWP	0.00	---	---	---	---	MSTT
Loc23	Clinton Munic Bldg	0.00	---	---	---	---	MSTT
Loc24	Jefferson Hills	0.14	---	---	---	---	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
Loc26	Elizabeth TWP Municipal Bldg	0.00	---	---	---	---	MSTT
Loc27	Marshall TWP	0.00	---	---	---	---	MSTT
Loc28	Plum Municipal Bldg	0.00	---	---	---	---	MSTT
Loc29	Bell Acres Munic Bldg	0.00	---	---	---	---	MSTT
Loc30	McCandless Twn Hall	0.01	---	---	---	---	MSTT
Loc31	Hampton Municipal Bldg	0.00	---	---	---	---	MSTT
Loc32	Arnold	0.00	---	---	---	---	MSTT
Loc33	Richland TWP	0.00	---	---	---	---	MSTT

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

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	0.05	0.11	0.06	-0.01	-20.0	
Loc08	AC Health Dept Bldg	0.58	0.94	0.64	-0.06	-10.3	
KPIT	Greater Pittsburgh Int'l	0.12	0.19	0.13	-0.01	-8.3	
Loc14	Churchill Munic Bldg	0.45	0.63	0.48	-0.03	-6.7	
Loc16	Castle Shannon	0.62	1.19	0.66	-0.04	-6.5	
Loc24	Jefferson Hills	0.20	0.43	0.21	-0.01	-5.0	
Loc06	Carnegie Transit Time	0.72	1.08	0.75	-0.03	-4.2	
Loc05	Upper St. Clair	0.32	0.56	0.33	-0.01	-3.1	
Loc12	Baldwin	0.94	1.32	0.95	-0.01	-1.1	
Loc01	PWSA-Montana St.	0.05	0.06	0.05	0.00	0.0	
Loc02	ALCOSAN WWTP Lab	0.06	0.07	0.06	0.00	0.0	
Loc15	Trafford Maint Bldg	1.40	2.20	1.40	0.00	0.0	
Loc22	North Fayette TWP	0.52	0.76	0.52	0.00	0.0	
Loc23	Clinton Munic Bldg	0.24	0.47	0.24	0.00	0.0	
Loc28	Plum Municipal Bldg	0.30	0.52	0.30	0.00	0.0	
Loc29	Bell Acres Munic Bldg	0.13	0.13	0.13	0.00	0.0	
Loc31	Hampton Municipal Bldg	0.93	0.99	0.93	0.00	0.0	
Loc32	Arnold	0.44	0.58	0.44	0.00	0.0	
Loc33	Richland TWP	1.42	1.73	1.42	0.00	0.0	
Loc17	Chartiers Pump Station	0.71	1.09	0.70	0.01	1.4	
Loc20	Gascola Eq Facility	0.72	0.93	0.71	0.01	1.4	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
KAGC	Pittsburgh Allegheny Cty	1.09	1.30	1.05	0.04	3.7	
Loc11	M-46 Access Shaft	0.52	0.57	0.50	0.02	3.8	
Loc19	Sandy Creek Eq Facility	1.45	1.63	1.39	0.06	4.1	
Loc07	Greentree Munic Bldg	0.44	0.51	0.42	0.02	4.5	
Loc09	Univ of Pittsburgh	1.08	1.42	1.02	0.06	5.6	
Loc21	Moon TWP	0.52	0.47	0.49	0.03	5.8	
03049500	Allegheny River at Natrona	0.05	---	---	---	---	U
Loc03	Shaler Munic Bldg	0.01	---	---	---	---	MSTT
Loc04	Kennedy Twp PS	0.04	---	---	---	---	MSTT
Loc10	PWSA-Highland Park	ND	---	---	---	---	ND
Loc13	M-59 Access Shaft	ND	---	---	---	---	ND
Loc18	Oakdale Pump Station	ND	---	---	---	---	ND
Loc25	White Oak Public Works Bldg	0.03	---	---	---	---	S
Loc26	Elizabeth TWP Municipal Bldg	0.03	---	---	---	---	MSTT
Loc27	Marshall TWP	0.20	---	---	---	---	O
Loc30	McCandless Twn Hall	0.04	---	---	---	---	U

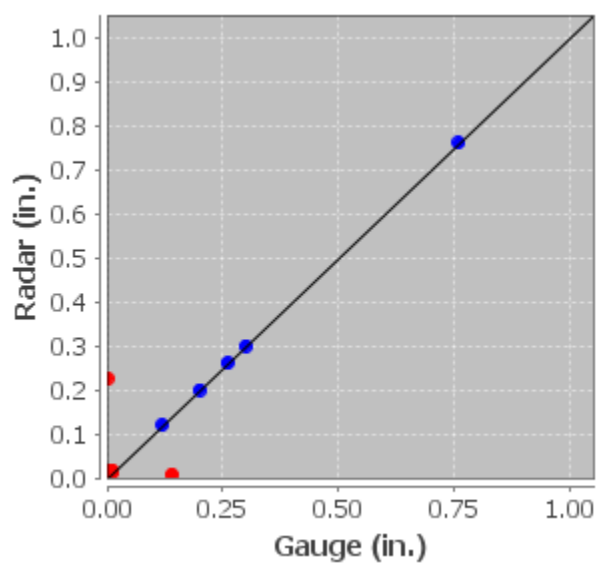


Figure 28. Scatter Plot of RG Pairs for Event 7a

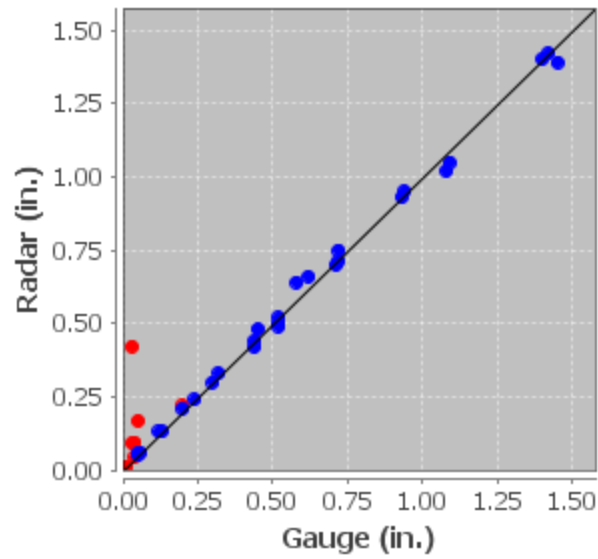


Figure 29. Scatter Plot of RG Pairs for Event 7b

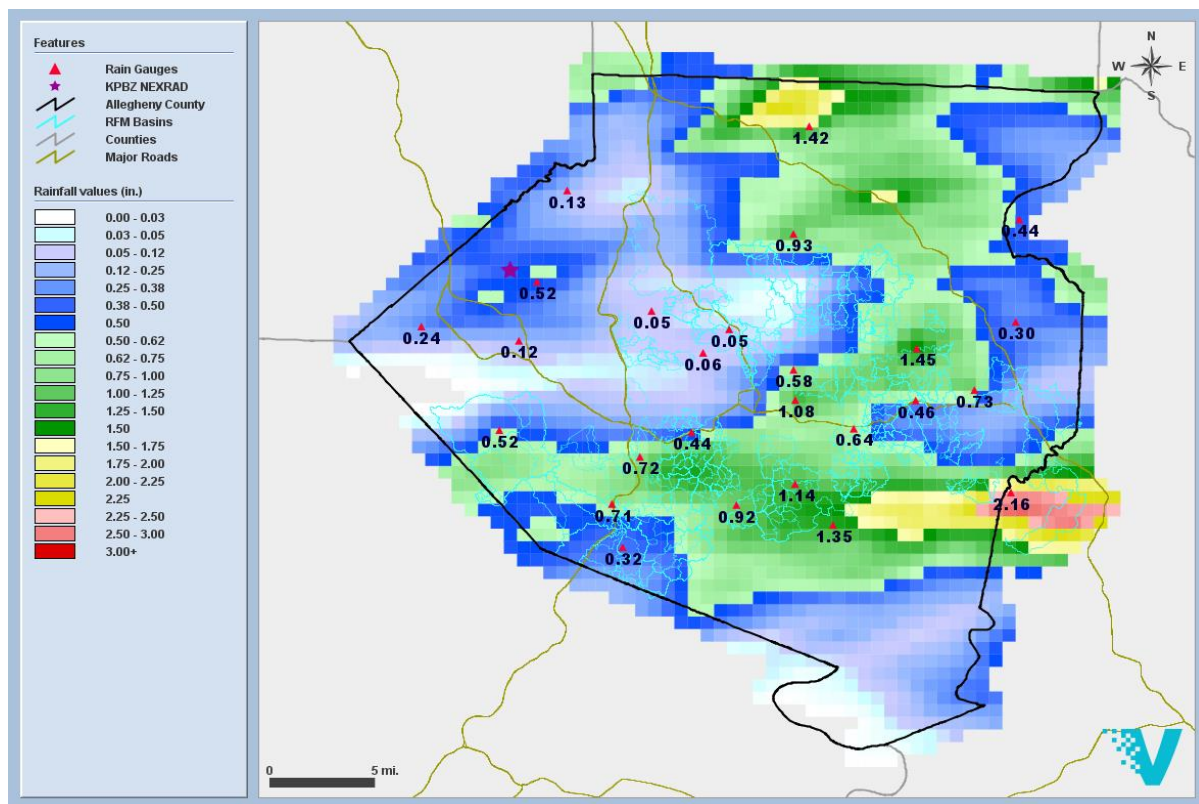


Figure 30. GARR Storm Total for Event 7

Table 38. Depth Duration Frequency Analyses for Event 7

Duration	Depth (in)	Pixel	Time (EDT)	Frequency
15 minutes	0.986	150116	2019-07-30 21:00	10 yr.
30 minutes	1.474	150114	2019-07-30 21:00	10 yr.
1 hour	2.048	149115	2019-07-30 21:05	10 yr.
2 hour	2.141	149115	2019-07-30 21:05	10 yr.
3 hour	2.176	149115	2019-07-30 21:30	10 yr.
6 hour	2.597	167147	2019-07-30 23:25	10 yr.

Appendices

[Appendix A](#) - Gauge Performance Exclusion Table
[Appendix B](#) - Gauge Statistical Criteria Exclusion Table
[Appendix C](#) - Event 1 (2019-07-02) CDPs
[Appendix D](#) - Event 2 (2019-07-06) CDPs
[Appendix E](#) - Event 3 (2019-07-07) CDPs
[Appendix F](#) - Event 4 (2019-07-11) CDPs
[Appendix G](#) - Event 5 (2019-07-17) CDPs
[Appendix H](#) - Event 6 (2019-07-22) CDPs
[Appendix I](#) - Event 7 (2019-07-30) 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 #	<u>E1</u>	<u>E2</u>	<u>E3a</u>	<u>E3b</u>	<u>E4a</u>
Event Date	2019-07-02	2019-07-06	2019-07-07	2019-07-07	2019-07-11
Start Time (EDT)	2019-07-02 11:05	2019-07-06 07:05	2019-07-07 03:05	2019-07-07 10:05	2019-07-11 03:05
End Time (EDT)	2019-07-03 05:00	2019-07-06 21:00	2019-07-07 10:00	2019-07-07 21:00	2019-07-11 07:00
Loc01	U	U	U		O
Loc02					
Loc03					
Loc04					
Loc05	C	C	C	C	
Loc06					
Loc07					
Loc08					
Loc09					
Loc10	ND	ND	ND	ND	ND
Loc11					
Loc12					
Loc13	ND	ND	ND	ND	ND
Loc14					
Loc15					
Loc16					
Loc17					
Loc18	ND	ND	ND	ND	ND
Loc19					
Loc20	ND	ND	ND	ND	ND
Loc21					
Loc22					
Loc23					
Loc24					
Loc25					

Event #	E1	E2	E3a	E3b	E4a
Event Date	2019-07-02	2019-07-06	2019-07-07	2019-07-07	2019-07-11
Start Time (EDT)	2019-07-02 11:05	2019-07-06 07:05	2019-07-07 03:05	2019-07-07 10:05	2019-07-11 03:05
End Time (EDT)	2019-07-03 05:00	2019-07-06 21:00	2019-07-07 10:00	2019-07-07 21:00	2019-07-11 07:00
Loc26	C	C	C	C	
Loc27					
Loc28					
Loc29					
Loc30					
Loc31					
Loc32					
Loc33					
KAGC			U		
KPIT					
03049500					
03085734					

Event #	E4b	E4c	E4d	E5a	E5b
Event Date	2019-07-11	2019-07-11	2019-07-11	2019-07-17	2019-07-17
Start Time (EDT)	2019-07-11 07:05	2019-07-11 09:05	2019-07-11 10:05	2019-07-17 08:05	2019-07-17 11:15
End Time (EDT)	2019-07-11 09:00	2019-07-11 10:00	2019-07-11 22:00	2019-07-17 11:10	2019-07-17 13:45
Loc01					
Loc02					
Loc03					
Loc04					
Loc05	C	C	C		
Loc06	C		C		C
Loc07					
Loc08					
Loc09					
Loc10	ND	ND	ND	ND	ND
Loc11					
Loc12					
Loc13	ND	ND	ND	ND	ND
Loc14					
Loc15					
Loc16					
Loc17					
Loc18	ND	ND	ND	ND	ND
Loc19					
Loc20	ND	ND	ND		
Loc21	O				
Loc22					
Loc23					

Event #	E4b	E4c	E4d	E5a	E5b
Event Date	2019-07-11	2019-07-11	2019-07-11	2019-07-17	2019-07-17
Start Time (EDT)	2019-07-11 07:05	2019-07-11 09:05	2019-07-11 10:05	2019-07-17 08:05	2019-07-17 11:15
End Time (EDT)	2019-07-11 09:00	2019-07-11 10:00	2019-07-11 22:00	2019-07-17 11:10	2019-07-17 13:45
Loc24					
Loc25					
Loc26					
Loc27					
Loc28					
Loc29					
Loc30		U		U	
Loc31					
Loc32					
Loc33					
KAGC					
KPIT				U	O
03049500					
03085734					

Event #	E5c	E5d	E6a	E6b	E6c
Event Date	2019-07-17	2019-07-17	2019-07-22	2019-07-22	2019-07-22
Start Time (EDT)	2019-07-17 13:50	2019-07-17 17:35	2019-07-21 18:05	2019-07-21 23:05	2019-07-22 05:35
End Time (EDT)	2019-07-17 17:30	2019-07-18 01:00	2019-07-21 23:00	2019-07-22 05:30	2019-07-22 08:30
Loc01					
Loc02					
Loc03					
Loc04					
Loc05					
Loc06	C	C	C	C	C
Loc07					
Loc08					
Loc09					
Loc10	ND	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					

Event #	E5c	E5d	E6a	E6b	E6c
Event Date	2019-07-17	2019-07-17	2019-07-22	2019-07-22	2019-07-22
Start Time (EDT)	2019-07-17 13:50	2019-07-17 17:35	2019-07-21 18:05	2019-07-21 23:05	2019-07-22 05:35
End Time (EDT)	2019-07-17 17:30	2019-07-18 01:00	2019-07-21 23:00	2019-07-22 05:30	2019-07-22 08:30
Loc24					
Loc25			Z		
Loc26					
Loc27					
Loc28					
Loc29					
Loc30	U				
Loc31					
Loc32					
Loc33					
KAGC					
KPIT					
03049500	U			U	U
03085734					

Event #	E6d	E6e	E6f	E7a	E7b
Event Date	2019-07-22	2019-07-22	2019-07-22	2019-07-30	2019-07-30
Start Time (EDT)	2019-07-22 08:35	2019-07-22 12:05	2019-07-22 14:05	2019-07-30 15:05	2019-07-30 19:05
End Time (EDT)	2019-07-22 12:00	2019-07-22 14:00	2019-07-22 19:00	2019-07-30 19:00	2019-07-31 02:00
Loc01		O			
Loc02					
Loc03					
Loc04					
Loc05					
Loc06	C	C	C		
Loc07					
Loc08					
Loc09					
Loc10	ND	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					

Event #	E6d	E6e	E6f	E7a	E7b
Event Date	2019-07-22	2019-07-22	2019-07-22	2019-07-30	2019-07-30
Start Time (EDT)	2019-07-22 08:35	2019-07-22 12:05	2019-07-22 14:05	2019-07-30 15:05	2019-07-30 19:05
End Time (EDT)	2019-07-22 12:00	2019-07-22 14:00	2019-07-22 19:00	2019-07-30 19:00	2019-07-31 02:00
Loc24				O	
Loc25		Z	Z	Z	S
Loc26					
Loc27					O
Loc28					
Loc29					
Loc30		O			U
Loc31					
Loc32					
Loc33					
KAGC					
KPIT					
03049500	U	U			U
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 #	E1	E2	E3a	E3b	E4a
Event Date	2019-07-02	2019-07-06	2019-07-07	2019-07-07	2019-07-11
Start Time (EDT)	2019-07-02 11:05	2019-07-06 07:05	2019-07-07 03:05	2019-07-07 10:05	2019-07-11 03:05
End Time (EDT)	2019-07-03 05:00	2019-07-06 21:00	2019-07-07 10:00	2019-07-07 21:00	2019-07-11 07:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc01				MSTT	
Loc02					
Loc03				MSTT	
Loc04				MSTT	
Loc05					MSTT
Loc06					MSTT
Loc07				MSTT	MSTT
Loc08					
Loc09				MSTT	
Loc10					
Loc11				MSTT	MSTT
Loc12				MSTT	MSTT
Loc13					
Loc14				MSTT	
Loc15				MSTT	MSTT
Loc16			MSTT		MSTT
Loc17			MSTT		MSTT
Loc18					
Loc19				MSTT	
Loc20					
Loc21					
Loc22			MSTT		MSTT
Loc23			MSTT	MSTT	MSTT
Loc24				MSTT	MSTT

Event #	<u>E1</u>	<u>E2</u>	<u>E3a</u>	<u>E3b</u>	<u>E4a</u>
Event Date	2019-07-02	2019-07-06	2019-07-07	2019-07-07	2019-07-11
Start Time (EDT)	2019-07-02 11:05	2019-07-06 07:05	2019-07-07 03:05	2019-07-07 10:05	2019-07-11 03:05
End Time (EDT)	2019-07-03 05:00	2019-07-06 21:00	2019-07-07 10:00	2019-07-07 21:00	2019-07-11 07:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc25				MSTT	MSTT
Loc26					MSTT
Loc27			MSTT		MSTT
Loc28			MSTT	MSTT	
Loc29					
Loc30					
Loc31				MSTT	
Loc32			MSTT	MSTT	
Loc33	OAD		MSTT	MSTT	
KAGC				MSTT	MSTT
KPIT				MSTT	
03049500	MSTT		MSTT	MSTT	
03085734				MSTT	

Event #	<u>E4b</u>	<u>E4c</u>	<u>E4d</u>	<u>E5a</u>	<u>E5b</u>
Event Date	2019-07-11	2019-07-11	2019-07-11	2019-07-17	2019-07-17
Start Time (EDT)	2019-07-11 07:05	2019-07-11 09:05	2019-07-11 10:05	2019-07-17 08:05	2019-07-17 11:15
End Time (EDT)	2019-07-11 09:00	2019-07-11 10:00	2019-07-11 22:00	2019-07-17 11:10	2019-07-17 13:45
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KCCX LIII
Loc01		MSTT		MSTT	MSTT
Loc02		MSTT		MSTT	MSTT
Loc03		MSTT		MSTT	MSTT
Loc04		MSTT		MSTT	MSTT
Loc05				MSTT	MSTT
Loc06		MSTT		MSTT	
Loc07		MSTT		MSTT	MSTT
Loc08		MSTT		MSTT	MSTT
Loc09		MSTT		MSTT	MSTT
Loc10					
Loc11				MSTT	MSTT
Loc12		MSTT		MSTT	MSTT
Loc13					
Loc14				MSTT	MSTT
Loc15				MSTT	MSTT
Loc16		MSTT		MSTT	MSTT
Loc17		MSTT		MSTT	MSTT
Loc18					
Loc19		MSTT		MSTT	
Loc20				MSTT	MSTT
Loc21		MSTT			
Loc22		MSTT		MSTT	MSTT

Event #	E4b	E4c	E4d	E5a	E5b
Event Date	2019-07-11	2019-07-11	2019-07-11	2019-07-17	2019-07-17
Start Time (EDT)	2019-07-11 07:05	2019-07-11 09:05	2019-07-11 10:05	2019-07-17 08:05	2019-07-17 11:15
End Time (EDT)	2019-07-11 09:00	2019-07-11 10:00	2019-07-11 22:00	2019-07-17 11:10	2019-07-17 13:45
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KCCX LIII
Loc23		MSTT			MSTT
Loc24				MSTT	MSTT
Loc25				MSTT	MSTT
Loc26				MSTT	MSTT
Loc27	MSTT				MSTT
Loc28		MSTT		MSTT	MSTT
Loc29					MSTT
Loc30					
Loc31		MSTT		MSTT	MSTT
Loc32		MSTT		MSTT	
Loc33				MSTT	
KAGC				MSTT	MSTT
KPIT		MSTT			
03049500	OMFB	MSTT		MSTT	MSTT
03085734		MSTT		MSTT	MSTT

Event #	E5c	E5d	E6a	E6b	E6c
Event Date	2019-07-17	2019-07-17	2019-07-22	2019-07-22	2019-07-22
Start Time (EDT)	2019-07-17 13:50	2019-07-17 17:35	2019-07-21 18:05	2019-07-21 23:05	2019-07-22 05:35
End Time (EDT)	2019-07-17 17:30	2019-07-18 01:00	2019-07-21 23:00	2019-07-22 05:30	2019-07-22 08:30
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc01		OAD			MSTT
Loc02		MSTT			MSTT
Loc03					MSTT
Loc04					MSTT
Loc05		MSTT	MSTT		MSTT
Loc06					
Loc07					MSTT
Loc08		MSTT			MSTT
Loc09		MSTT			MSTT
Loc10					
Loc11		MSTT			MSTT
Loc12	MSTT	MSTT		MSTT	MSTT
Loc13					
Loc14		MSTT			
Loc15					MSTT
Loc16		MSTT			MSTT
Loc17		MSTT	MSTT		MSTT
Loc18					
Loc19					MSTT
Loc20		MSTT		MSTT	
Loc21					MSTT
Loc22		MSTT			MSTT

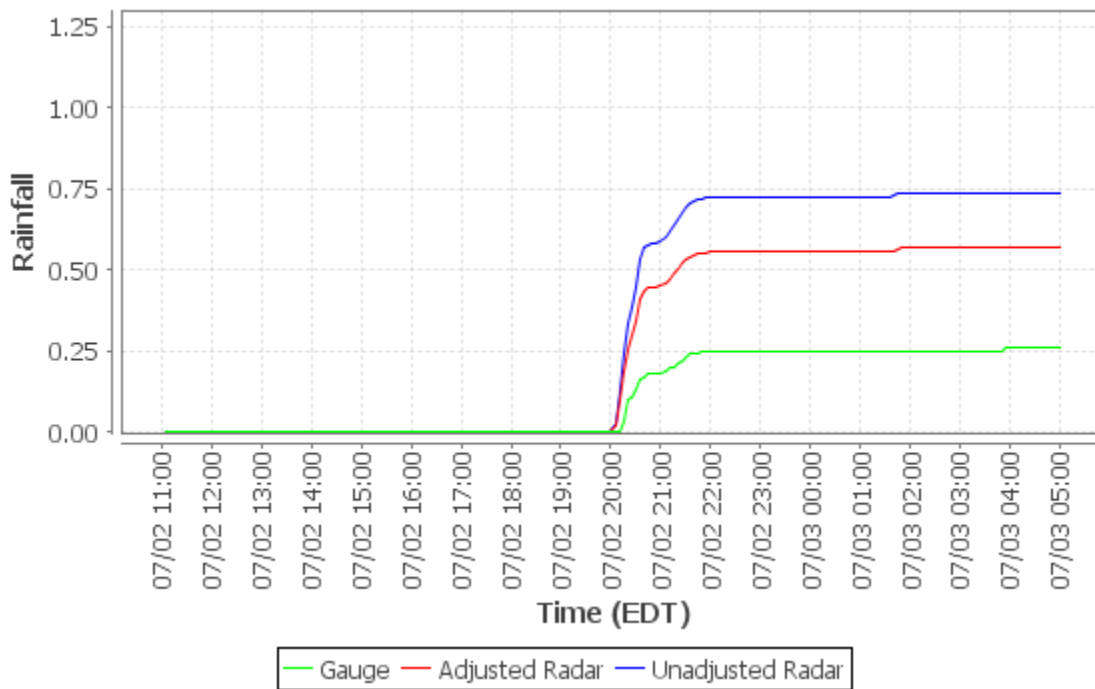
Event #	E5c	E5d	E6a	E6b	E6c
Event Date	2019-07-17	2019-07-17	2019-07-22	2019-07-22	2019-07-22
Start Time (EDT)	2019-07-17 13:50	2019-07-17 17:35	2019-07-21 18:05	2019-07-21 23:05	2019-07-22 05:35
End Time (EDT)	2019-07-17 17:30	2019-07-18 01:00	2019-07-21 23:00	2019-07-22 05:30	2019-07-22 08:30
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc23					MSTT
Loc24					MSTT
Loc25	MSTT	MSTT			MSTT
Loc26	MSTT	MSTT			MSTT
Loc27			MSTT		MSTT
Loc28		MSTT			
Loc29					
Loc30			MSTT		
Loc31					MSTT
Loc32		MSTT			MSTT
Loc33			MSTT		
KAGC		MSTT		MSTT	MSTT
KPIT					MSTT
03049500		MSTT			
03085734		MSTT			

Event #	E6d	E6e	E6f	E7a	E7b
Event Date	2019-07-22	2019-07-22	2019-07-22	2019-07-30	2019-07-30
Start Time (EDT)	2019-07-22 08:35	2019-07-22 12:05	2019-07-22 14:05	2019-07-30 15:05	2019-07-30 19:05
End Time (EDT)	2019-07-22 12:00	2019-07-22 14:00	2019-07-22 19:00	2019-07-30 19:00	2019-07-31 02:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc01			MSTT	MSTT	
Loc02			MSTT	MSTT	
Loc03			MSTT	MSTT	MSTT
Loc04			MSTT	MSTT	MSTT
Loc05				MSTT	
Loc06				MSTT	
Loc07	MSTT			MSTT	
Loc08			MSTT	MSTT	
Loc09	MSTT			MSTT	
Loc10					
Loc11			MSTT		
Loc12					
Loc13					
Loc14			MSTT	MSTT	
Loc15	MSTT		MSTT		
Loc16					
Loc17			MSTT	MSTT	
Loc18					
Loc19	MSTT		MSTT	MSTT	
Loc20	MSTT		MSTT	MSTT	
Loc21				MSTT	
Loc22			MSTT	MSTT	

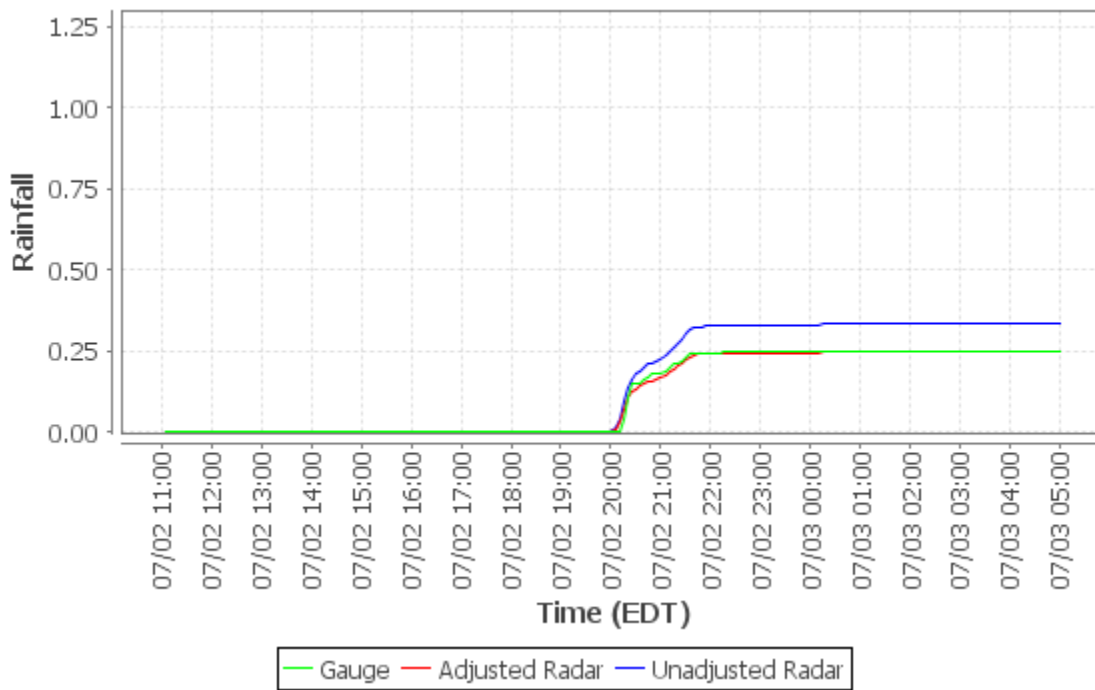
Event #	E6d	E6e	E6f	E7a	E7b
Event Date	2019-07-22	2019-07-22	2019-07-22	2019-07-30	2019-07-30
Start Time (EDT)	2019-07-22 08:35	2019-07-22 12:05	2019-07-22 14:05	2019-07-30 15:05	2019-07-30 19:05
End Time (EDT)	2019-07-22 12:00	2019-07-22 14:00	2019-07-22 19:00	2019-07-30 19:00	2019-07-31 02:00
Source	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII	KPBZ LII
Loc23			MSTT	MSTT	
Loc24	MSTT				
Loc25	MSTT				
Loc26				MSTT	MSTT
Loc27		MSTT	MSTT	MSTT	
Loc28				MSTT	
Loc29		MSTT		MSTT	
Loc30				MSTT	
Loc31	MSTT	OAD	MSTT	MSTT	
Loc32			MSTT	MSTT	
Loc33		MSTT		MSTT	
KAGC	MSTT		MSTT		
KPIT	MSTT		MSTT	MSTT	
03049500			MSTT	MSTT	
03085734	MSTT		MSTT	MSTT	

Appendix C - Event 1 (2019-07-02) CDPs

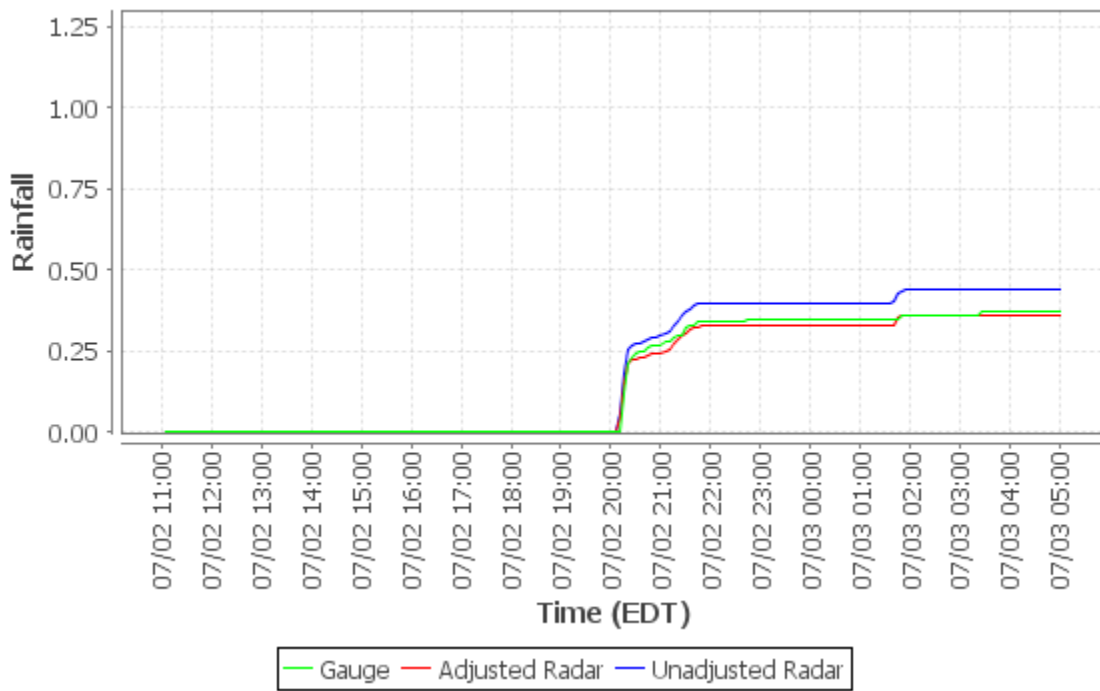
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



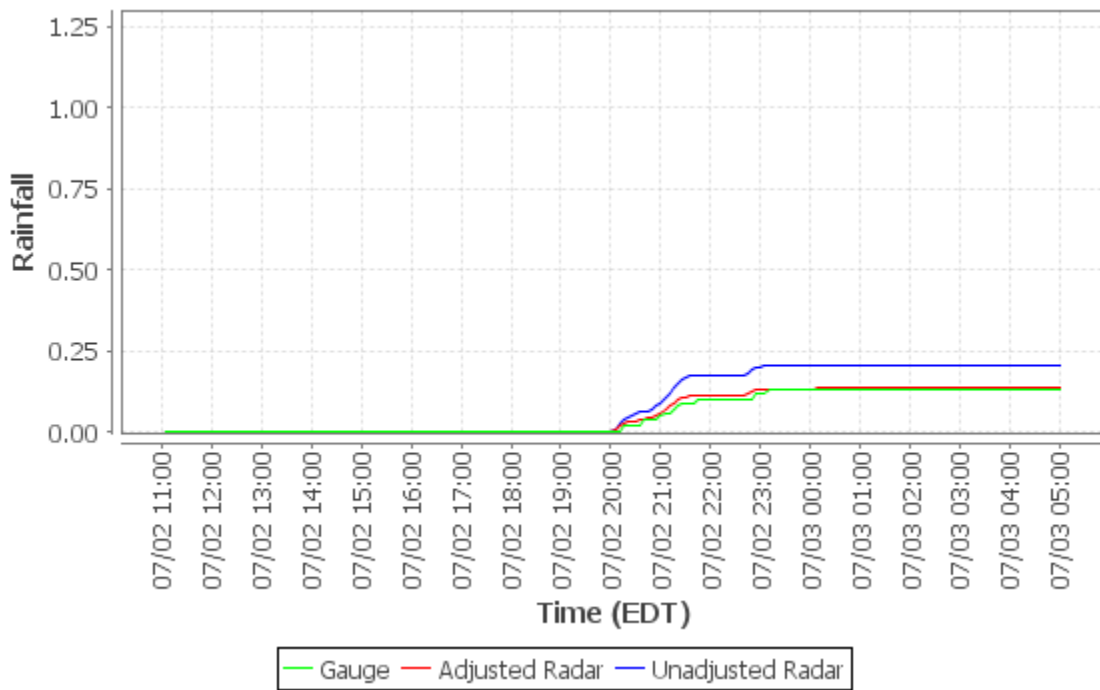
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



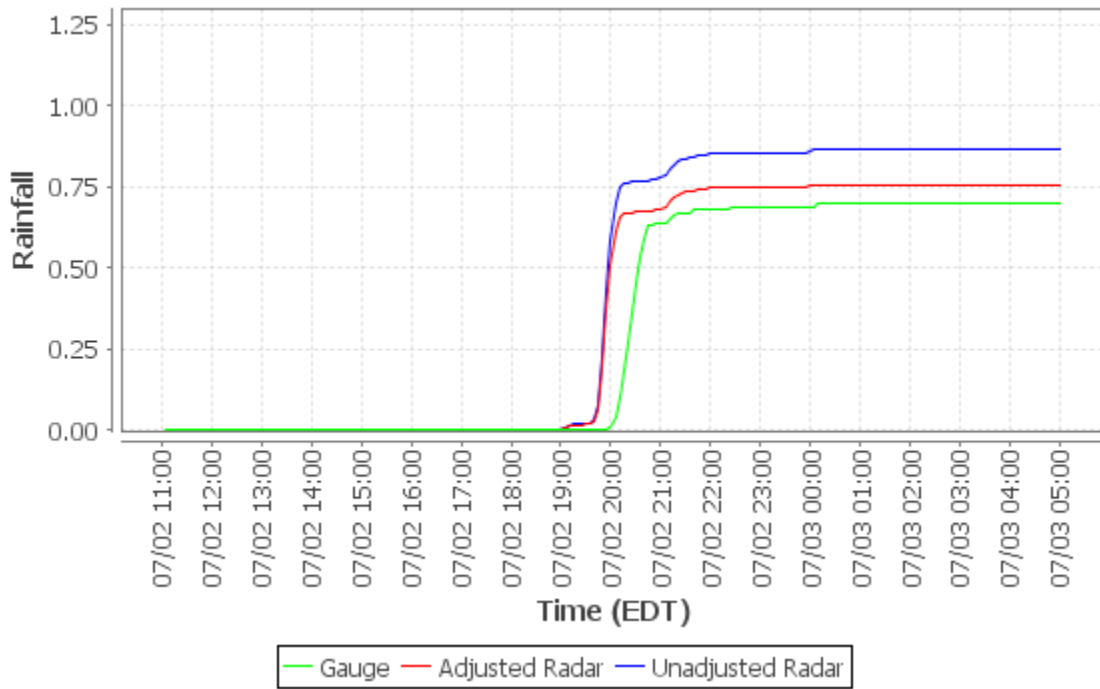
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



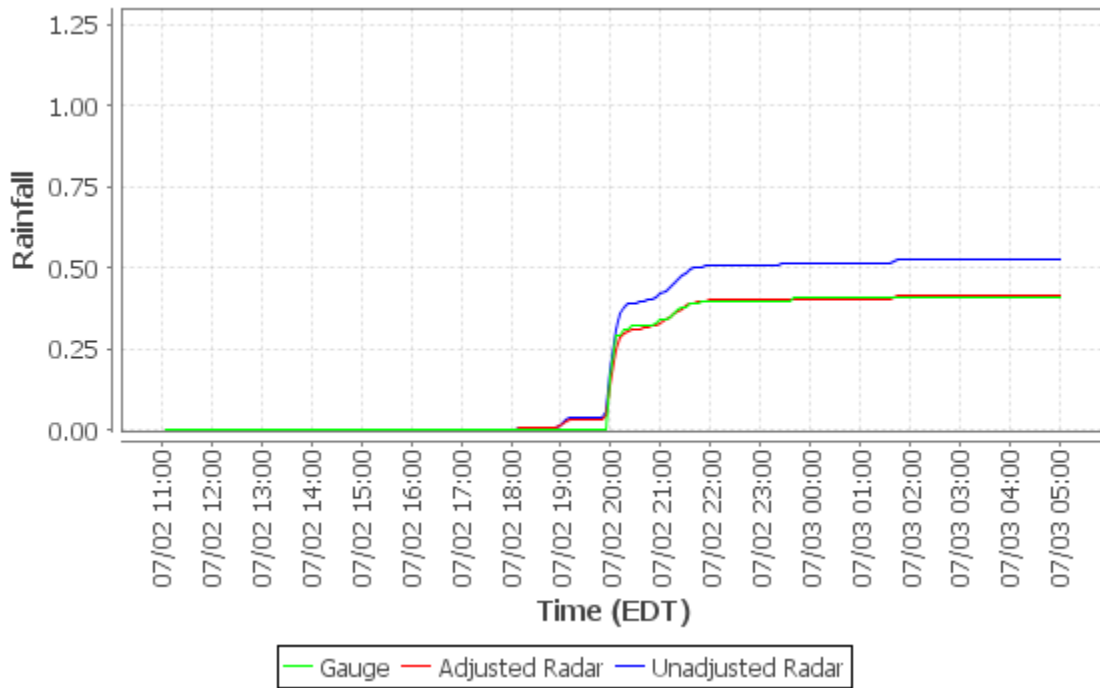
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



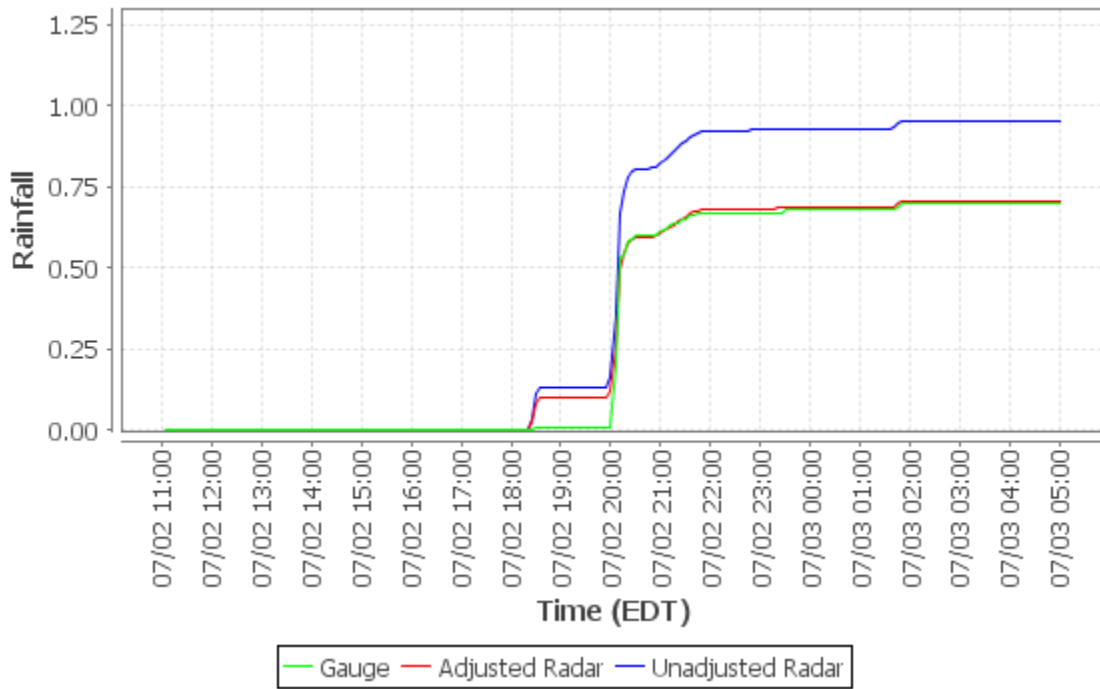
Cumulative Distribution Plot - Upper St. Clair (Loc05)



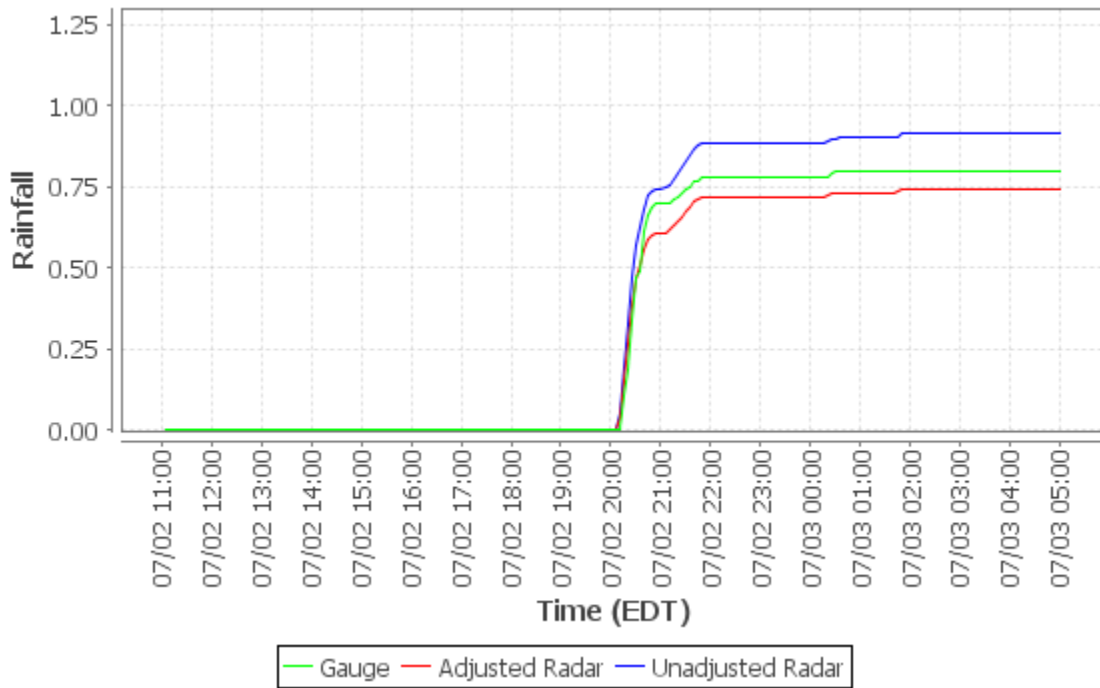
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



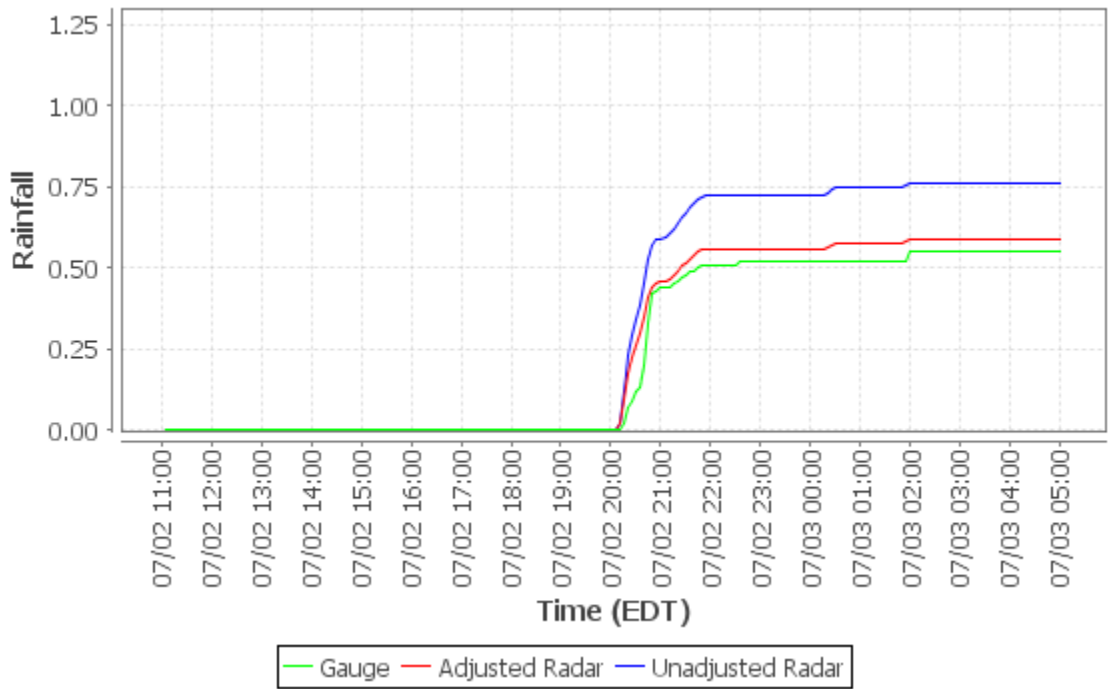
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



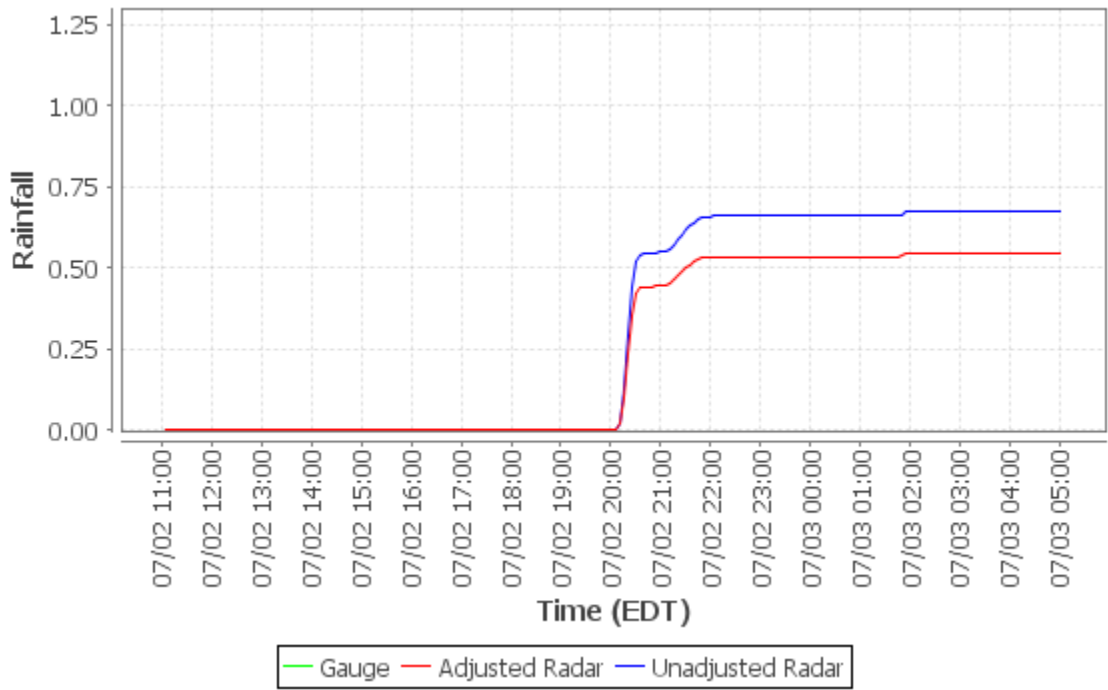
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



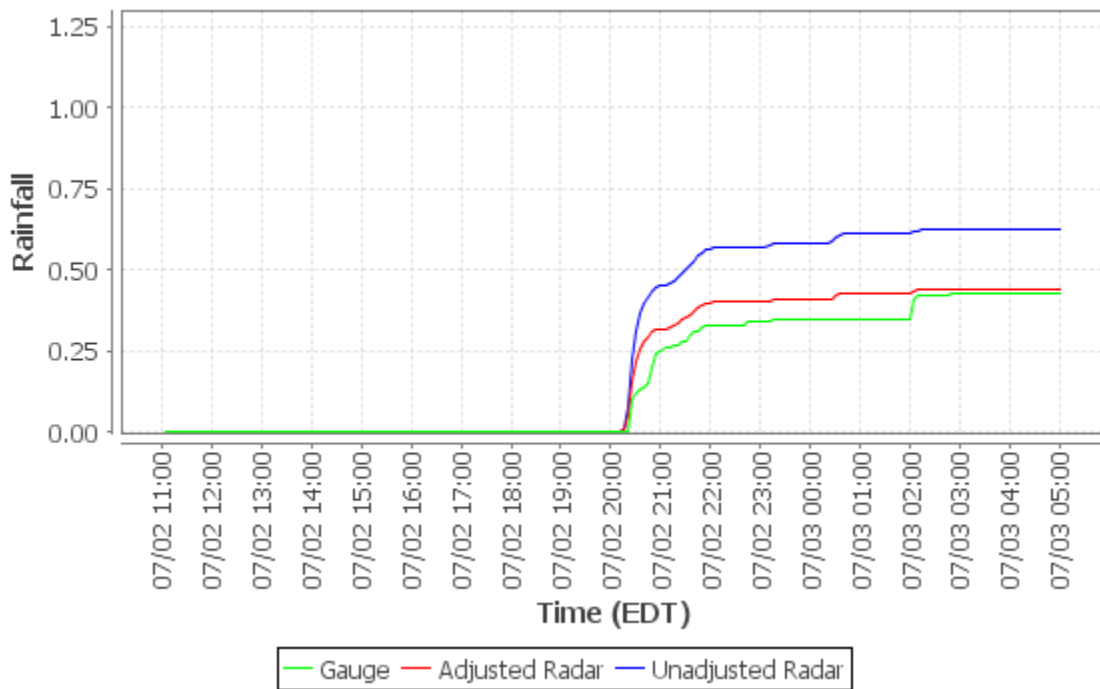
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



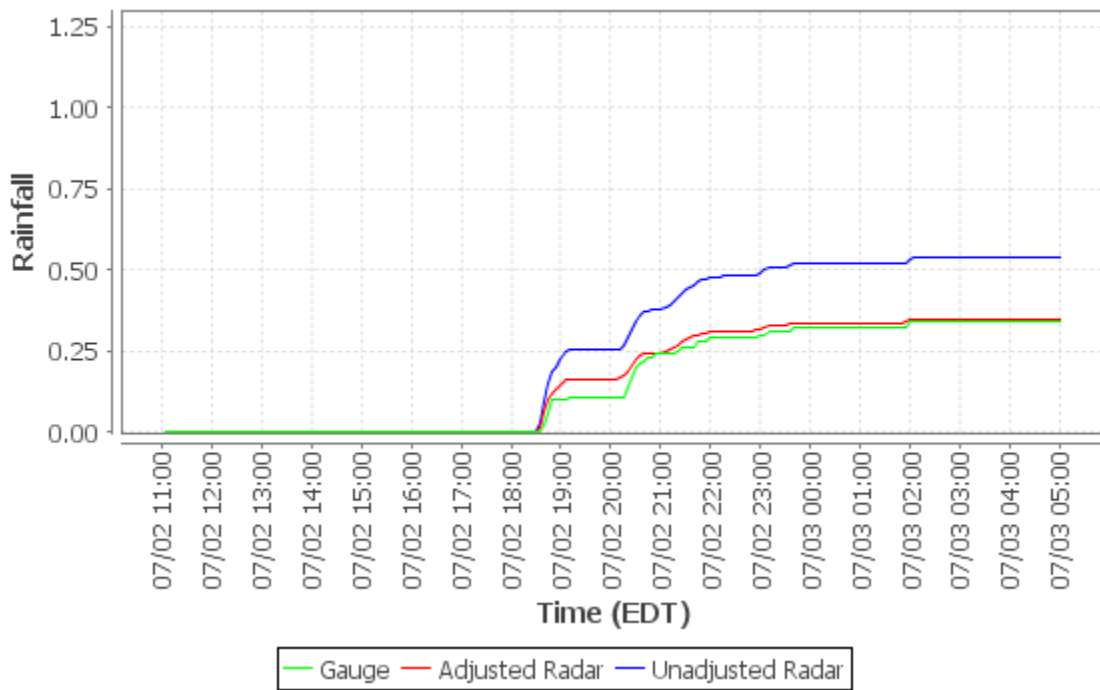
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



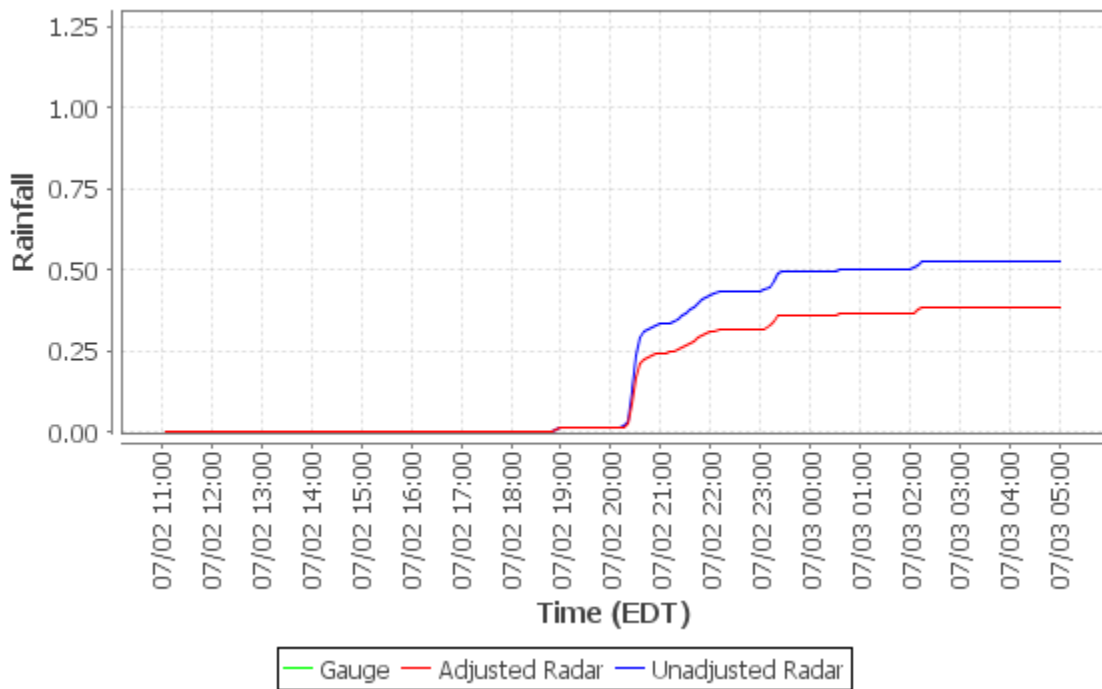
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



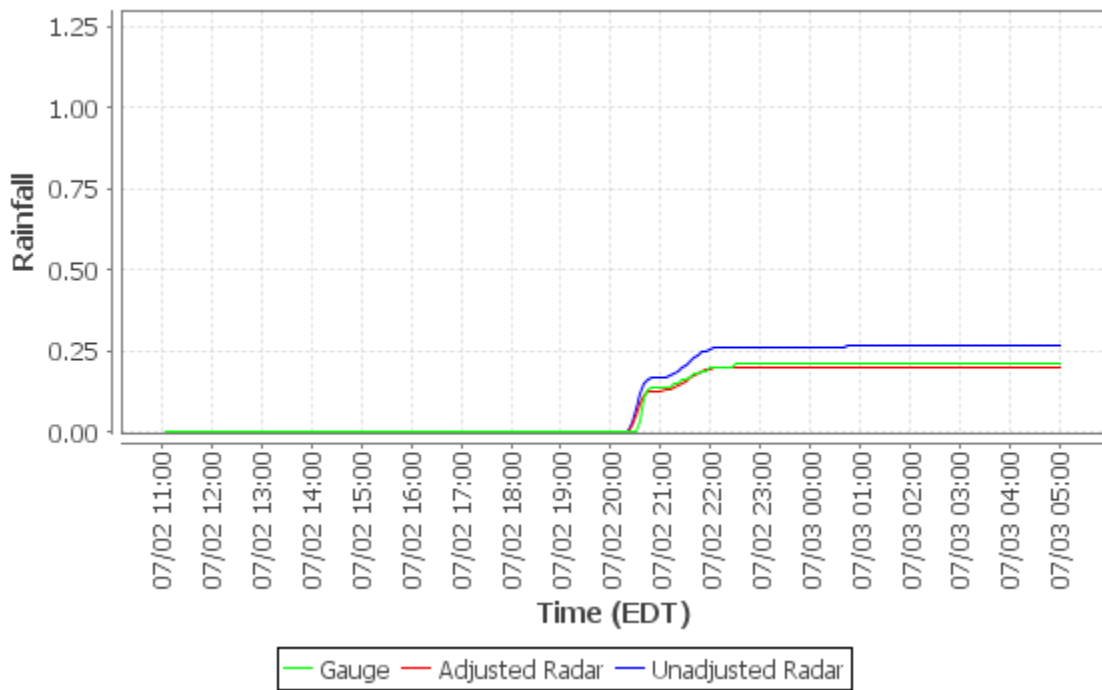
Cumulative Distribution Plot - Baldwin (Loc12)



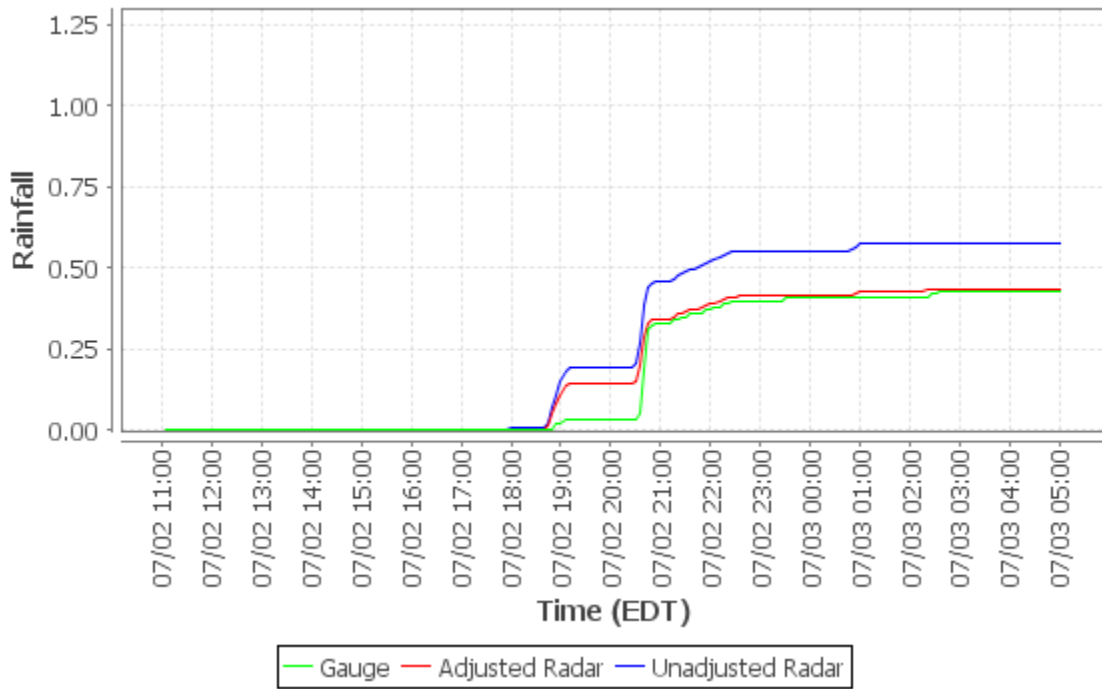
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



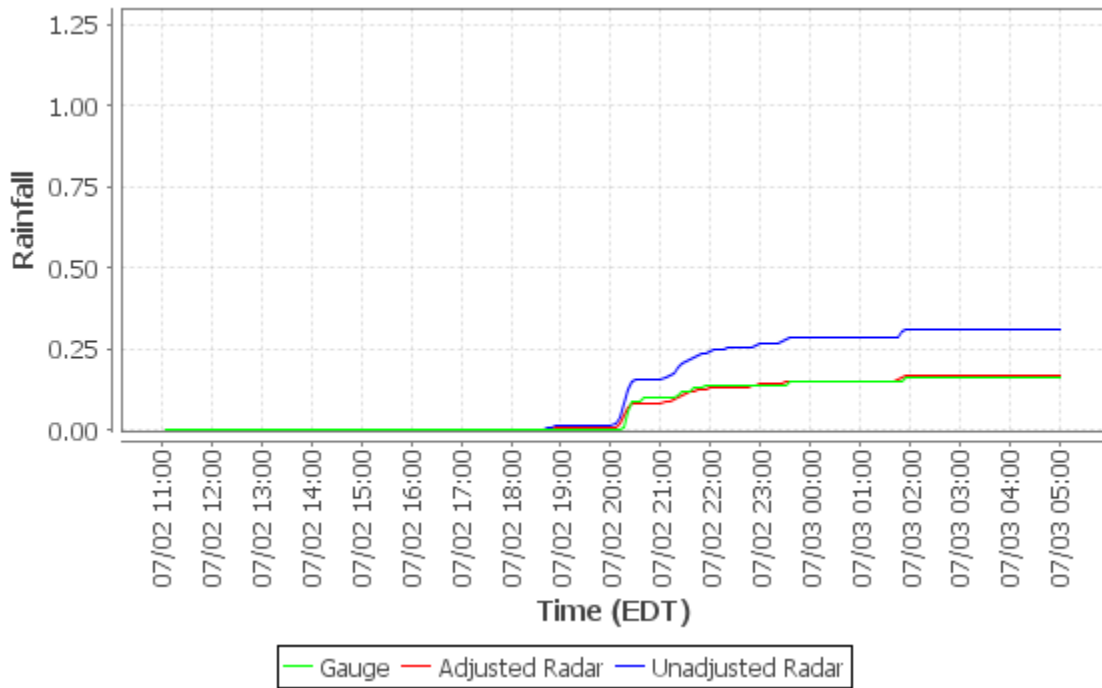
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



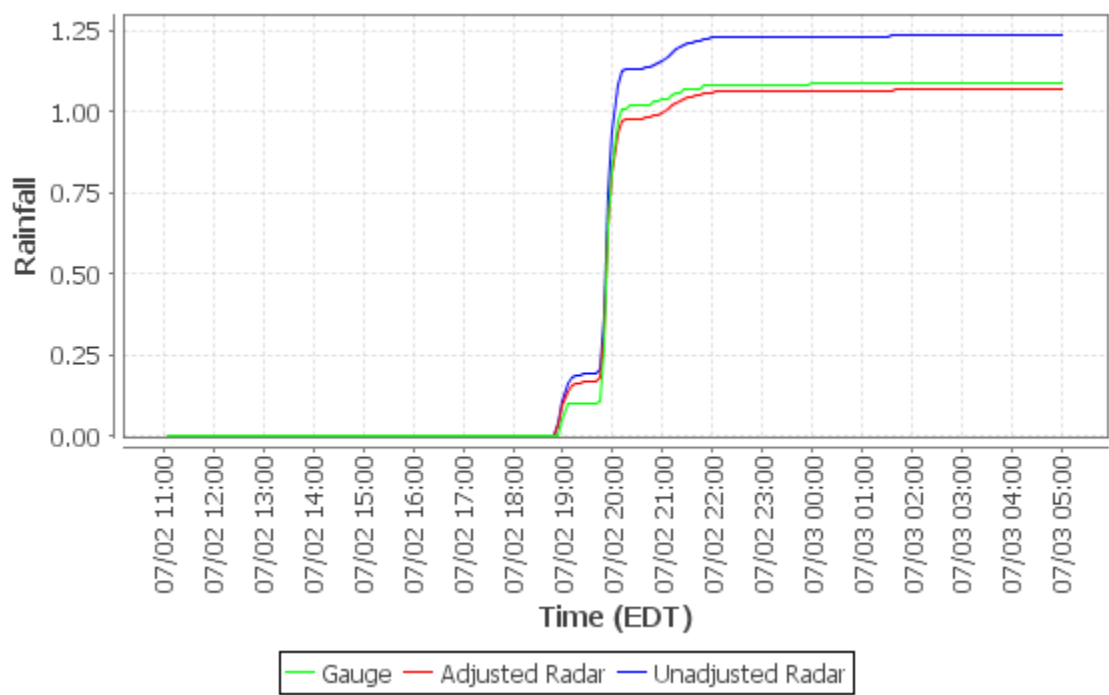
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



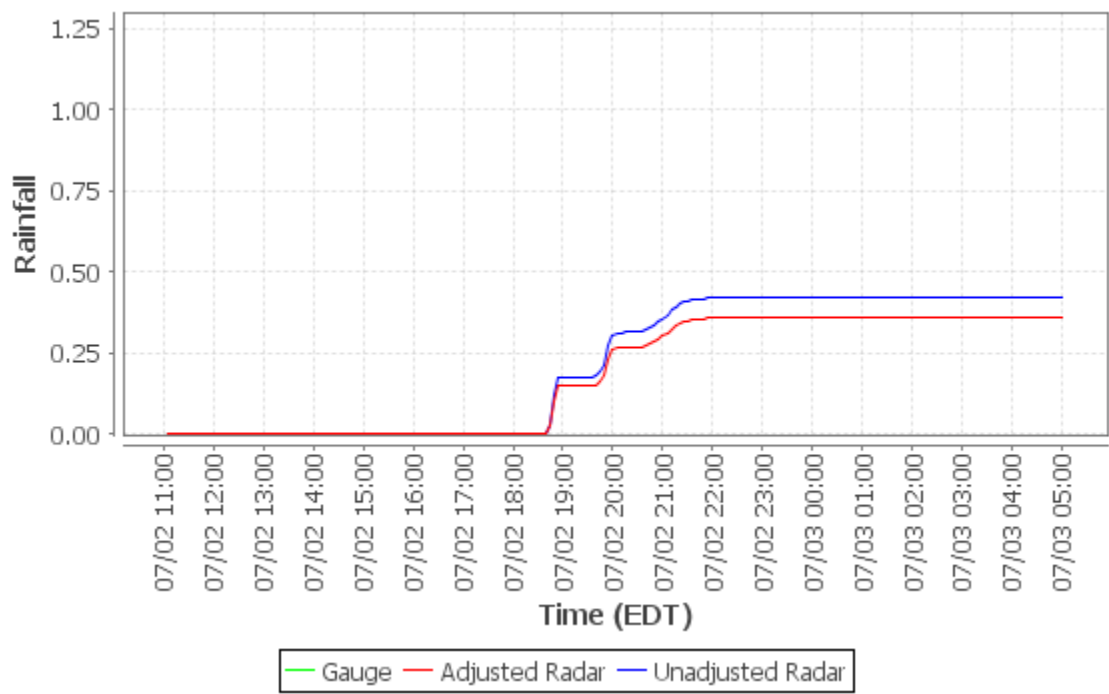
Cumulative Distribution Plot - Castle Shannon (Loc16)



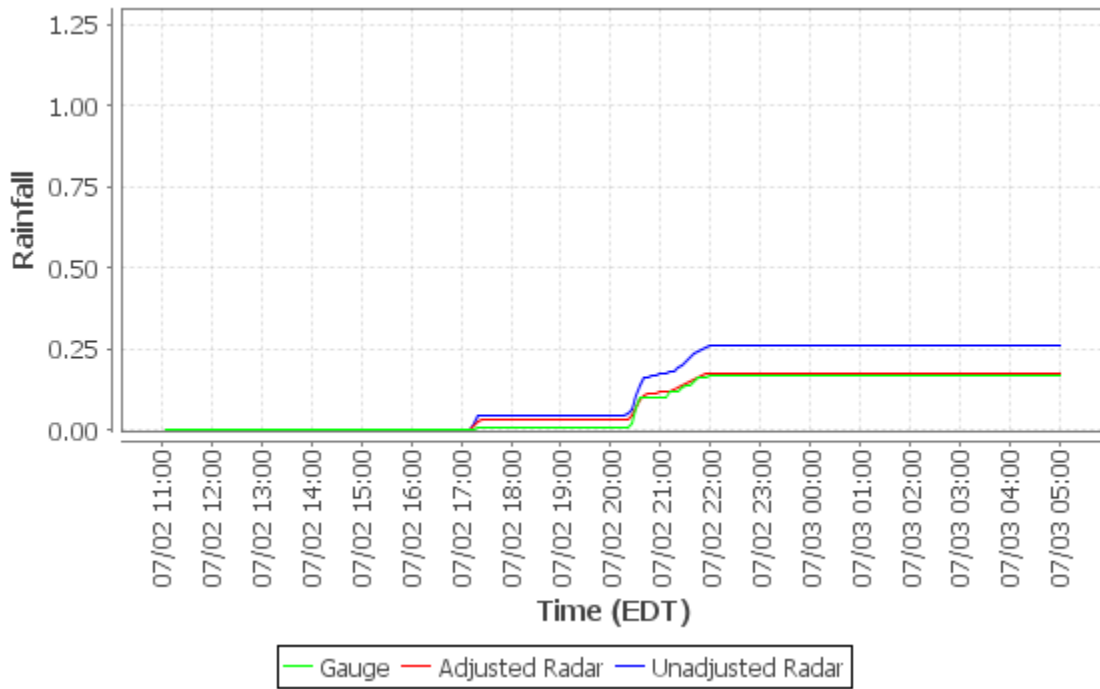
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



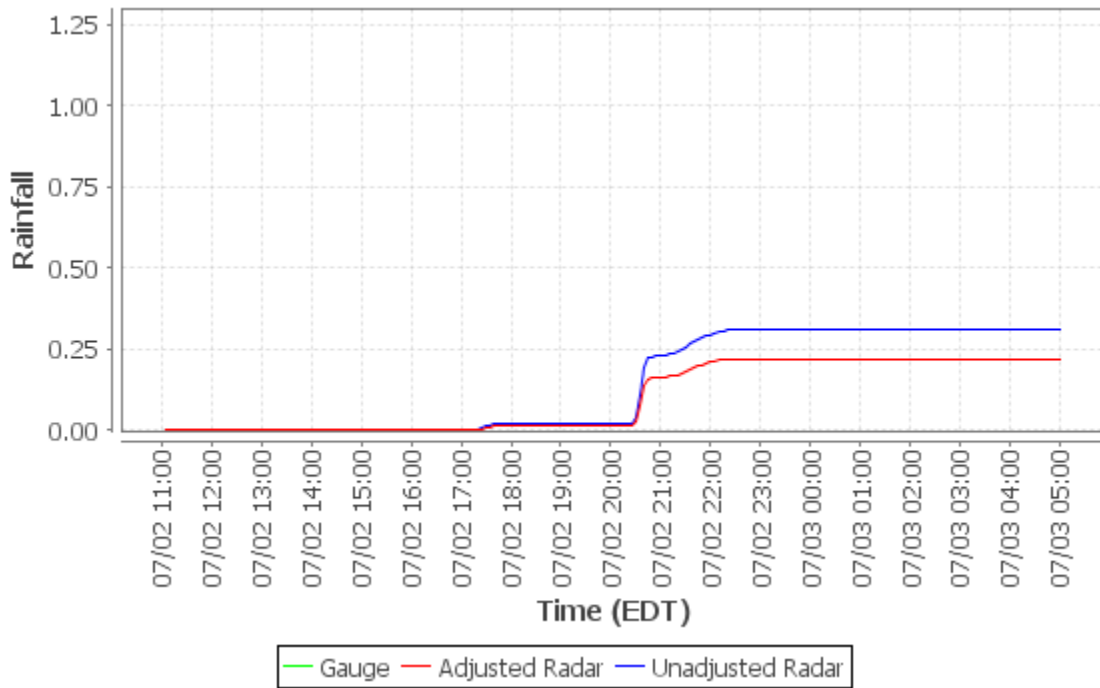
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



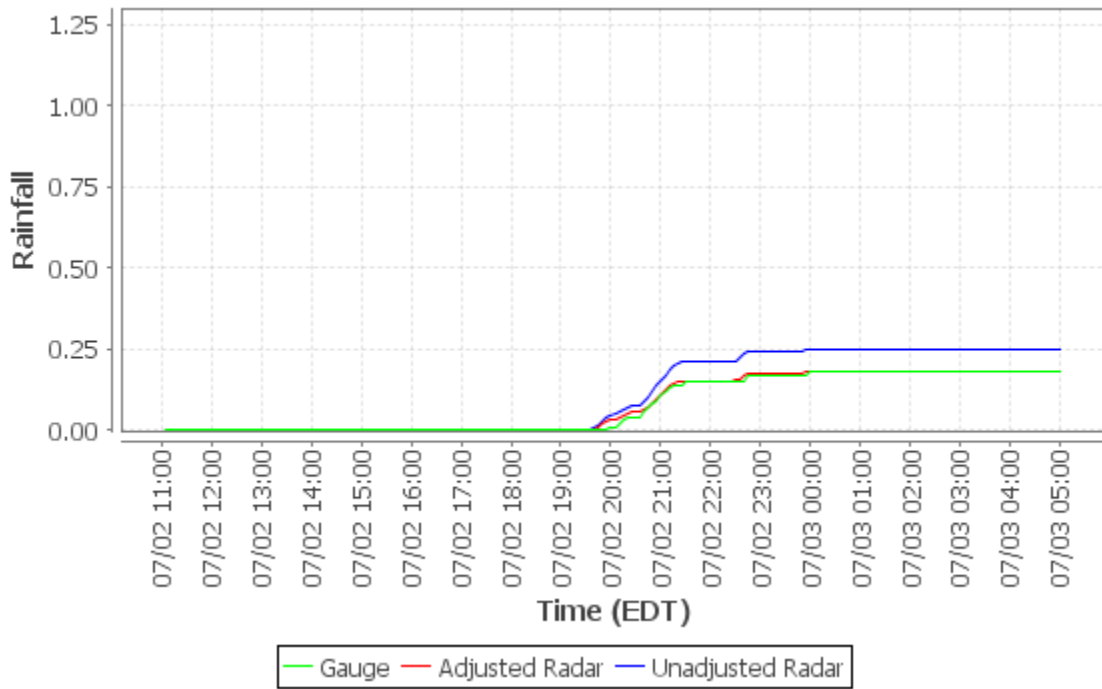
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



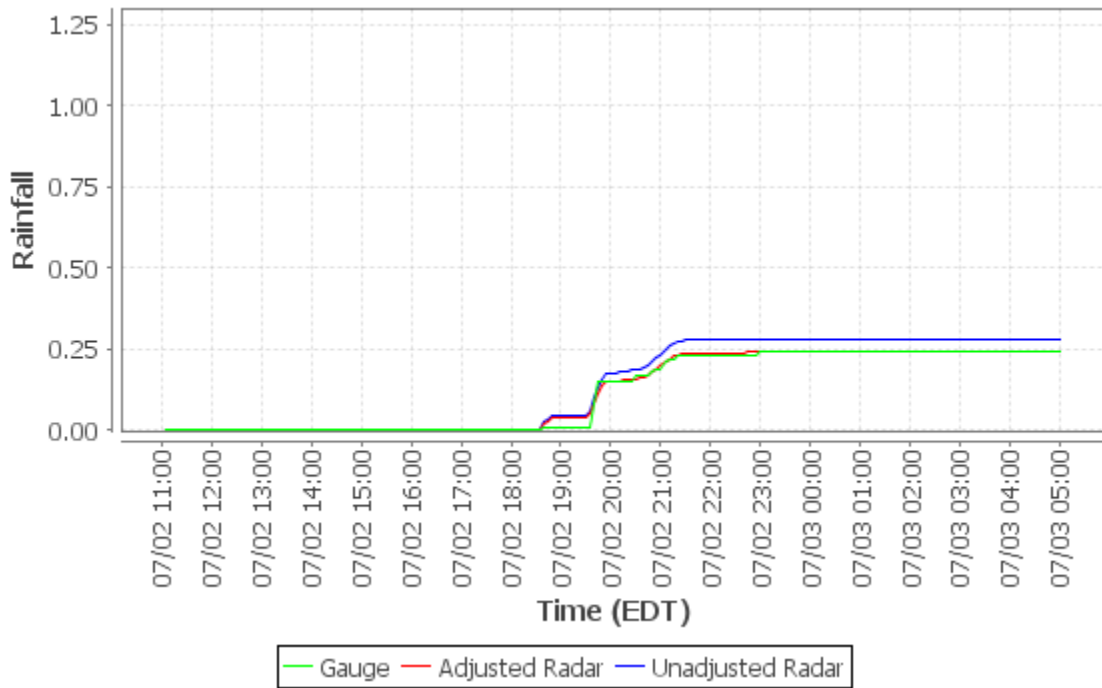
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



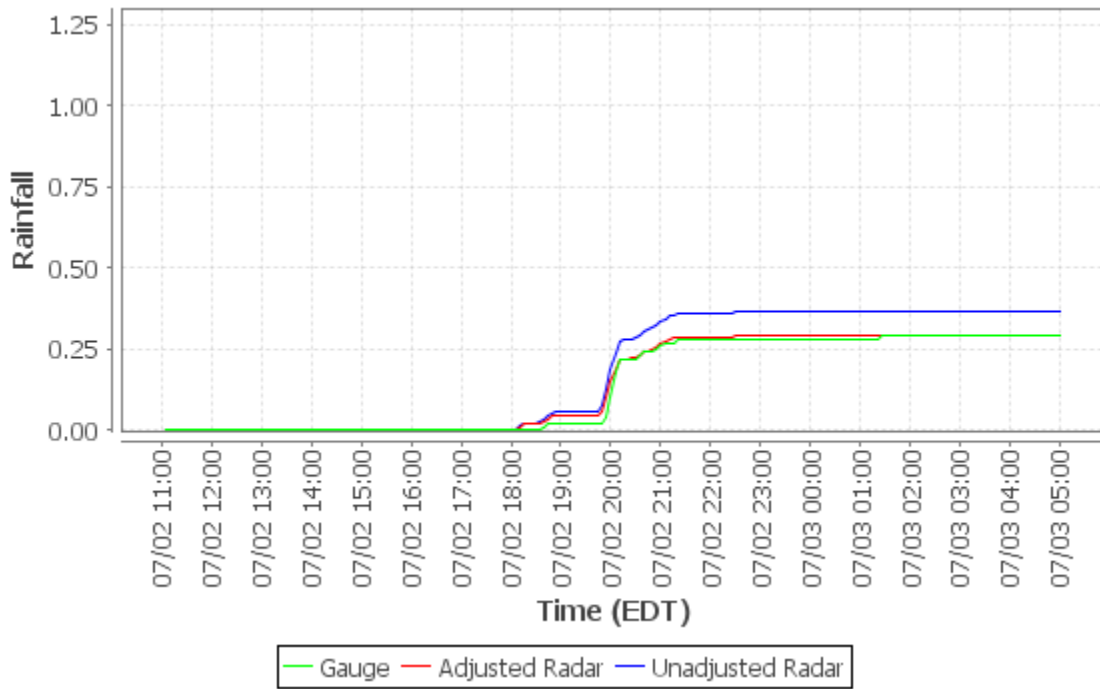
Cumulative Distribution Plot - Moon TWP (Loc21)



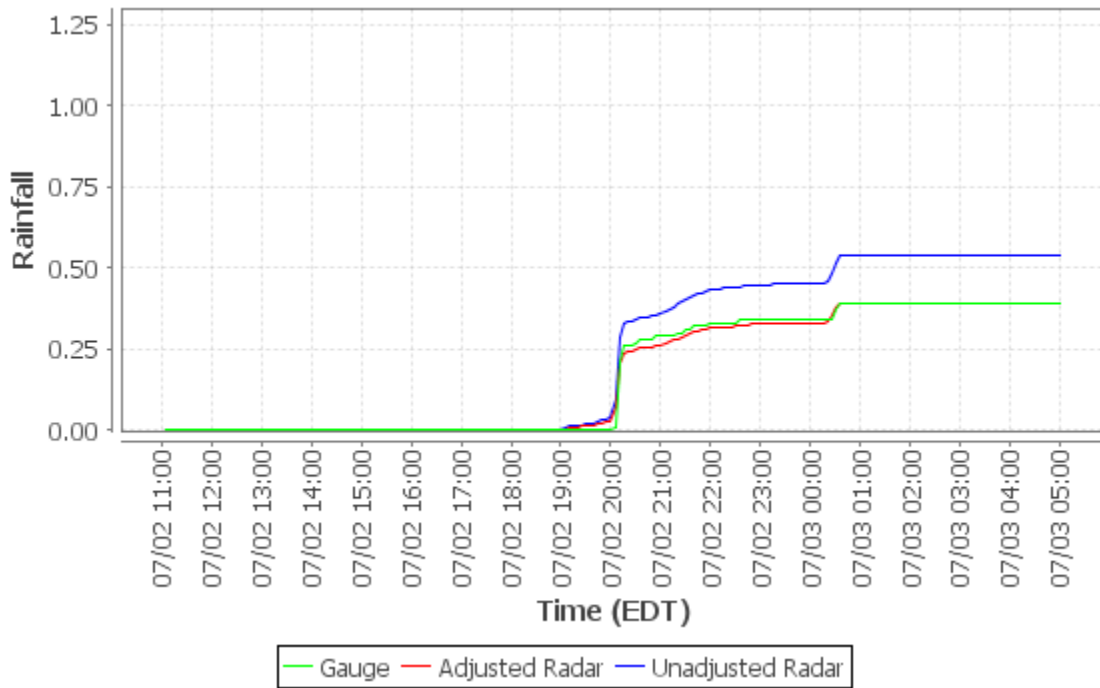
Cumulative Distribution Plot - North Fayette TWP (Loc22)



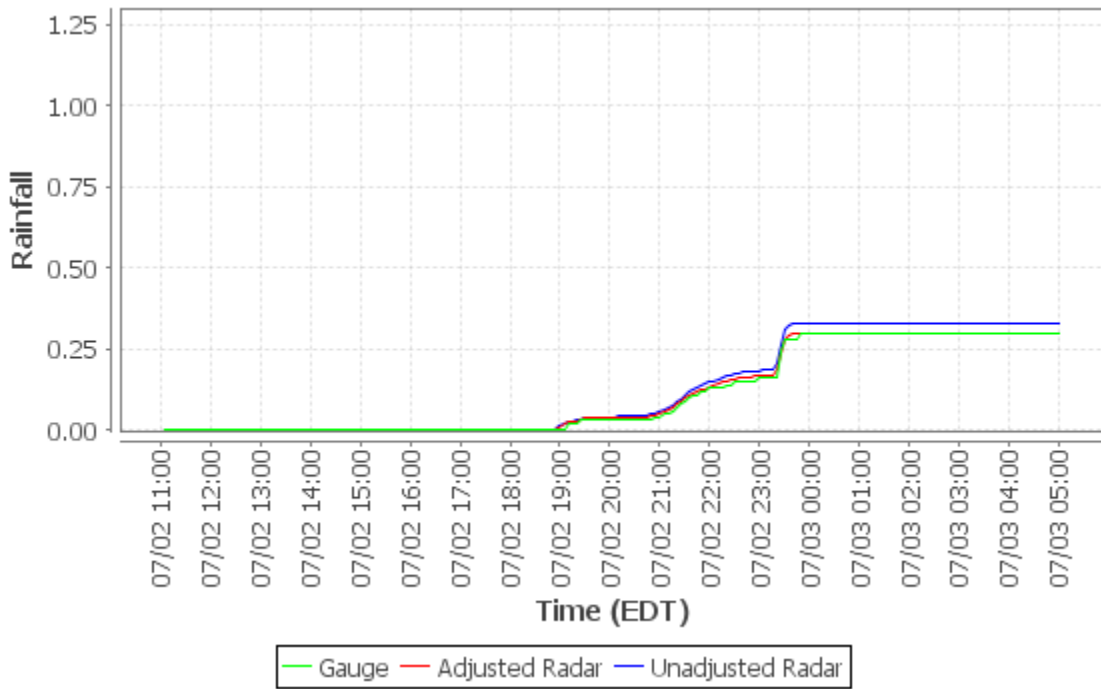
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



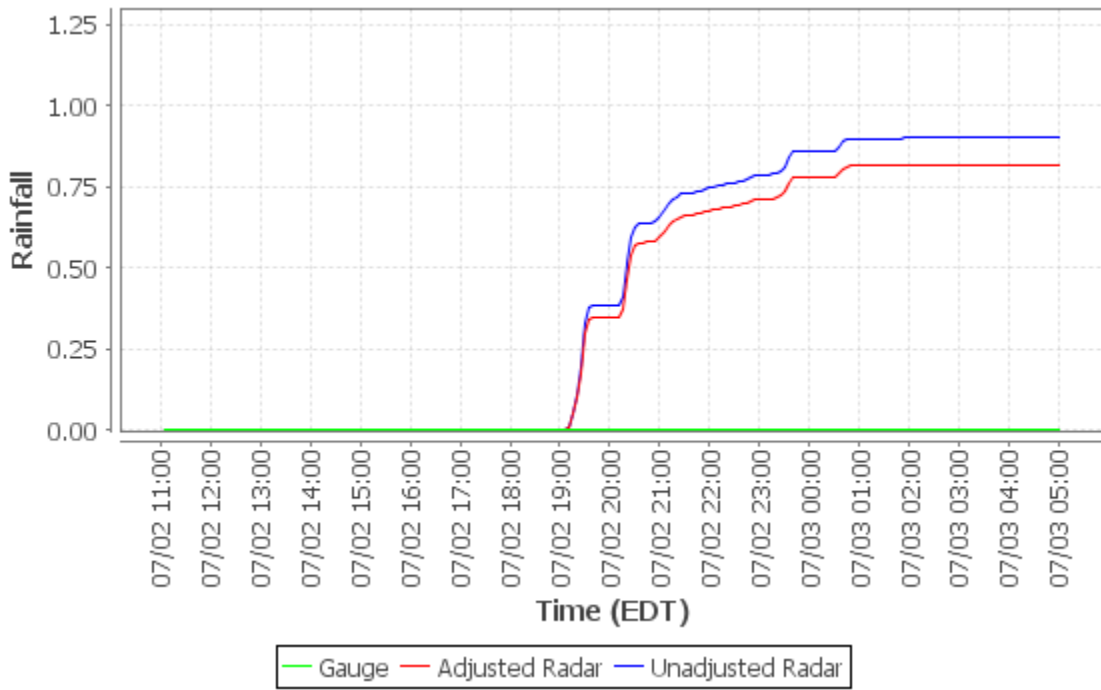
Cumulative Distribution Plot - Jefferson Hills (Loc24)



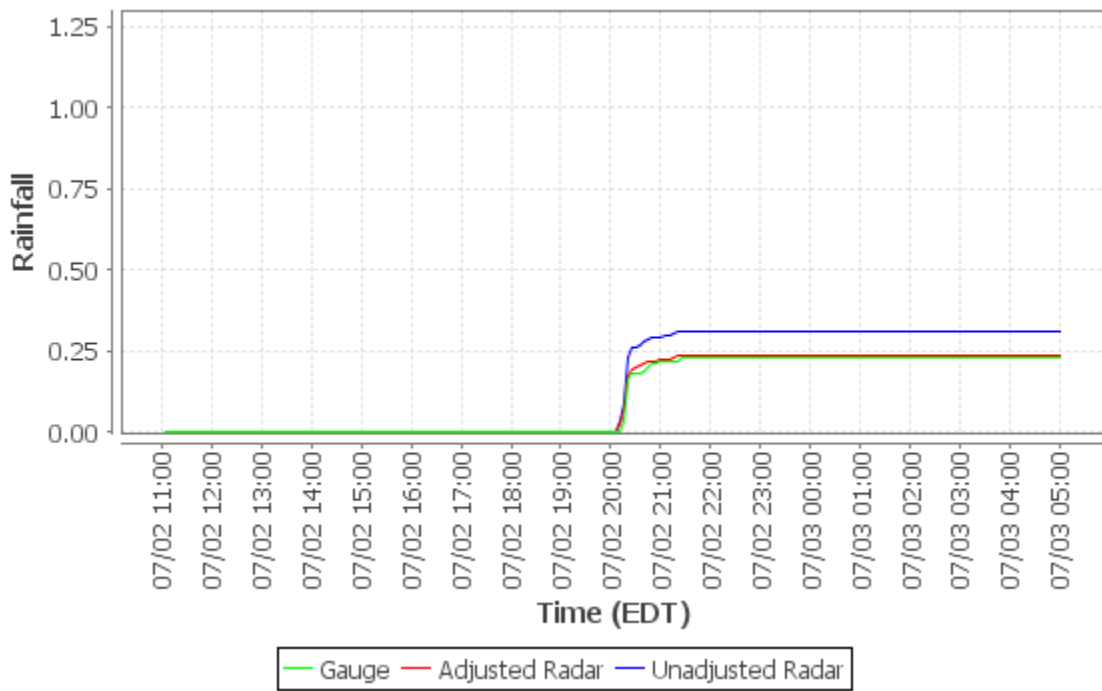
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



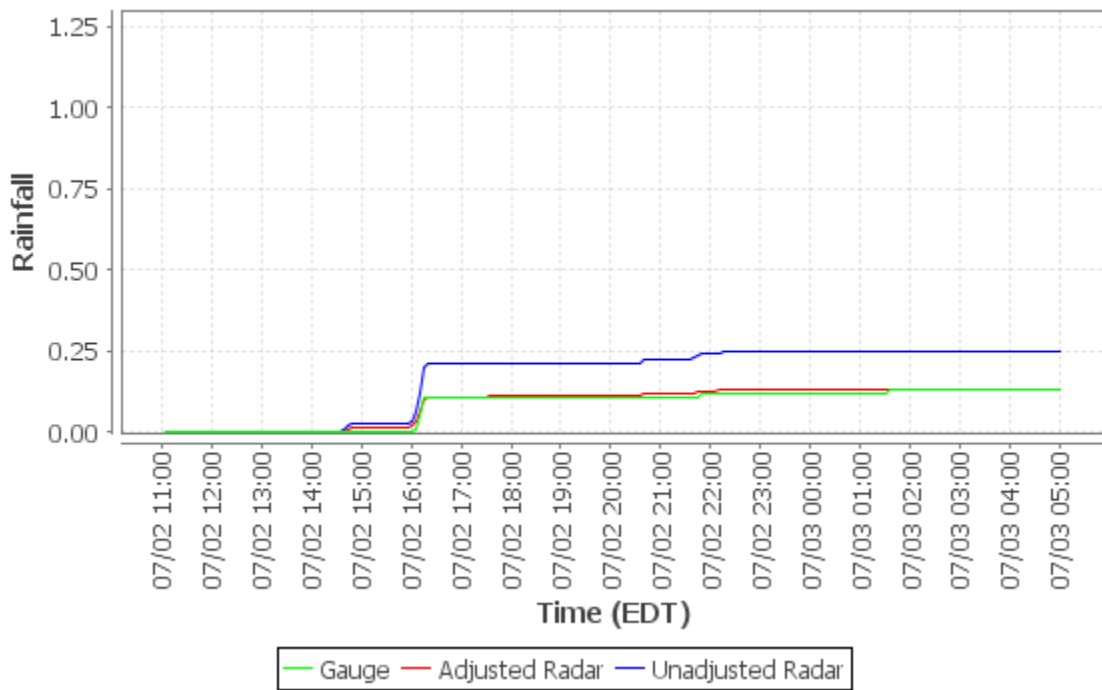
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



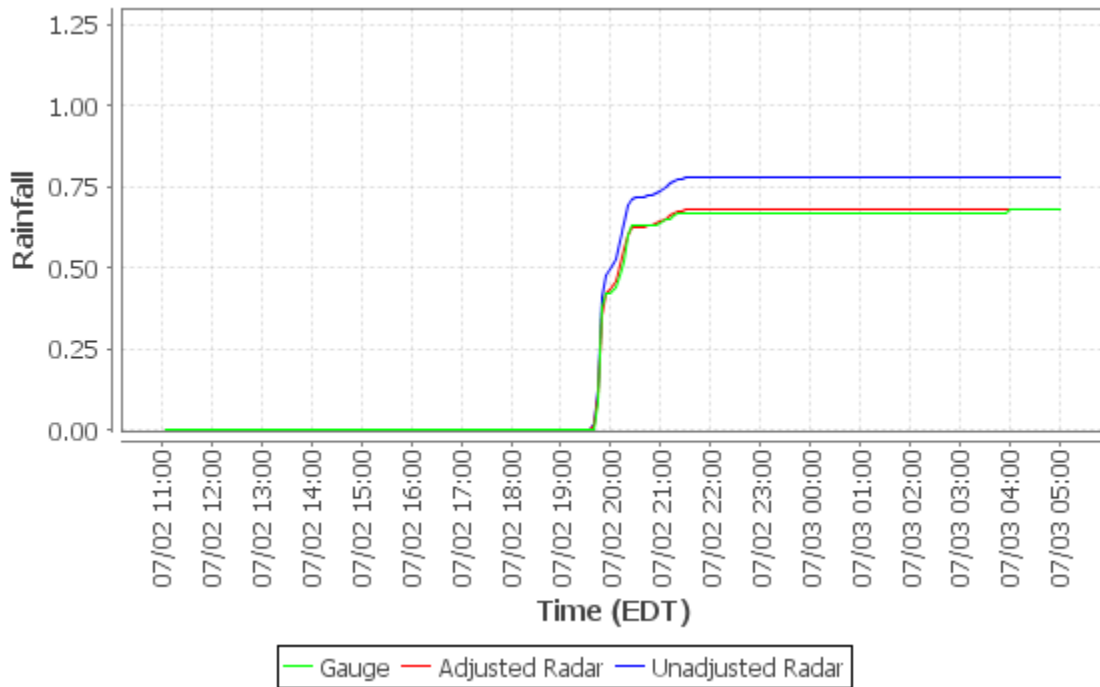
Cumulative Distribution Plot - Marshall TWP (Loc27)



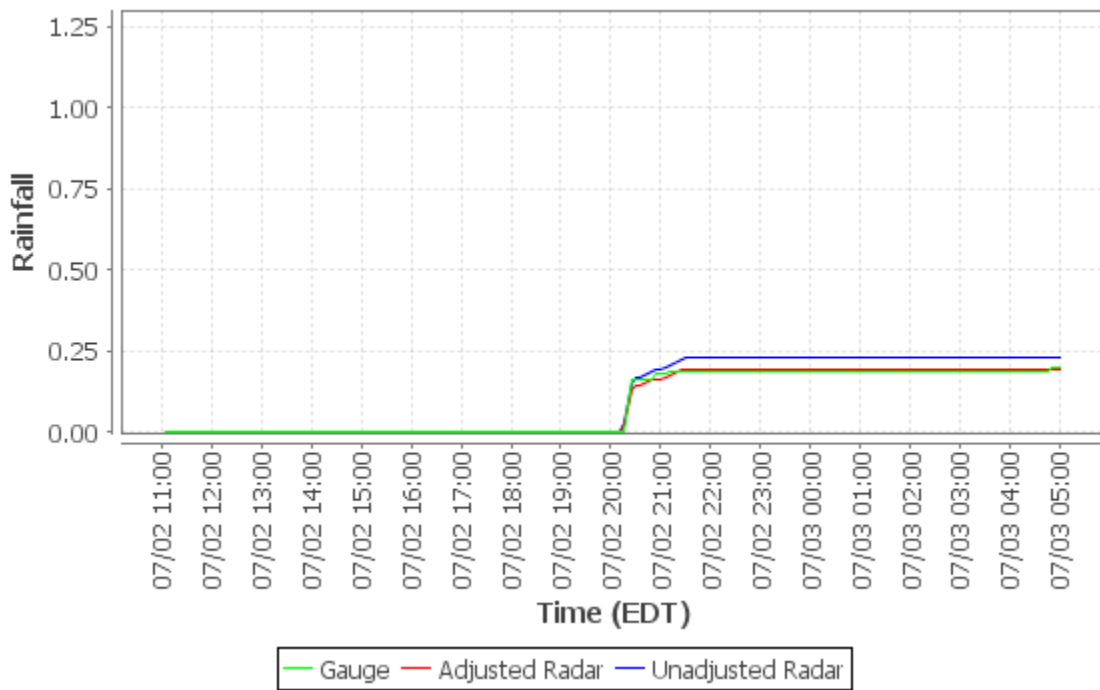
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



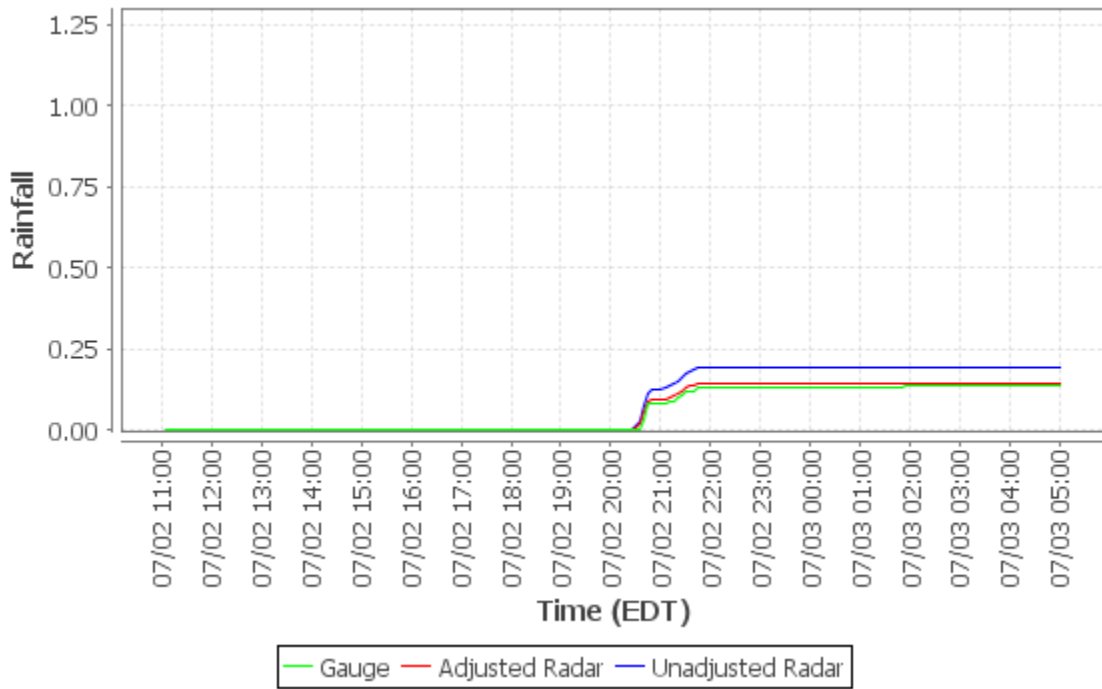
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



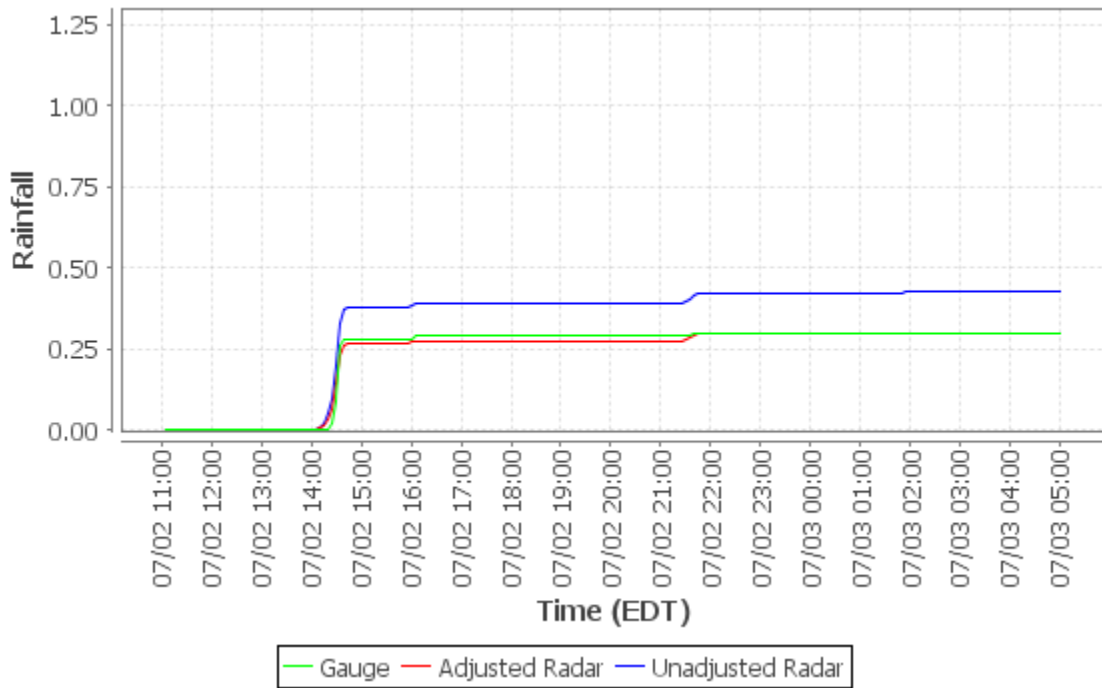
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



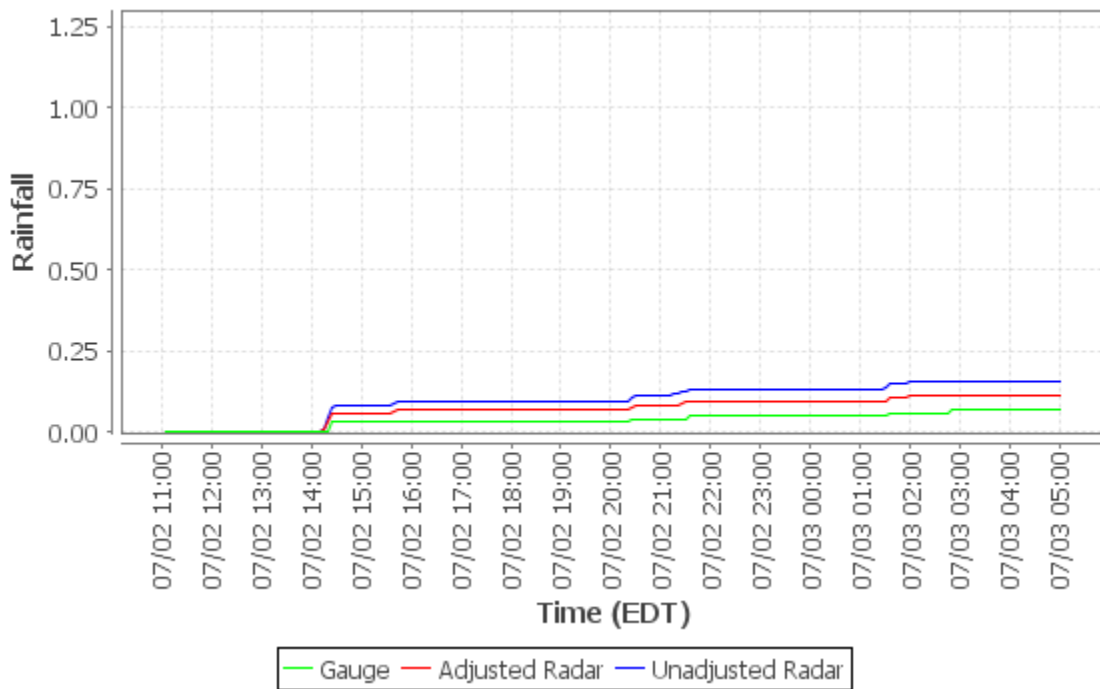
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



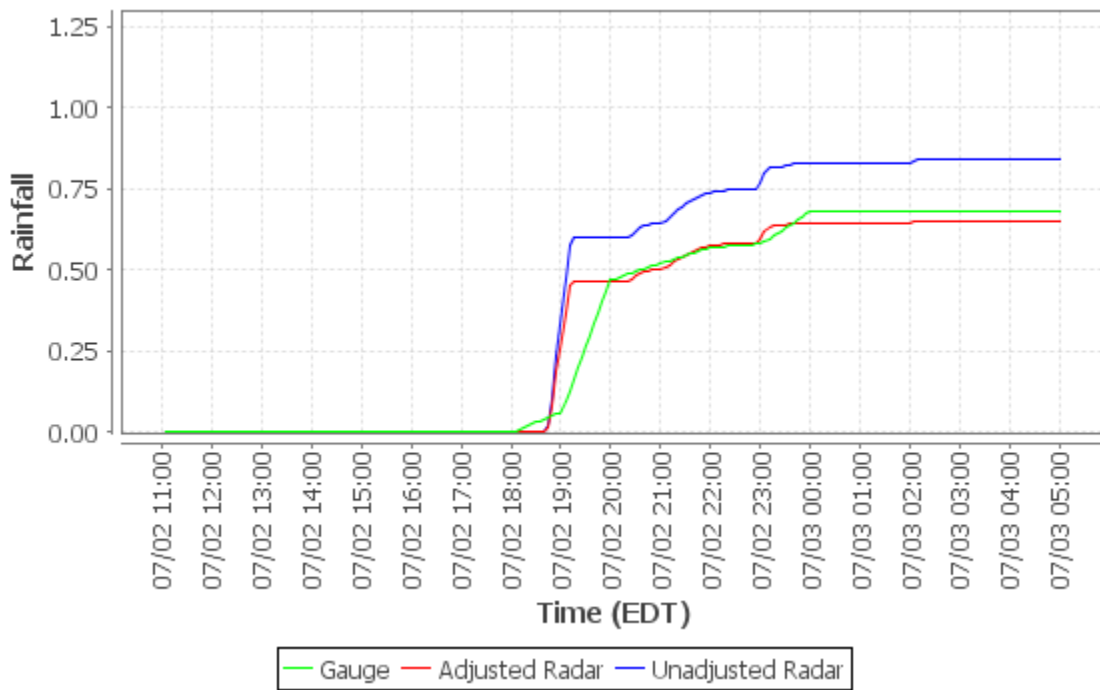
Cumulative Distribution Plot - Arnold (Loc32)



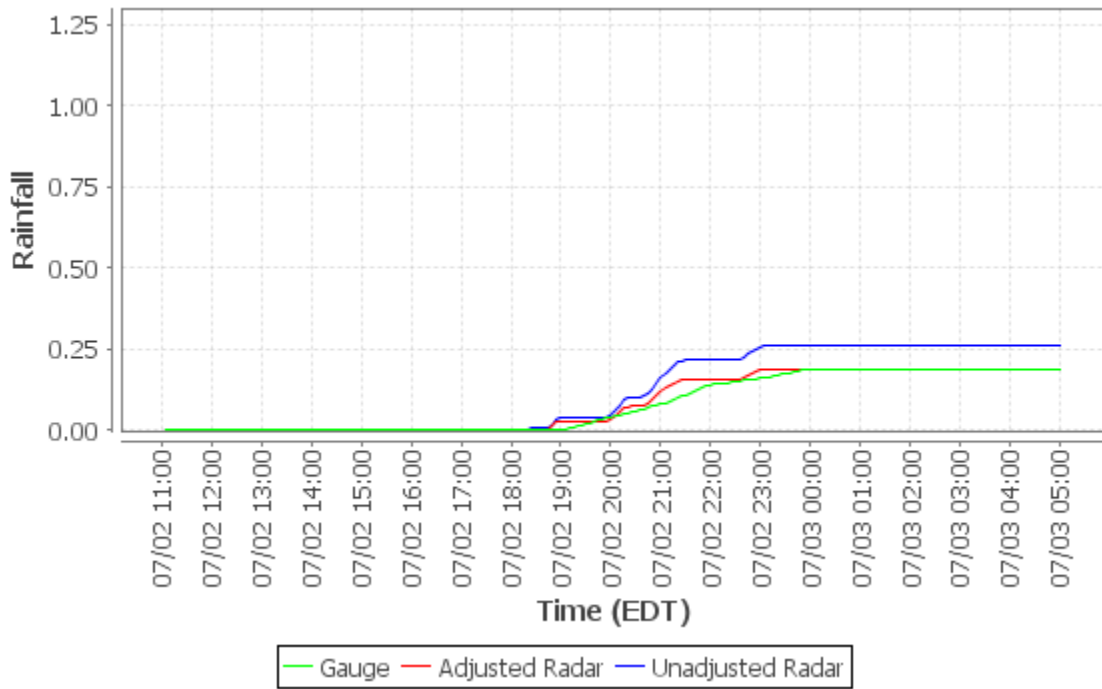
Cumulative Distribution Plot - Richland TWP (Loc33)



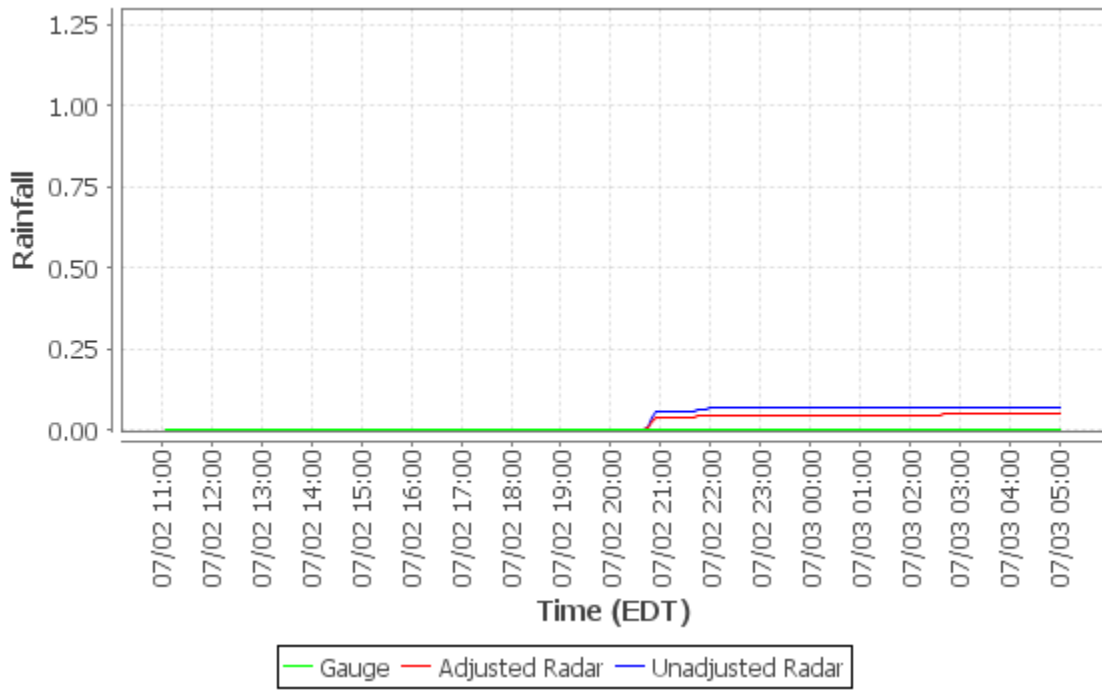
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



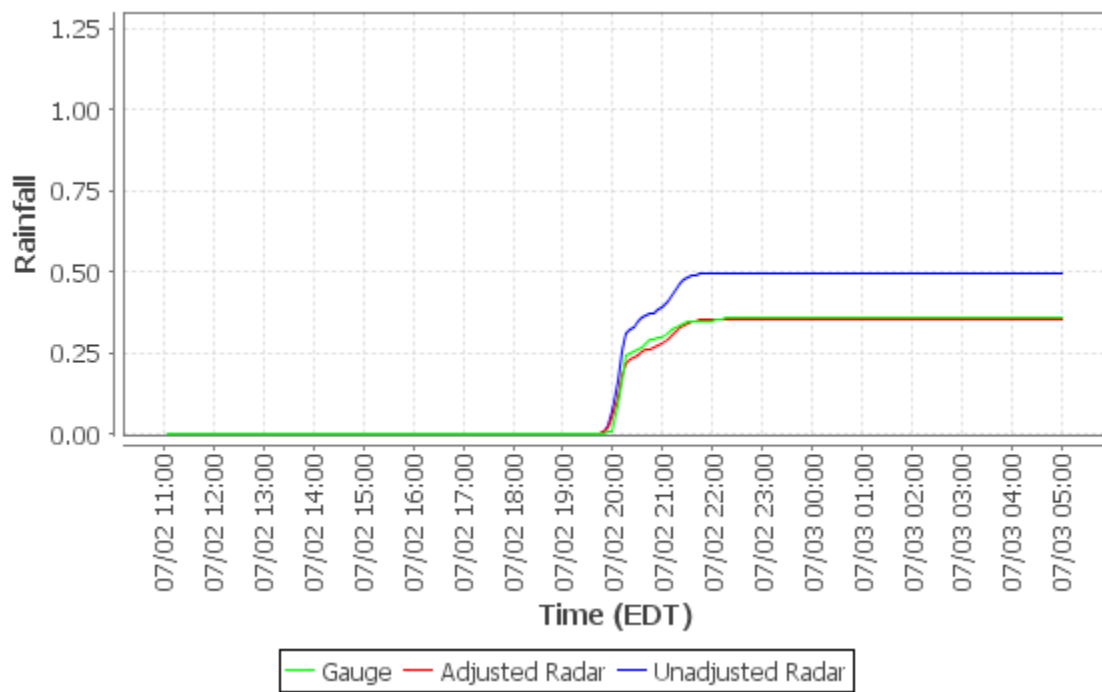
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

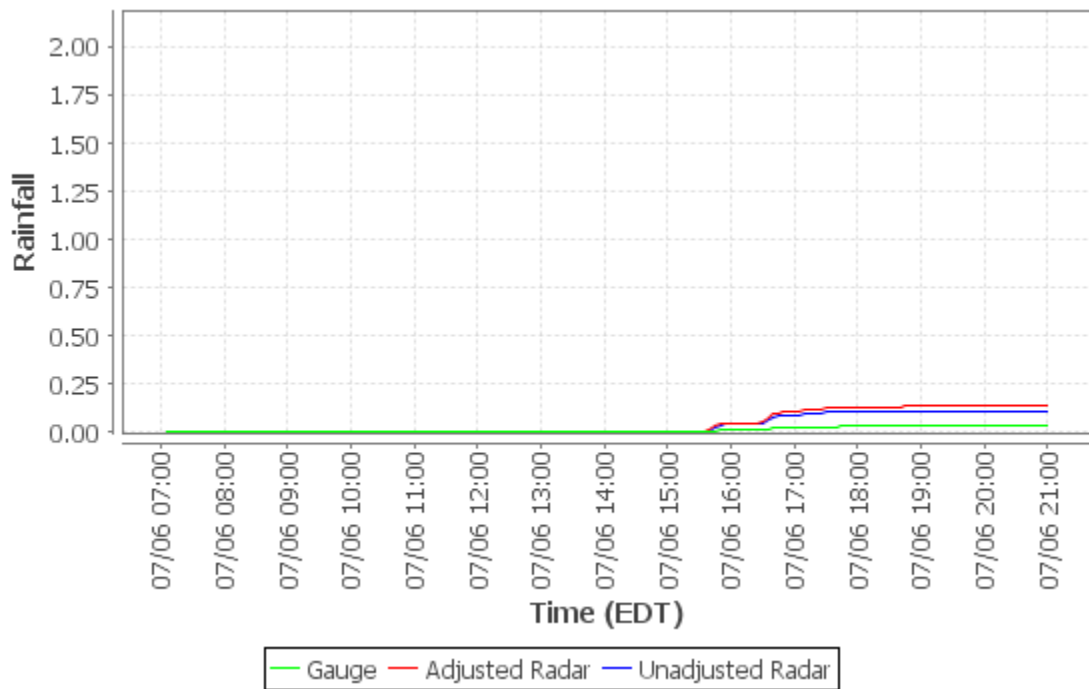


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

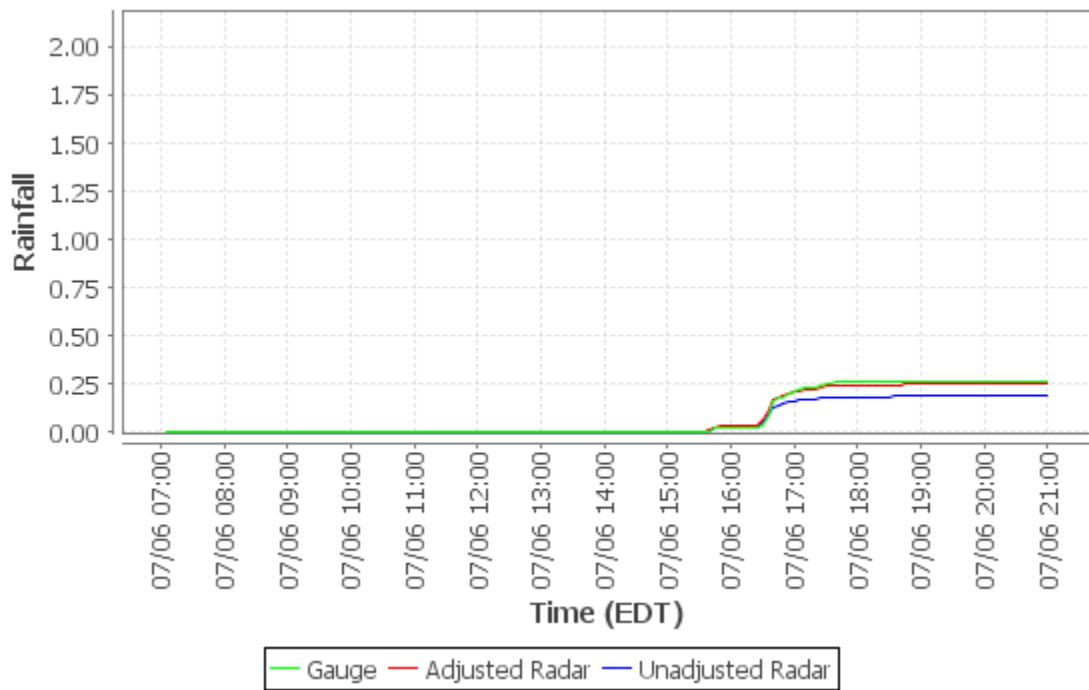


Appendix D - Event 2 (2019-07-06) CDPs

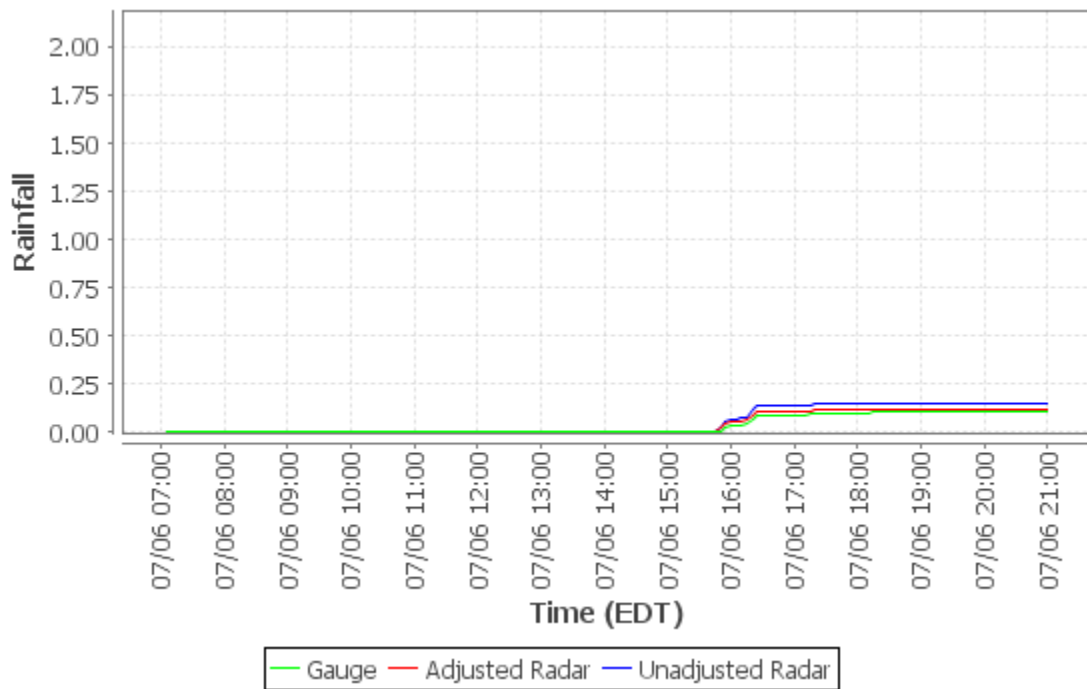
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



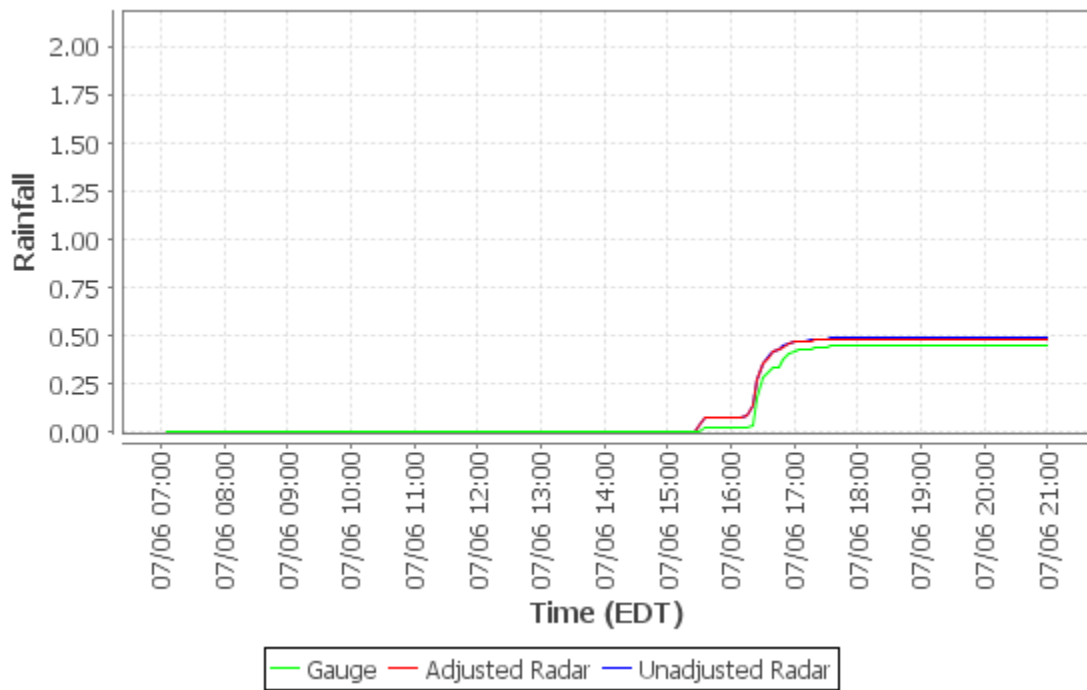
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



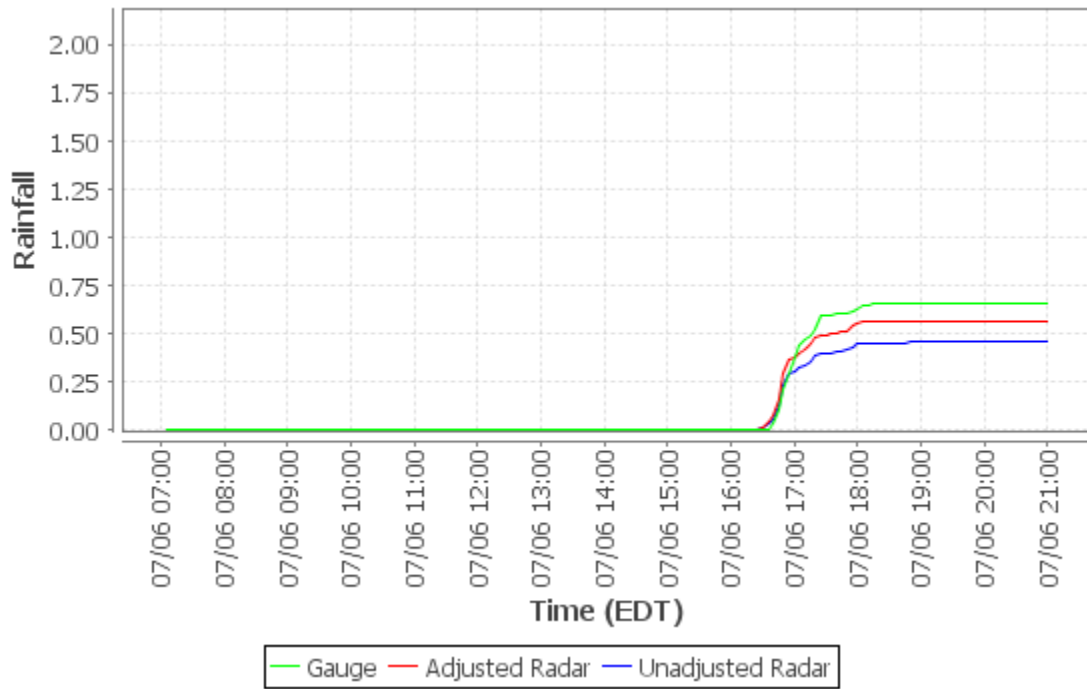
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



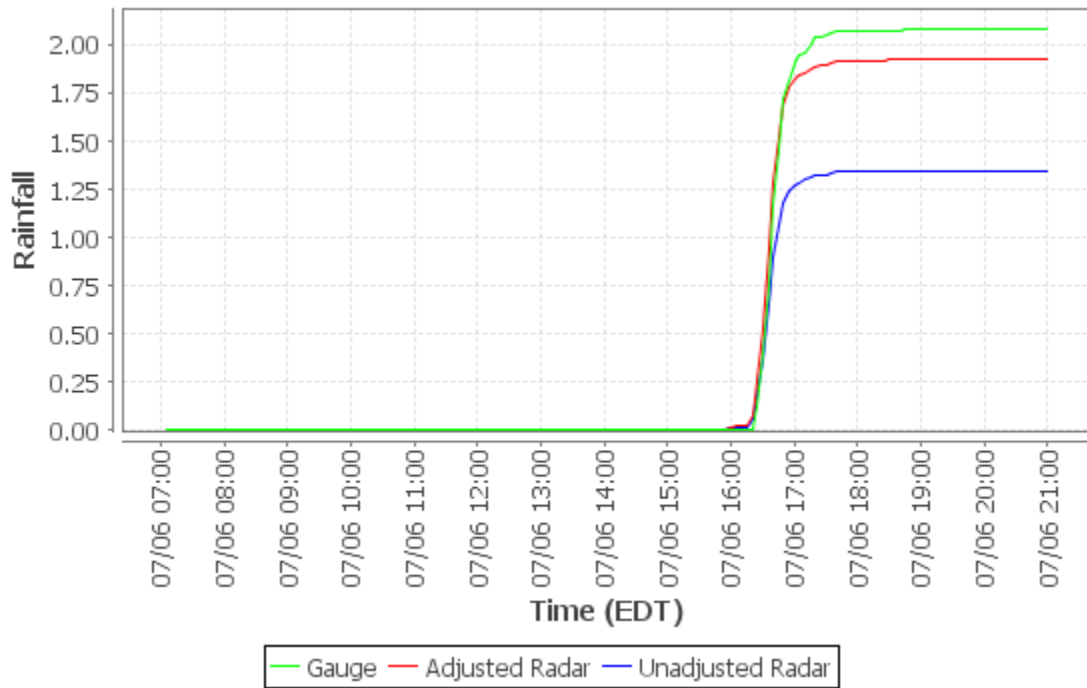
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



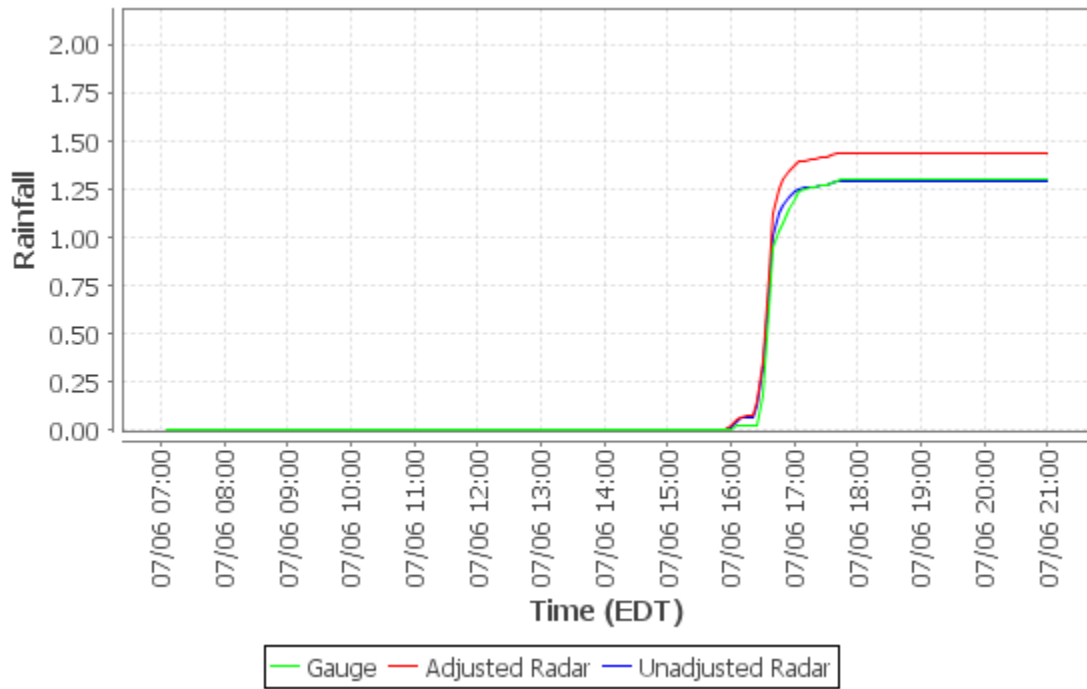
Cumulative Distribution Plot - Upper St. Clair (Loc05)



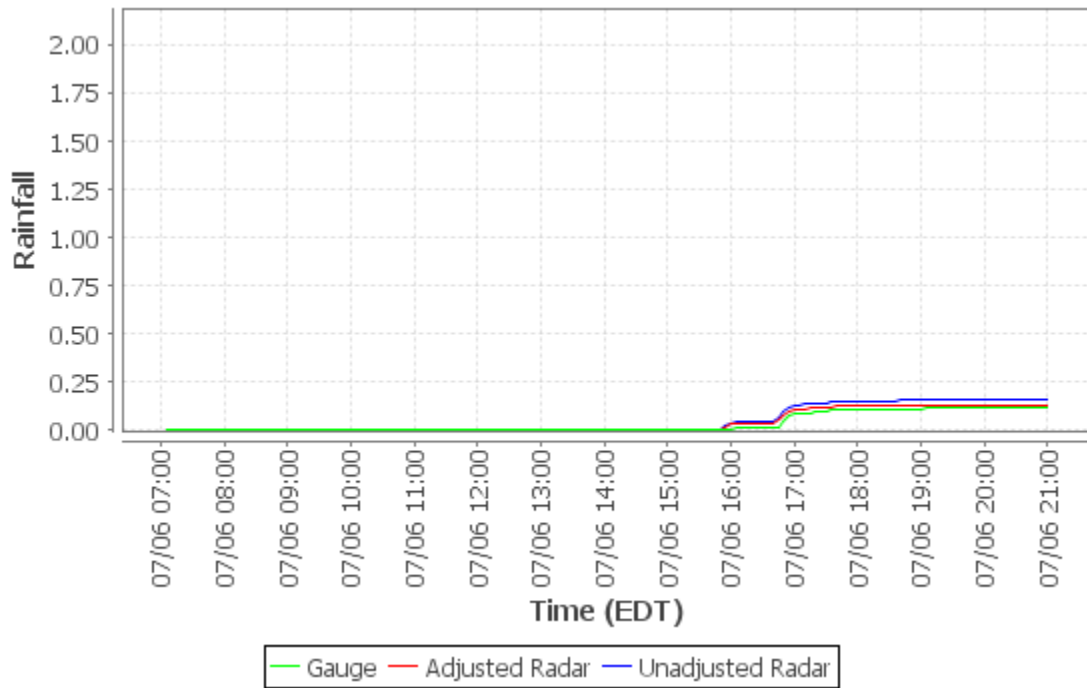
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



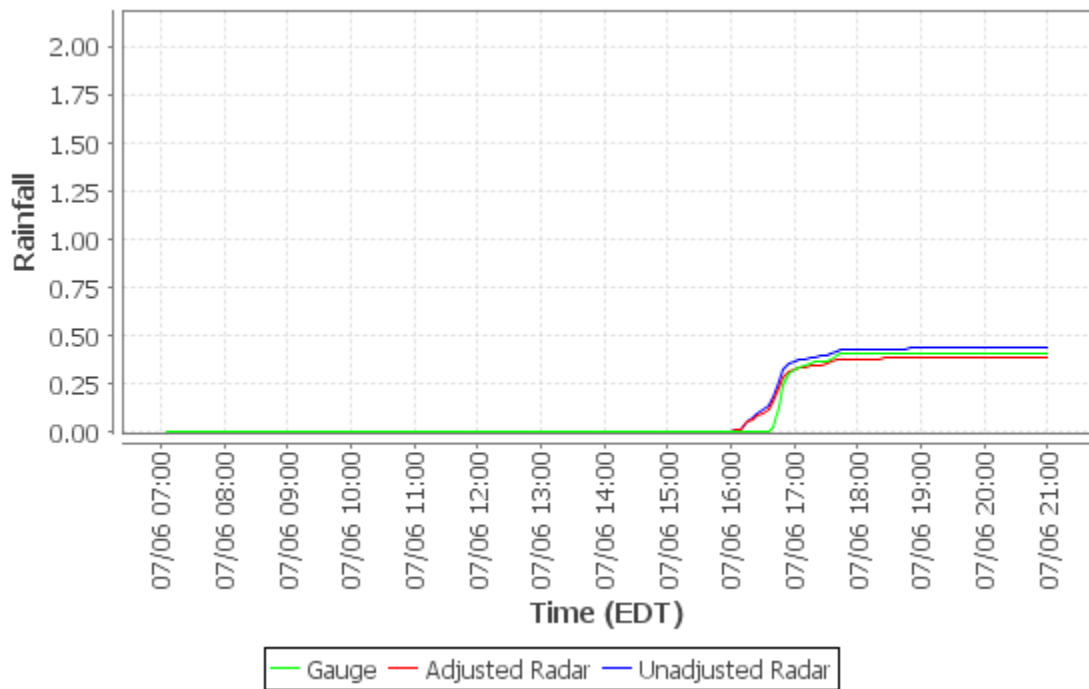
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



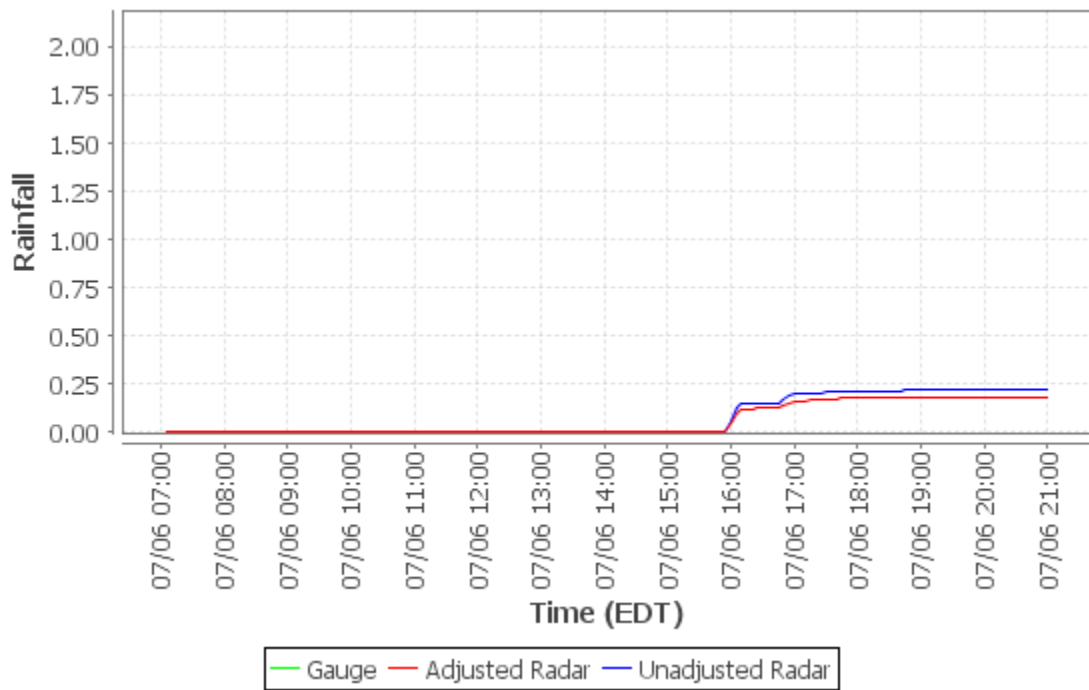
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



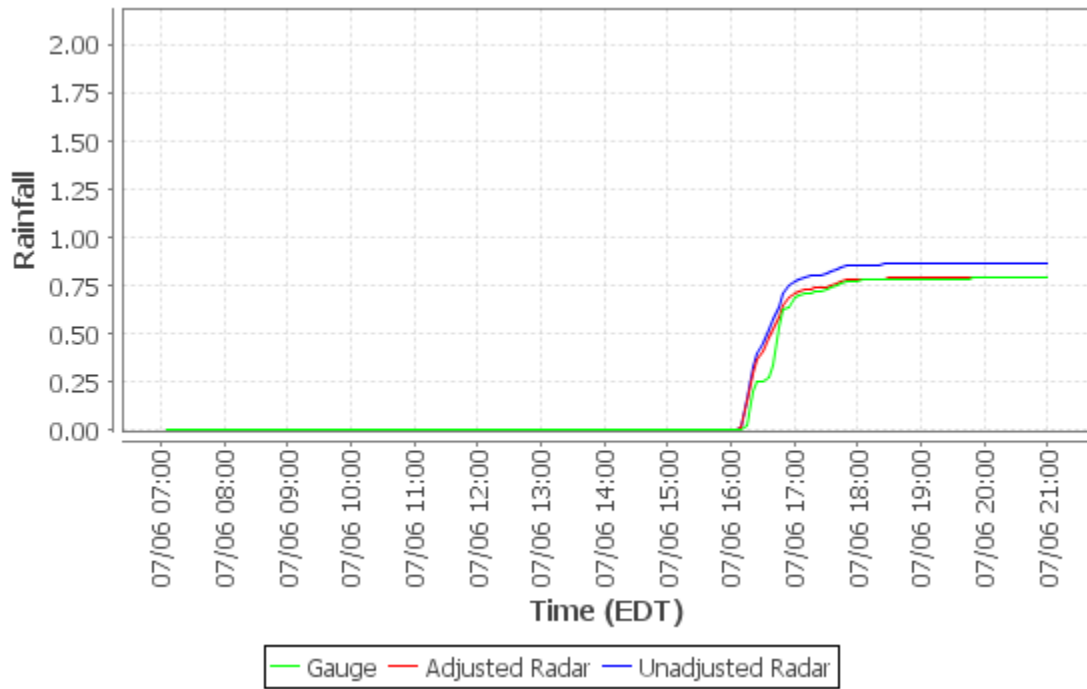
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



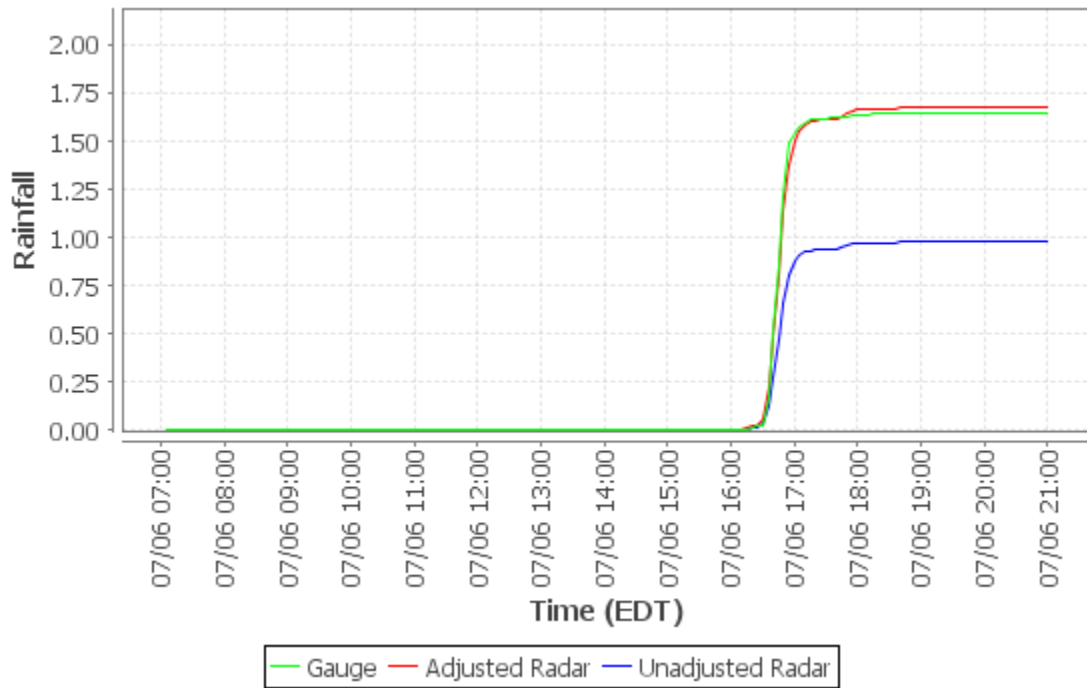
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



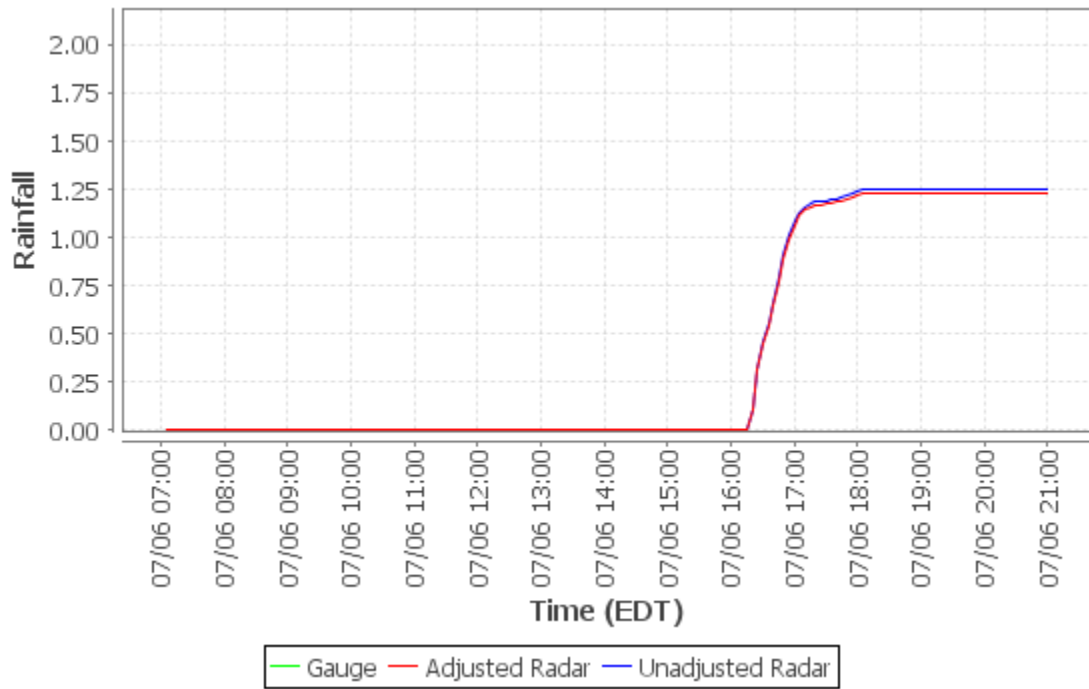
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



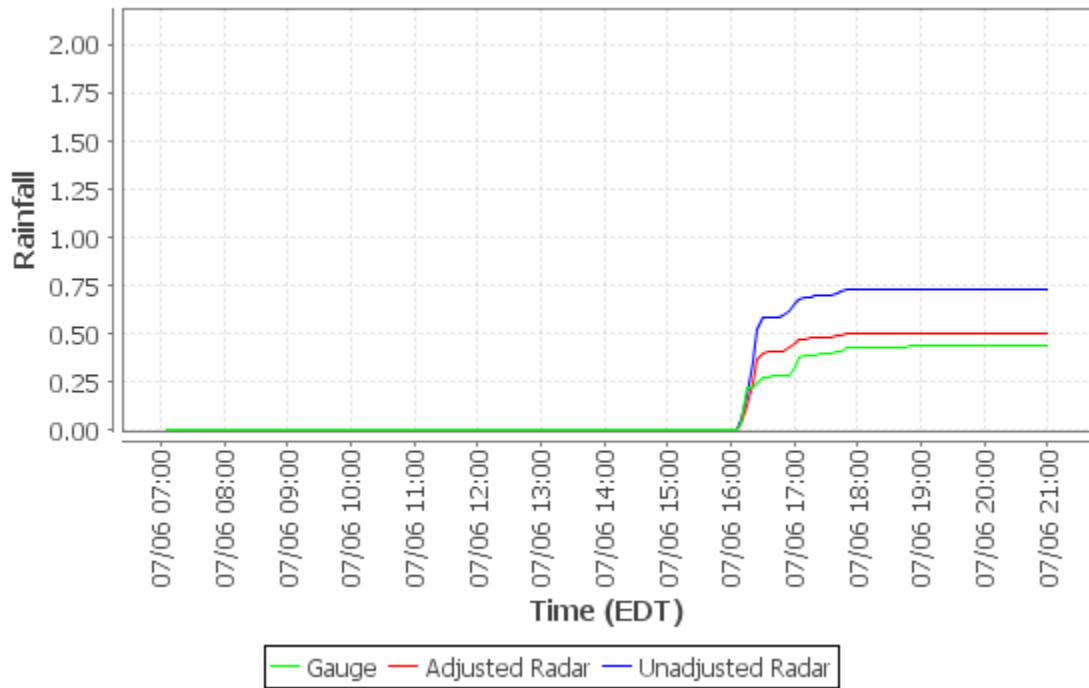
Cumulative Distribution Plot - Baldwin (Loc12)



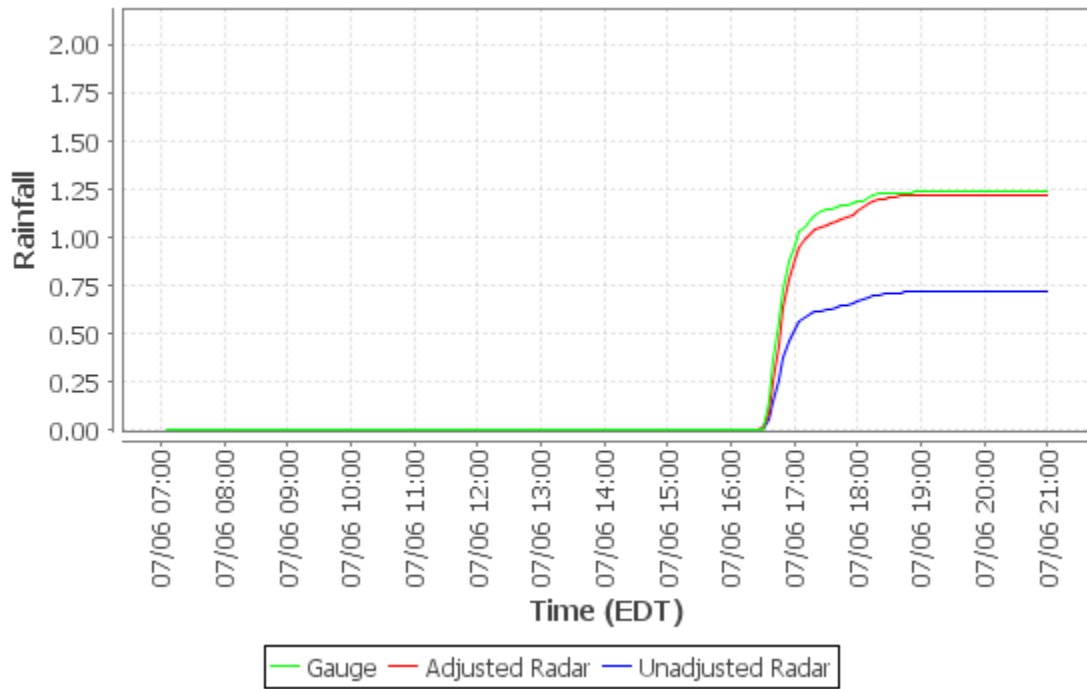
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



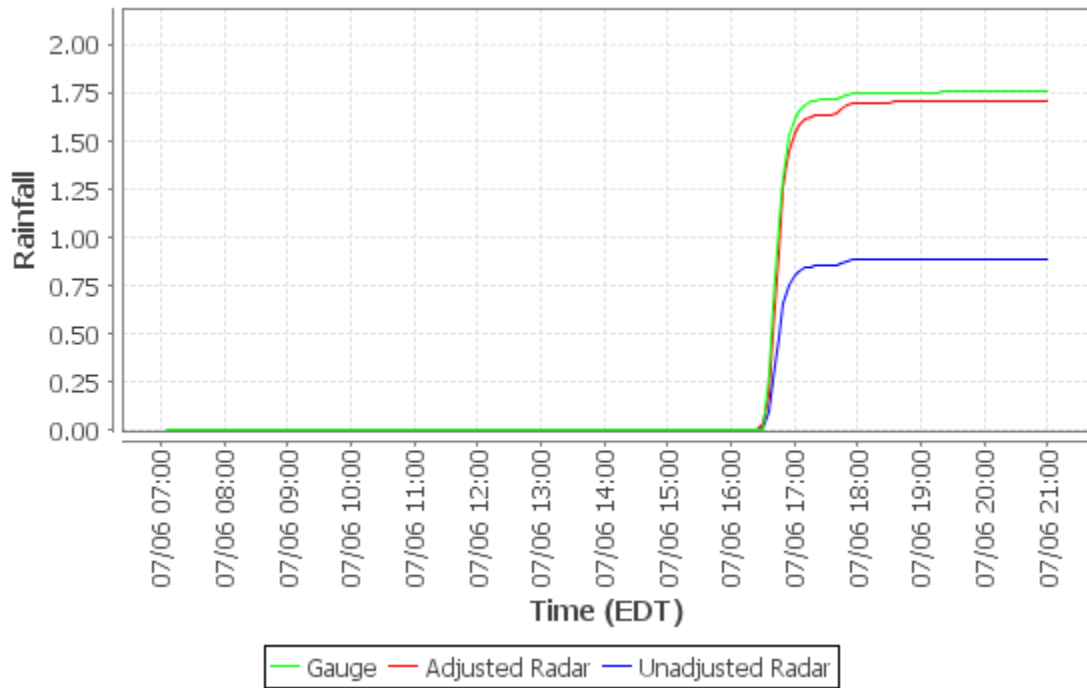
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



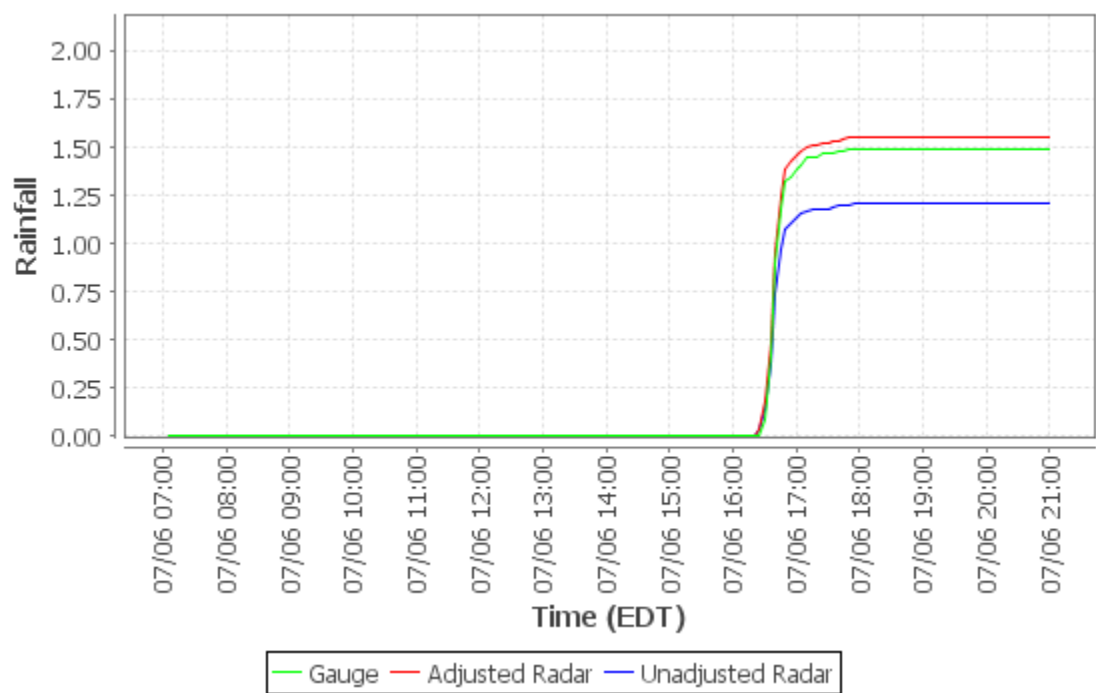
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



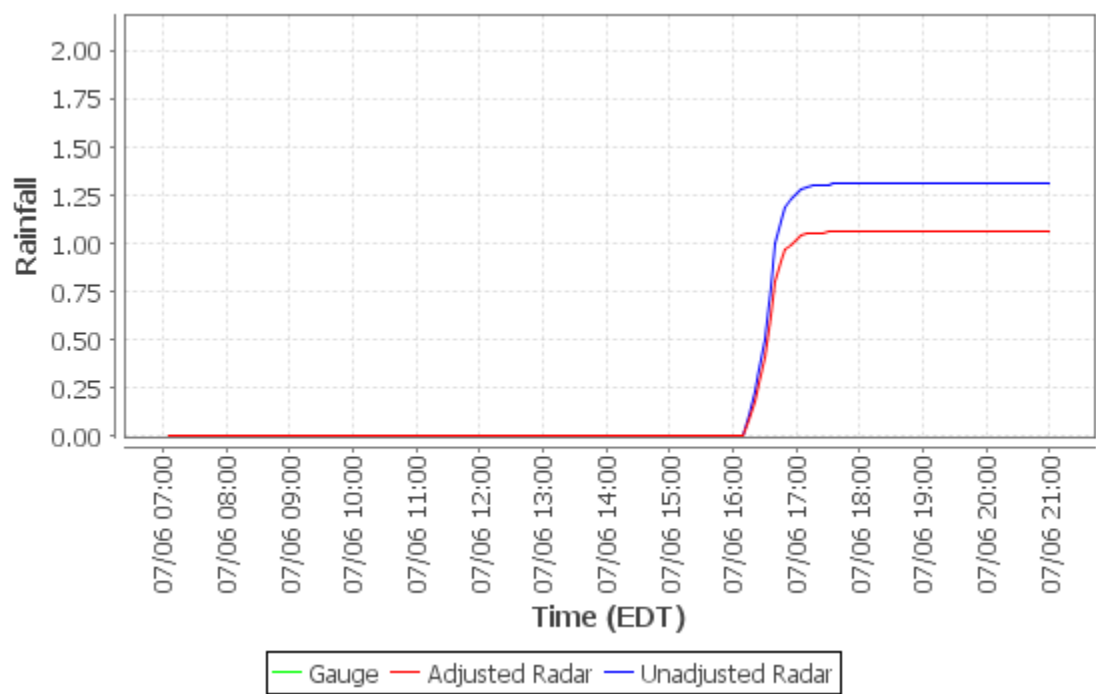
Cumulative Distribution Plot - Castle Shannon (Loc16)



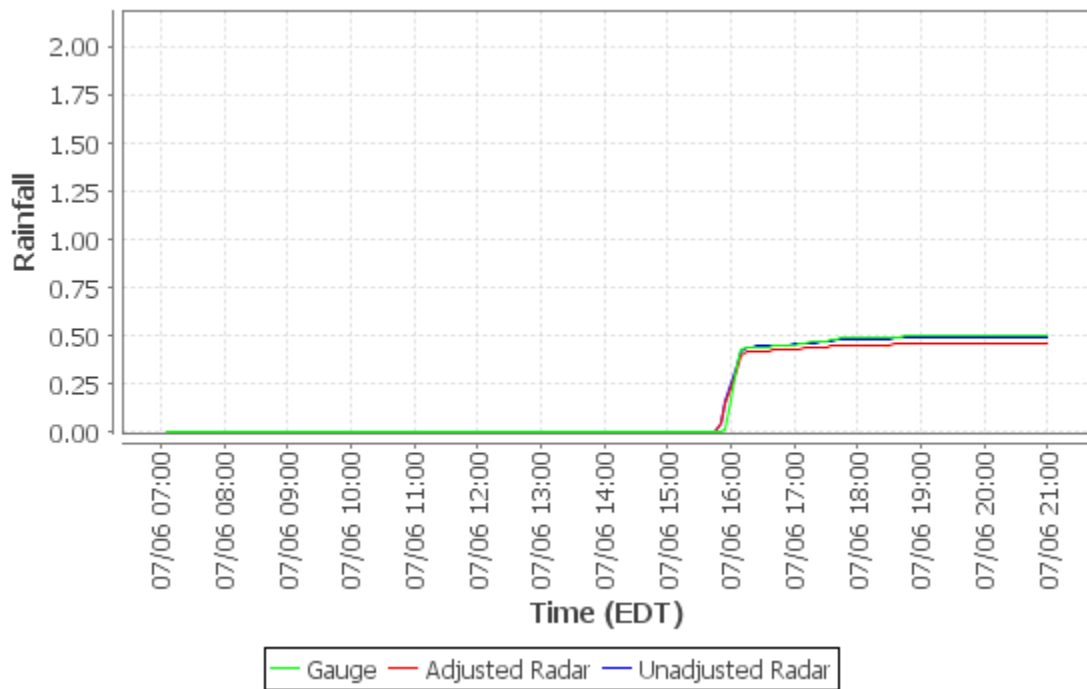
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



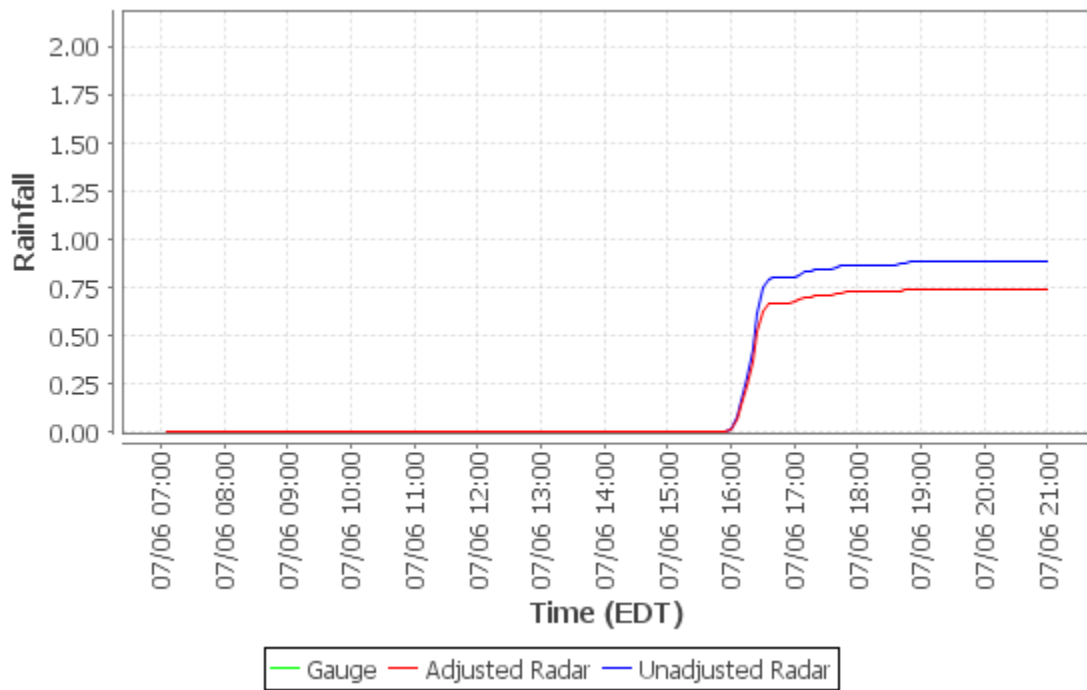
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



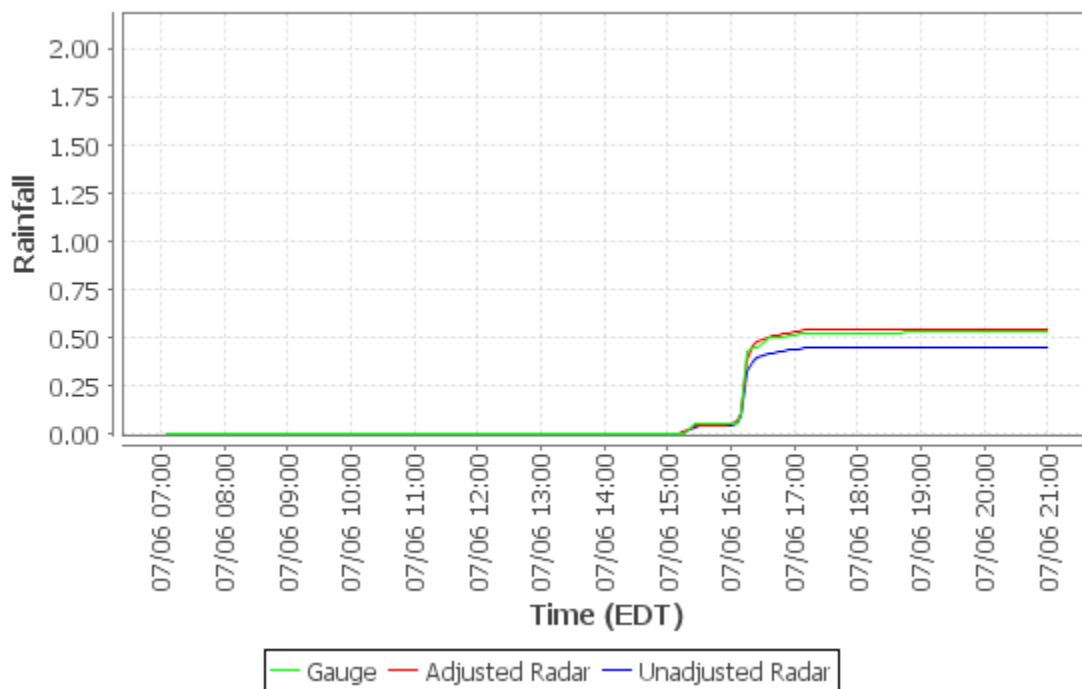
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



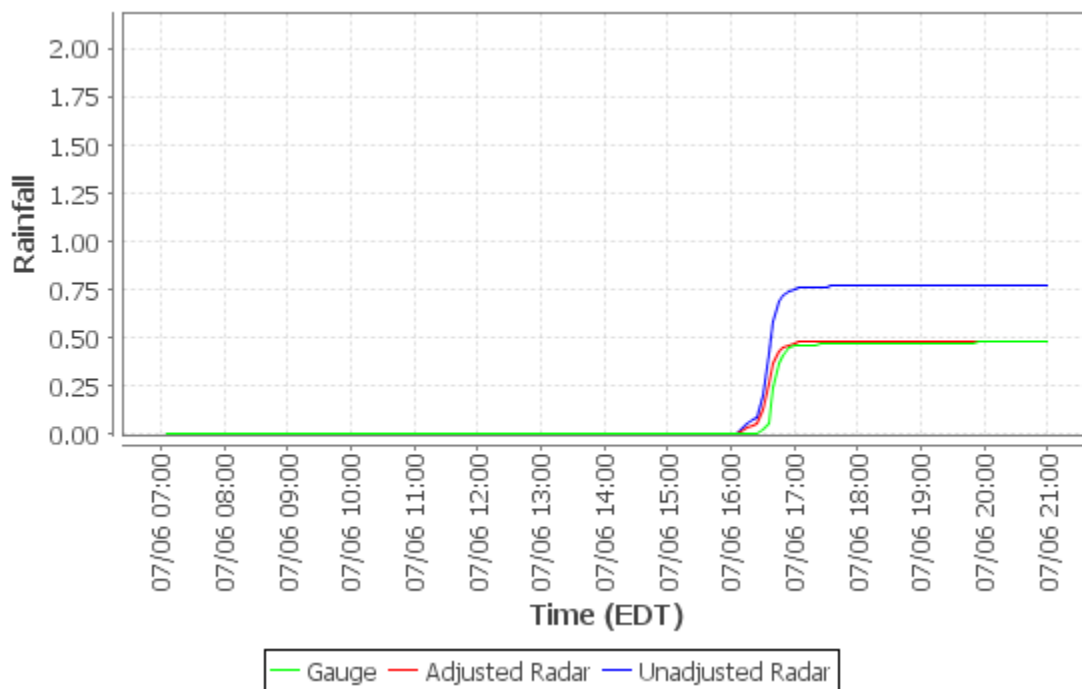
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



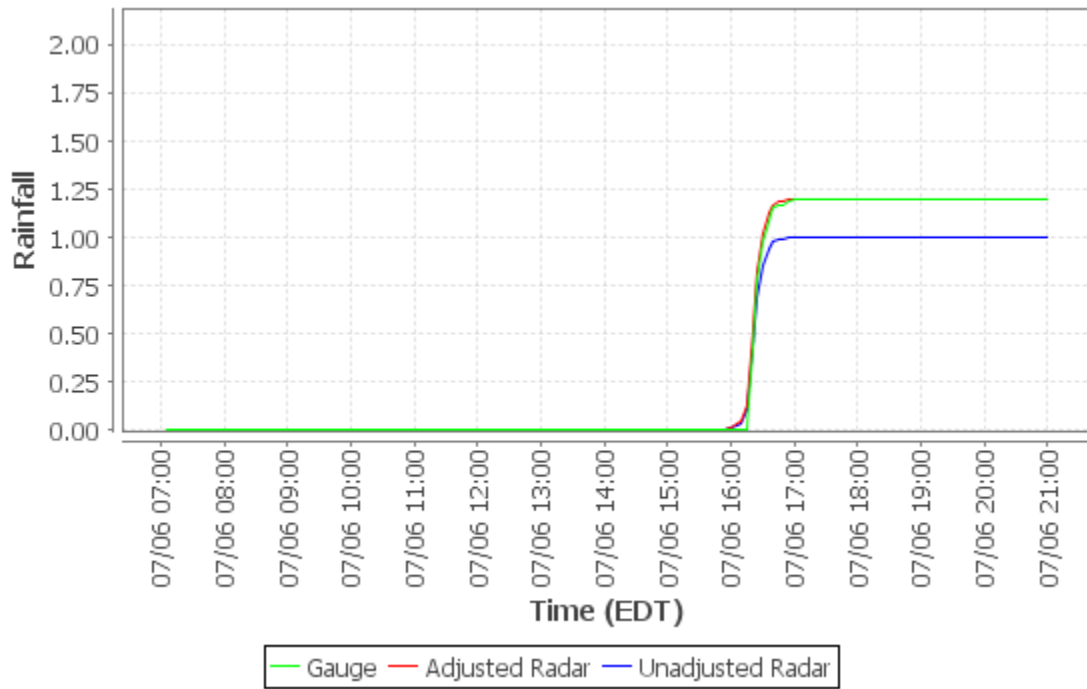
Cumulative Distribution Plot - Moon TWP (Loc21)



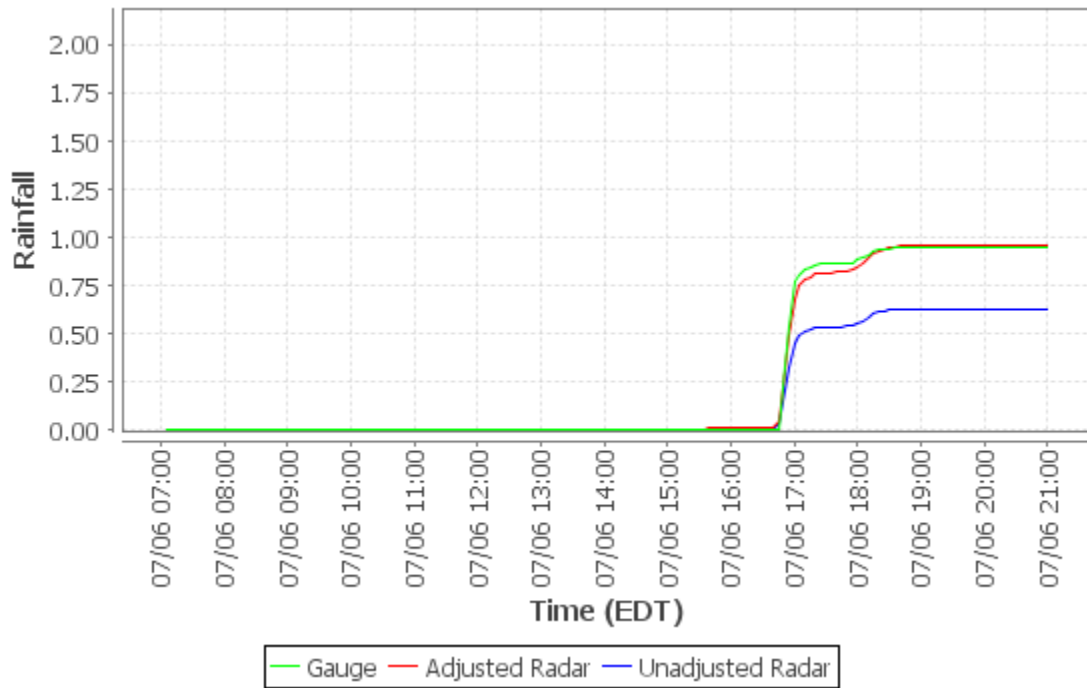
Cumulative Distribution Plot - North Fayette TWP (Loc22)



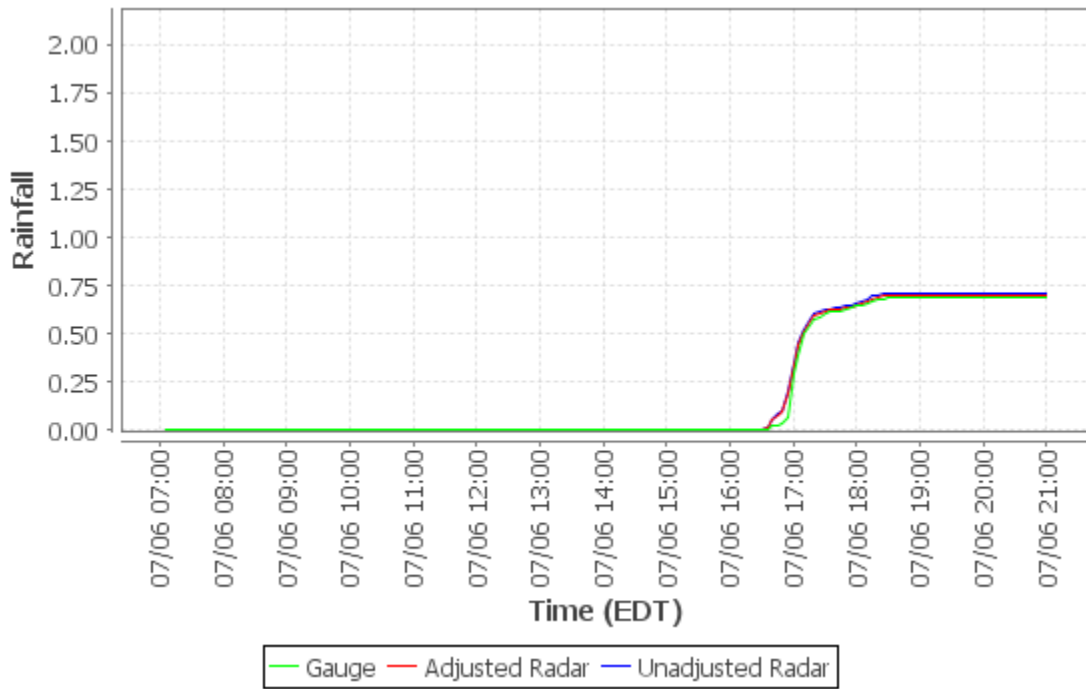
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



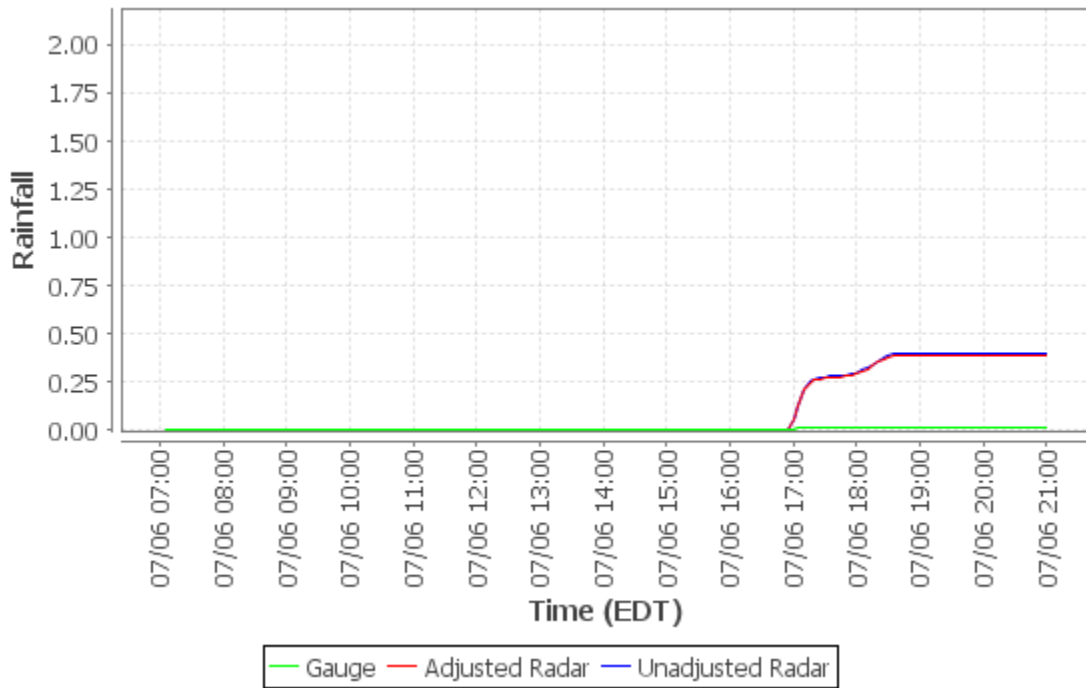
Cumulative Distribution Plot - Jefferson Hills (Loc24)



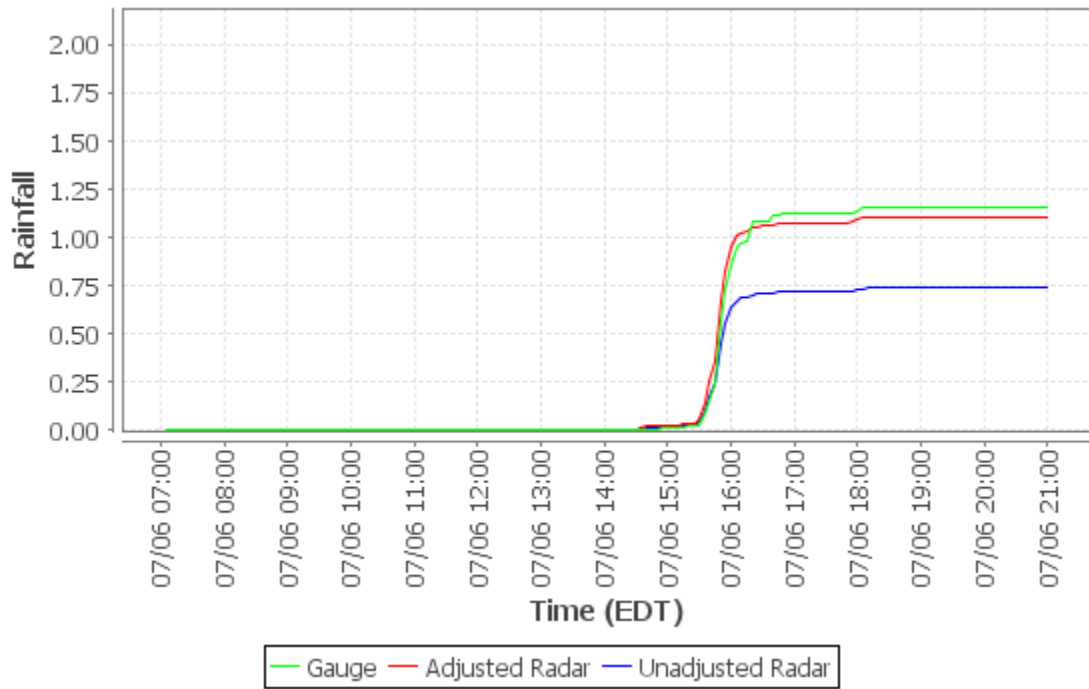
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



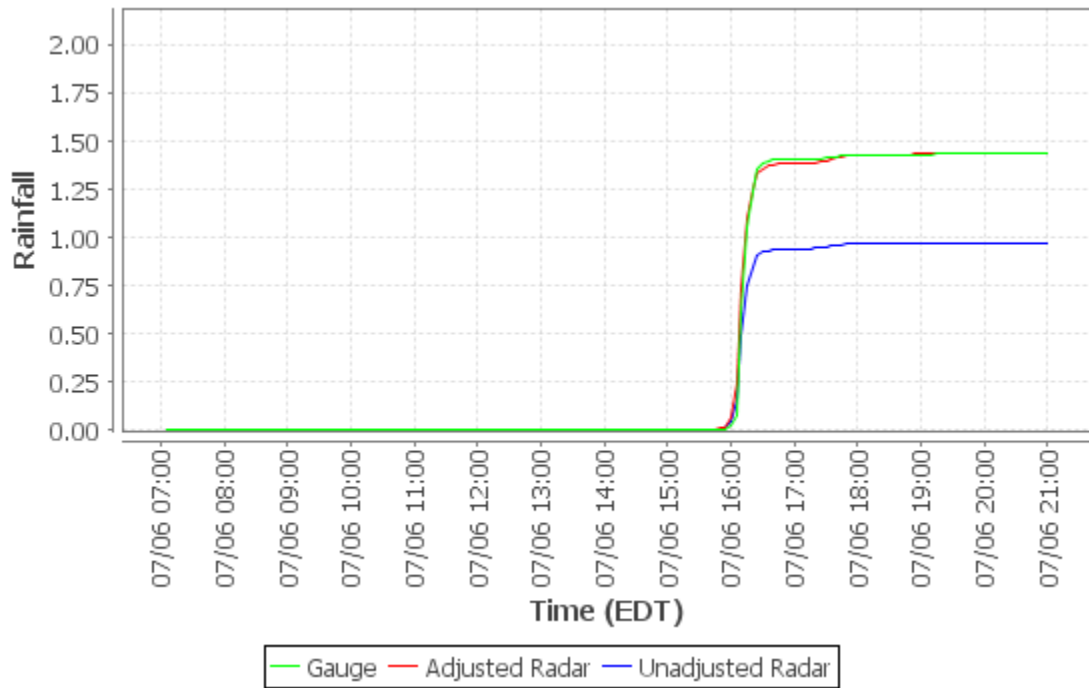
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



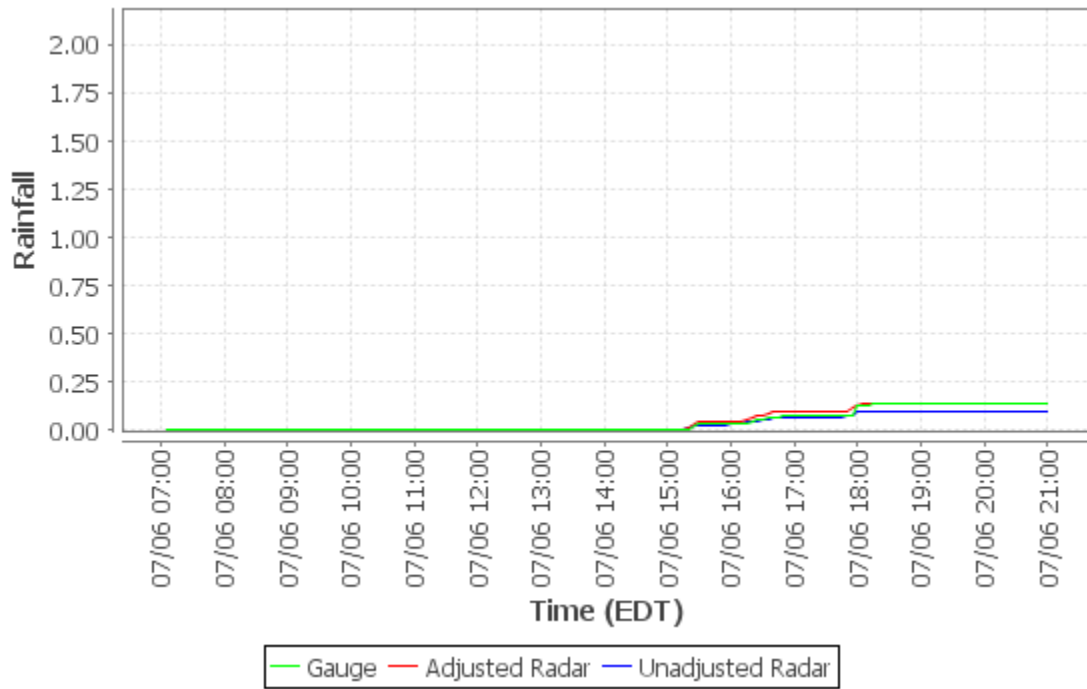
Cumulative Distribution Plot - Marshall TWP (Loc27)



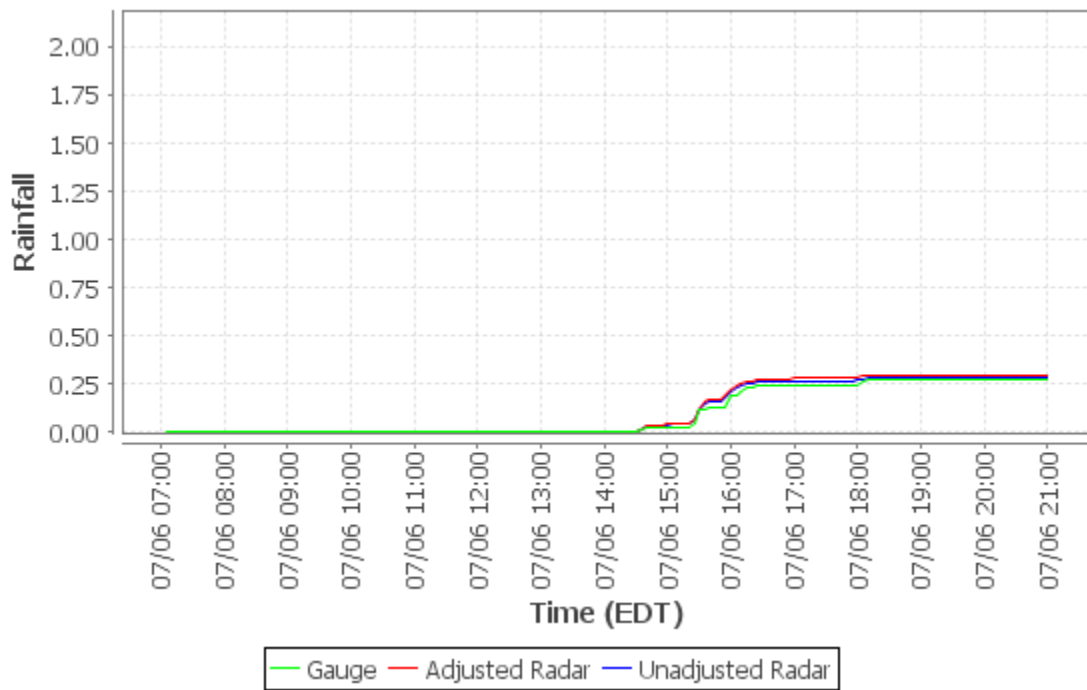
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



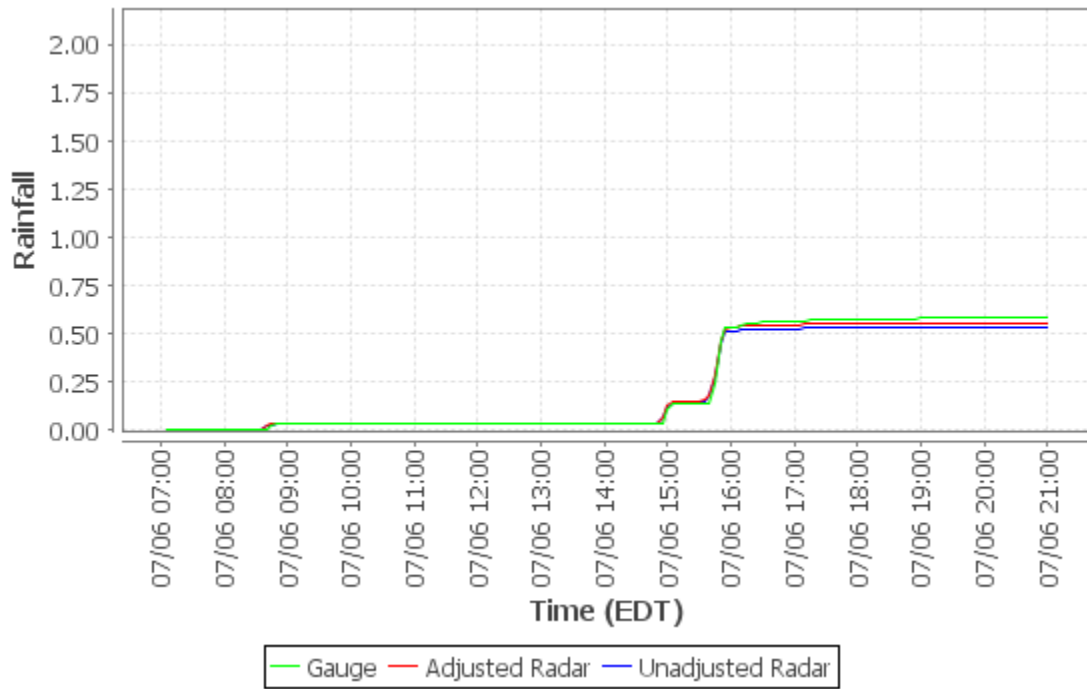
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



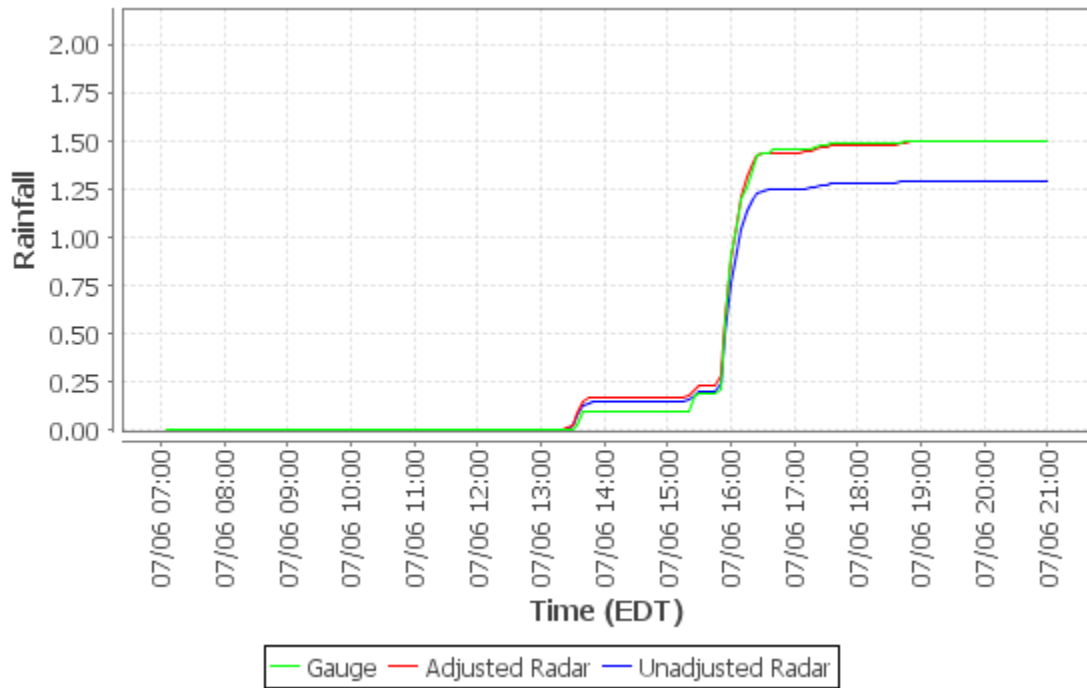
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



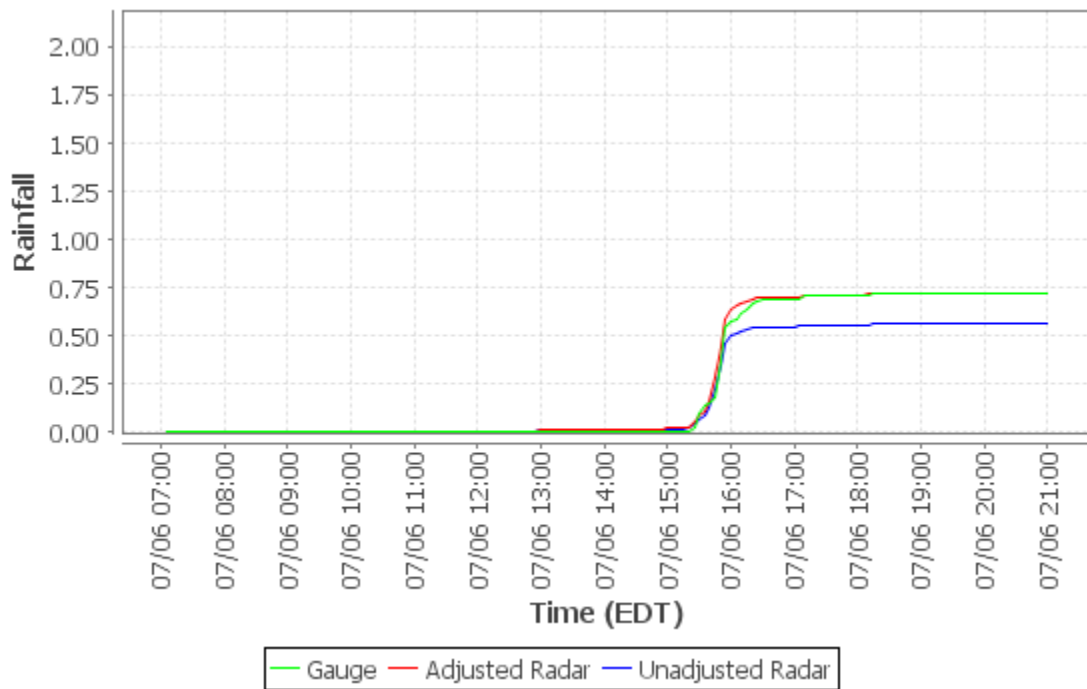
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



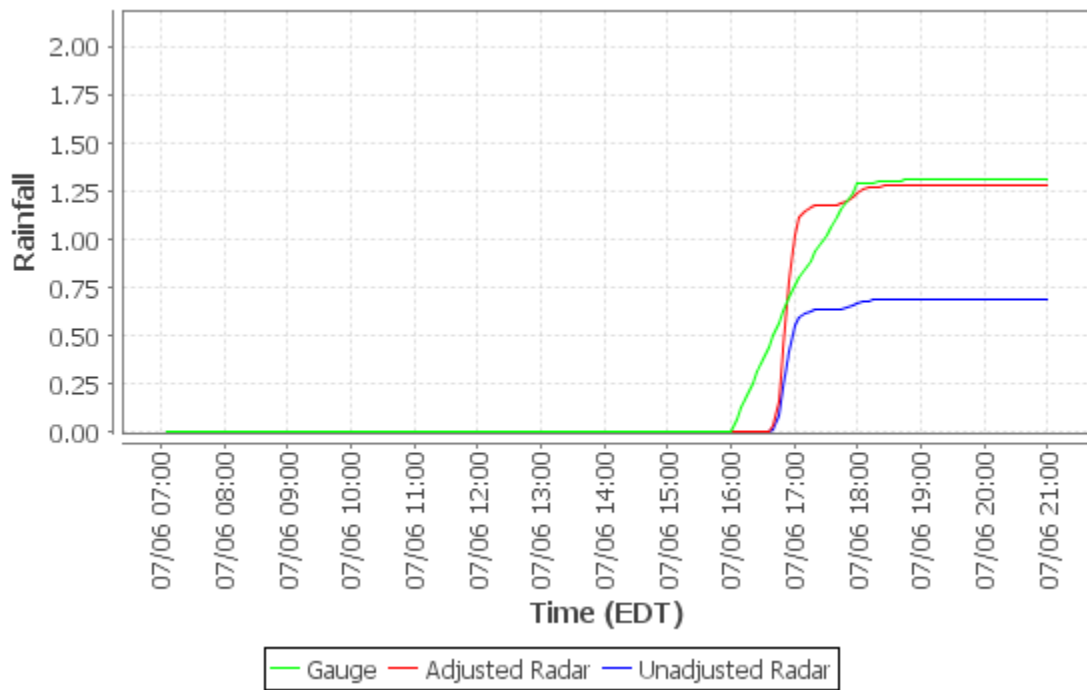
Cumulative Distribution Plot - Arnold (Loc32)



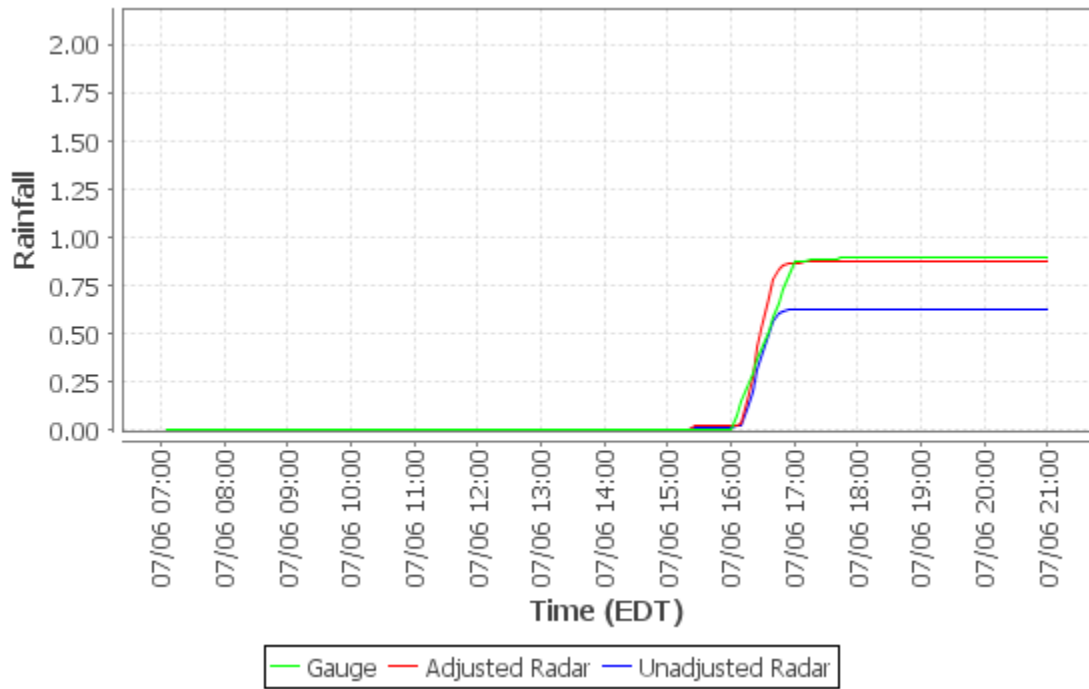
Cumulative Distribution Plot - Richland TWP (Loc33)



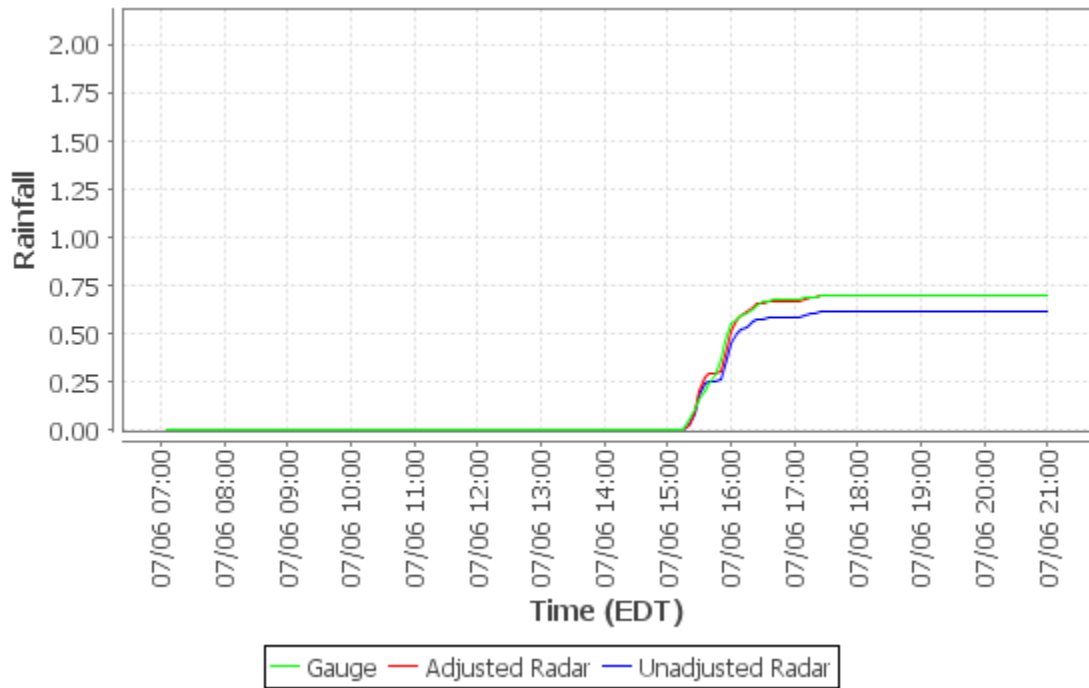
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



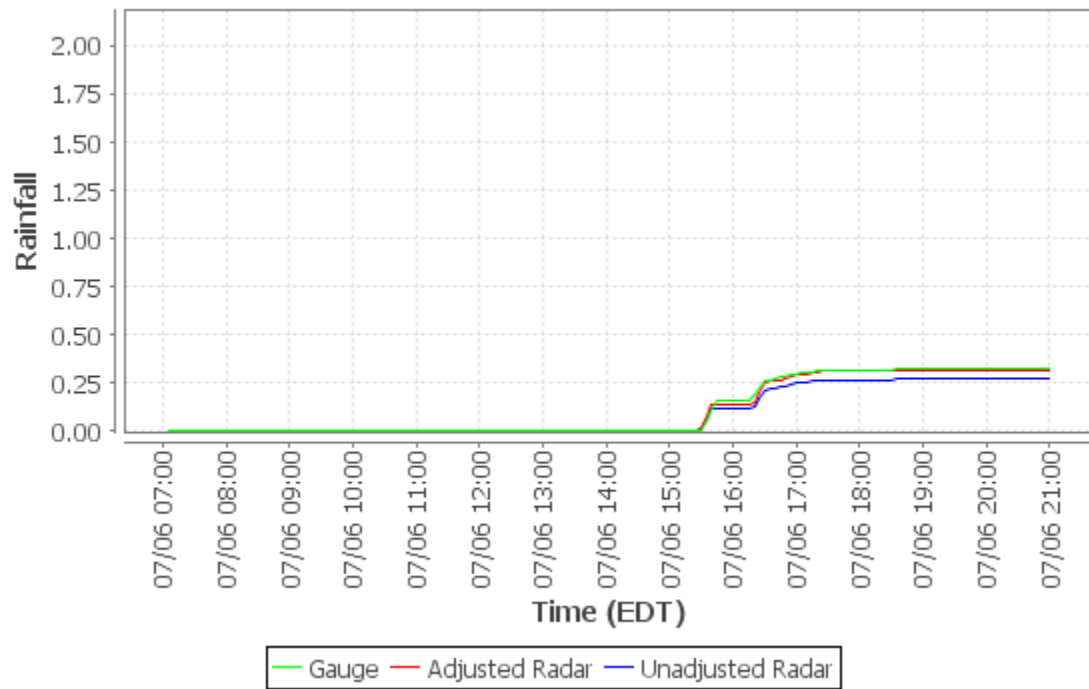
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

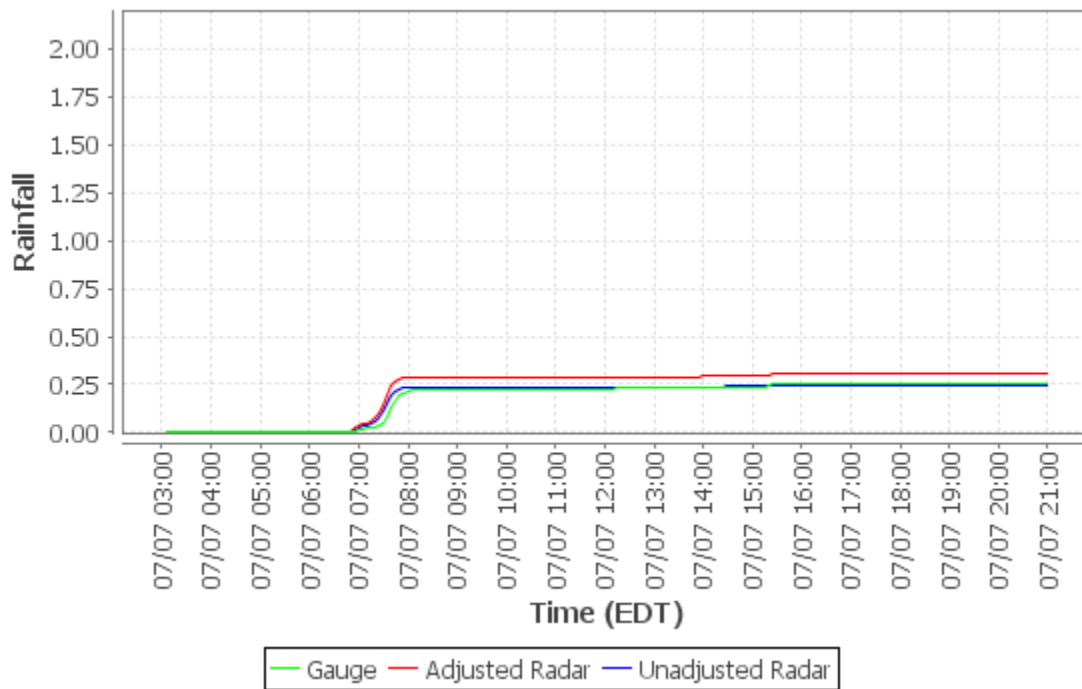


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

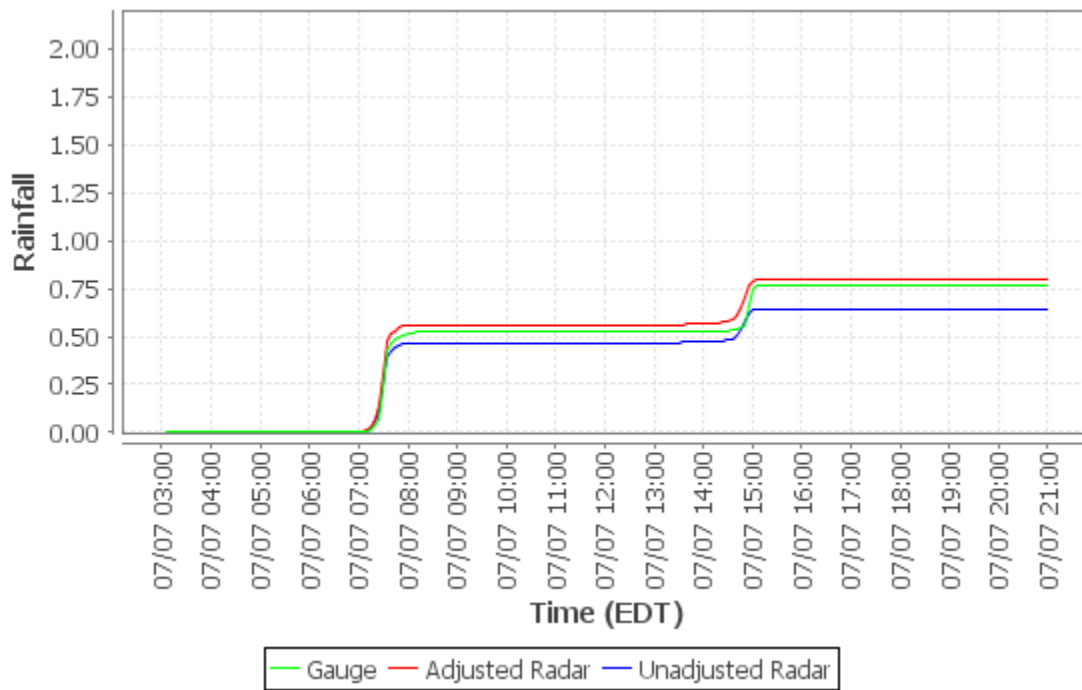


Appendix E - Event 3 (2019-07-07) CDPs

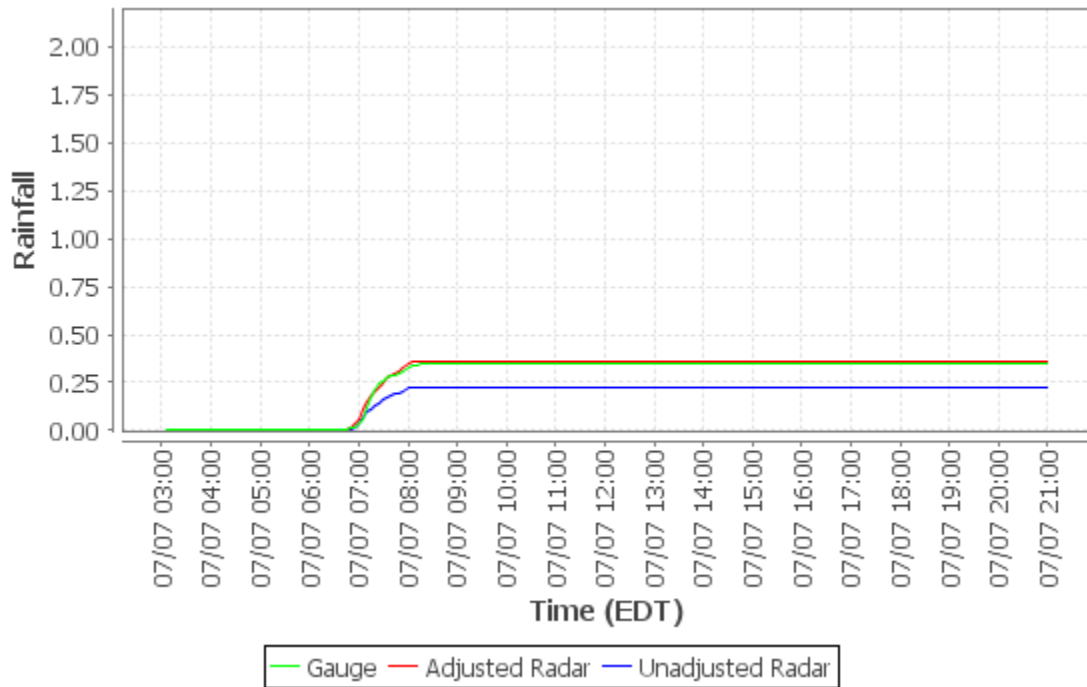
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



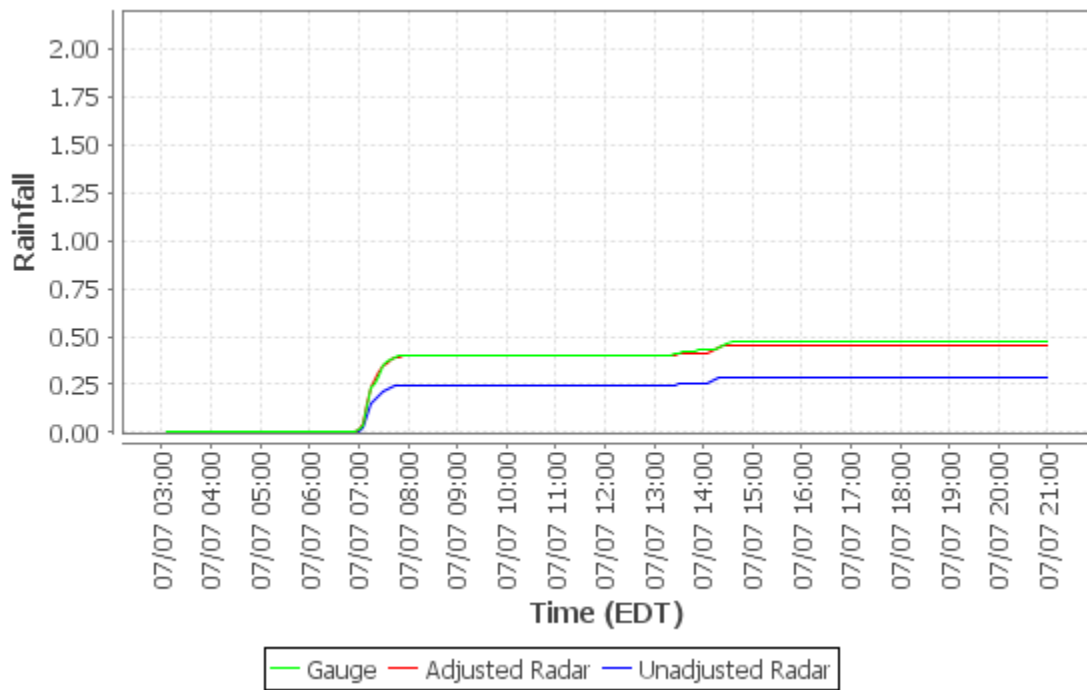
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



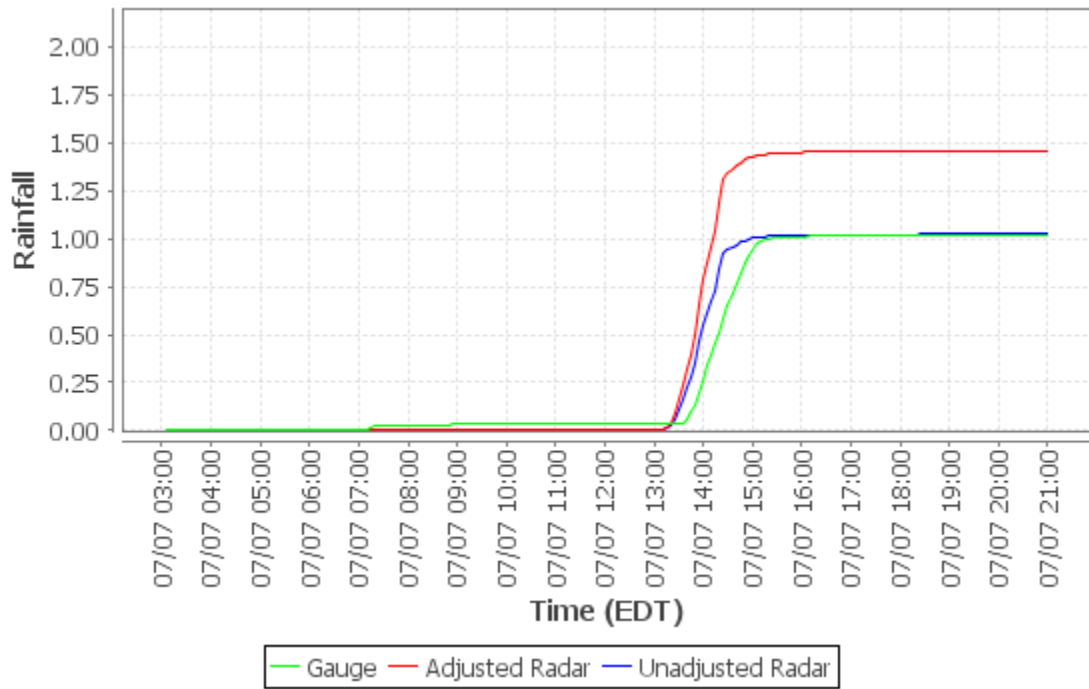
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



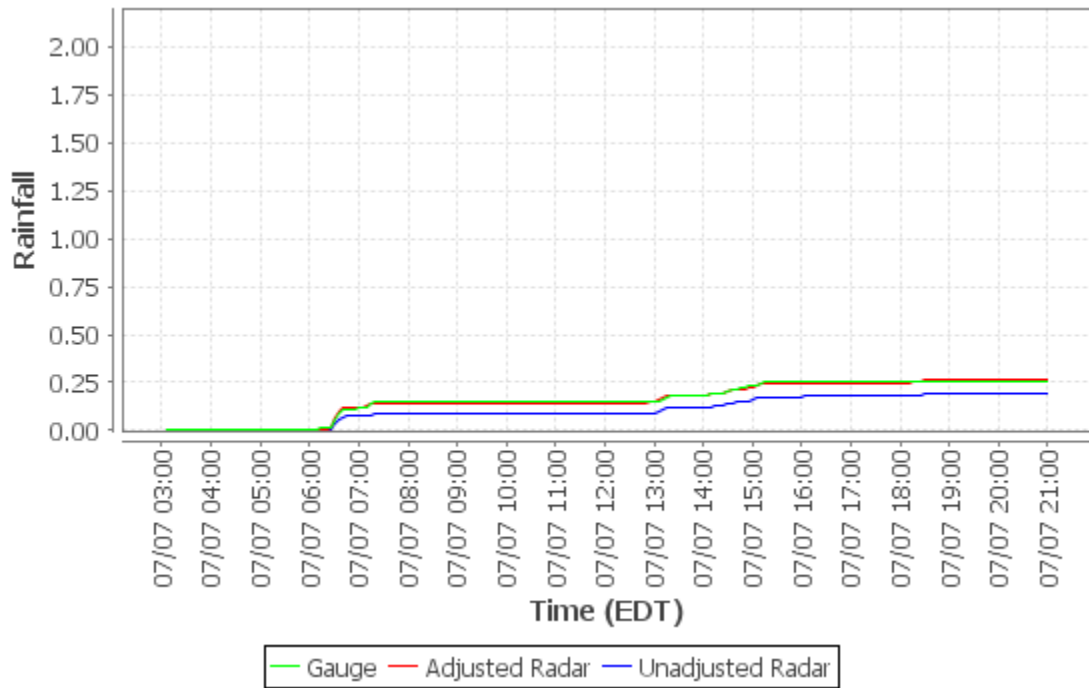
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



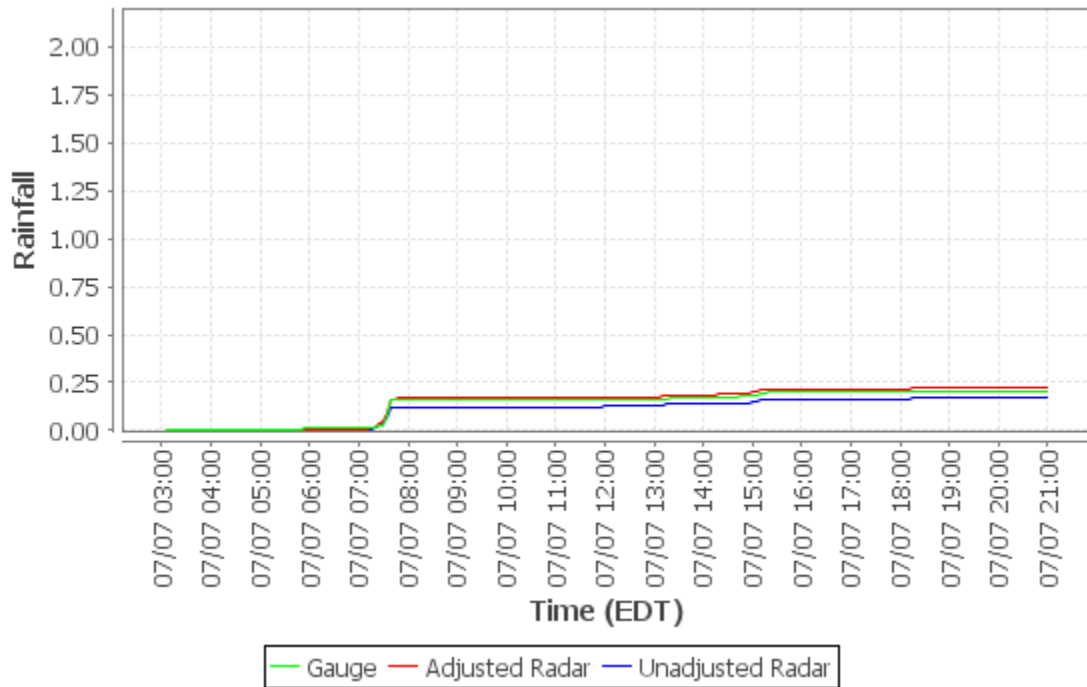
Cumulative Distribution Plot - Upper St. Clair (Loc05)



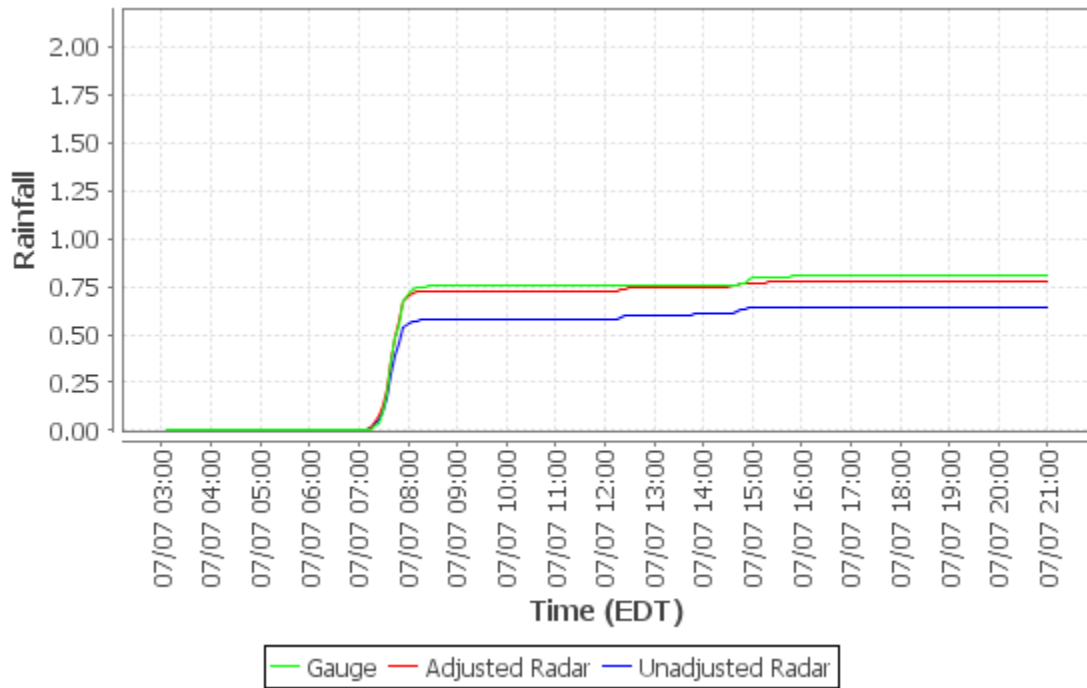
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



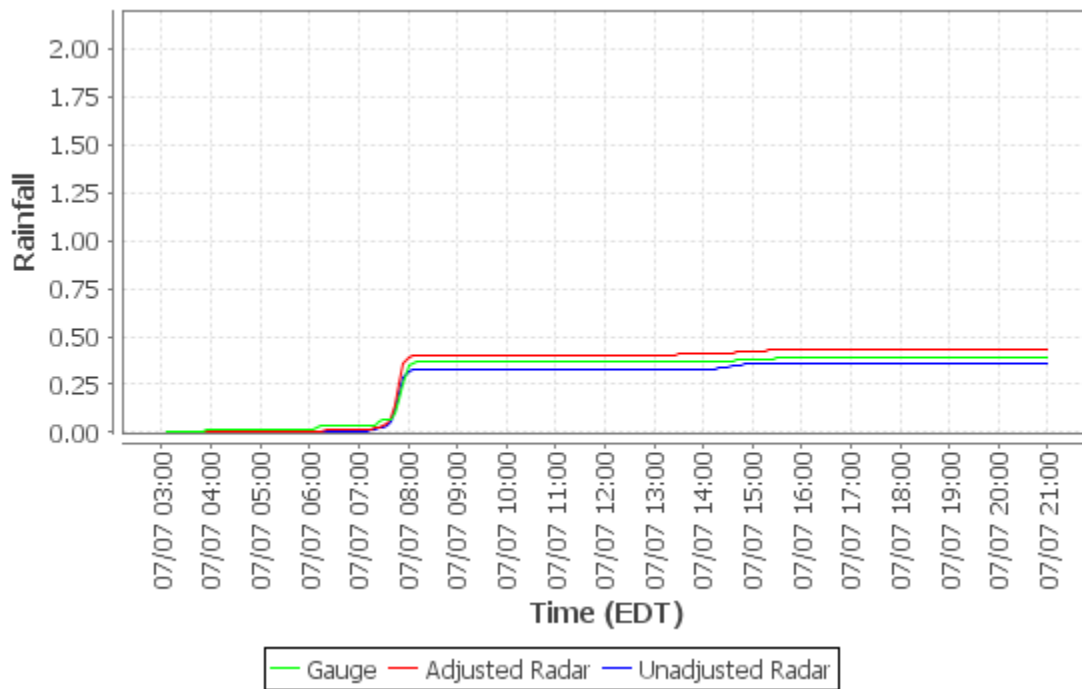
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



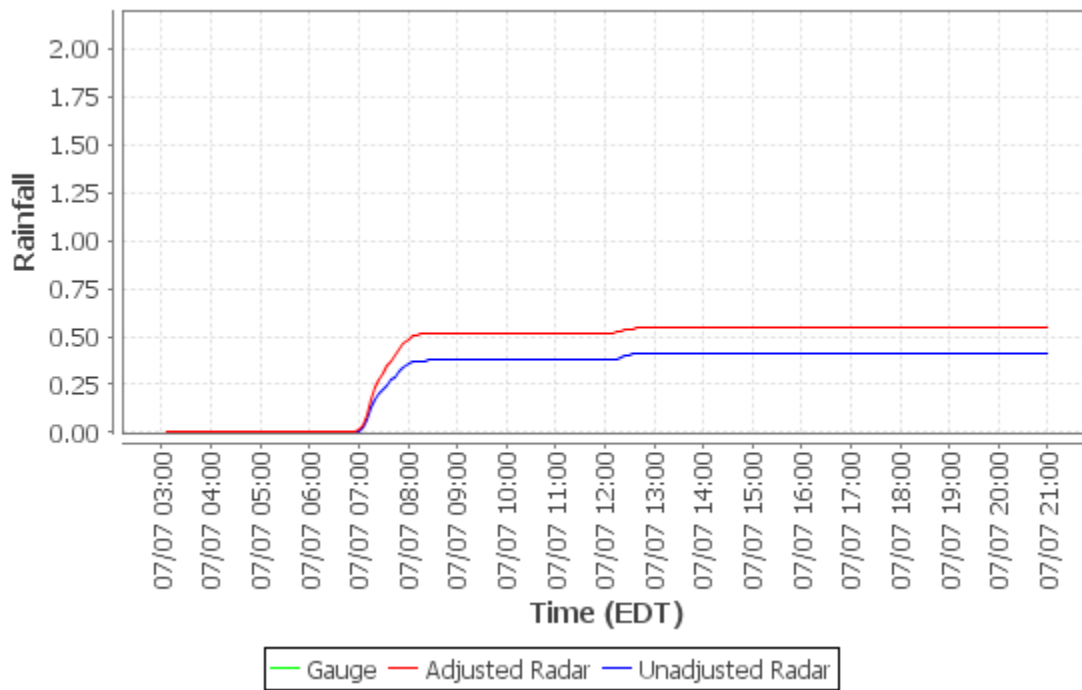
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



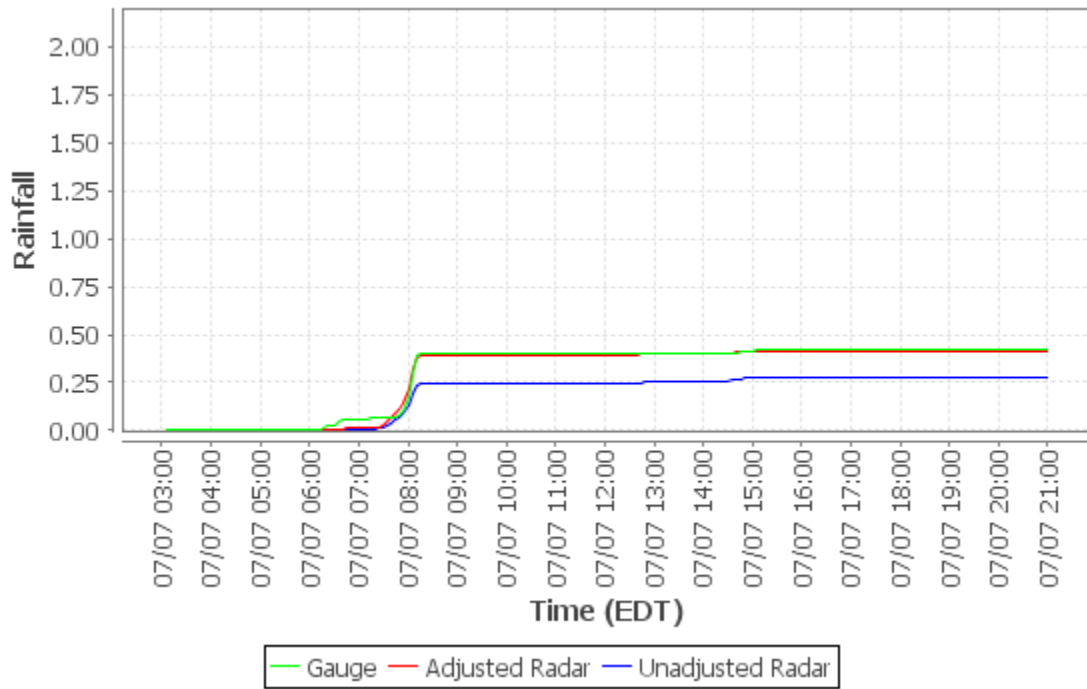
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



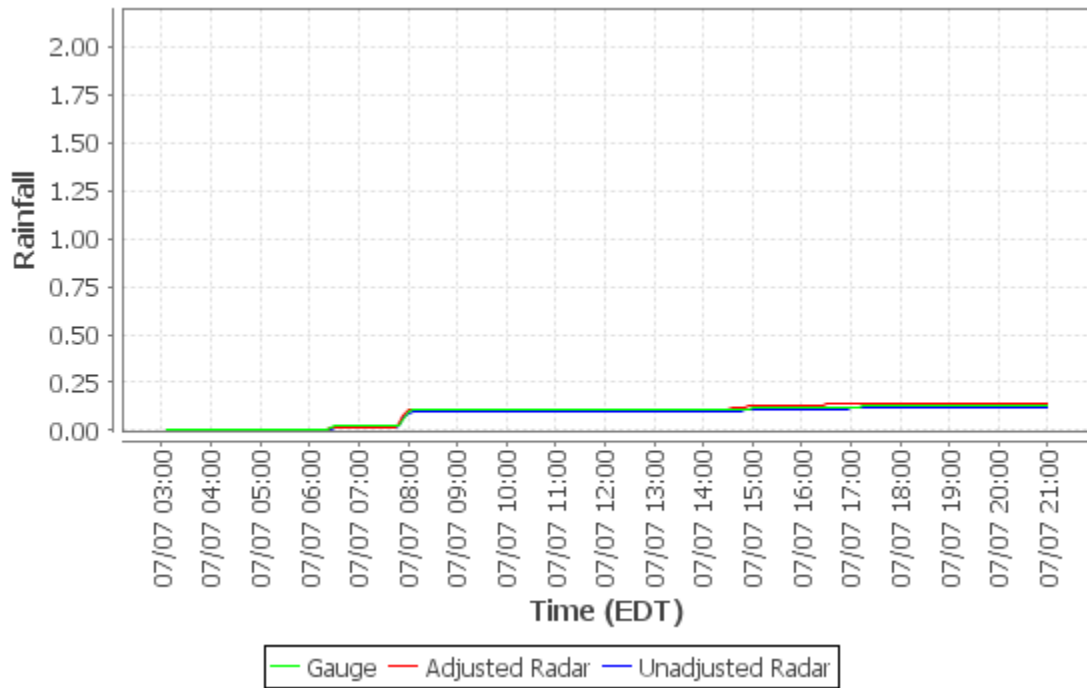
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



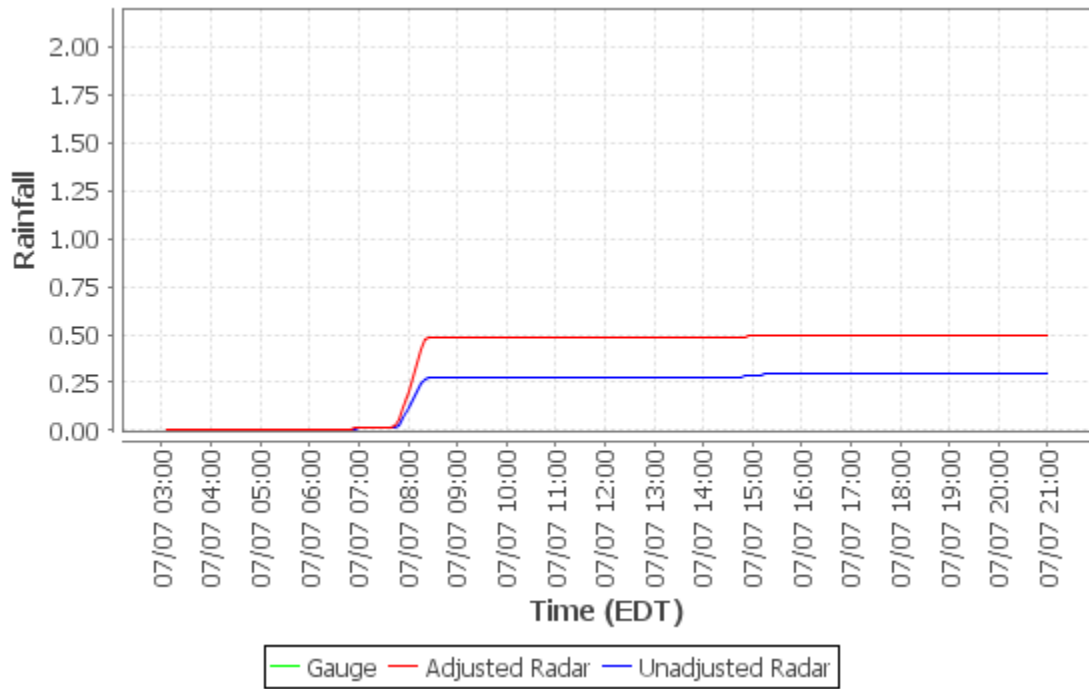
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



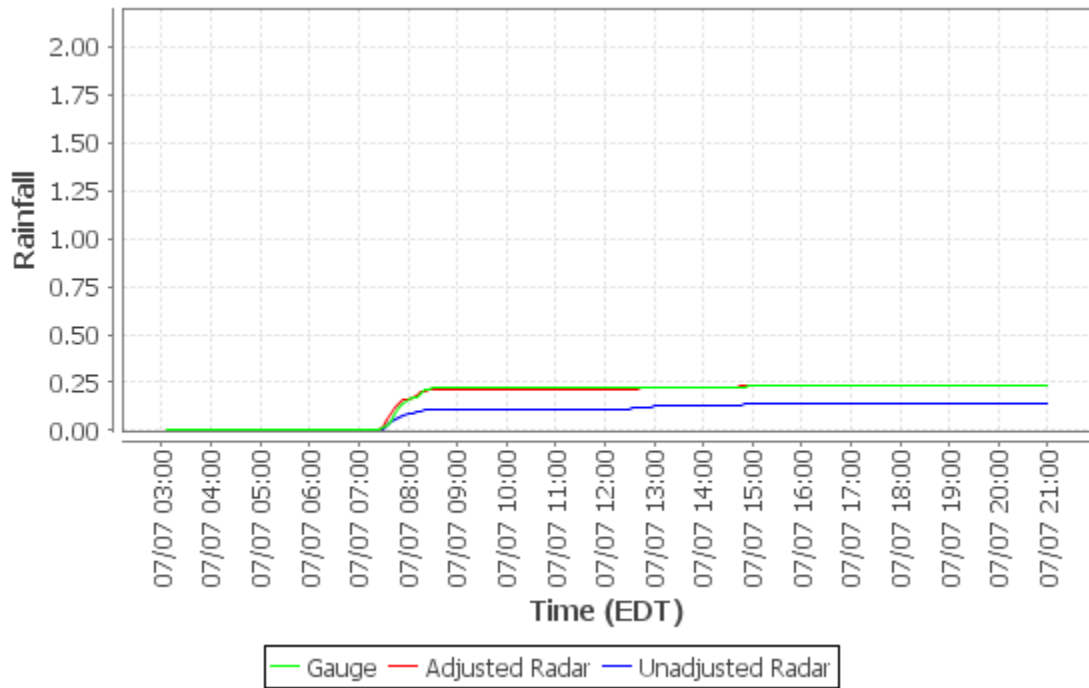
Cumulative Distribution Plot - Baldwin (Loc12)



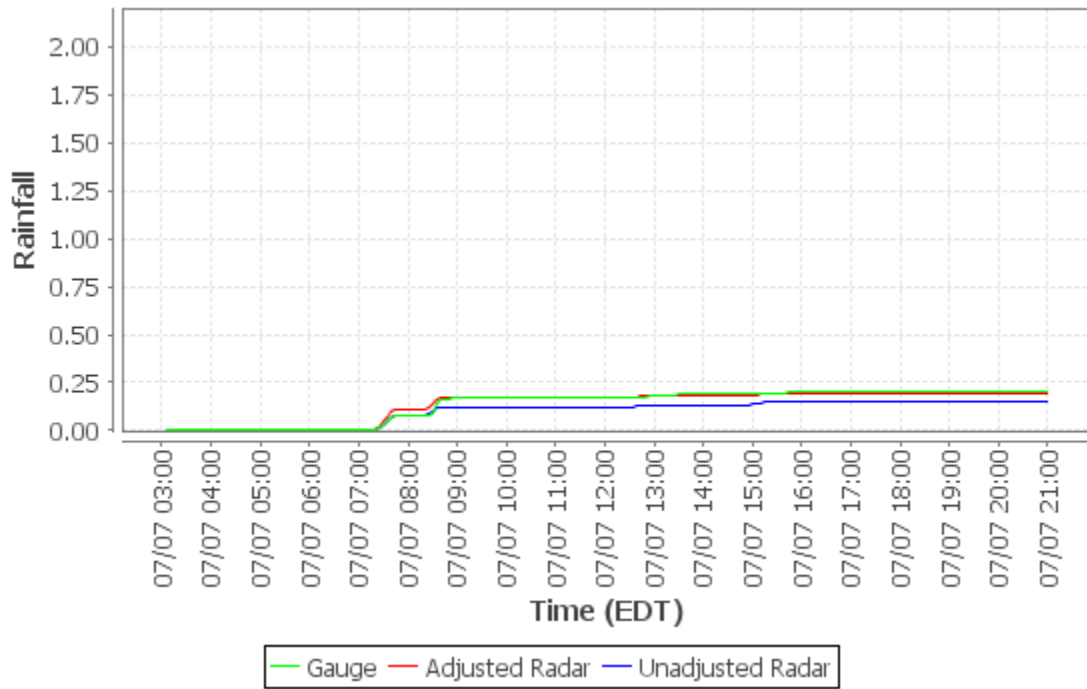
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



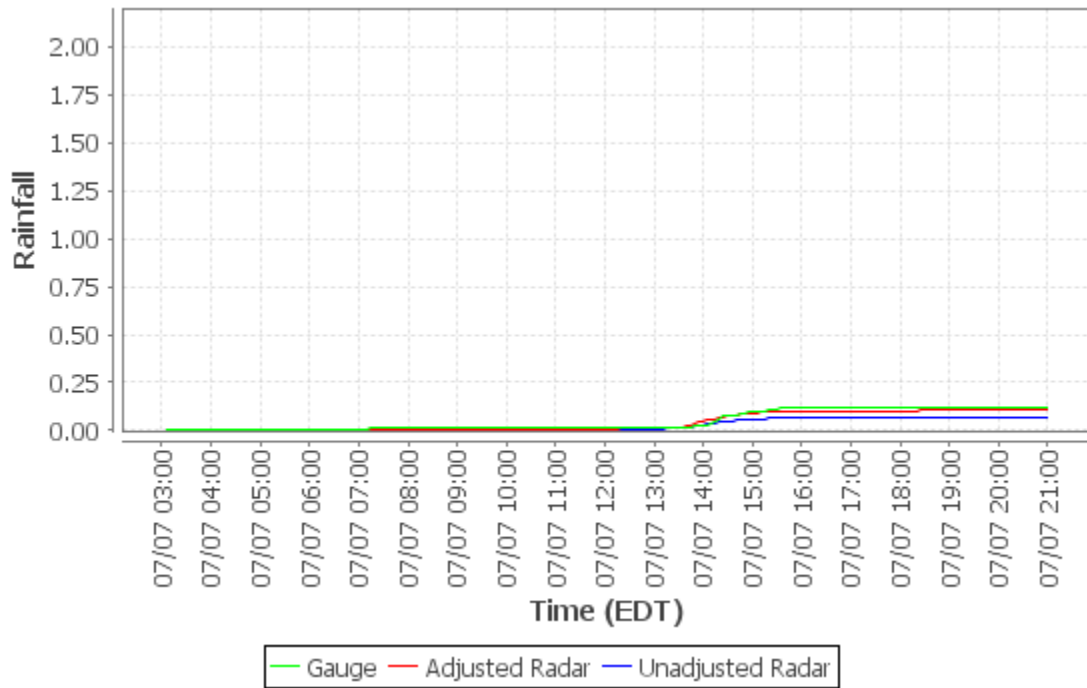
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



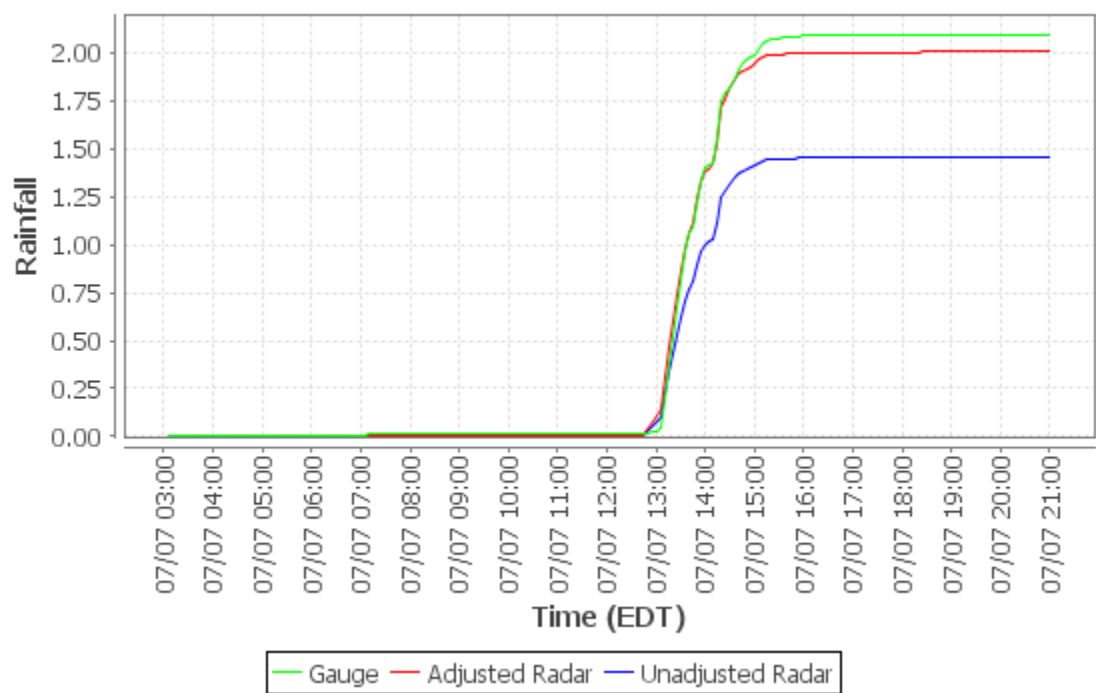
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



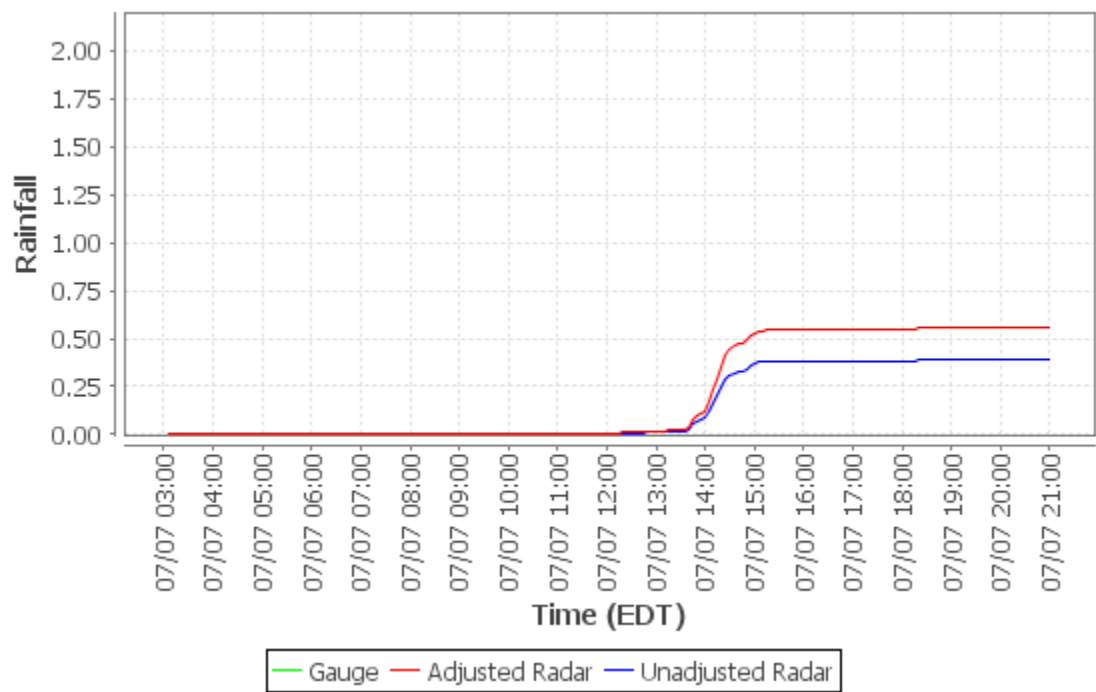
Cumulative Distribution Plot - Castle Shannon (Loc16)



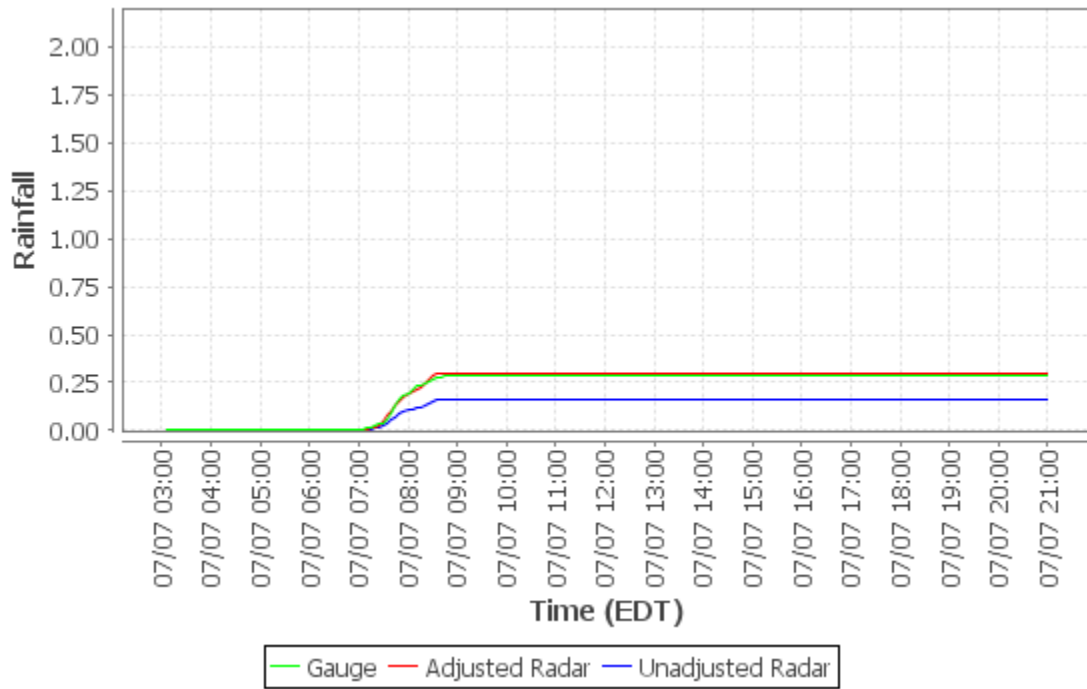
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



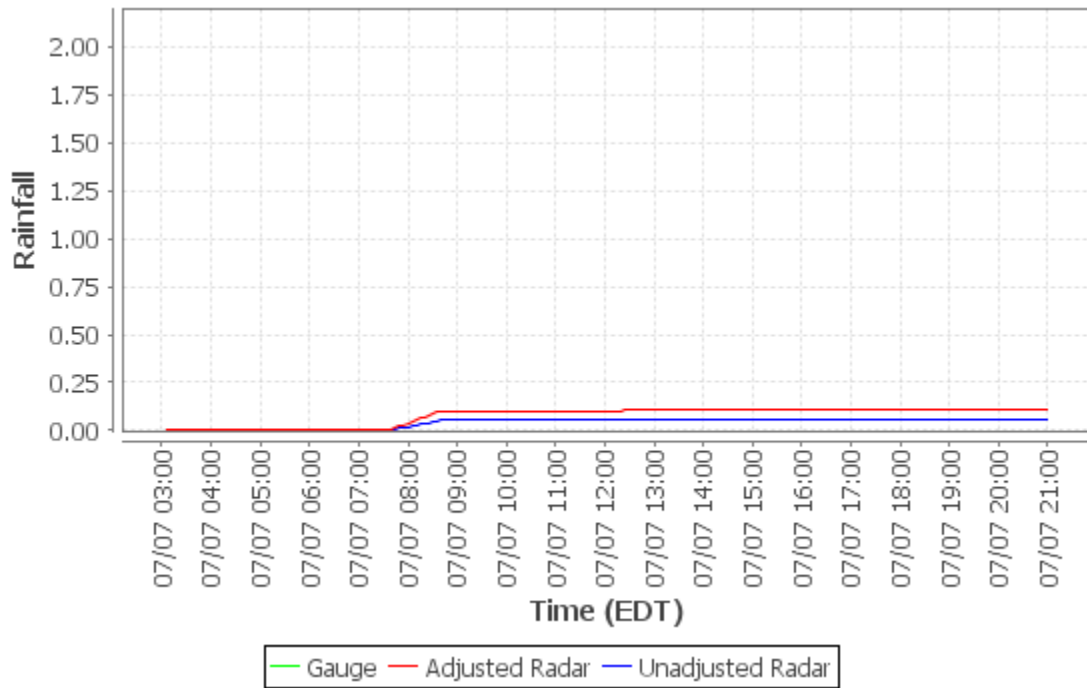
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



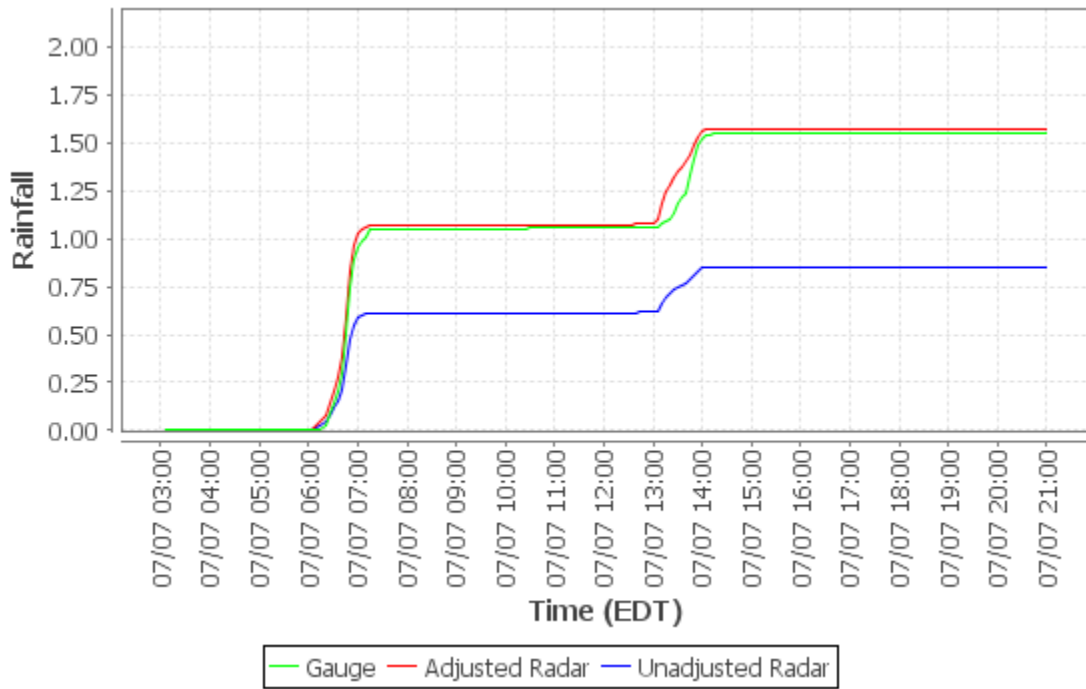
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



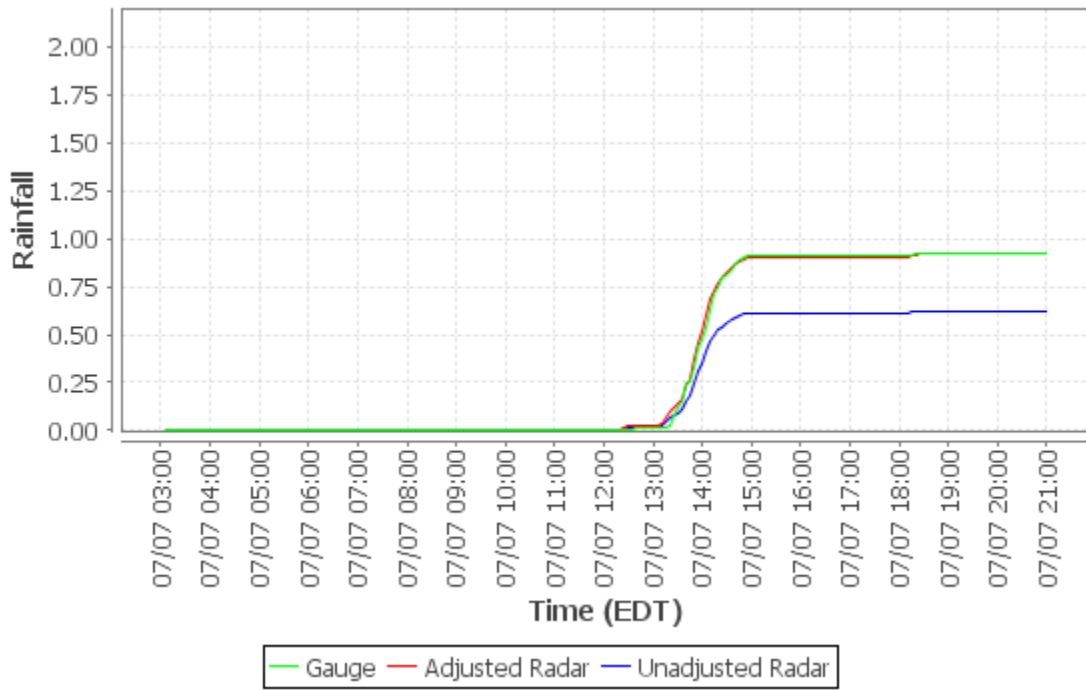
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



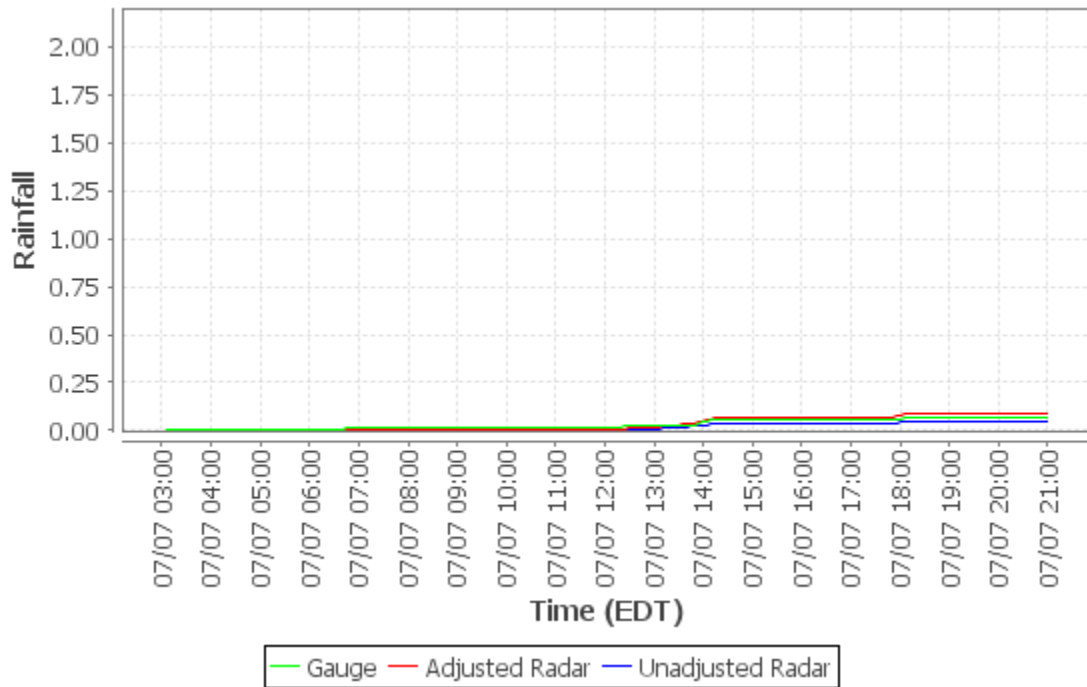
Cumulative Distribution Plot - Moon TWP (Loc21)



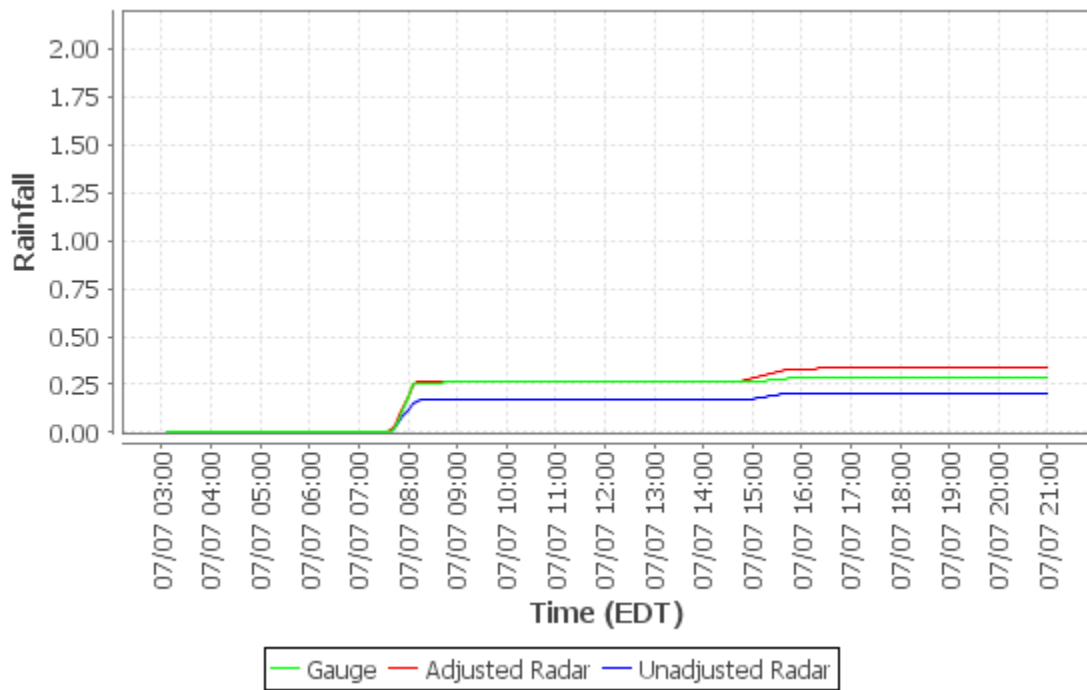
Cumulative Distribution Plot - North Fayette TWP (Loc22)



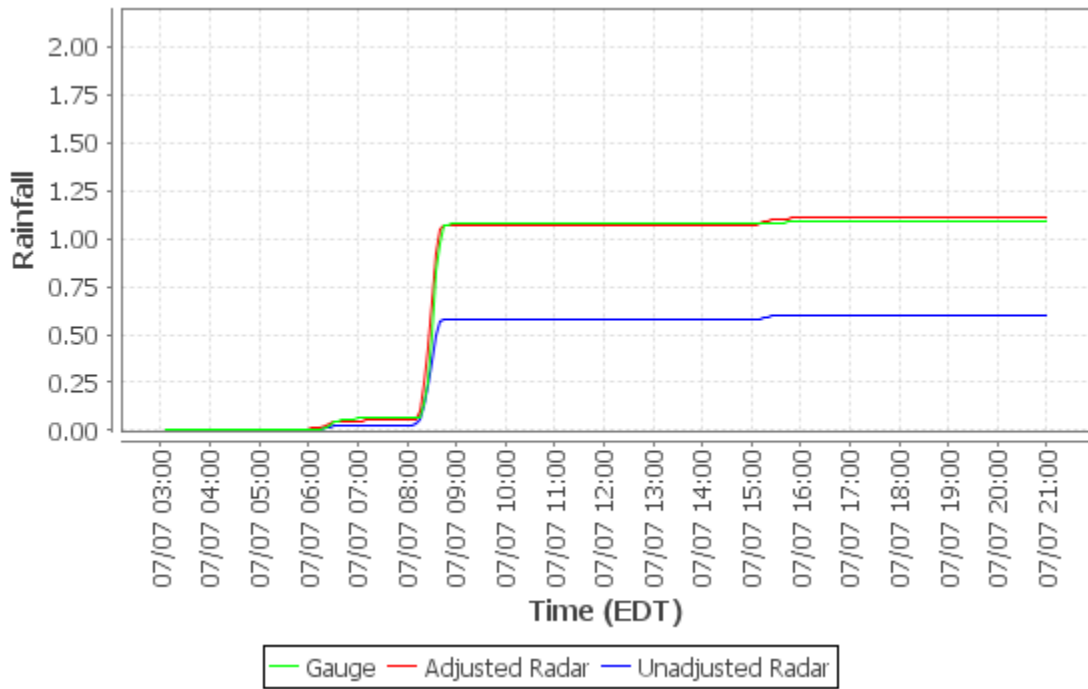
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



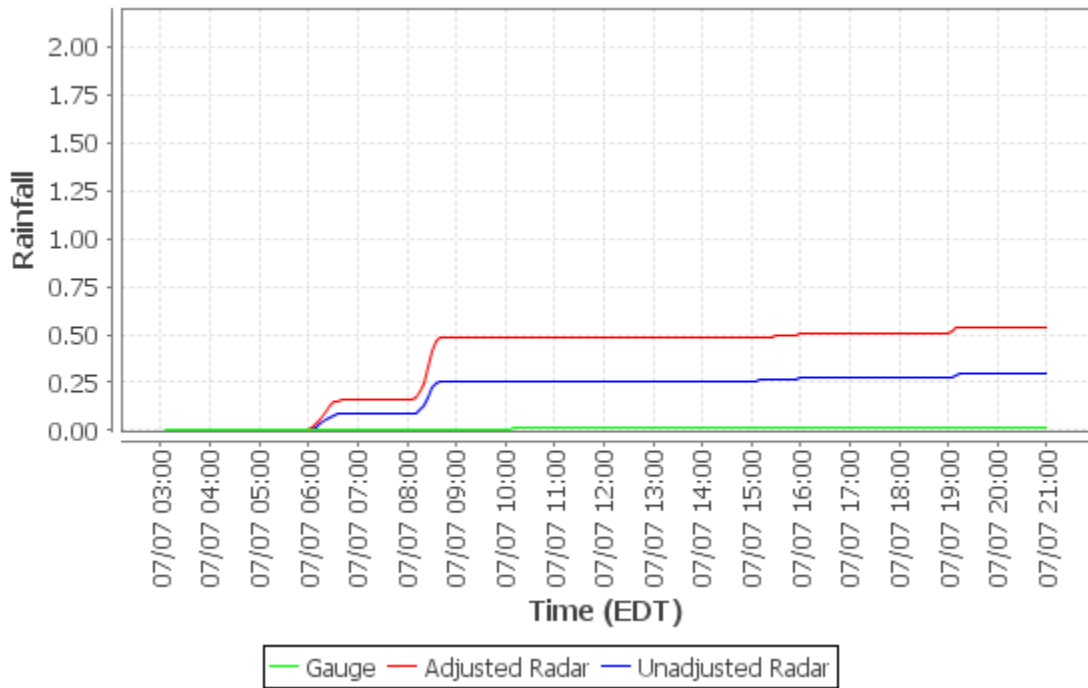
Cumulative Distribution Plot - Jefferson Hills (Loc24)



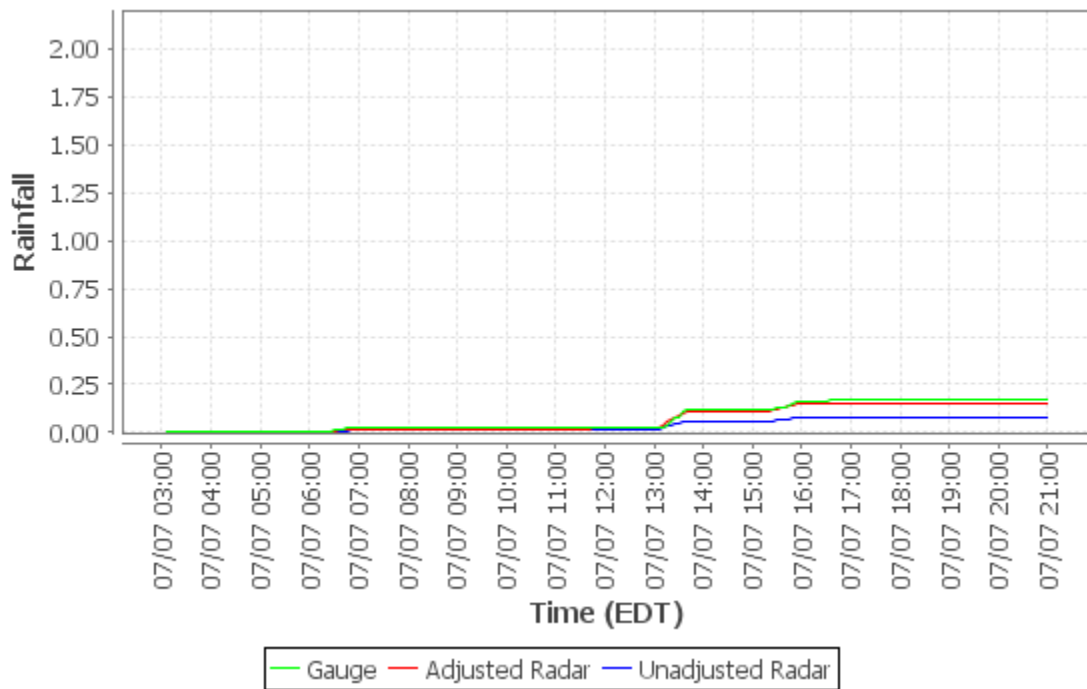
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



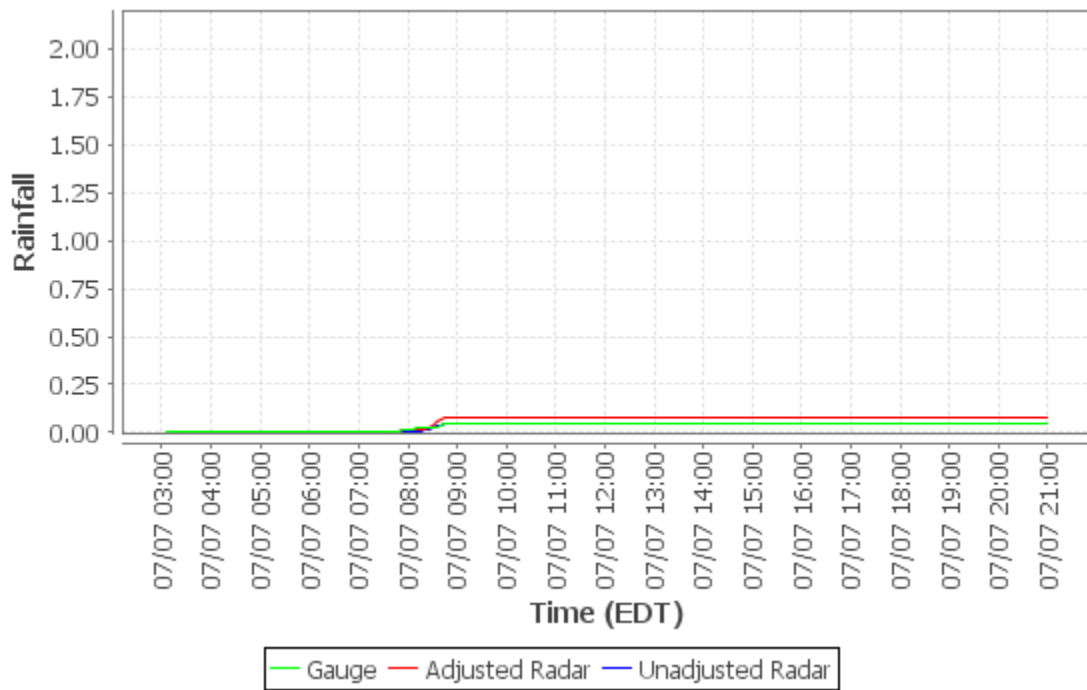
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



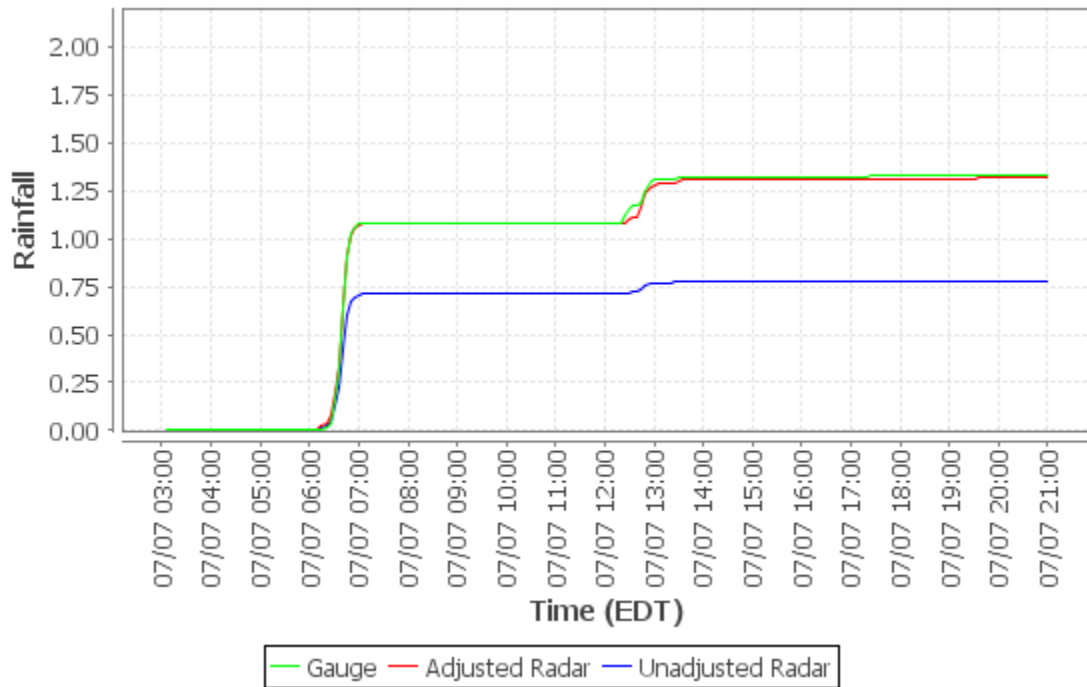
Cumulative Distribution Plot - Marshall TWP (Loc27)



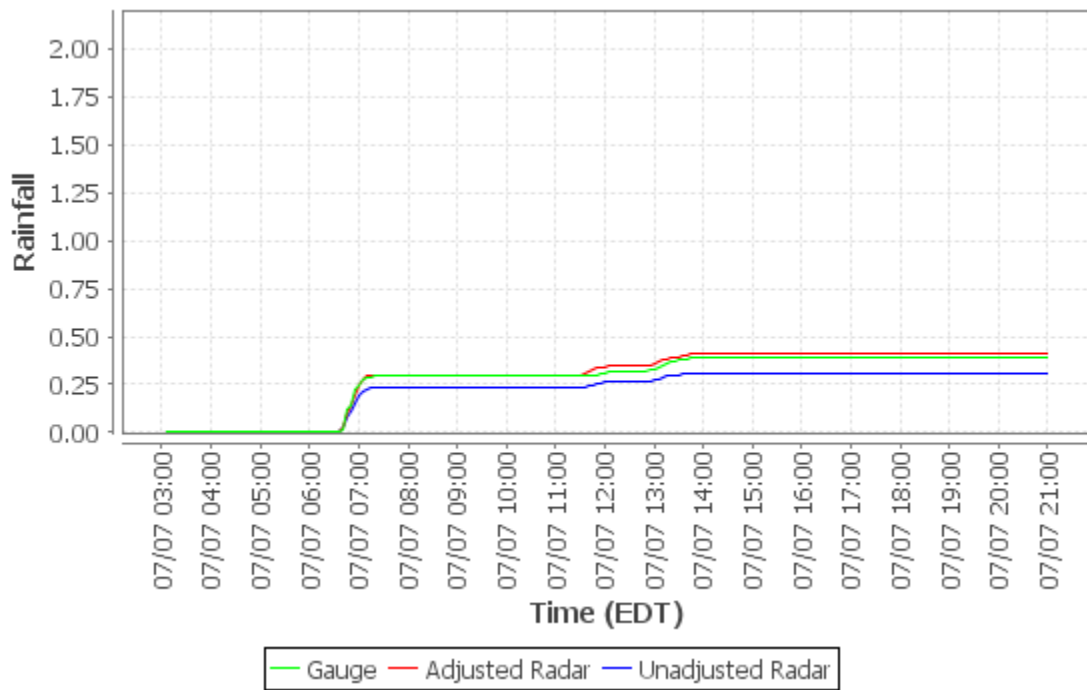
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



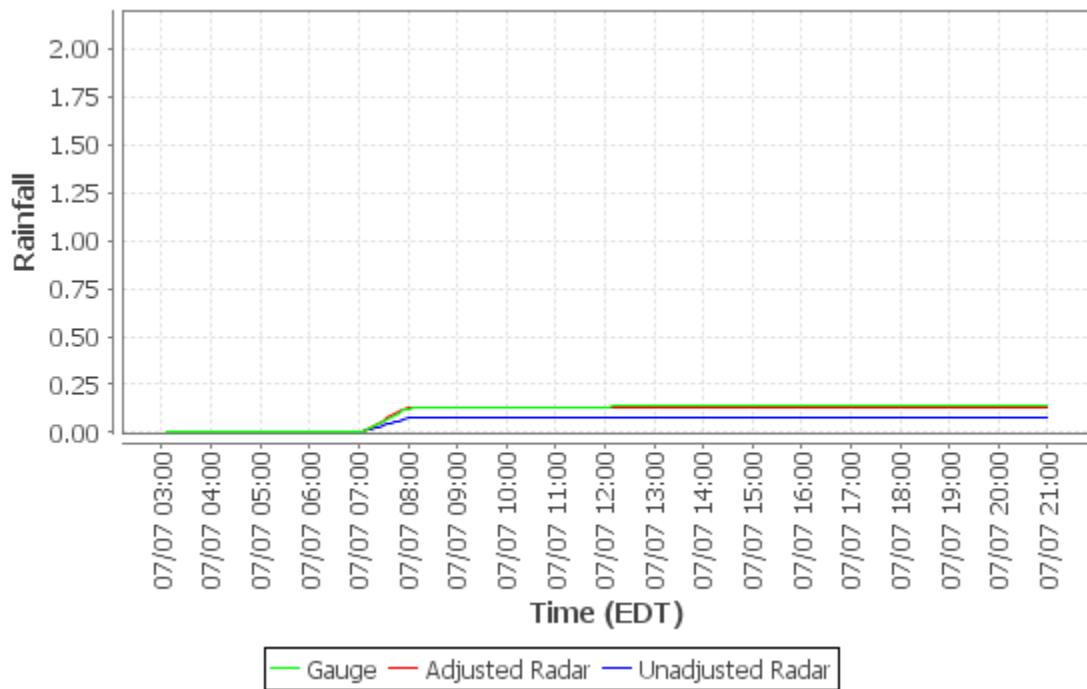
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



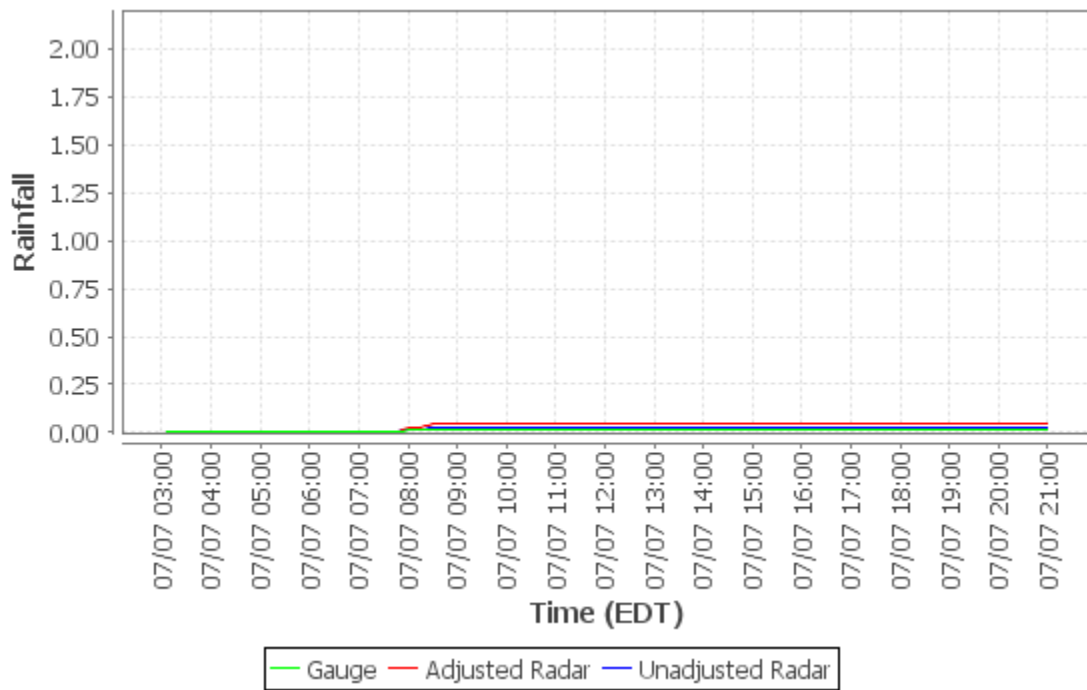
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



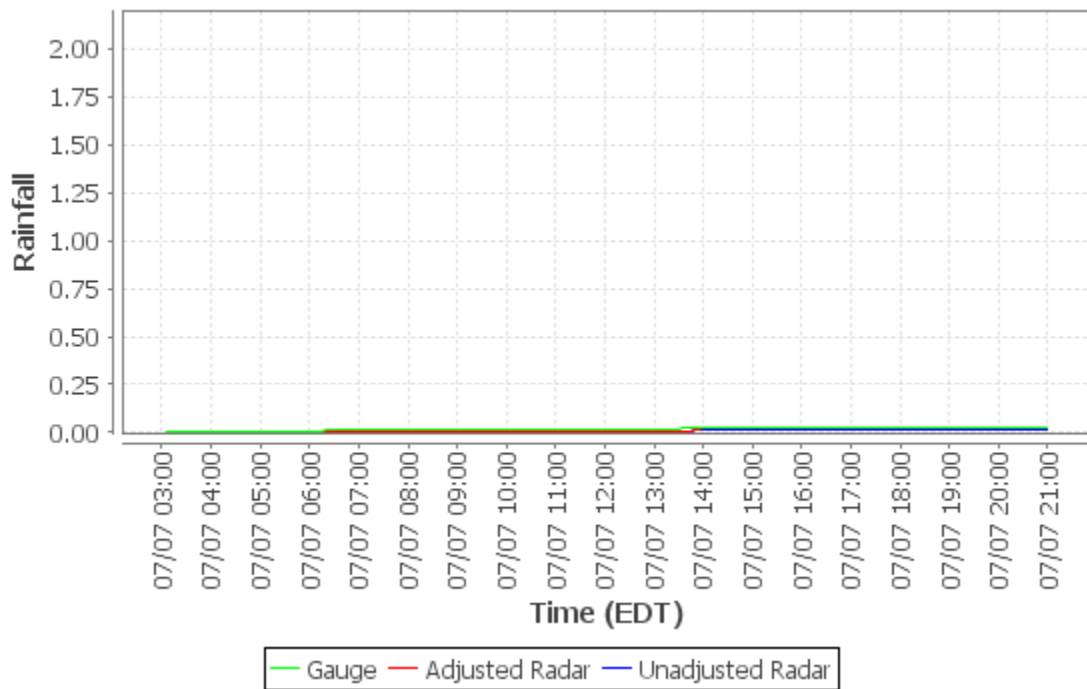
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



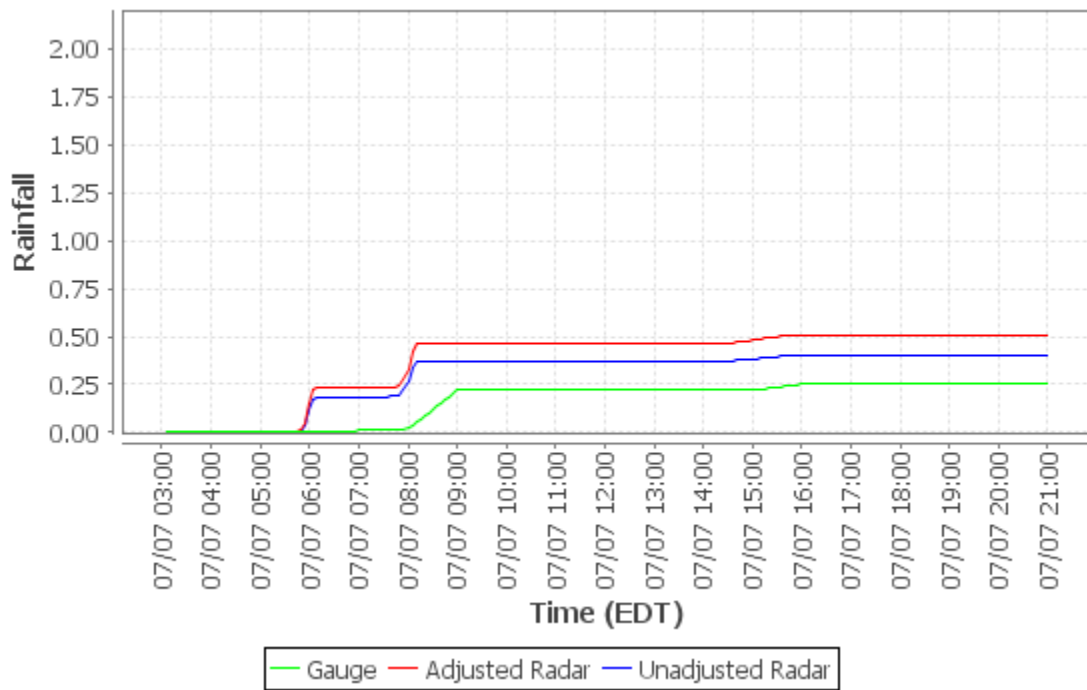
Cumulative Distribution Plot - Arnold (Loc32)



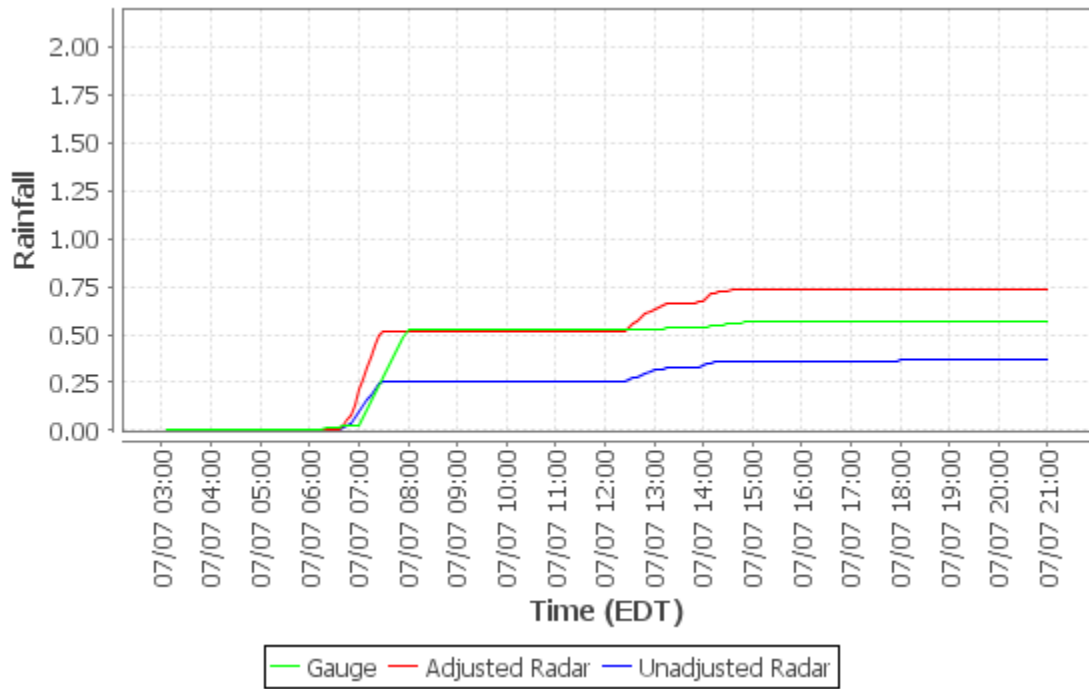
Cumulative Distribution Plot - Richland TWP (Loc33)



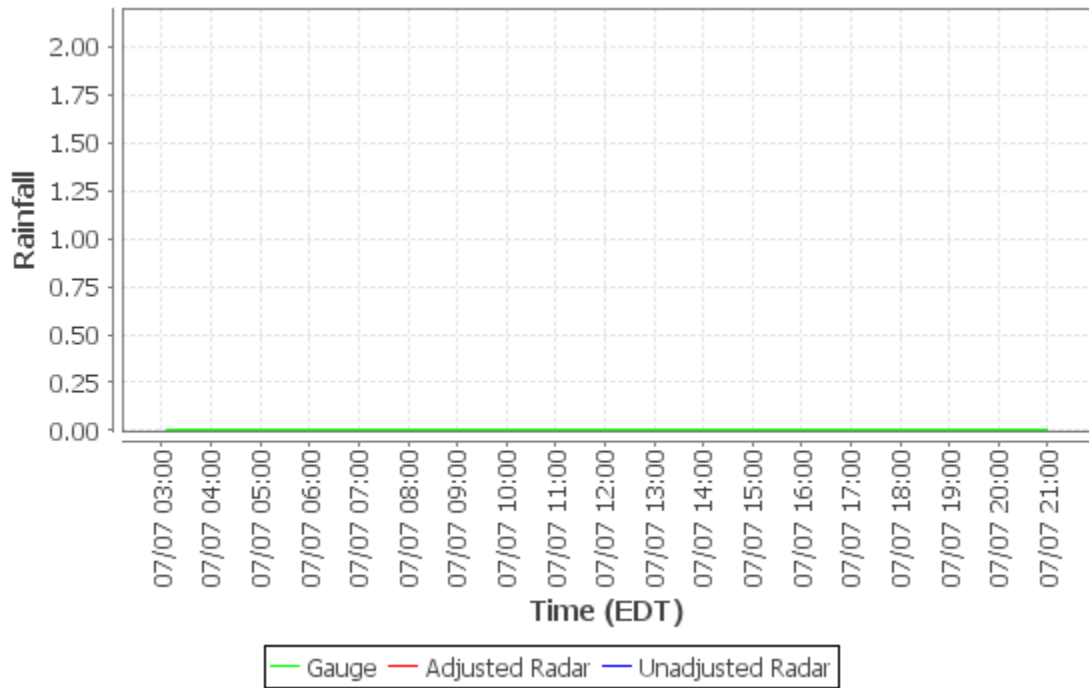
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



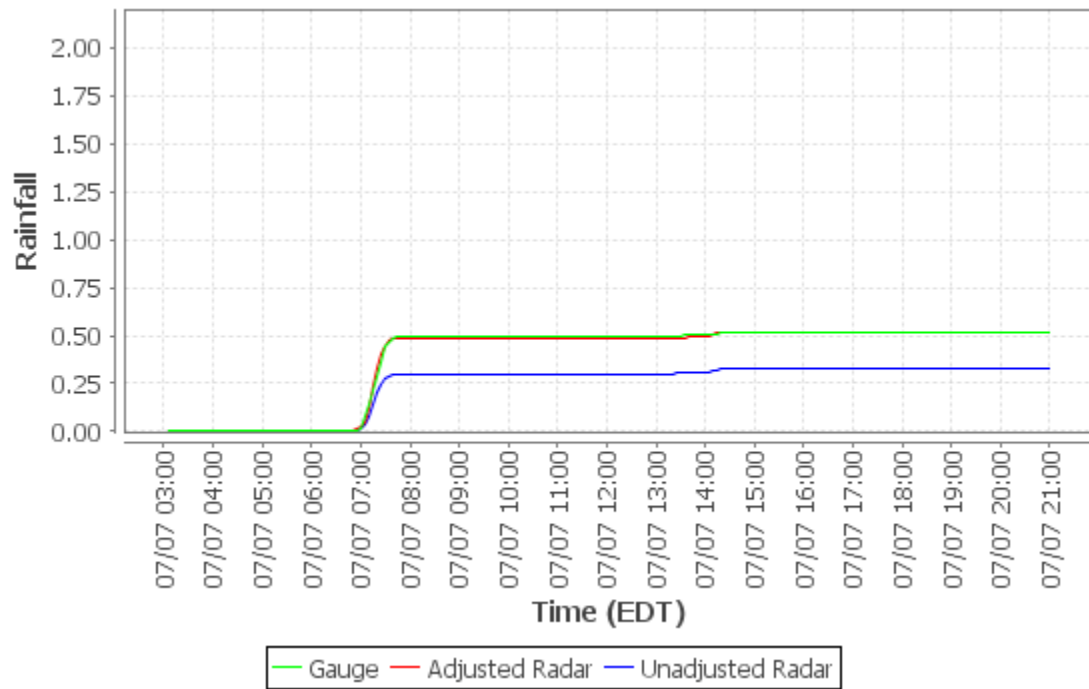
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

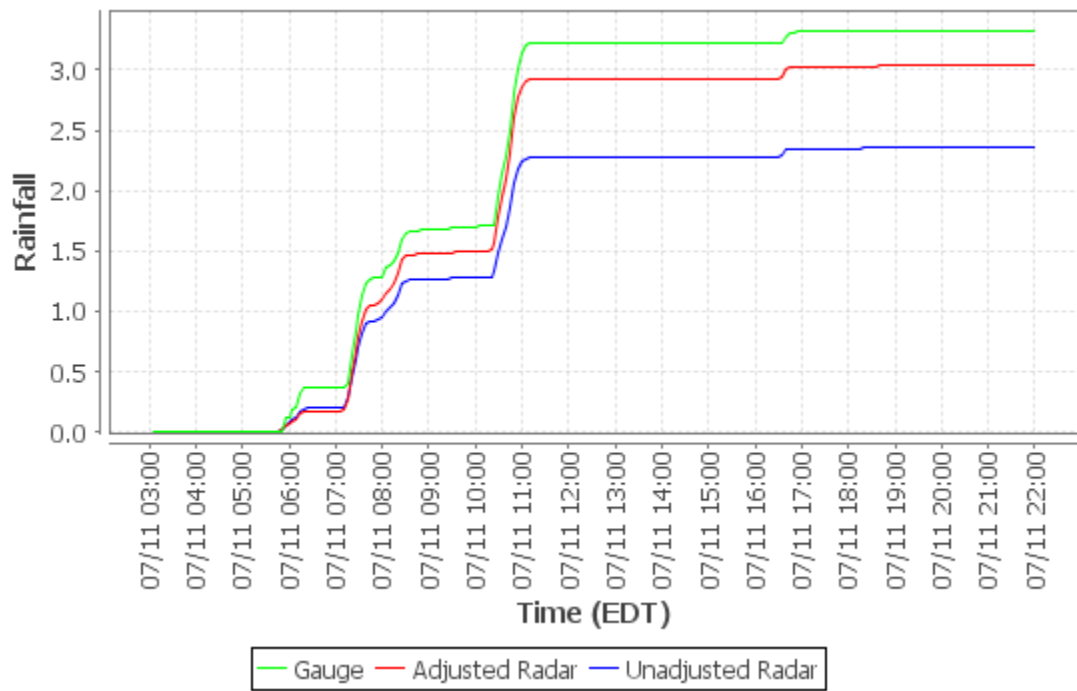


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

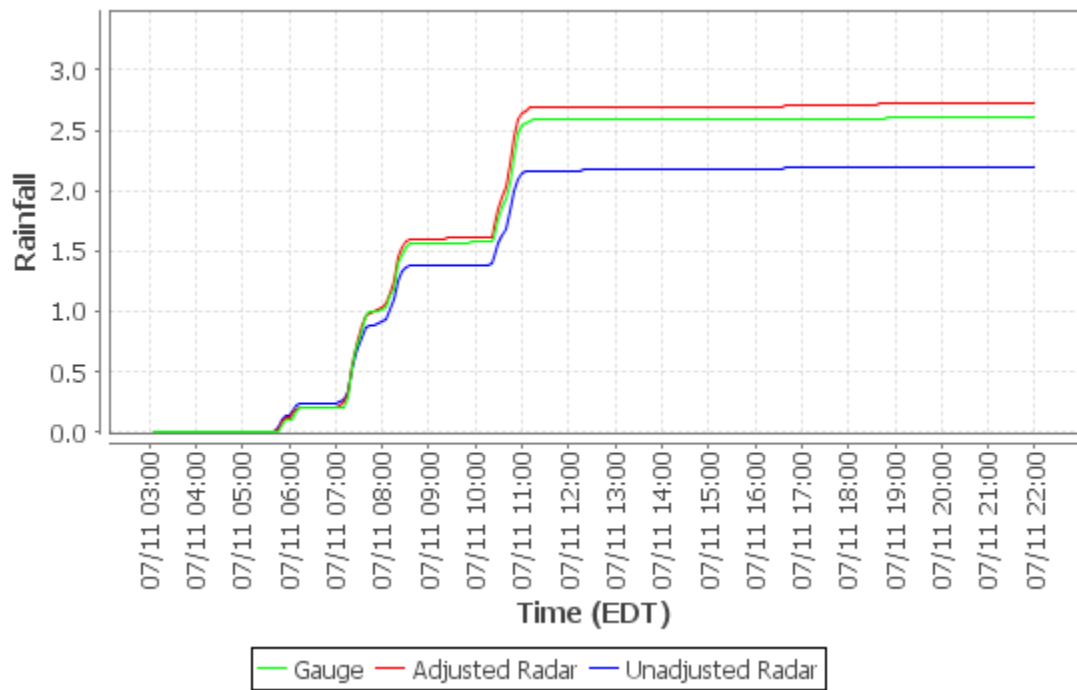


Appendix F - Event 4 (2019-07-11) CDPs

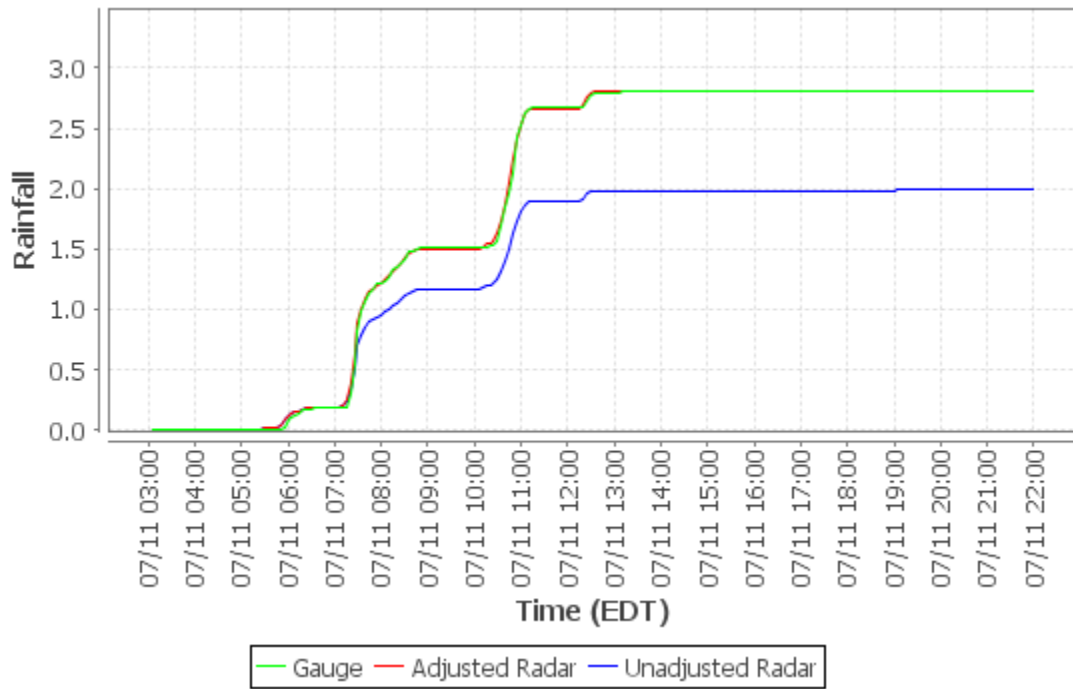
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



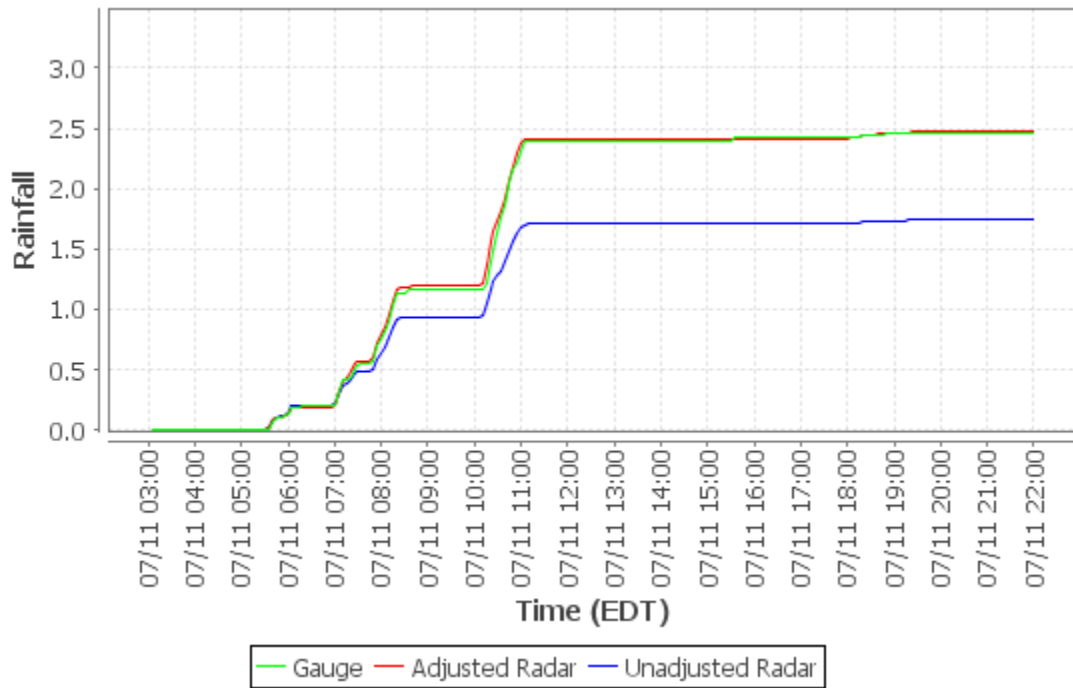
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



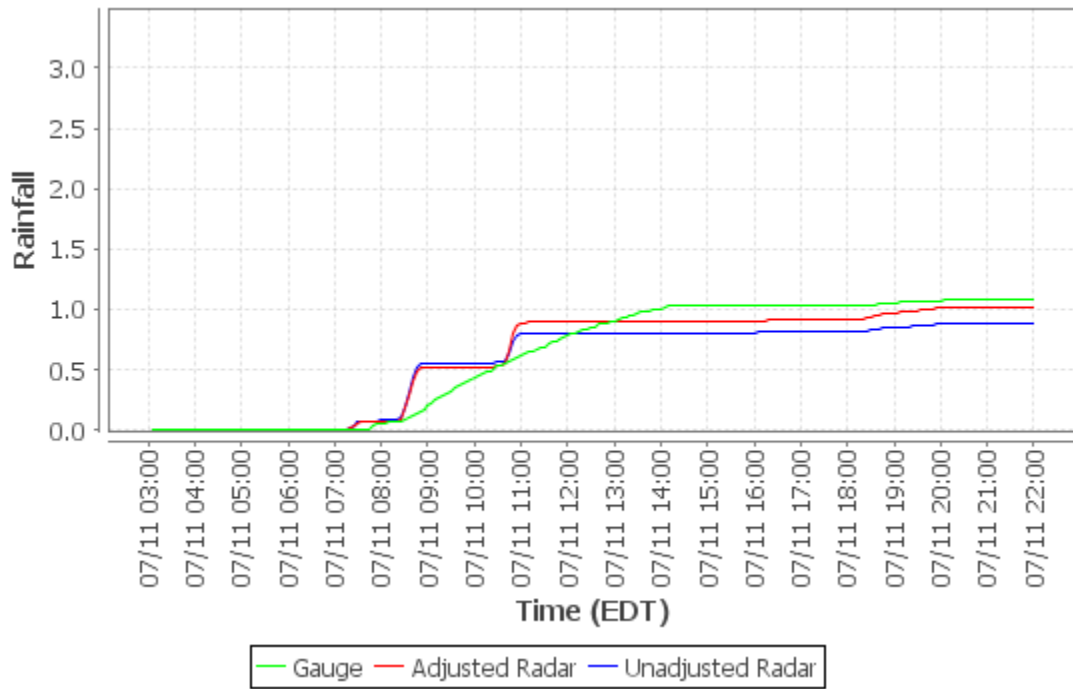
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



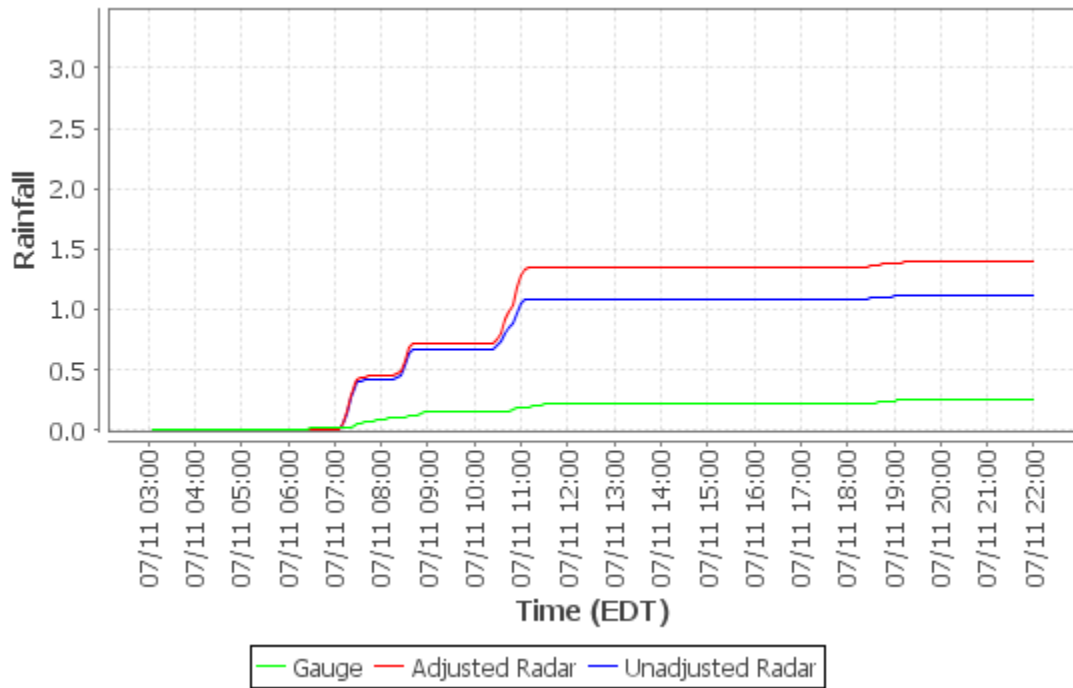
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



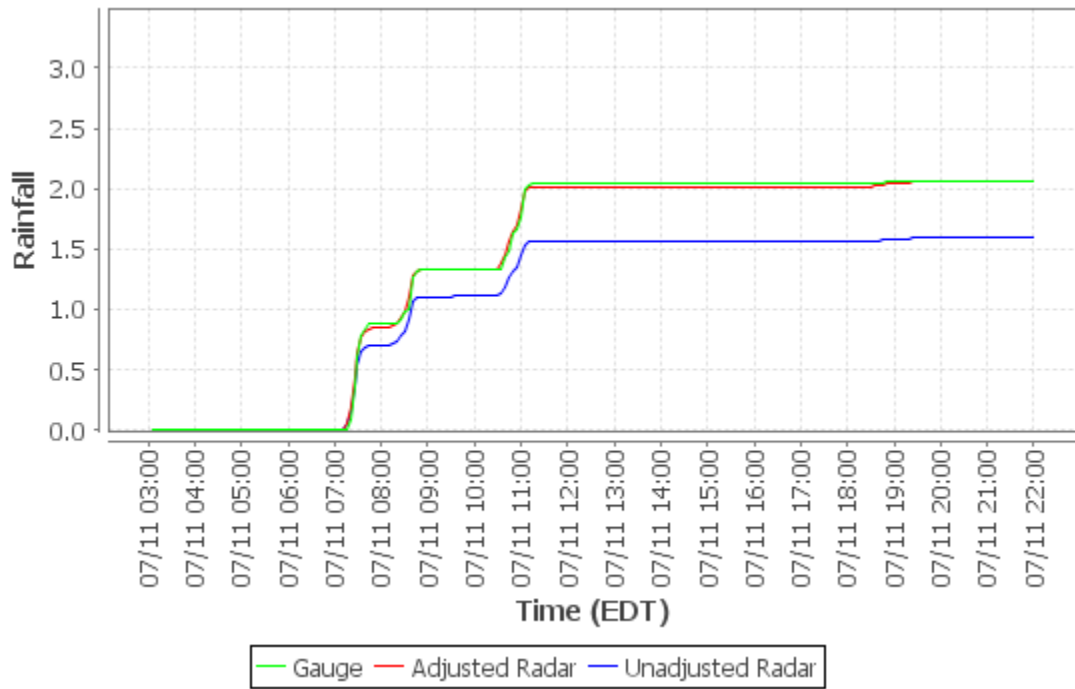
Cumulative Distribution Plot - Upper St. Clair (Loc05)



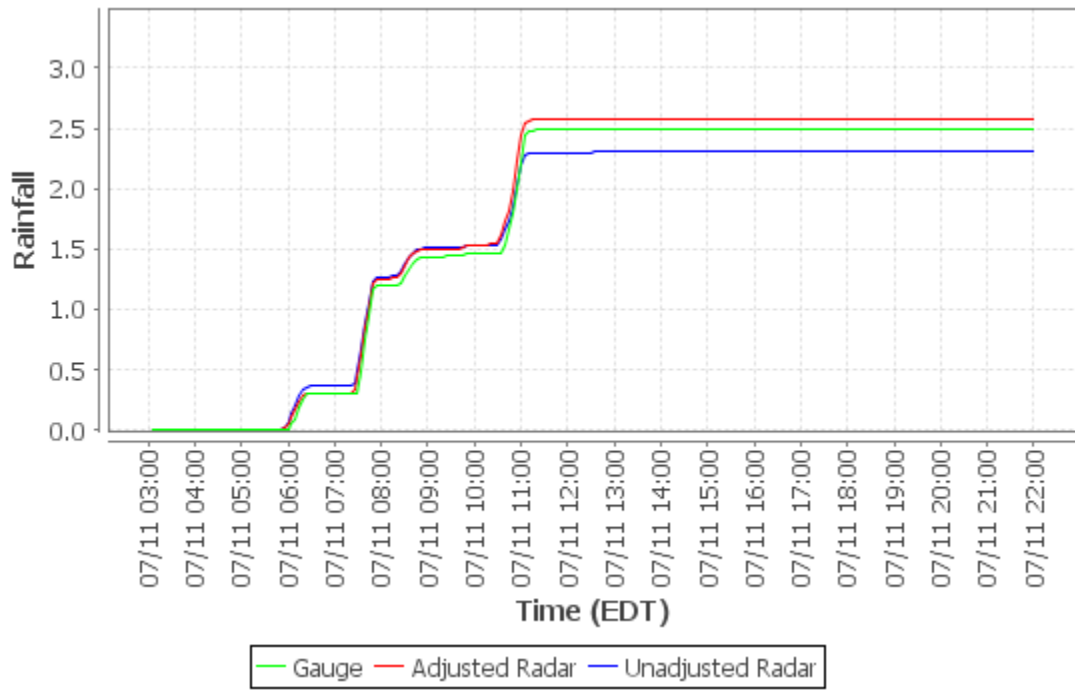
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



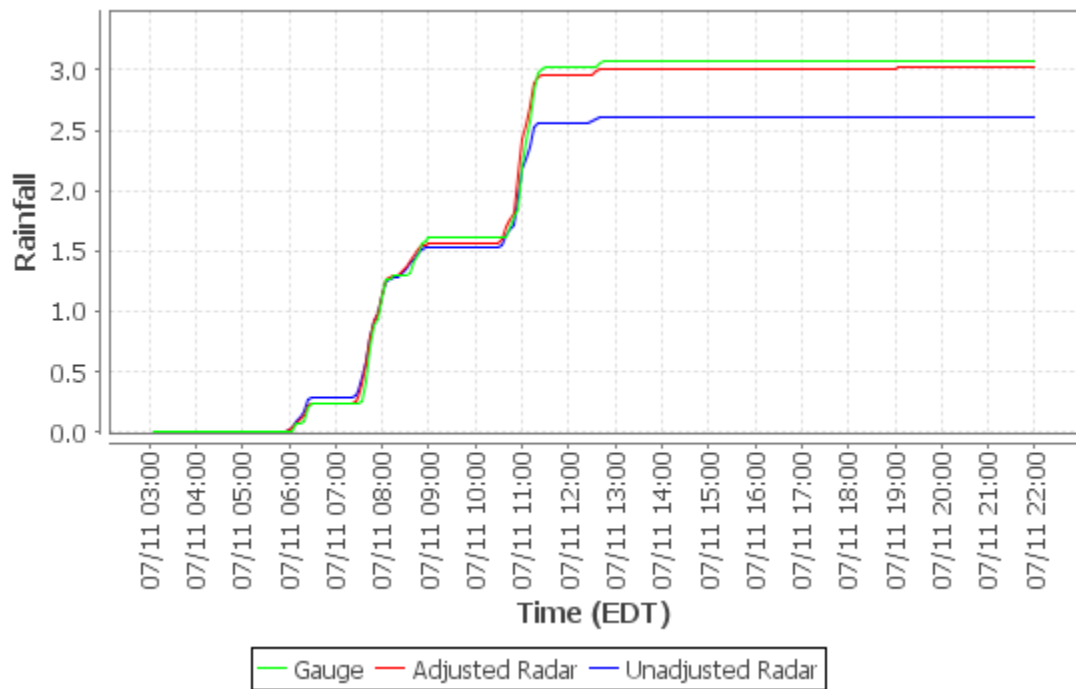
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



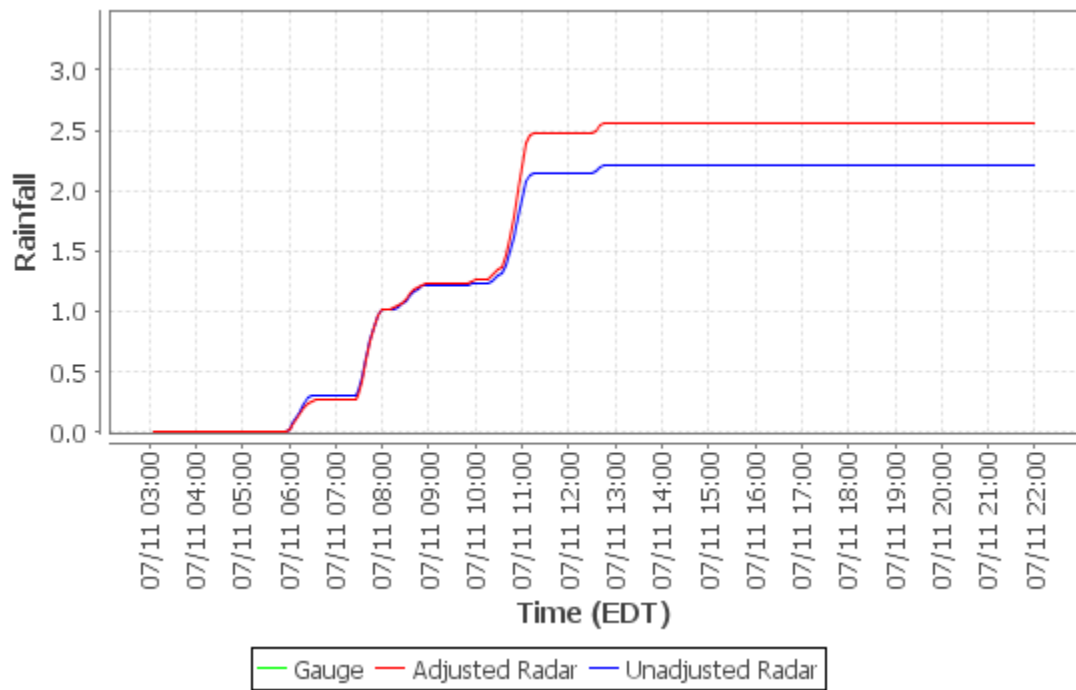
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



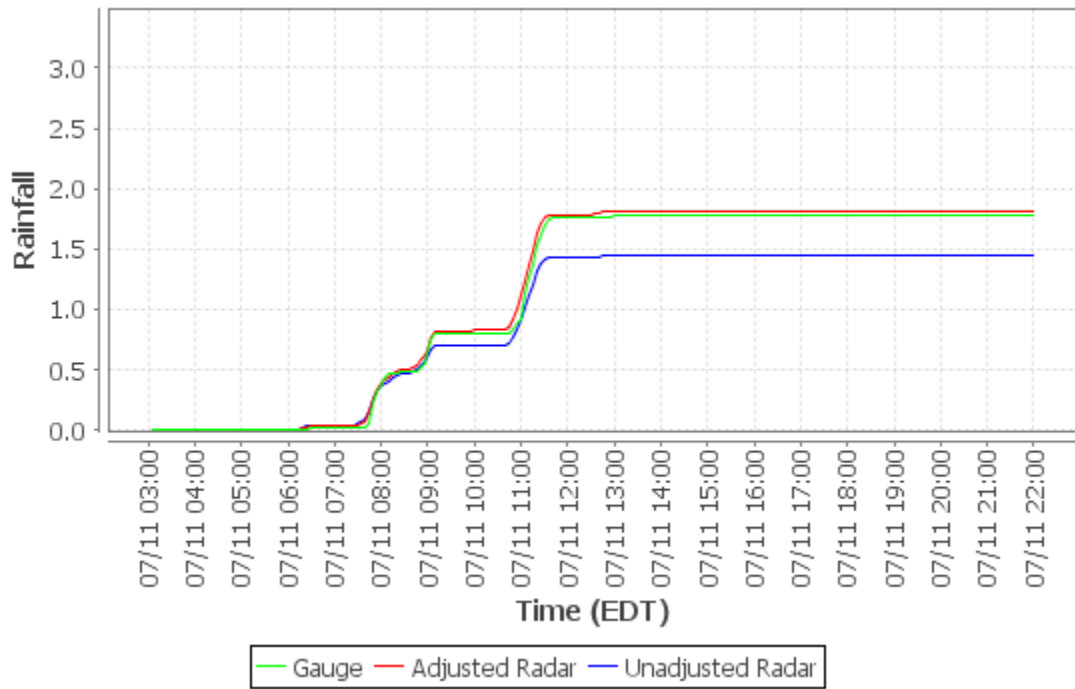
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



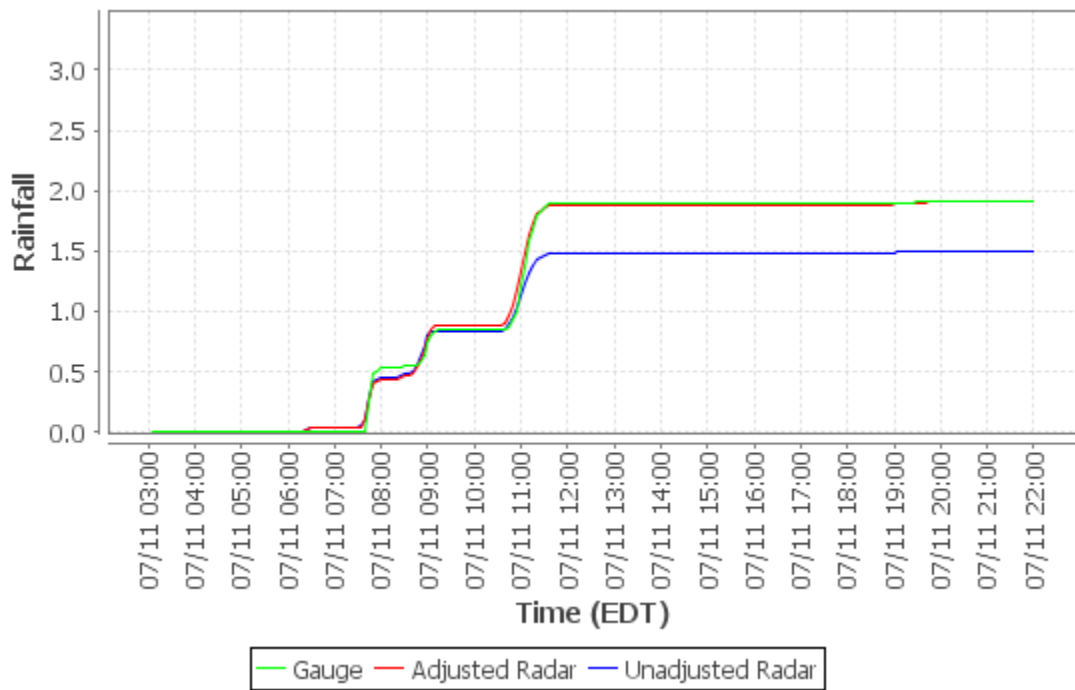
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



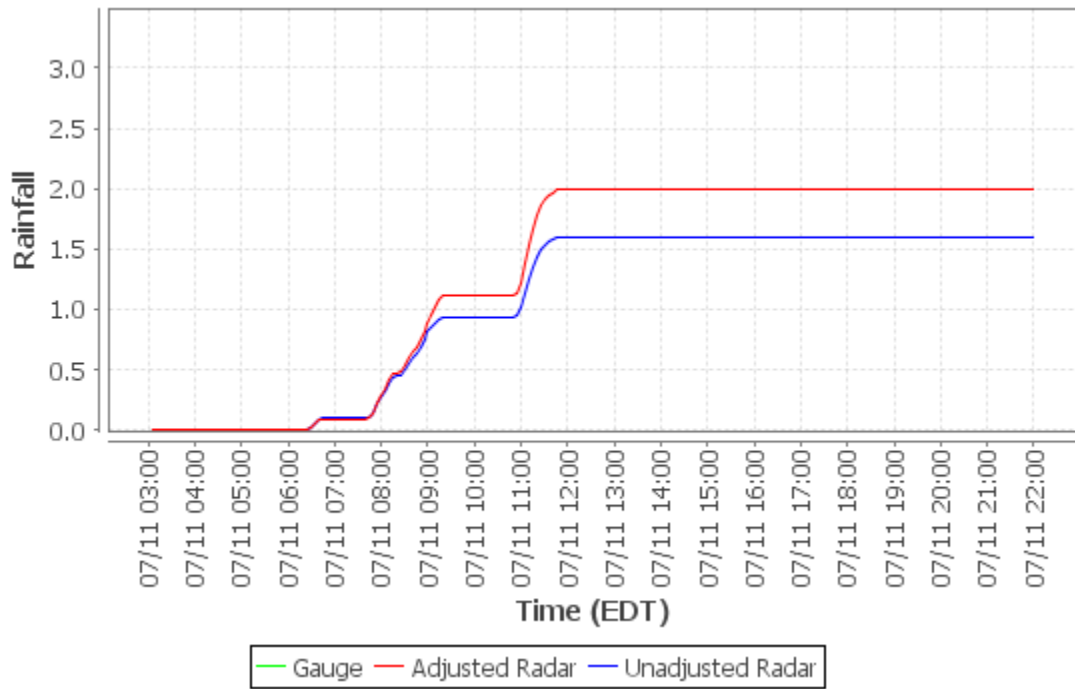
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



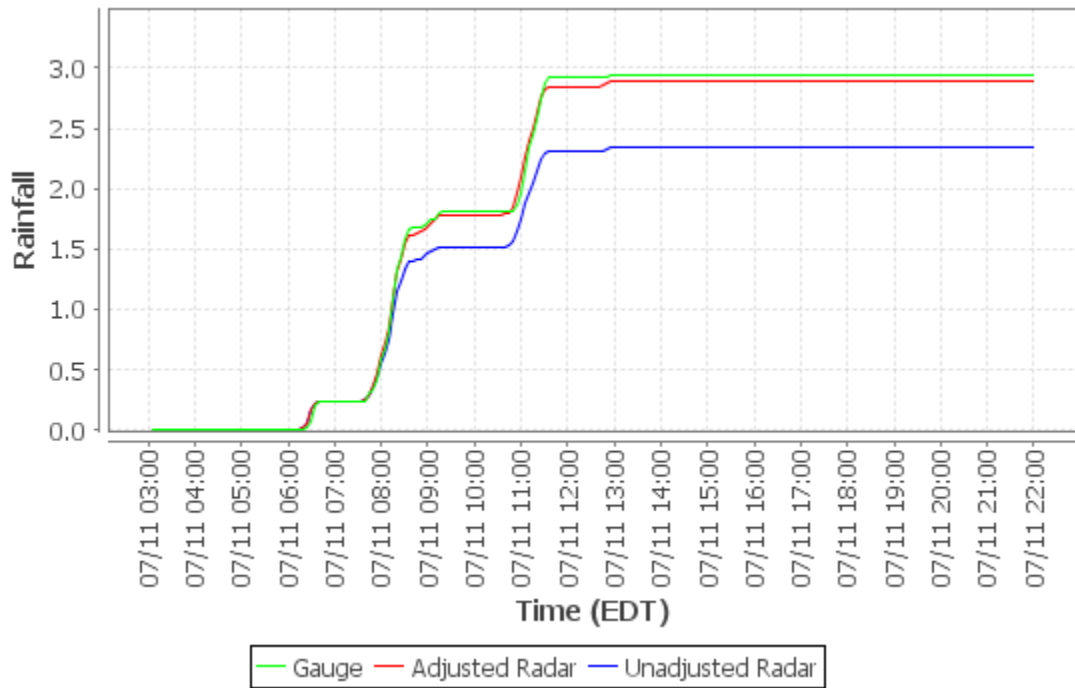
Cumulative Distribution Plot - Baldwin (Loc12)



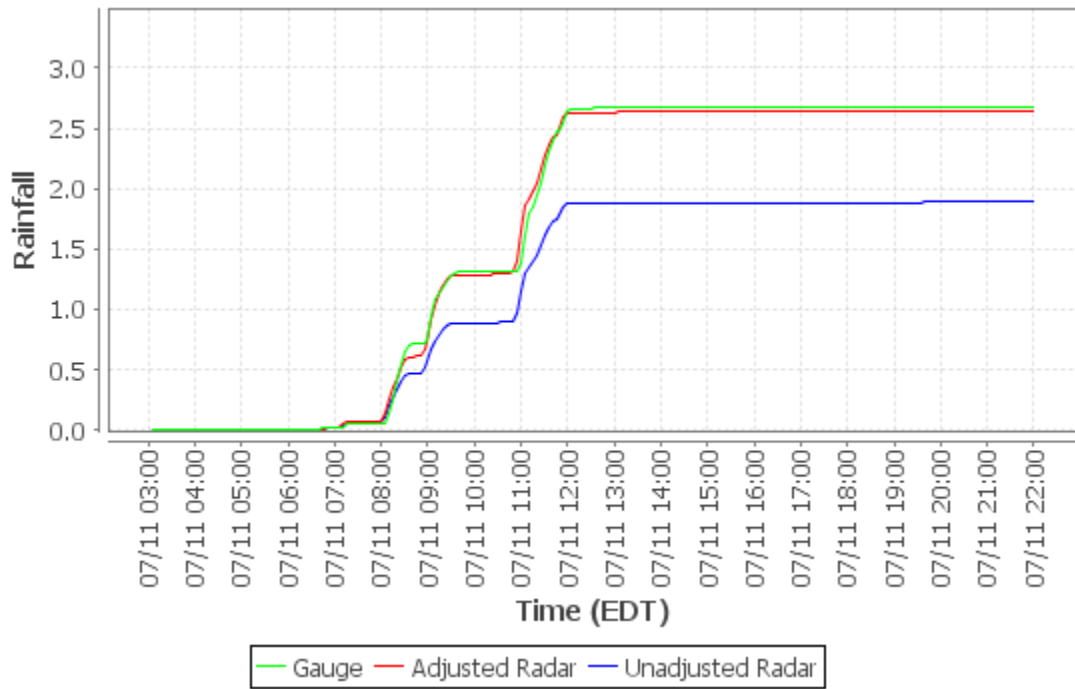
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



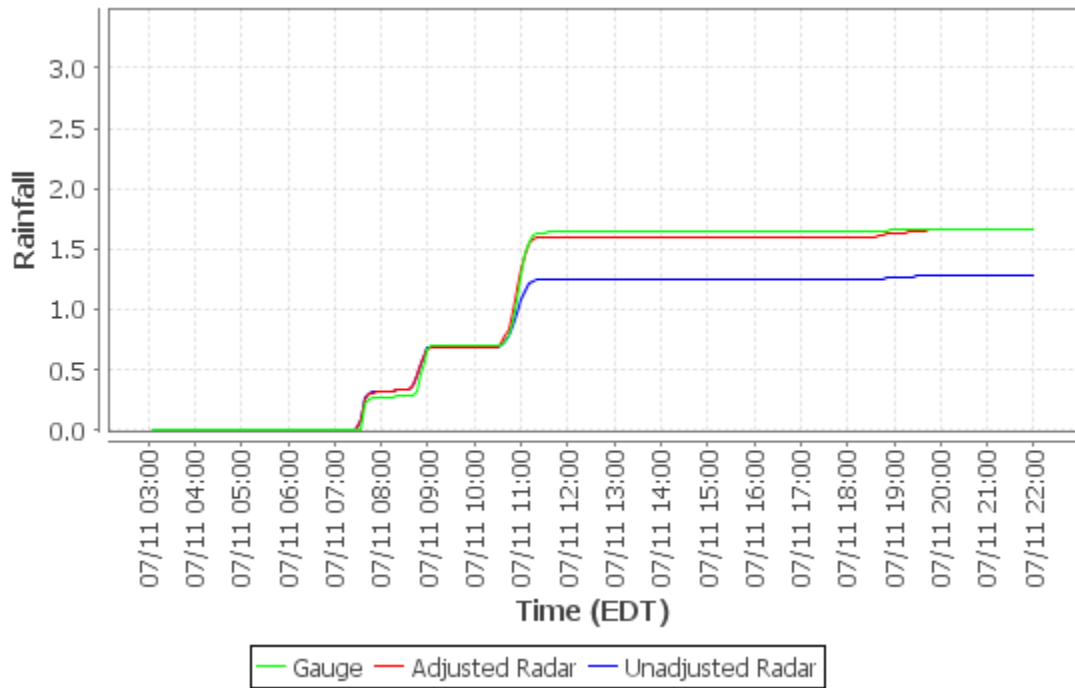
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



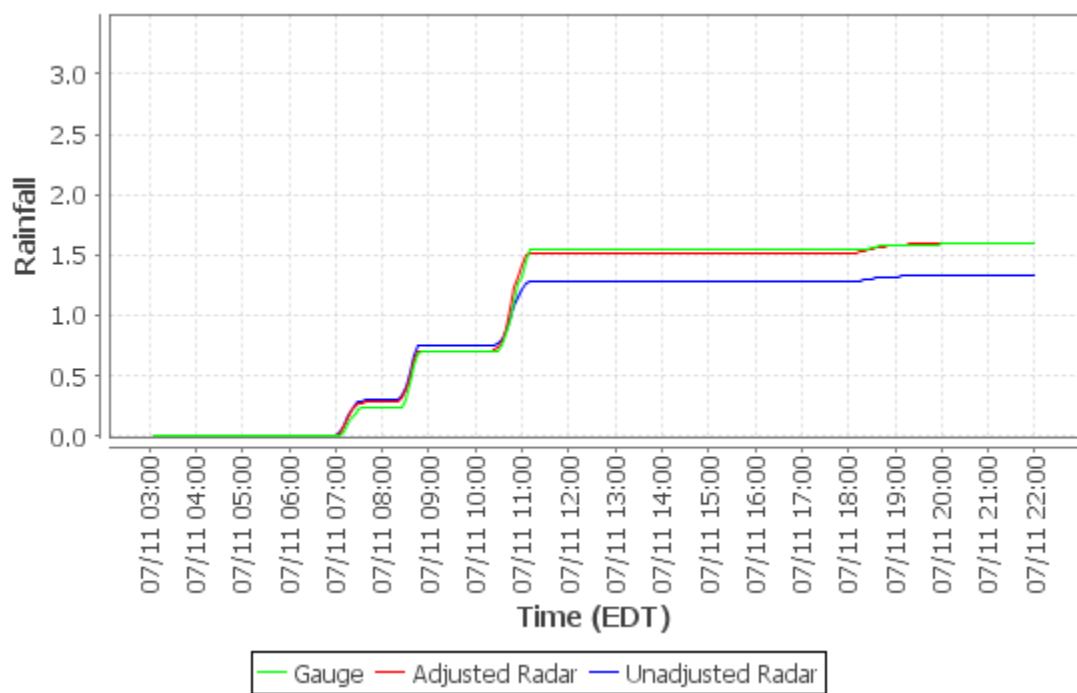
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



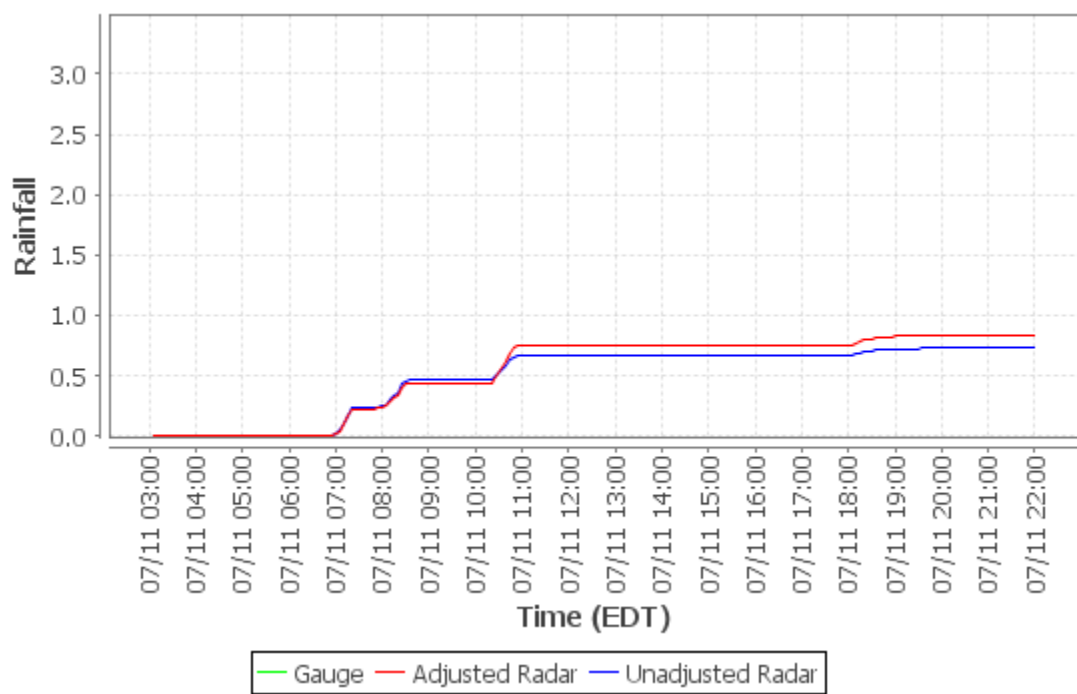
Cumulative Distribution Plot - Castle Shannon (Loc16)



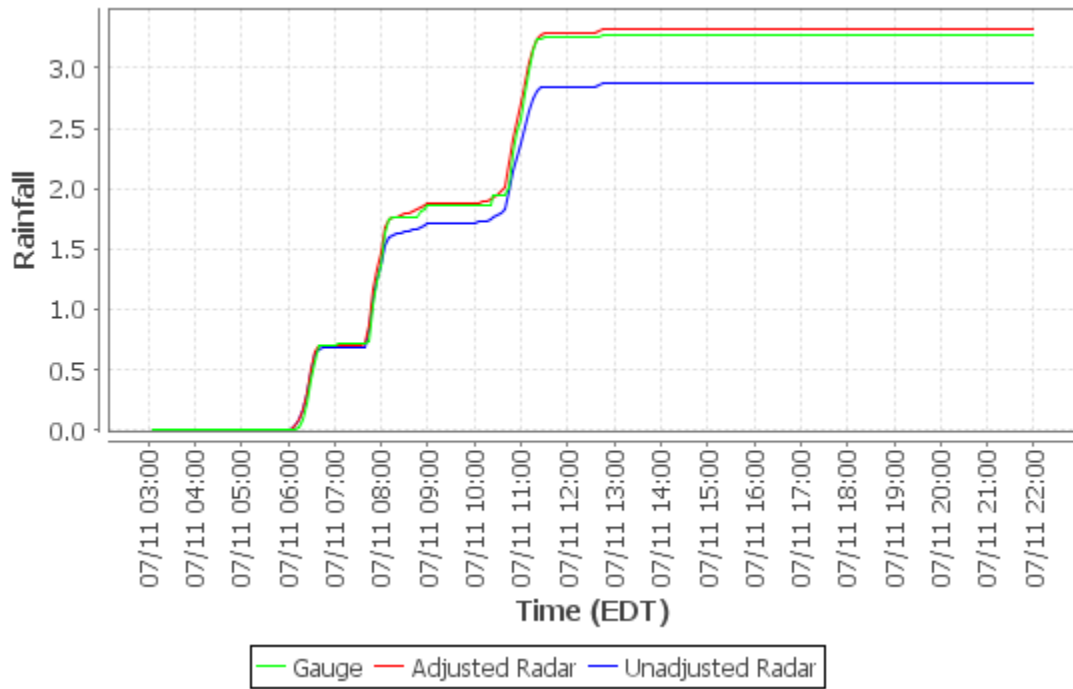
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



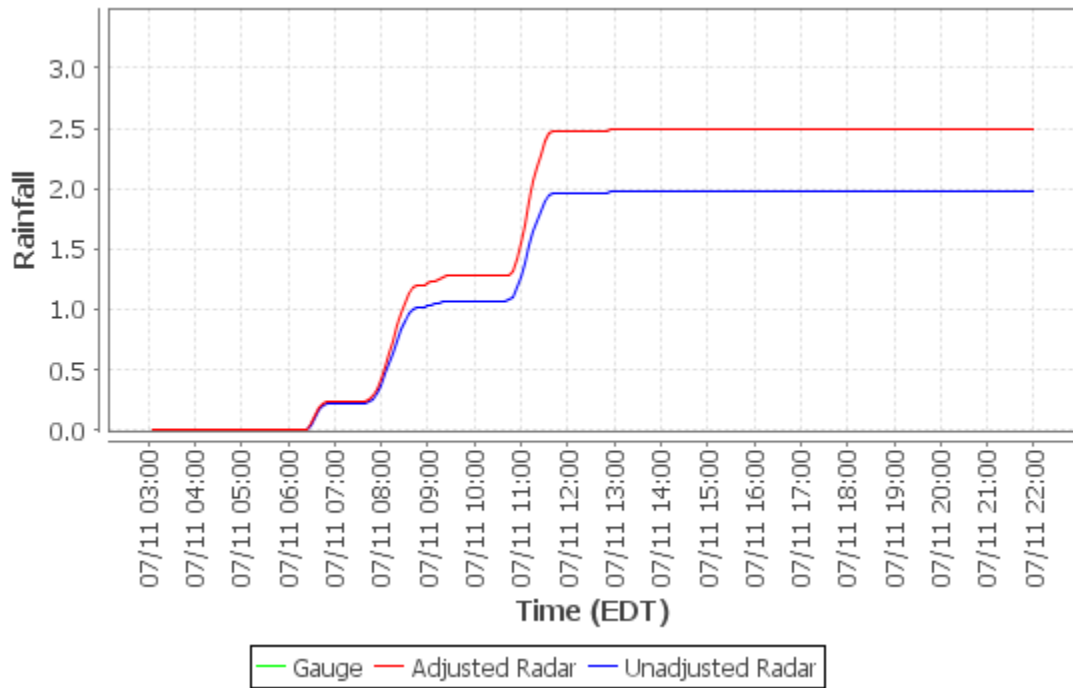
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



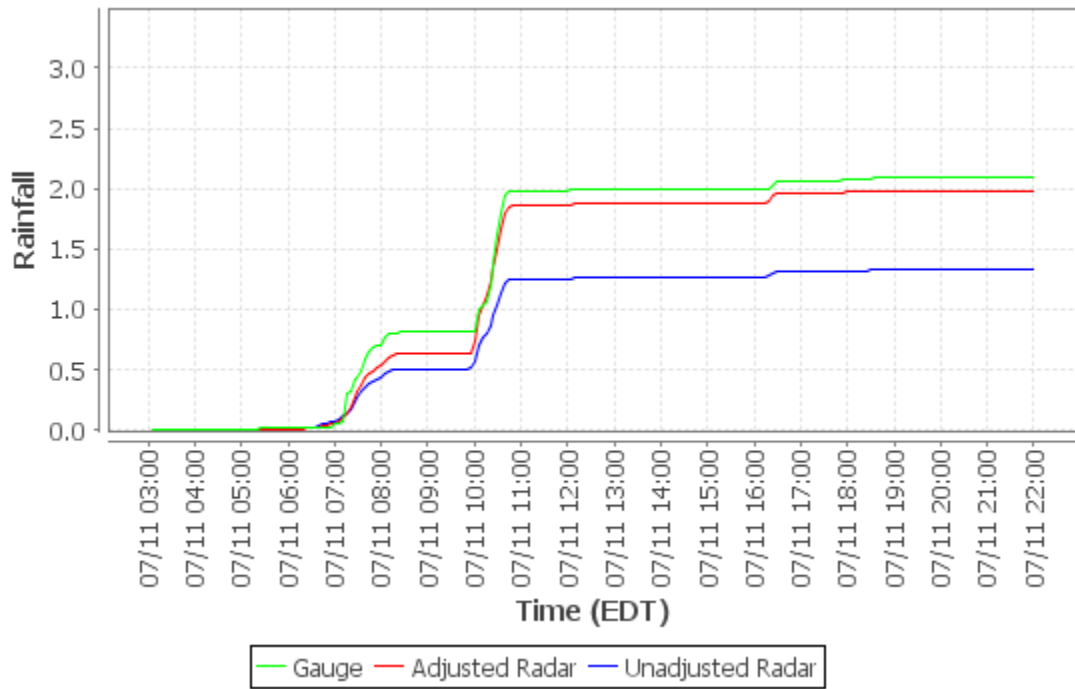
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



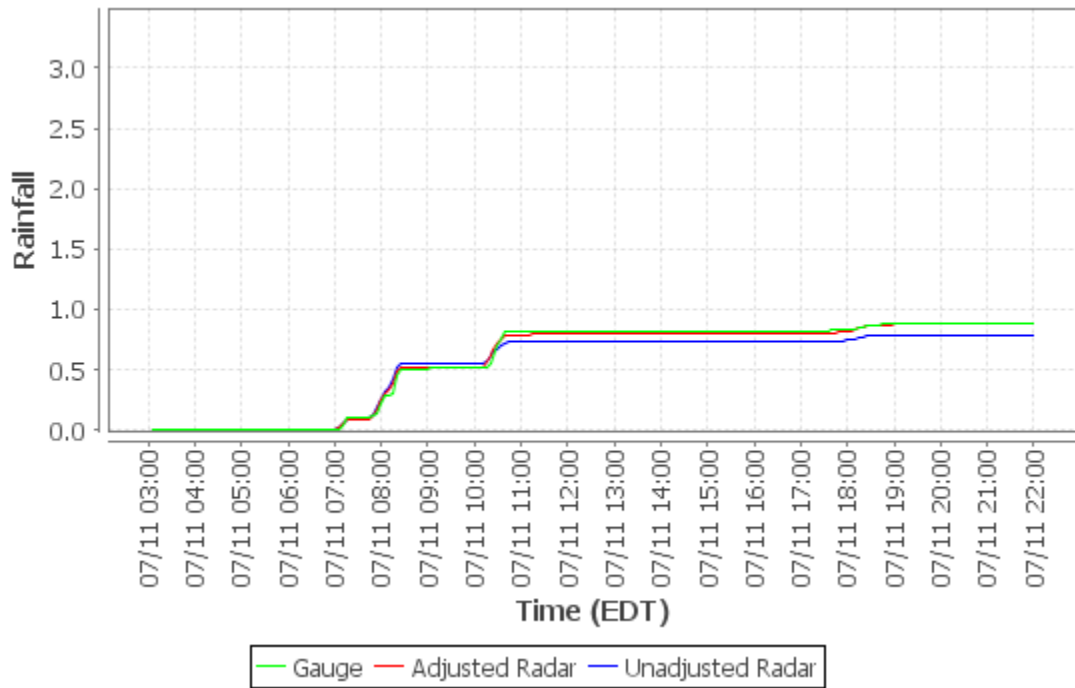
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



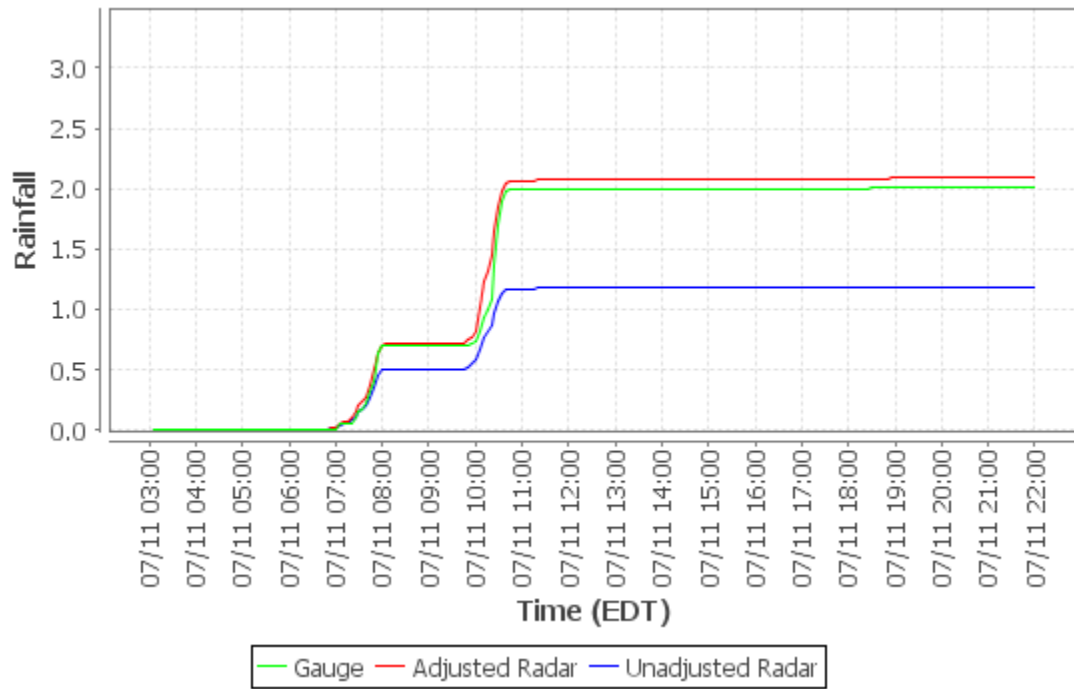
Cumulative Distribution Plot - Moon TWP (Loc21)



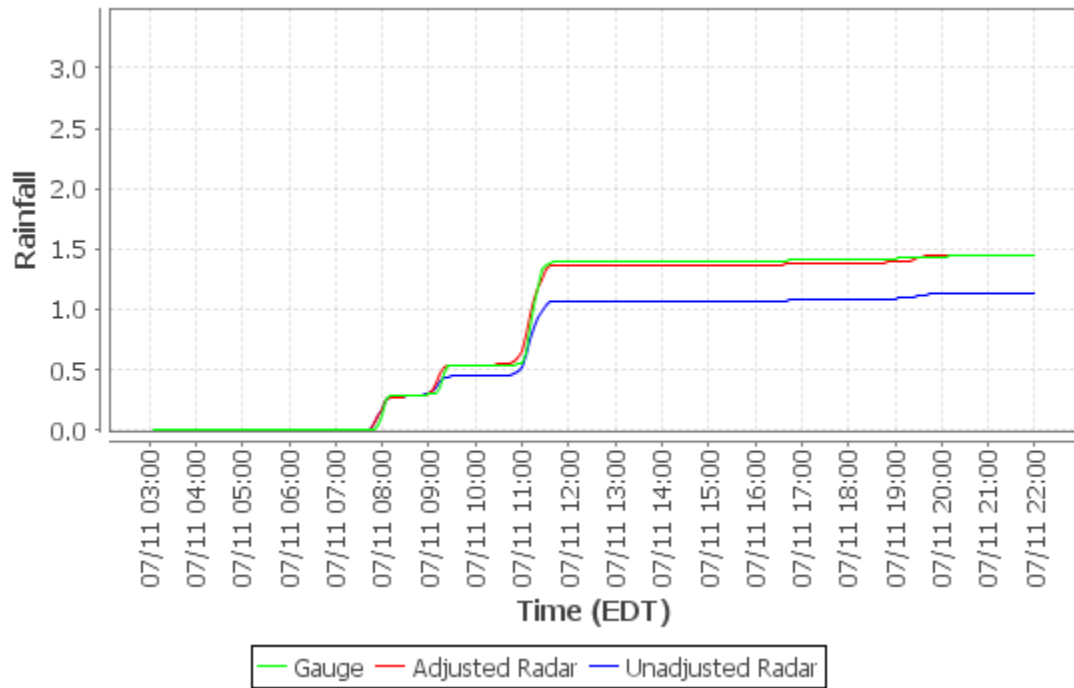
Cumulative Distribution Plot - North Fayette TWP (Loc22)



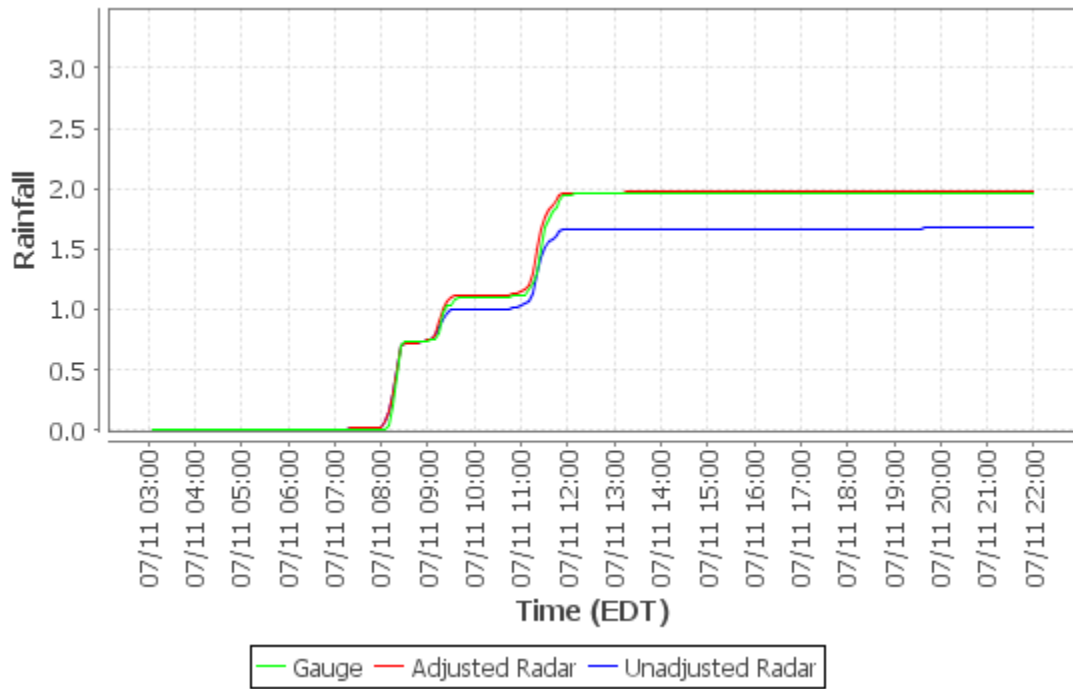
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



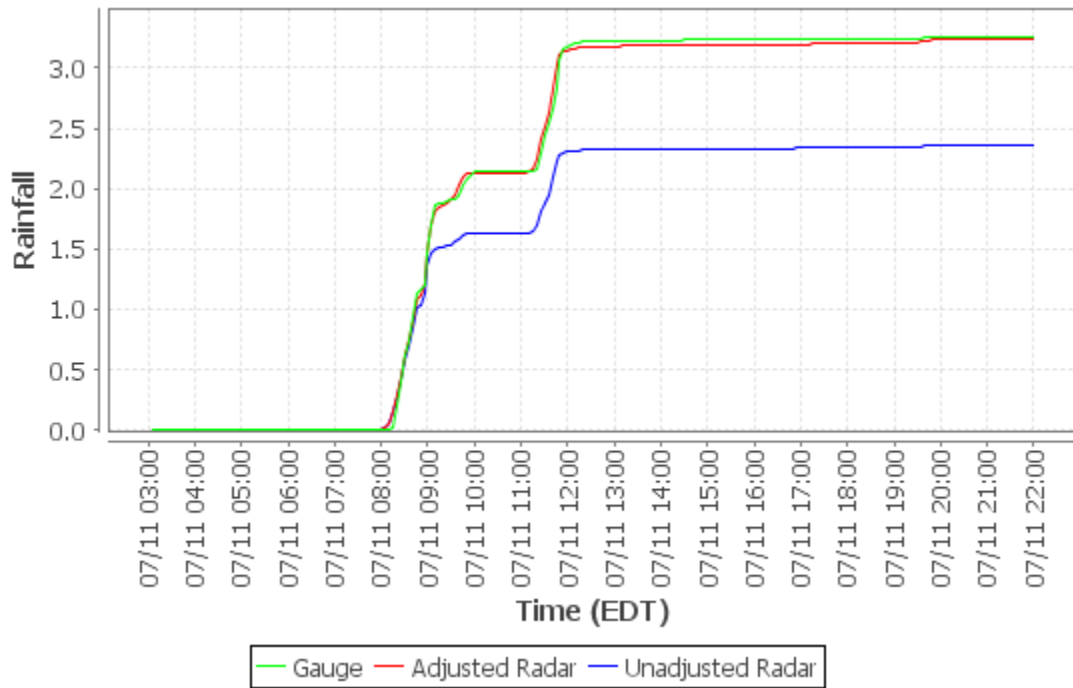
Cumulative Distribution Plot - Jefferson Hills (Loc24)



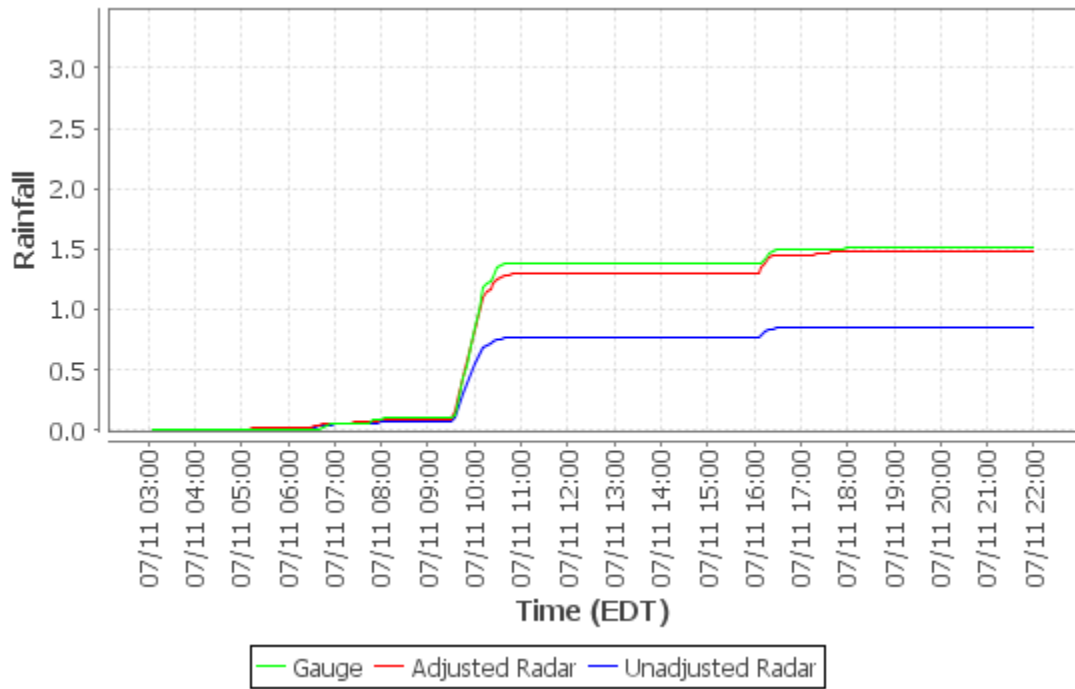
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



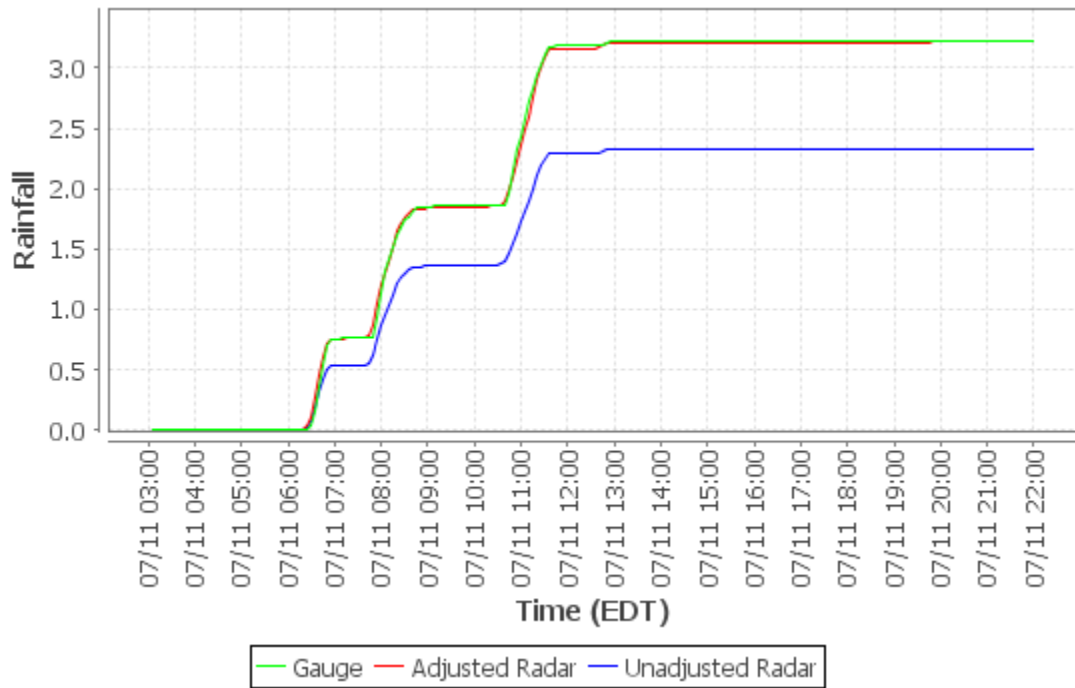
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



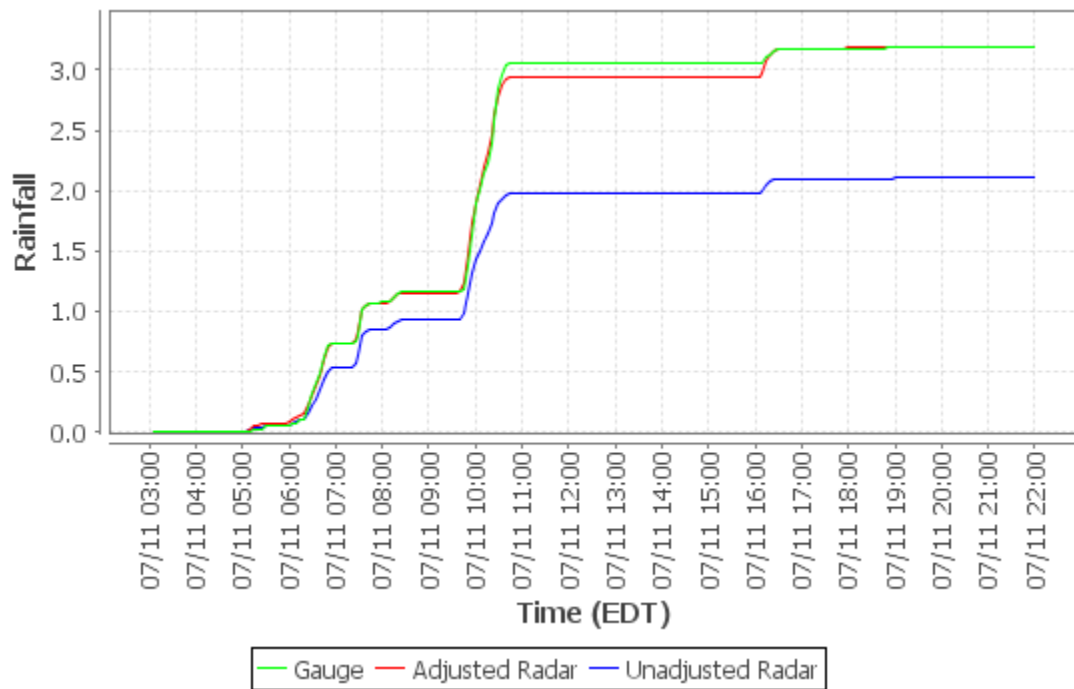
Cumulative Distribution Plot - Marshall TWP (Loc27)



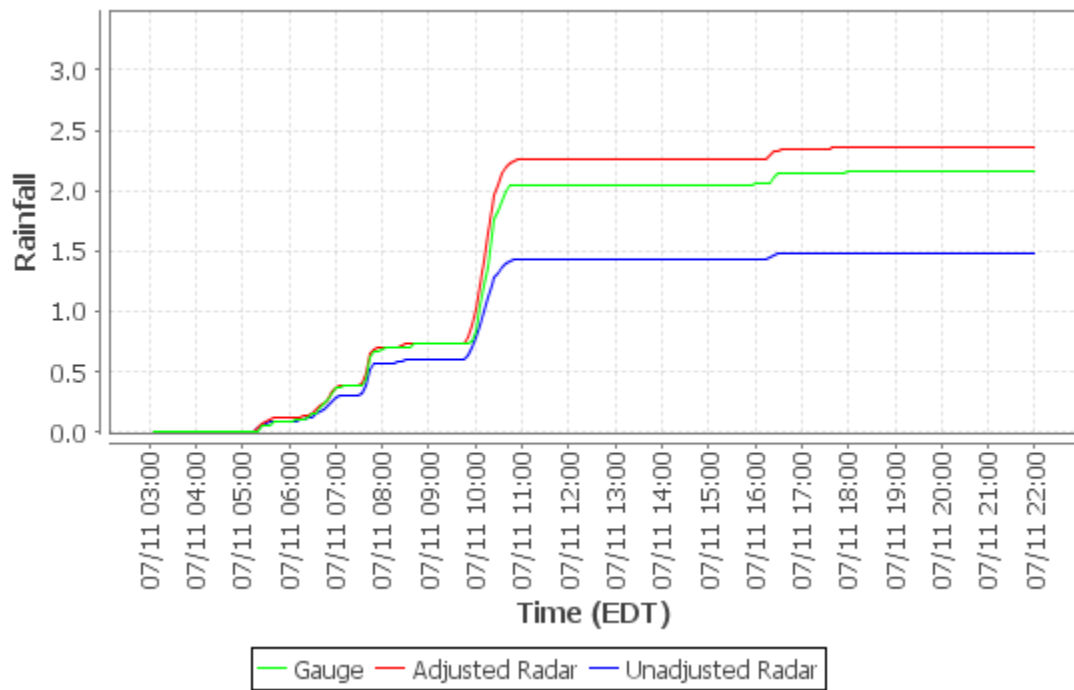
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



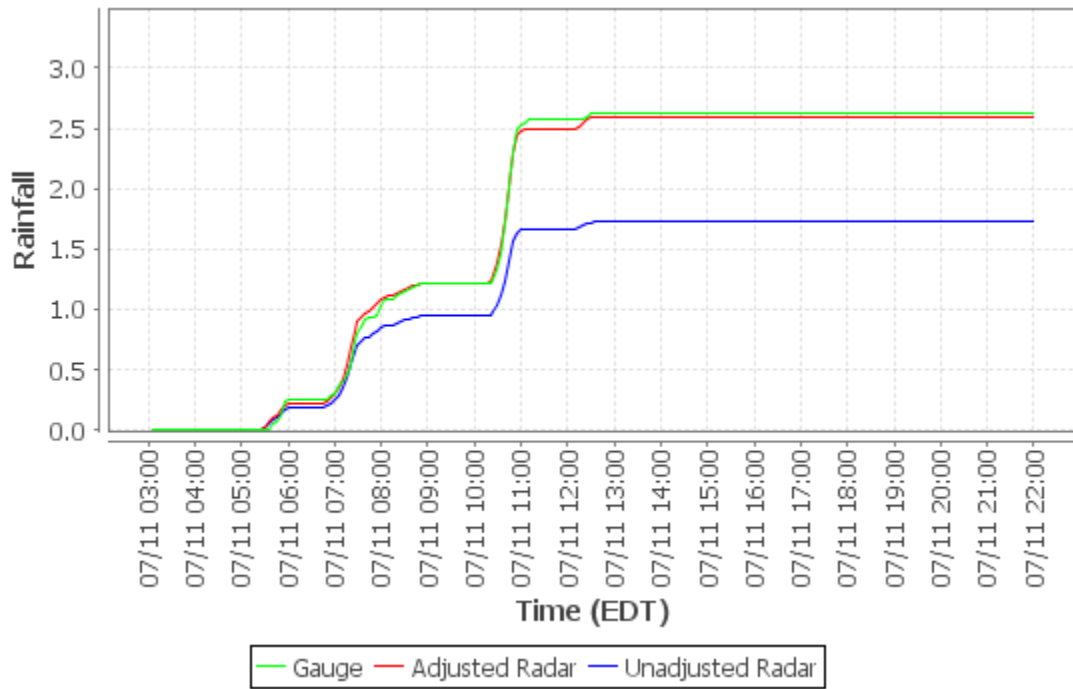
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



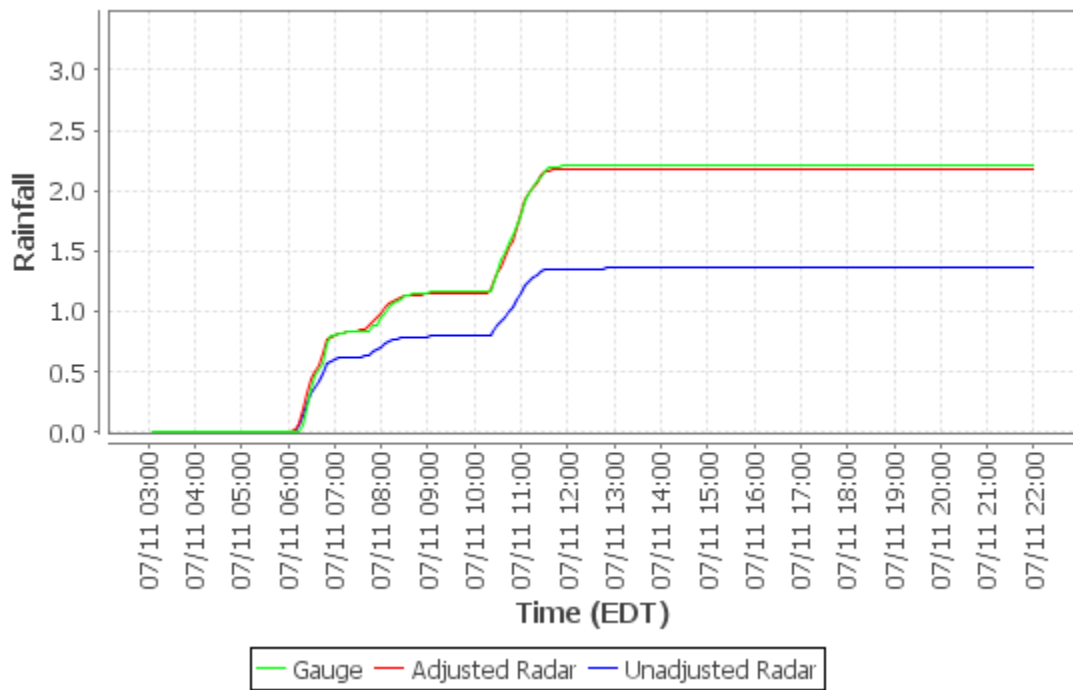
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



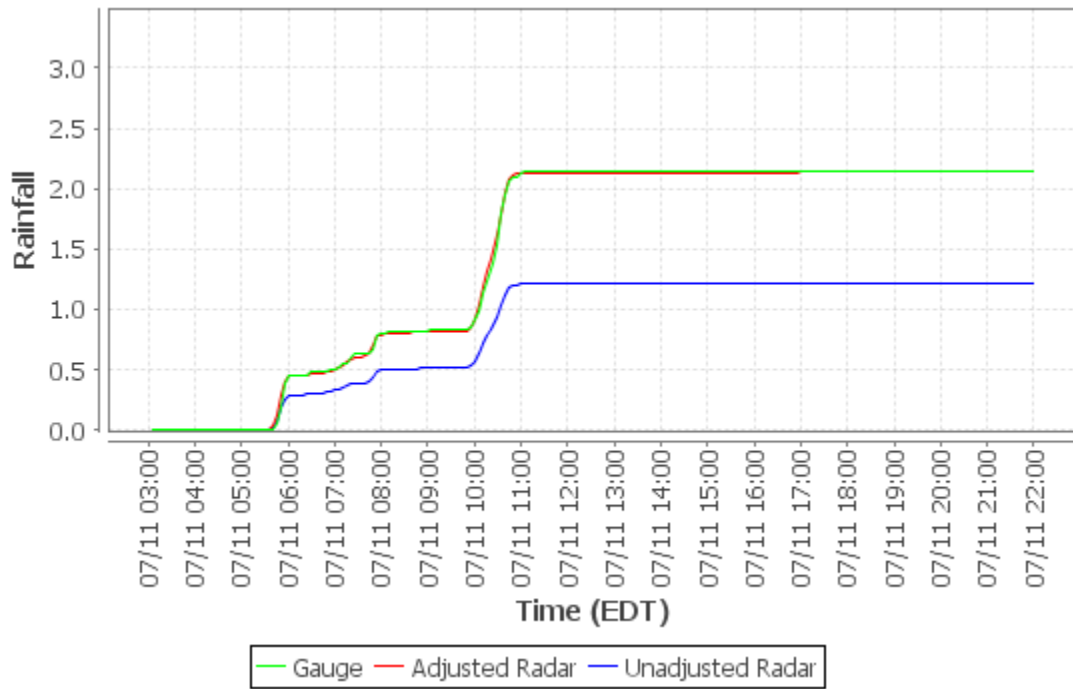
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



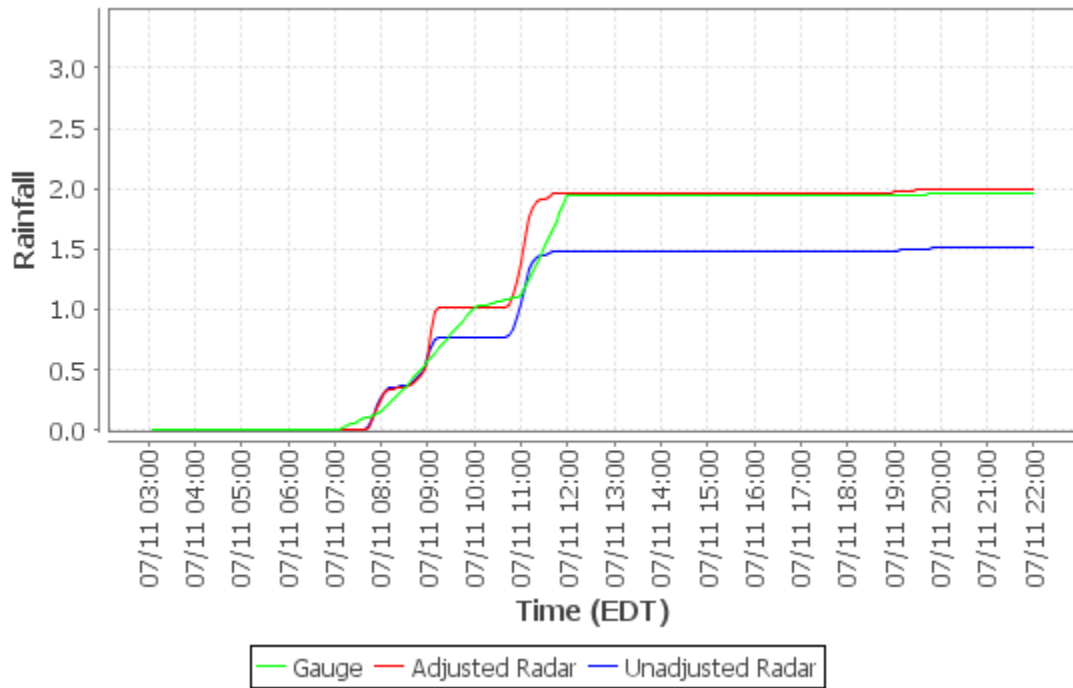
Cumulative Distribution Plot - Arnold (Loc32)



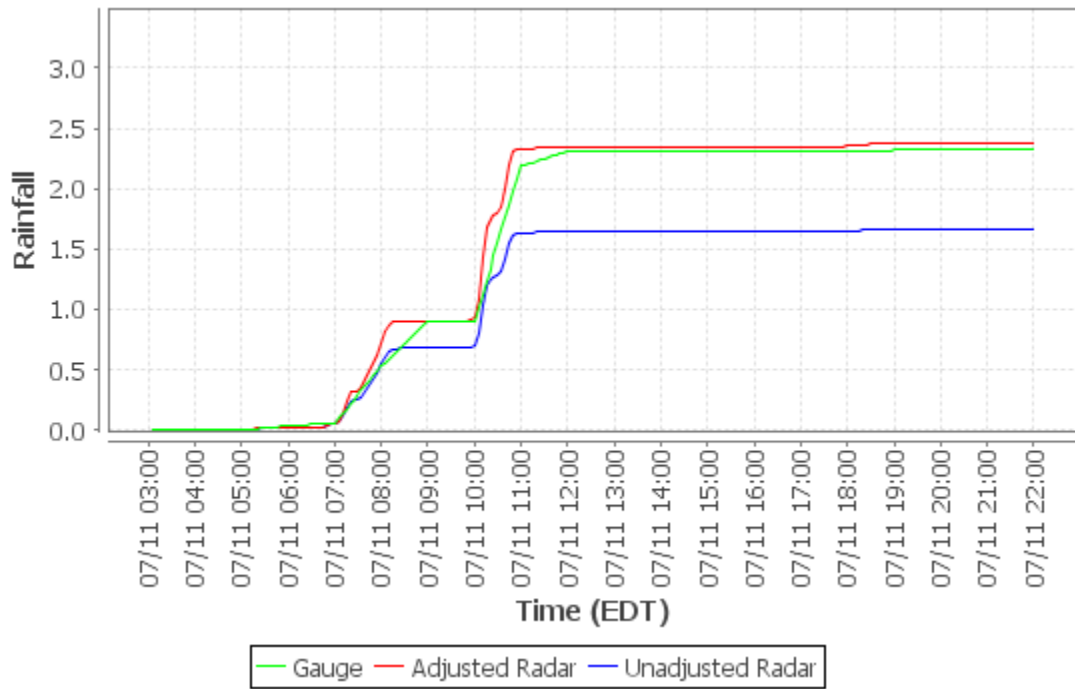
Cumulative Distribution Plot - Richland TWP (Loc33)



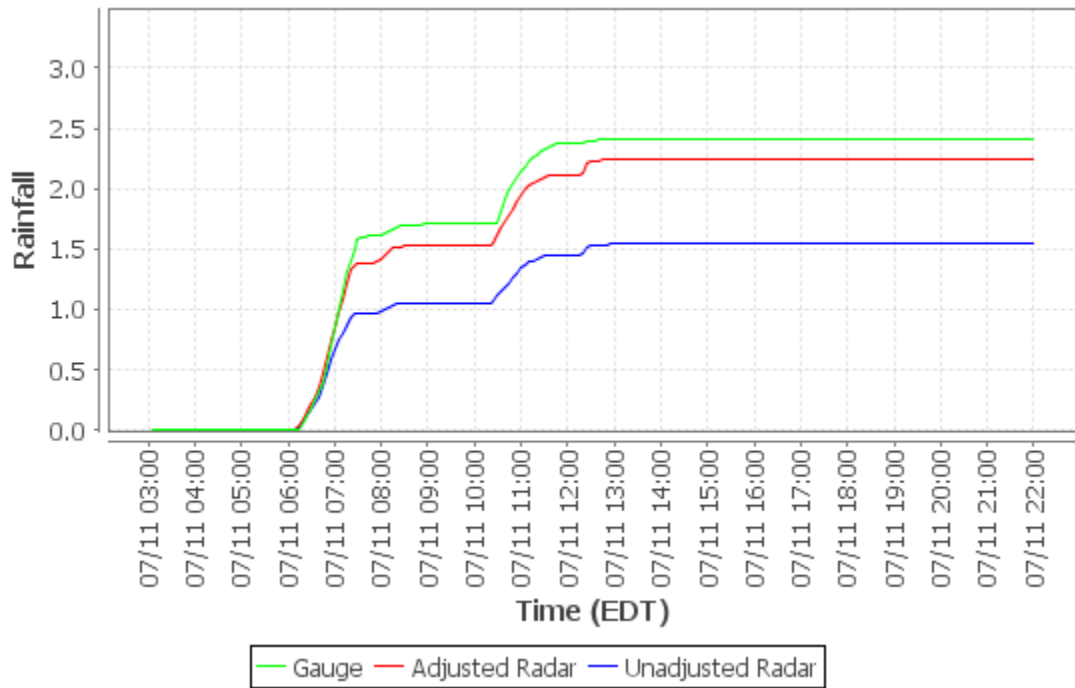
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



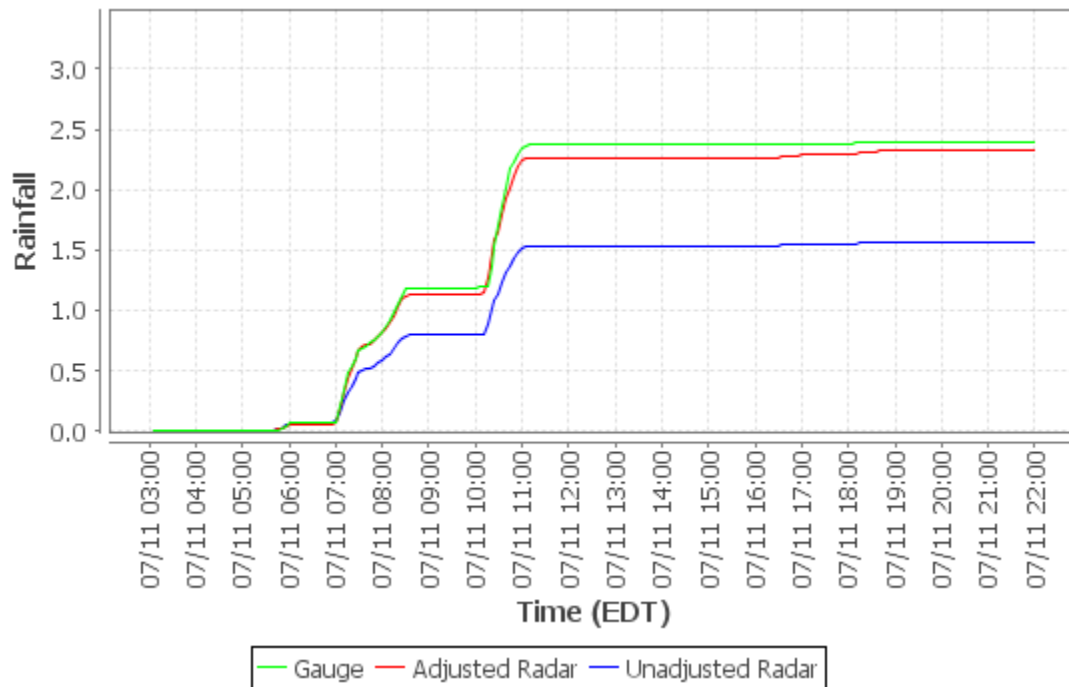
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

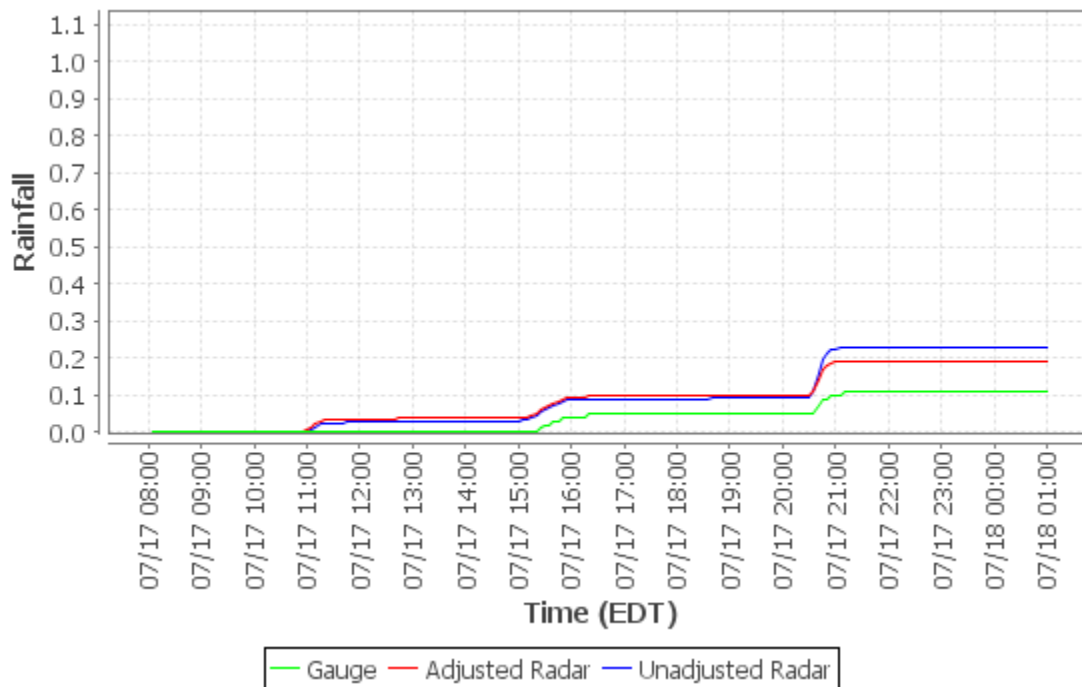


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

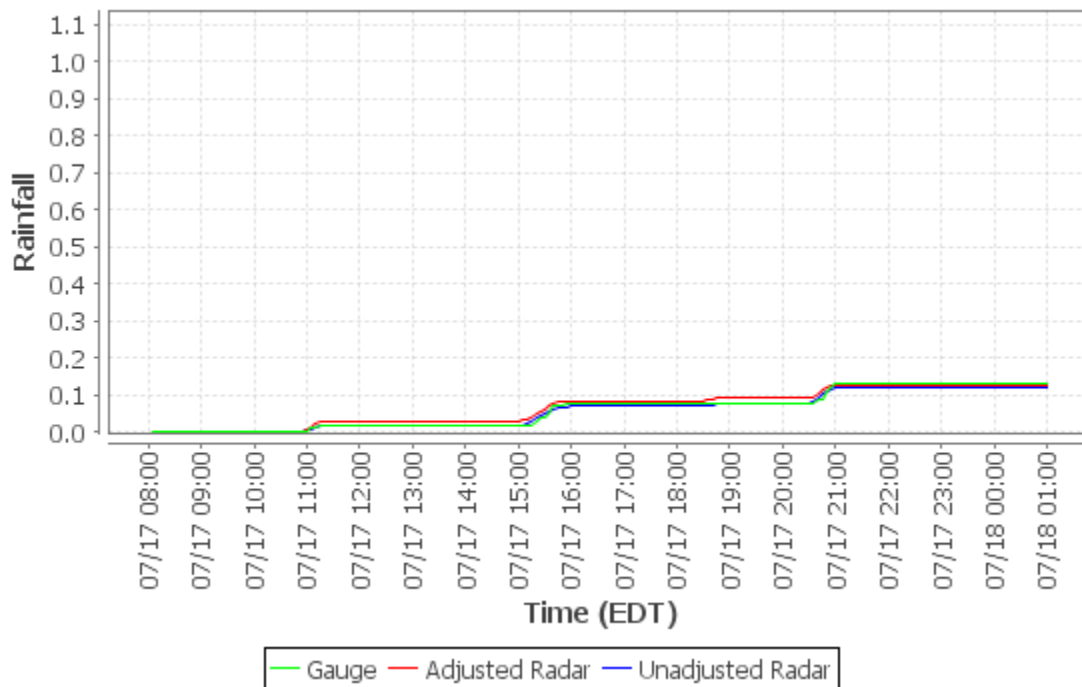


Appendix G - Event 5 (2019-07-17) CDPs

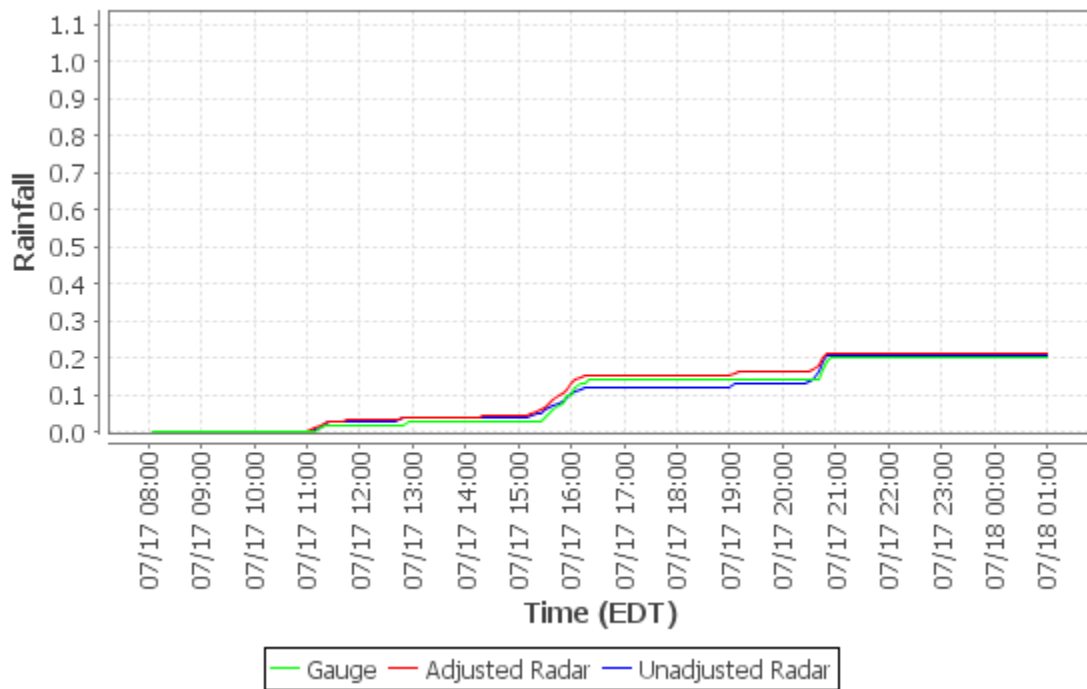
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



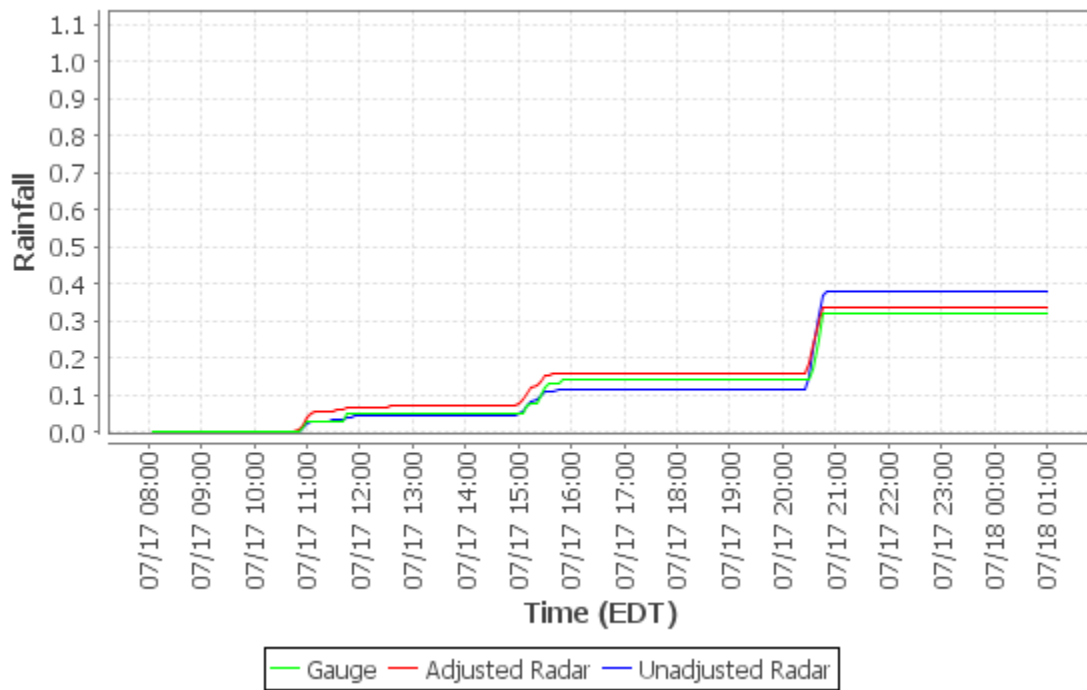
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



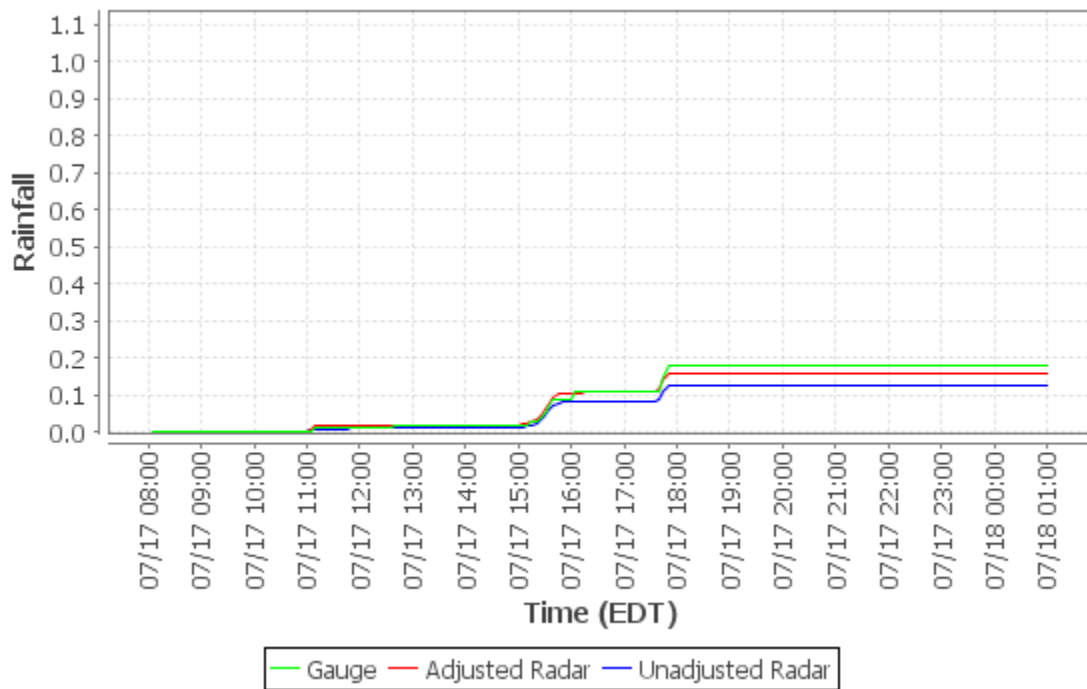
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



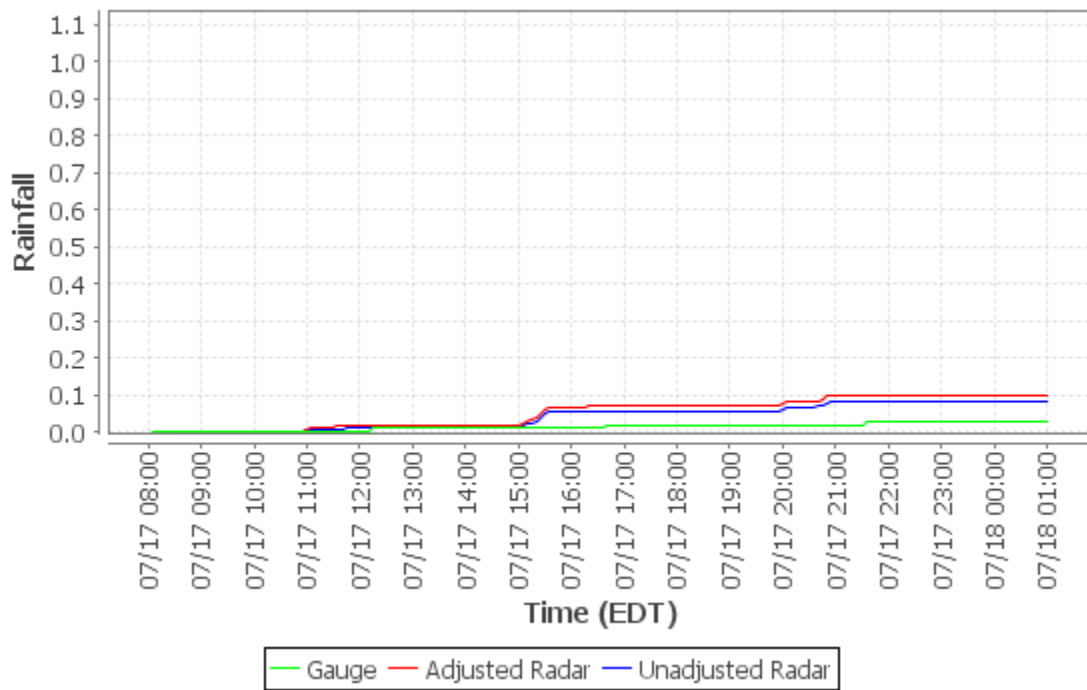
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



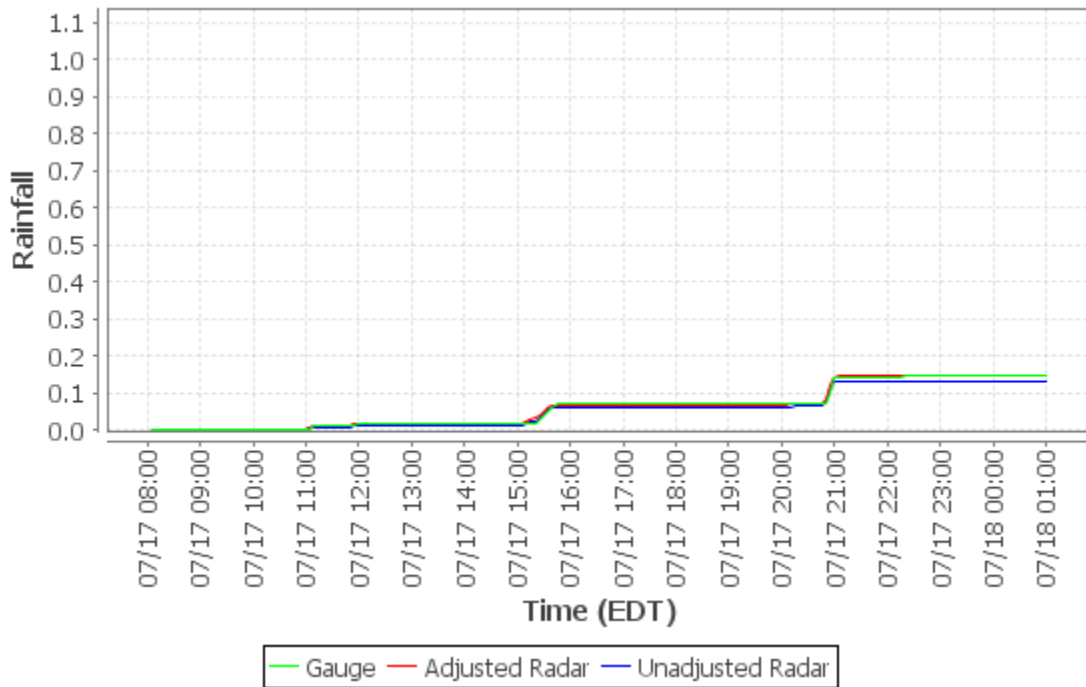
Cumulative Distribution Plot - Upper St. Clair (Loc05)



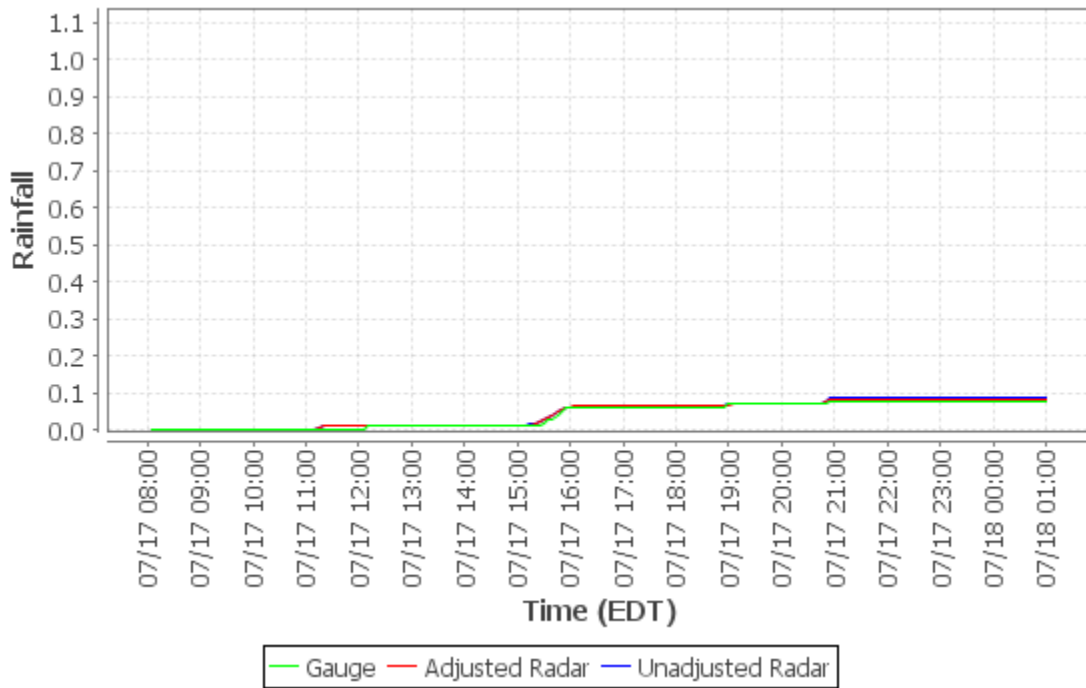
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



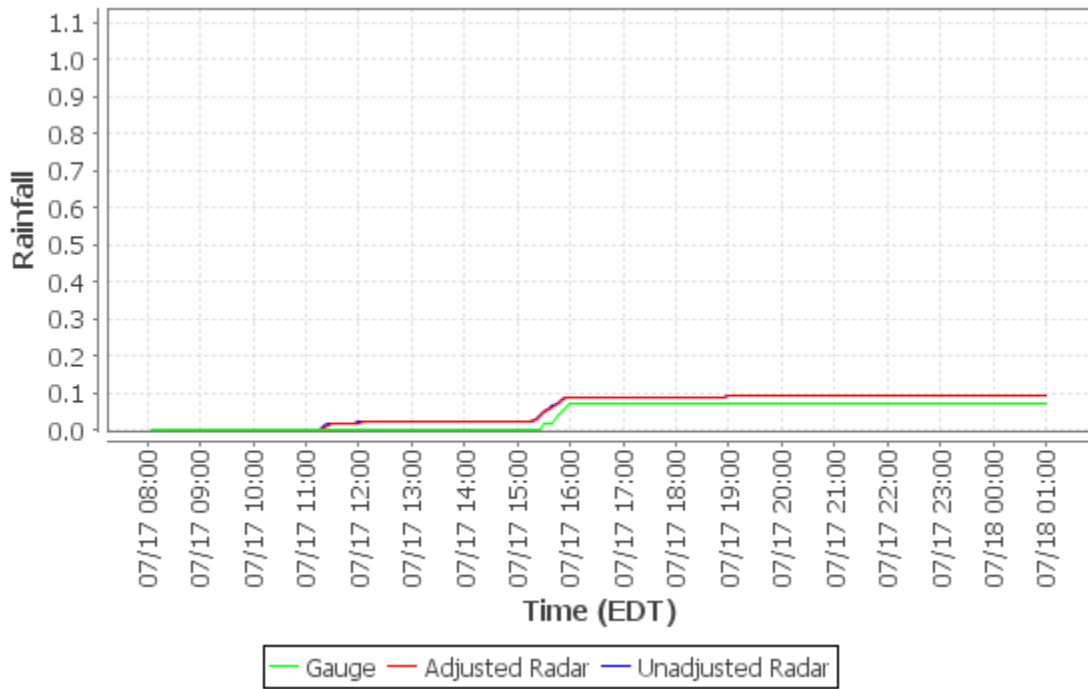
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



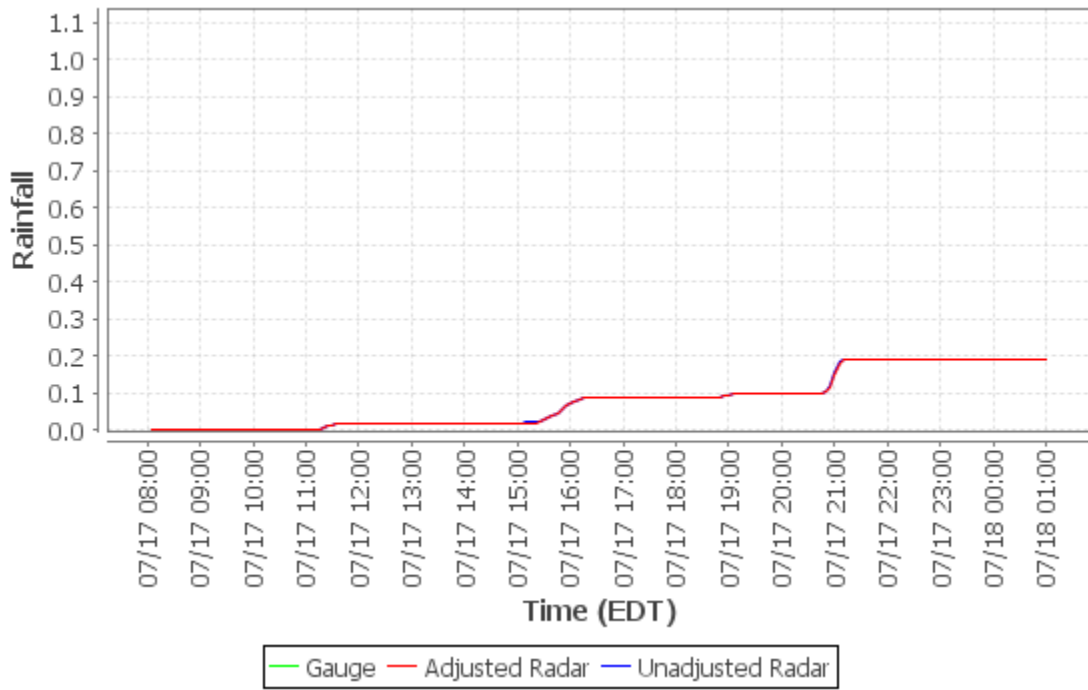
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



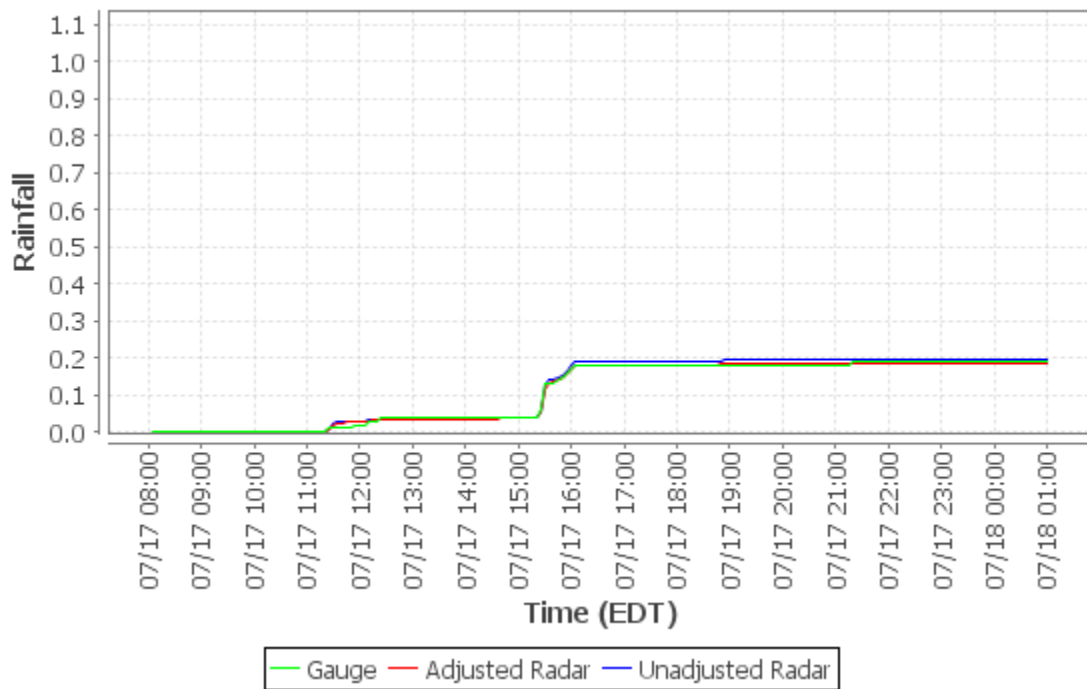
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



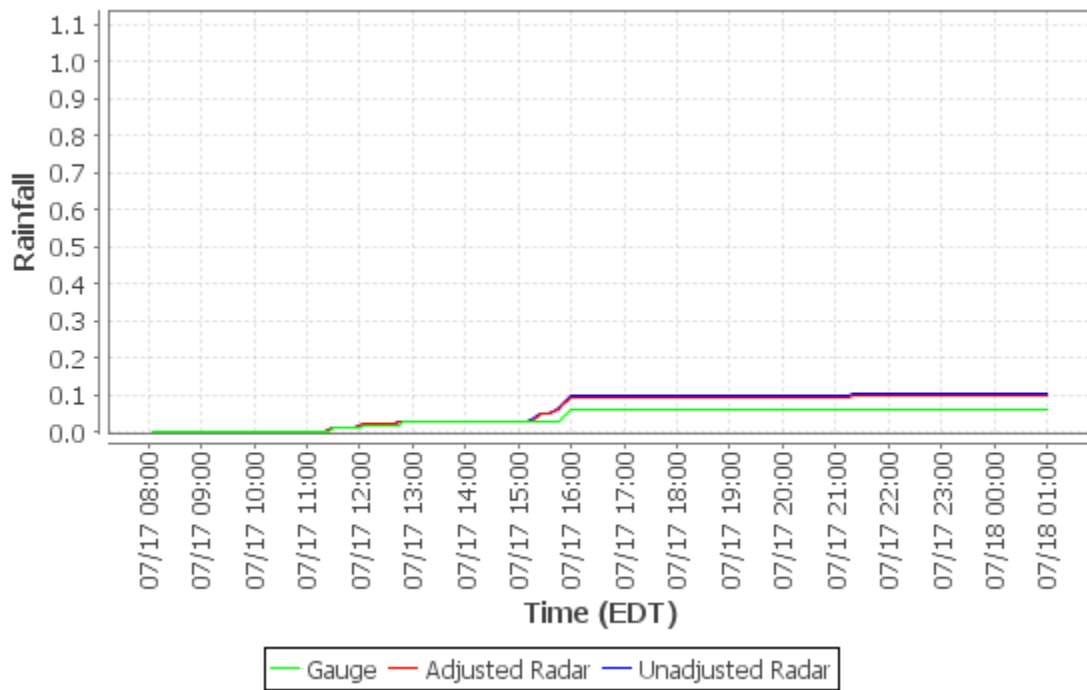
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



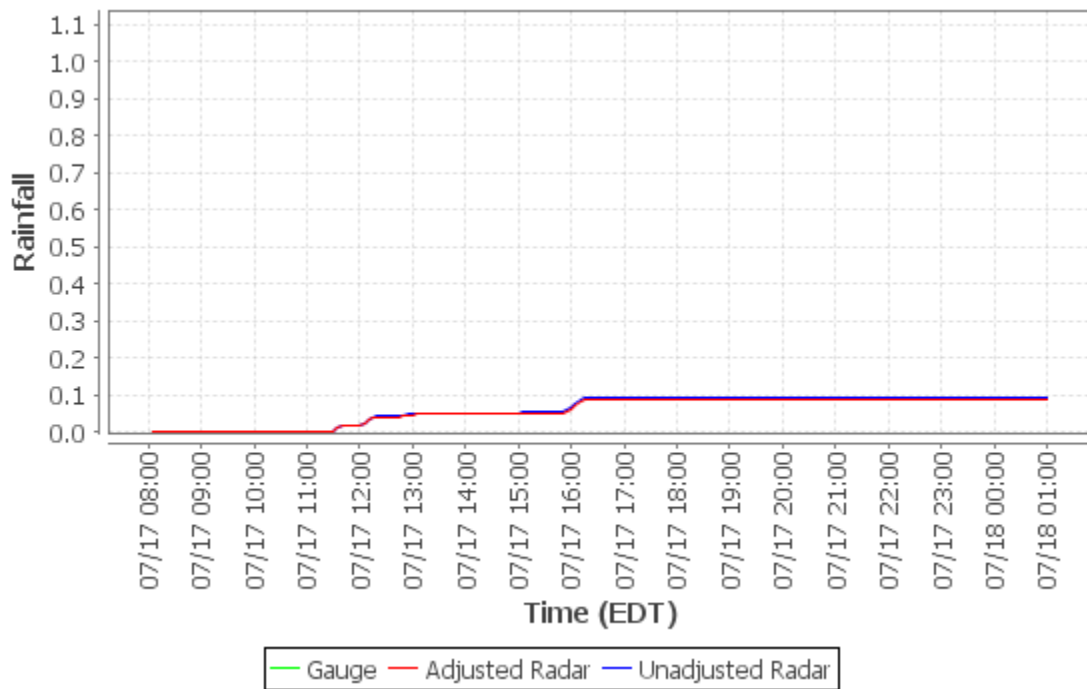
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



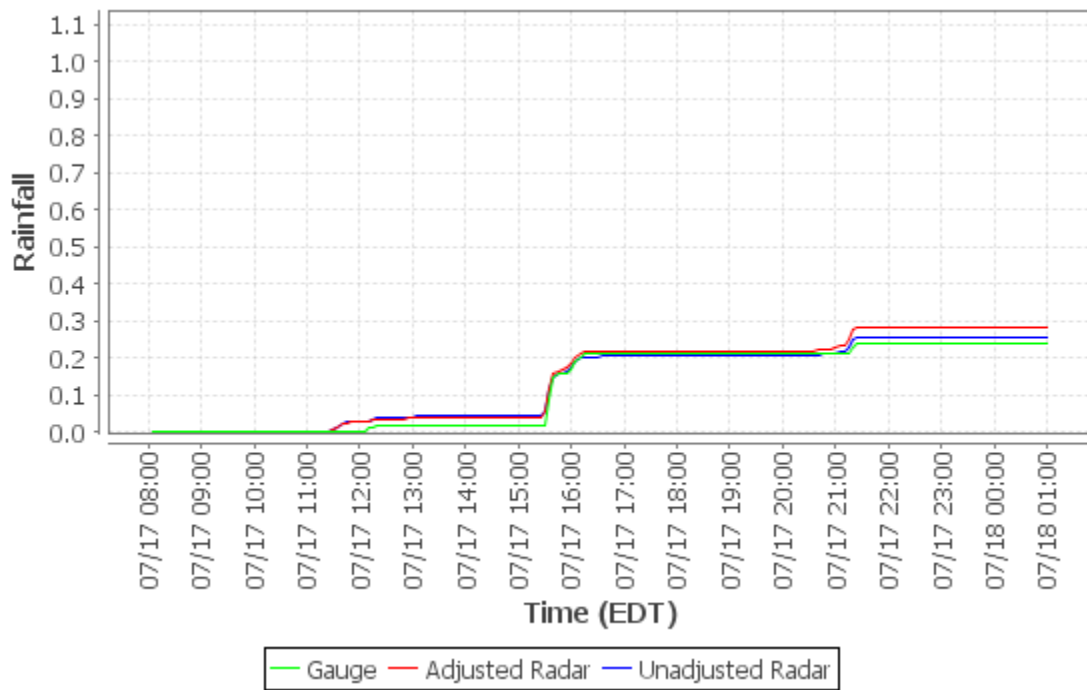
Cumulative Distribution Plot - Baldwin (Loc12)



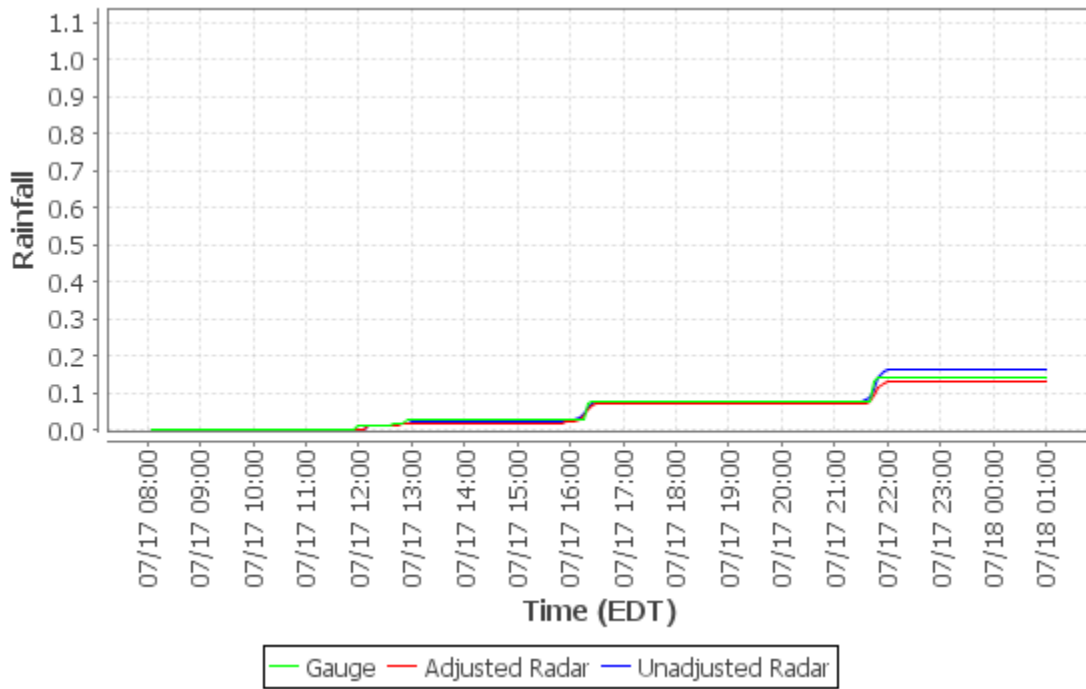
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



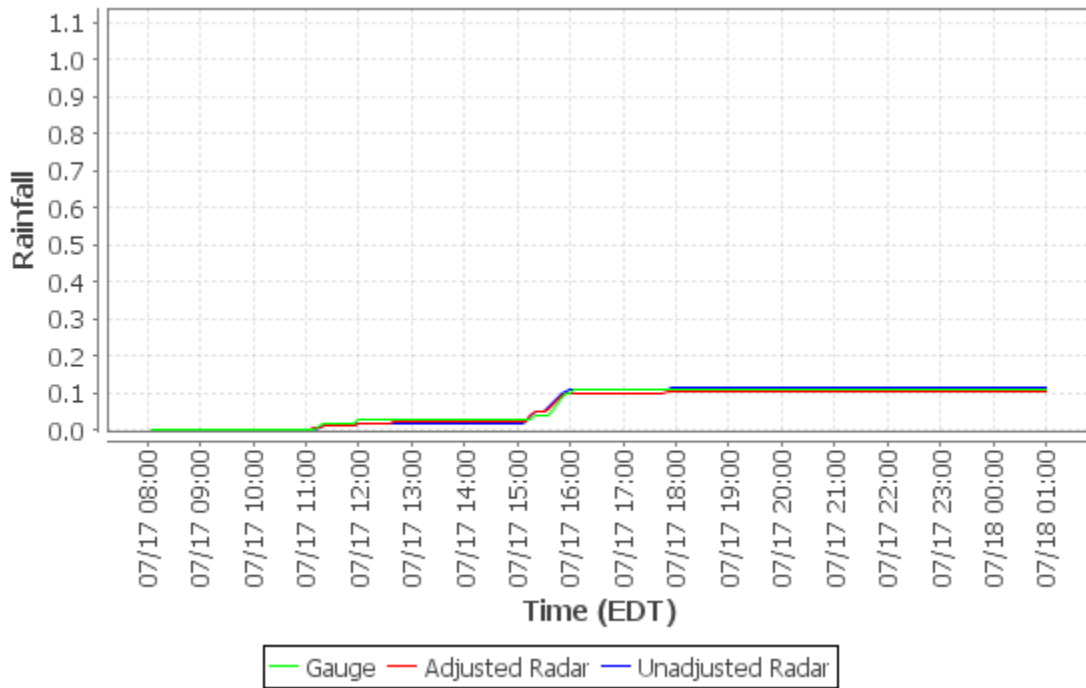
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



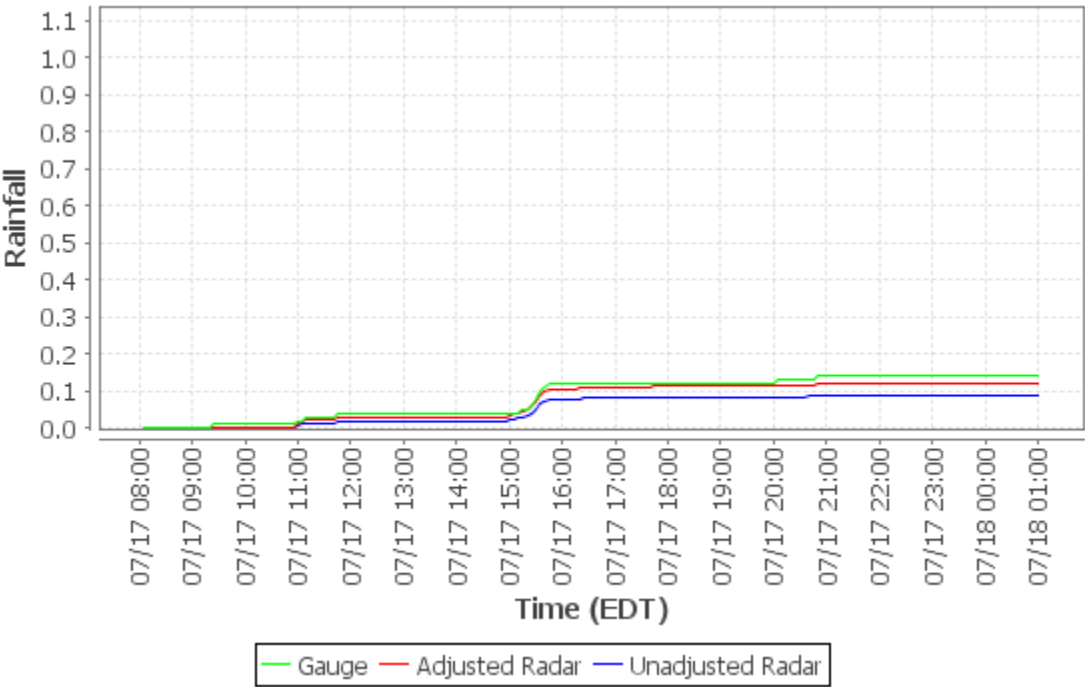
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



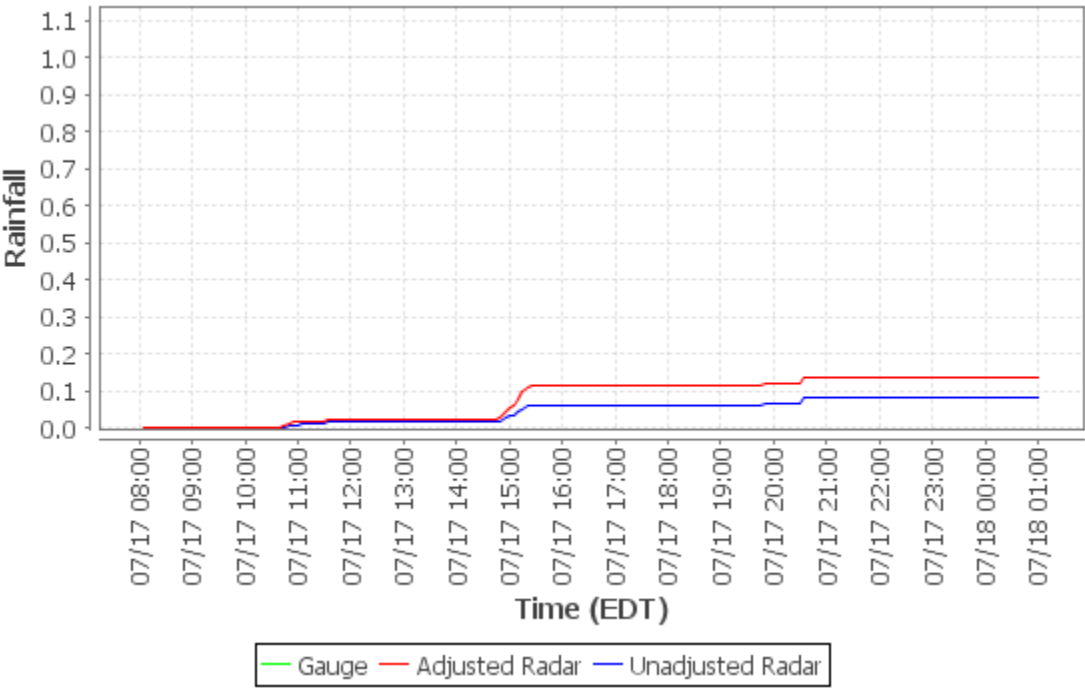
Cumulative Distribution Plot - Castle Shannon (Loc16)



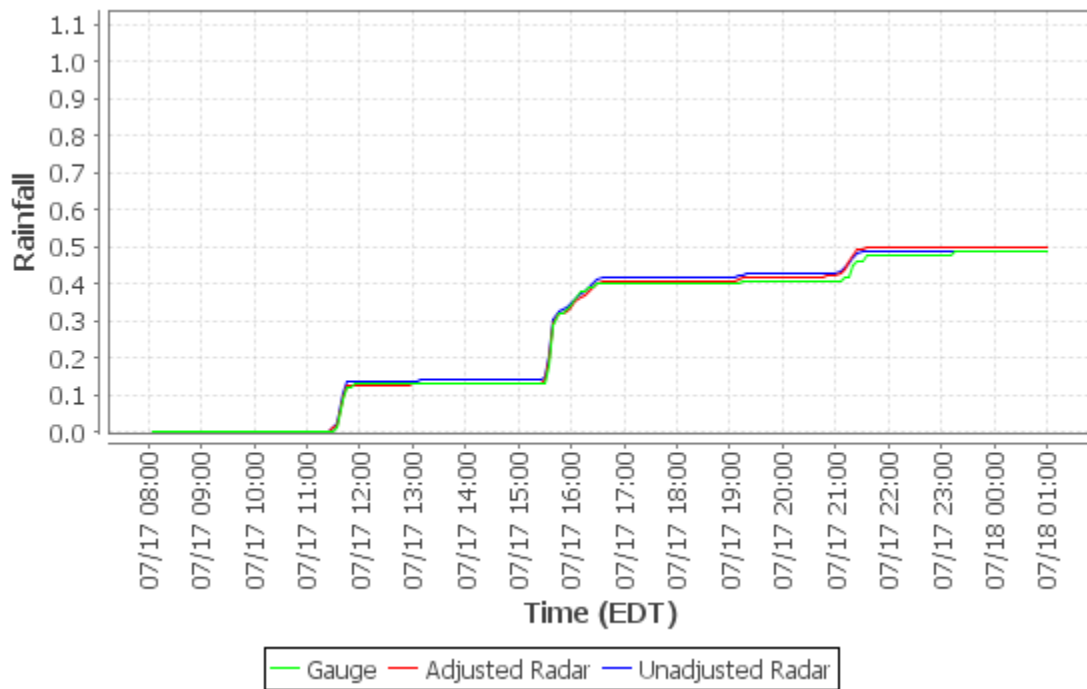
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



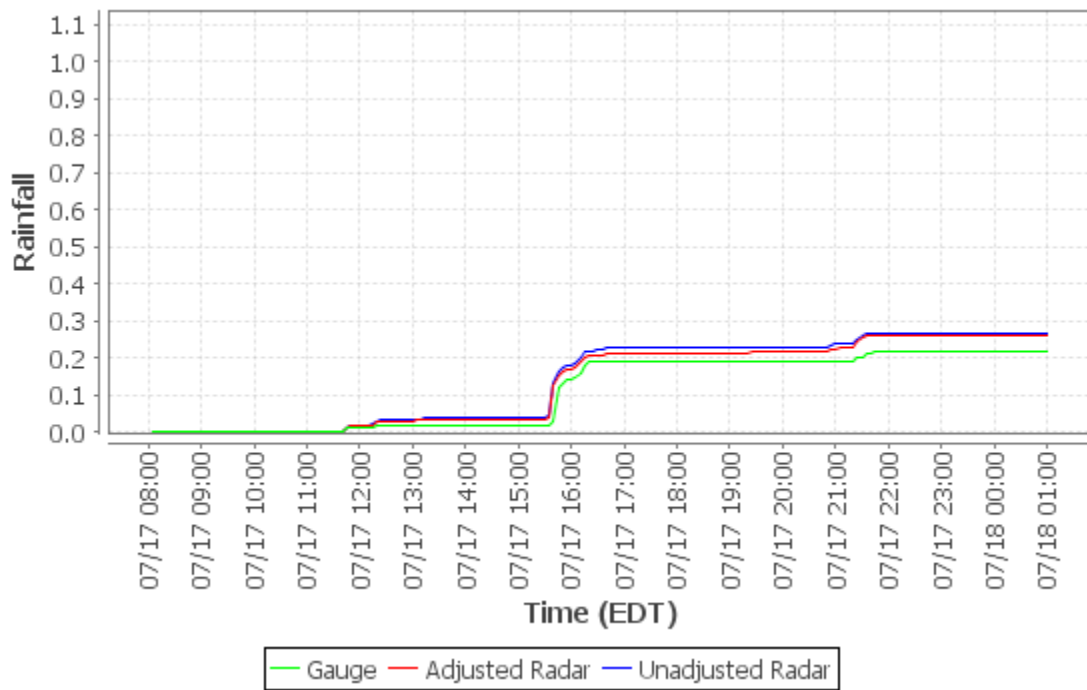
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



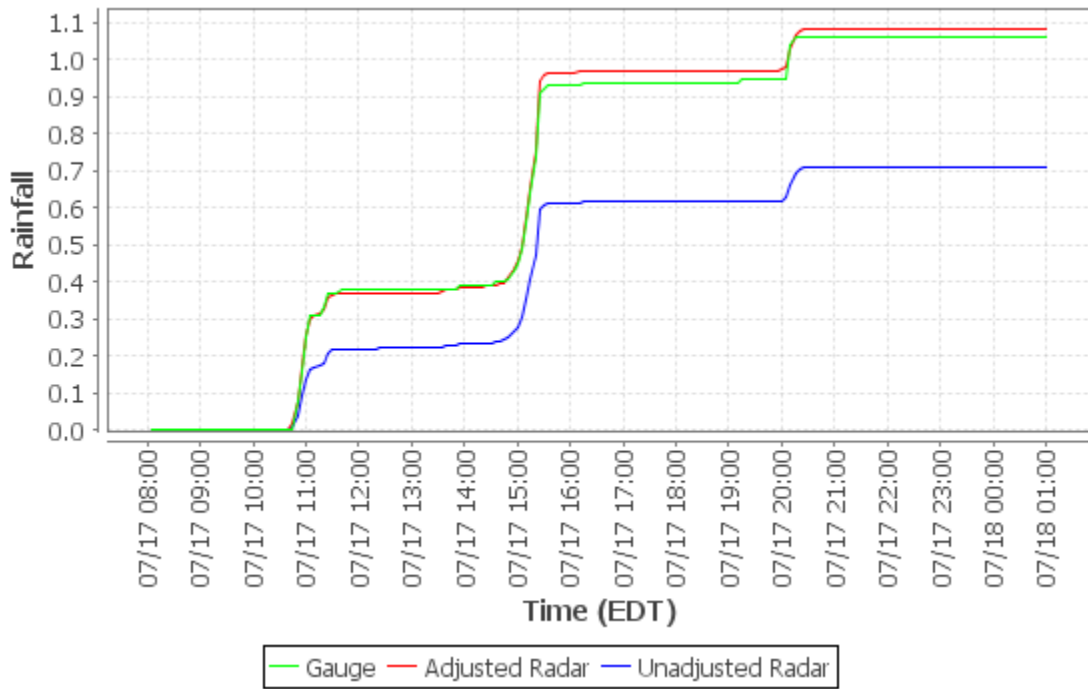
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



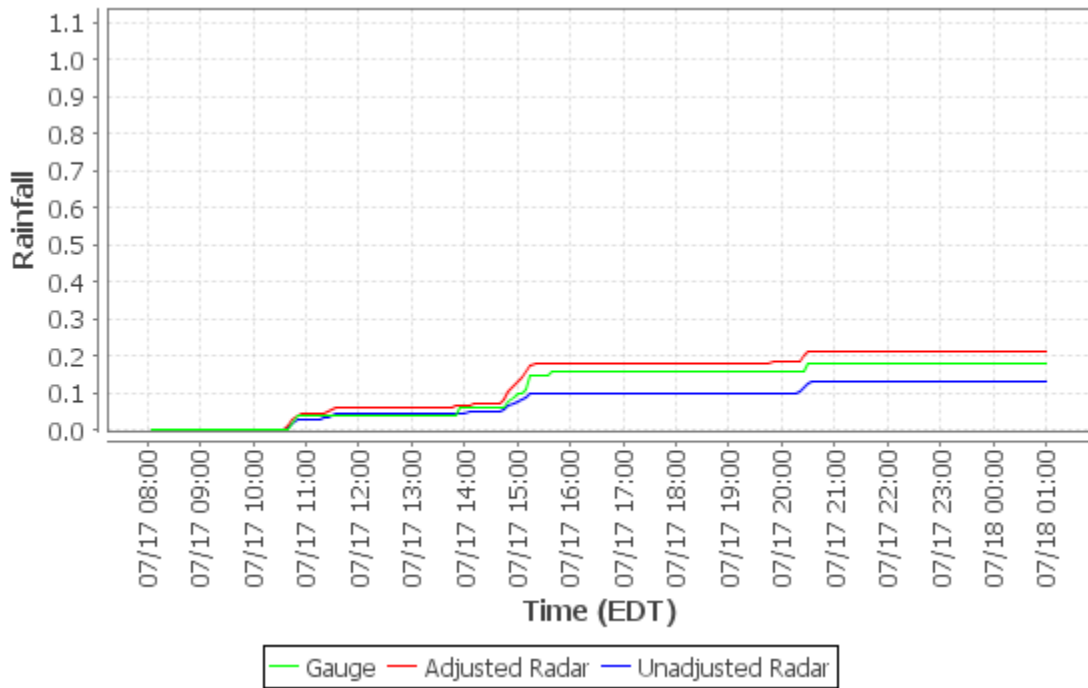
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



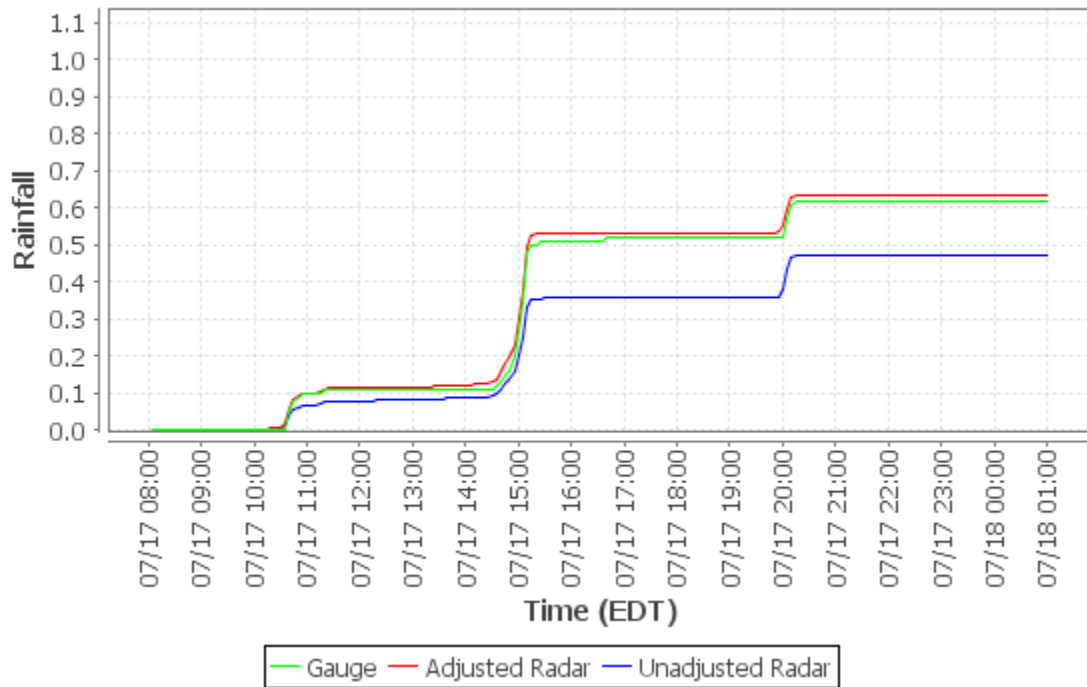
Cumulative Distribution Plot - Moon TWP (Loc21)



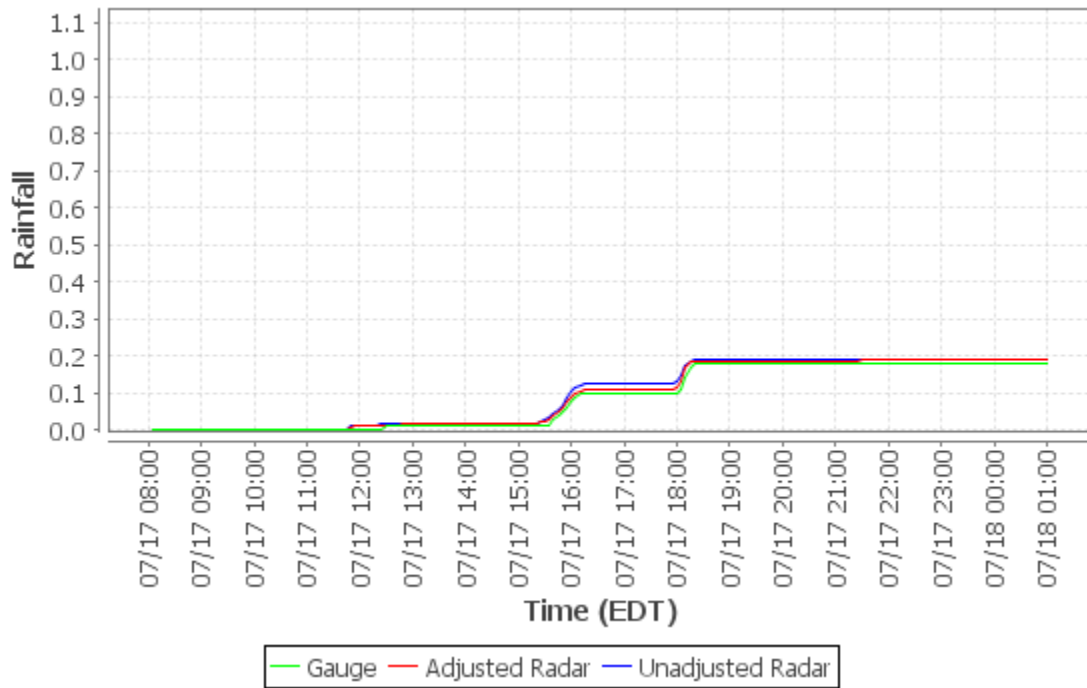
Cumulative Distribution Plot - North Fayette TWP (Loc22)



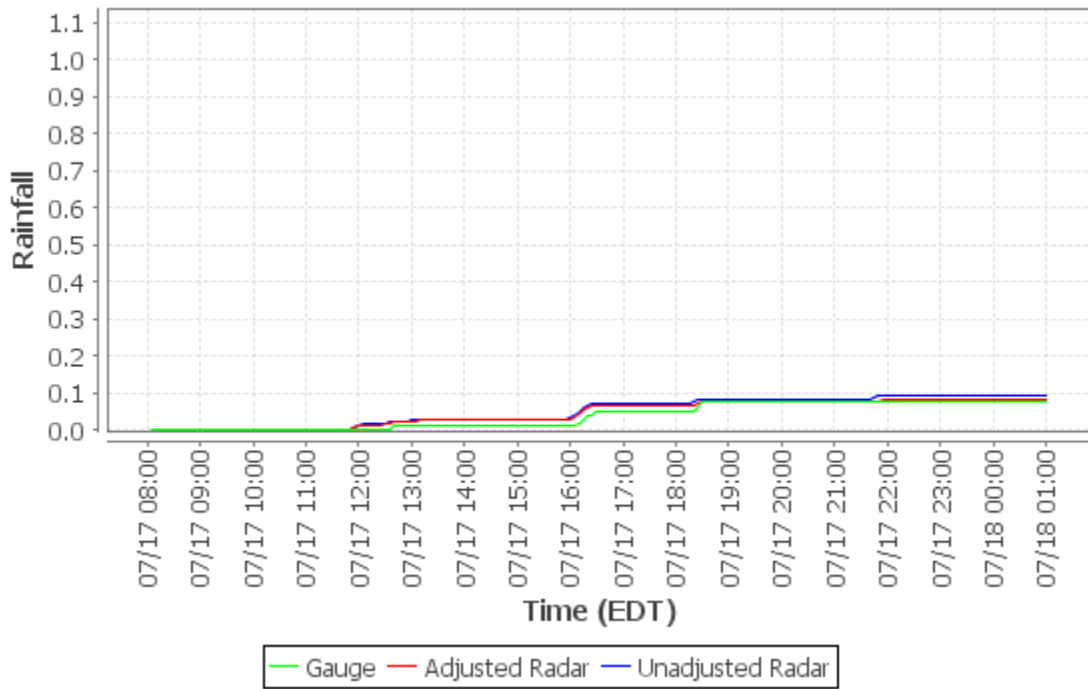
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



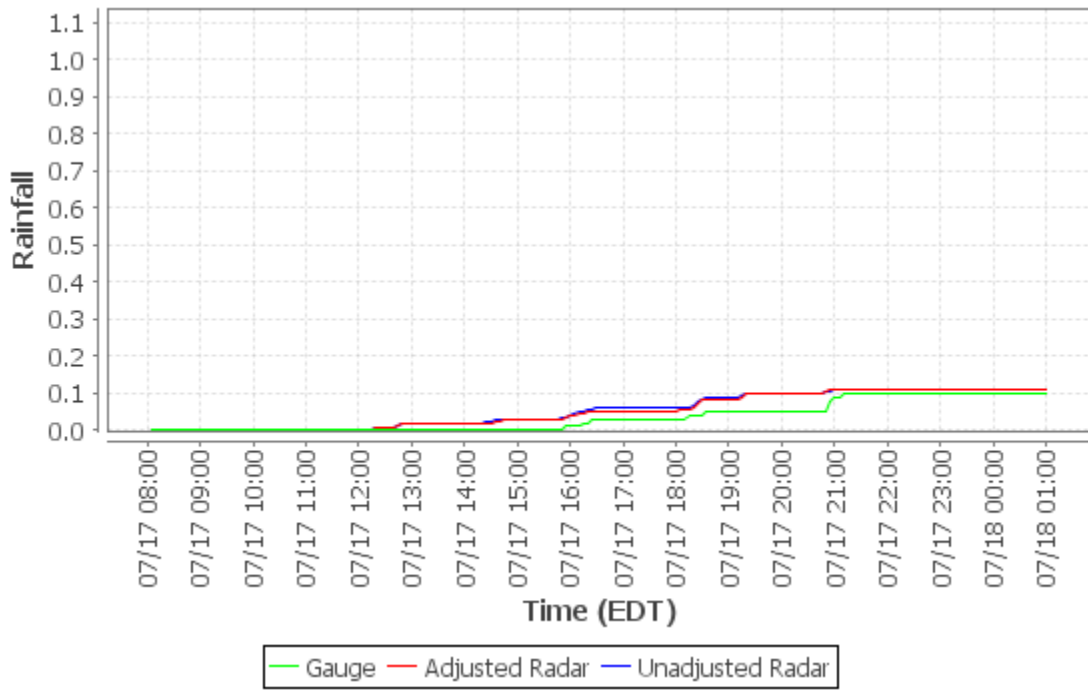
Cumulative Distribution Plot - Jefferson Hills (Loc24)



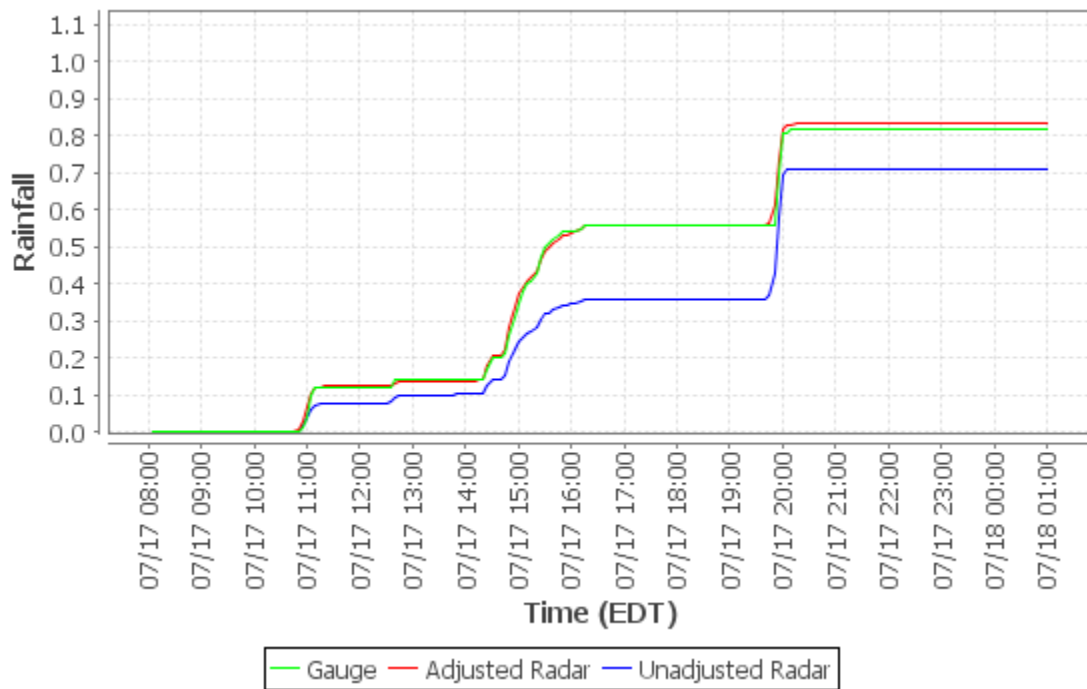
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



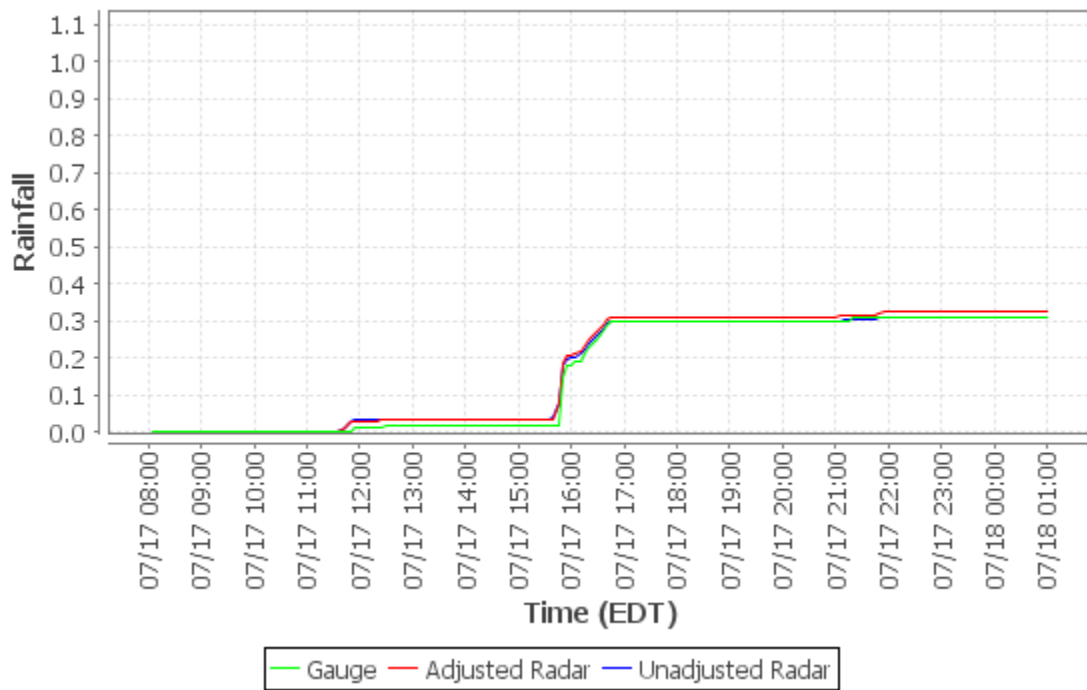
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



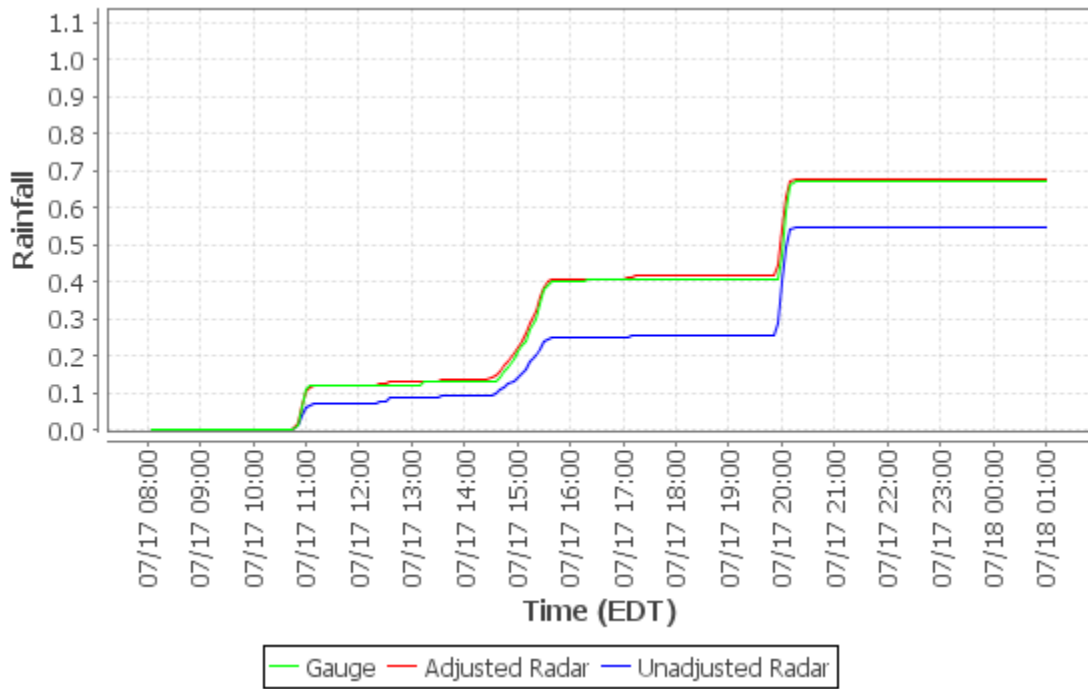
Cumulative Distribution Plot - Marshall TWP (Loc27)



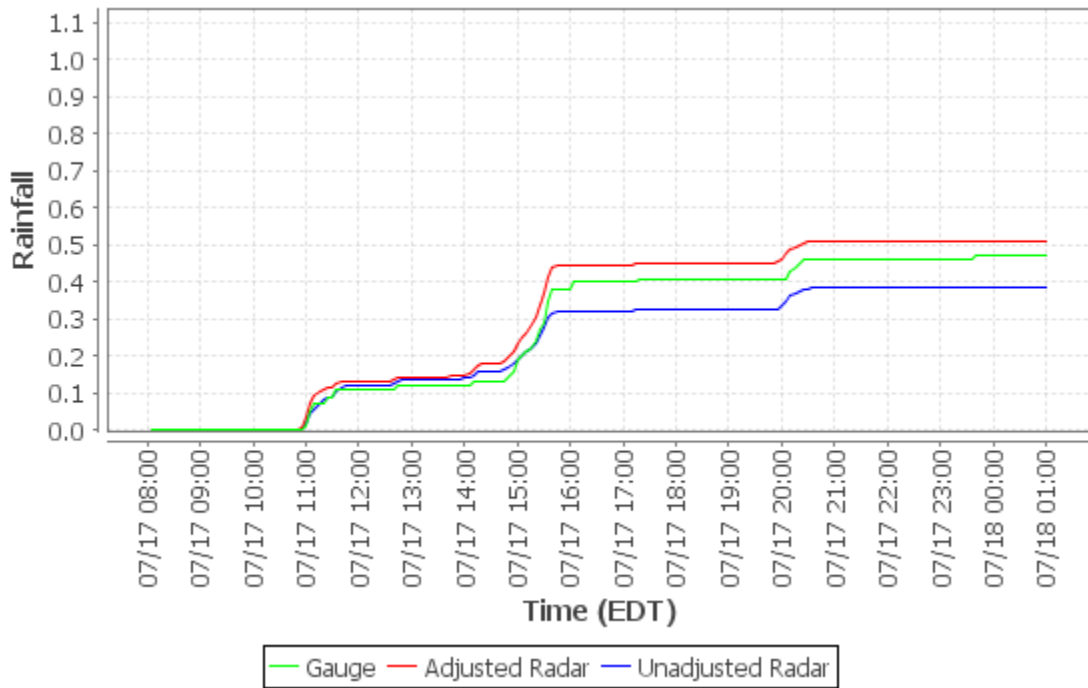
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



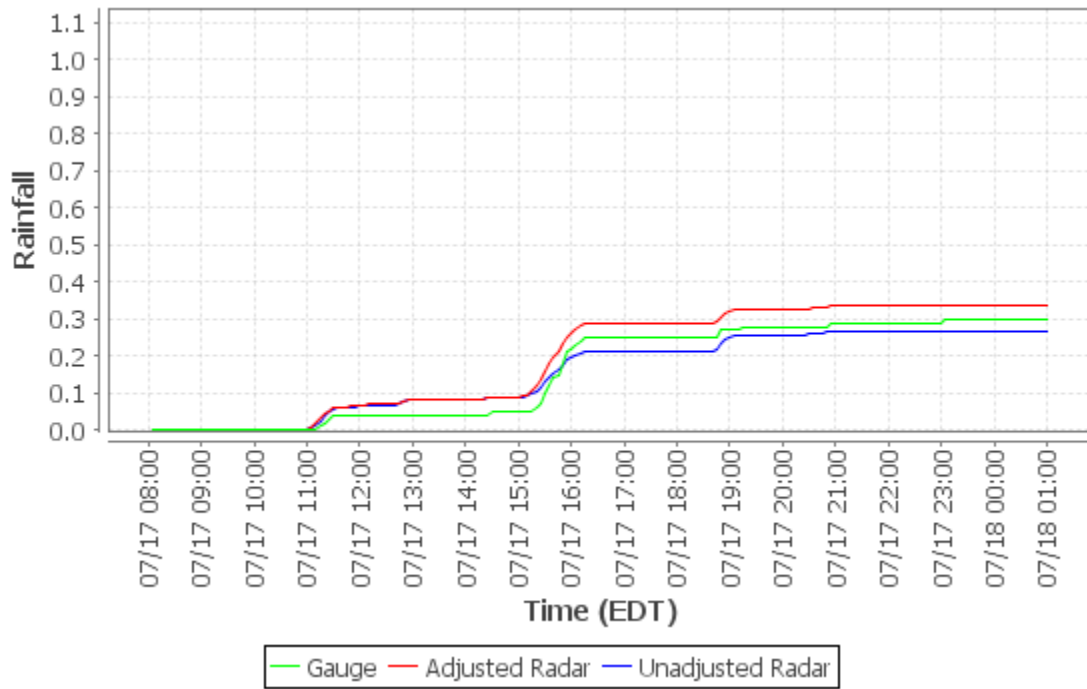
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



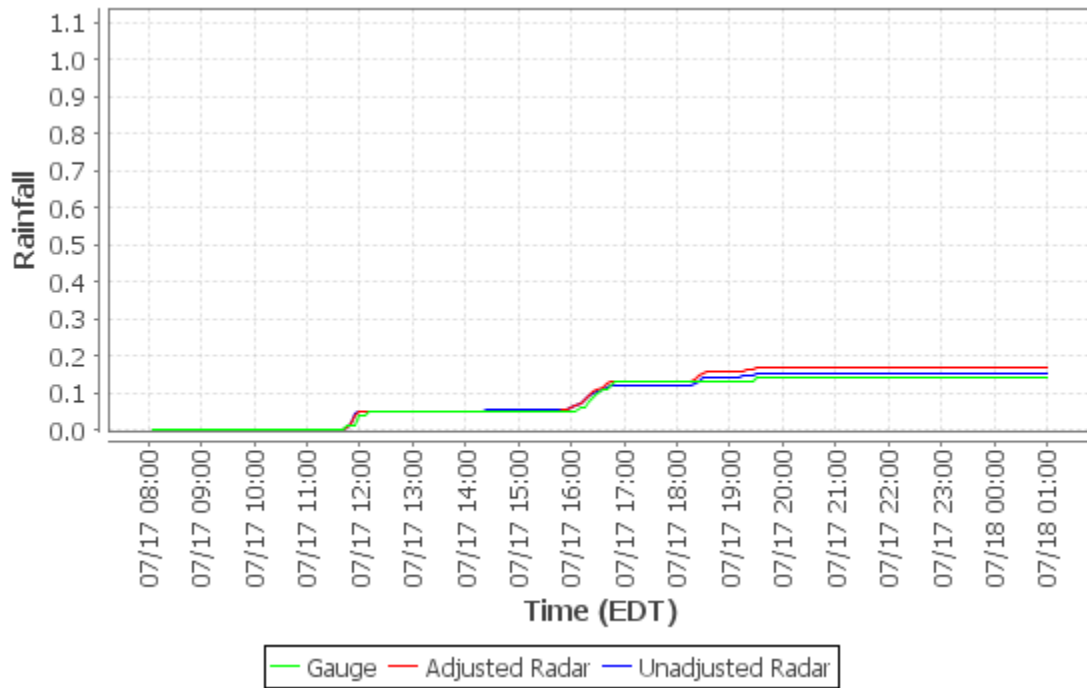
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



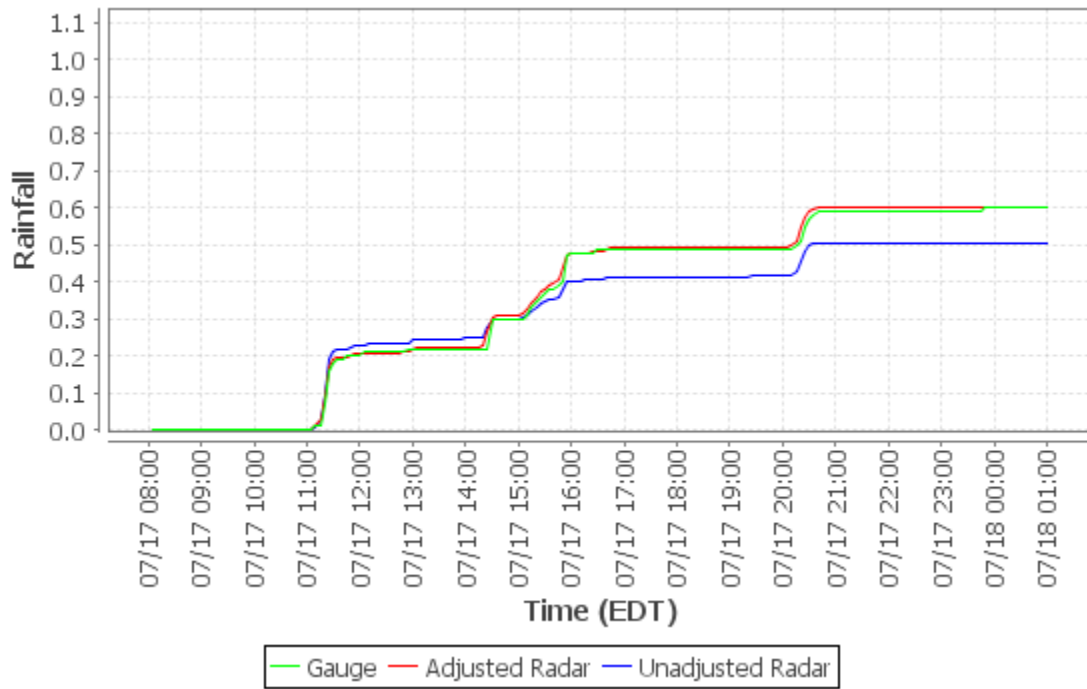
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



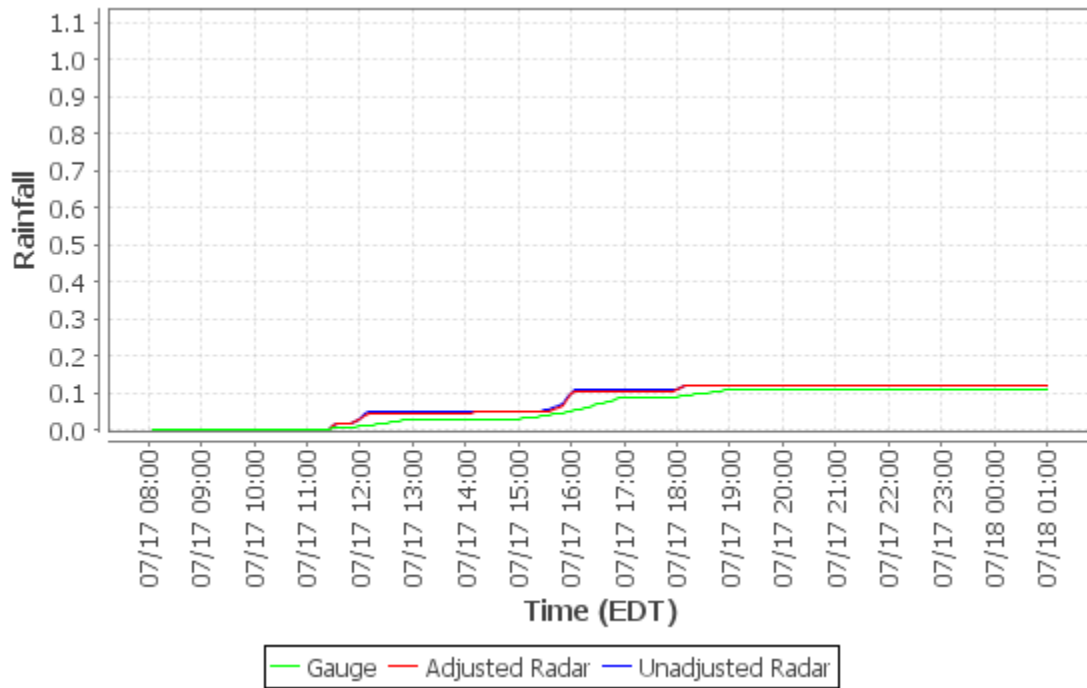
Cumulative Distribution Plot - Arnold (Loc32)



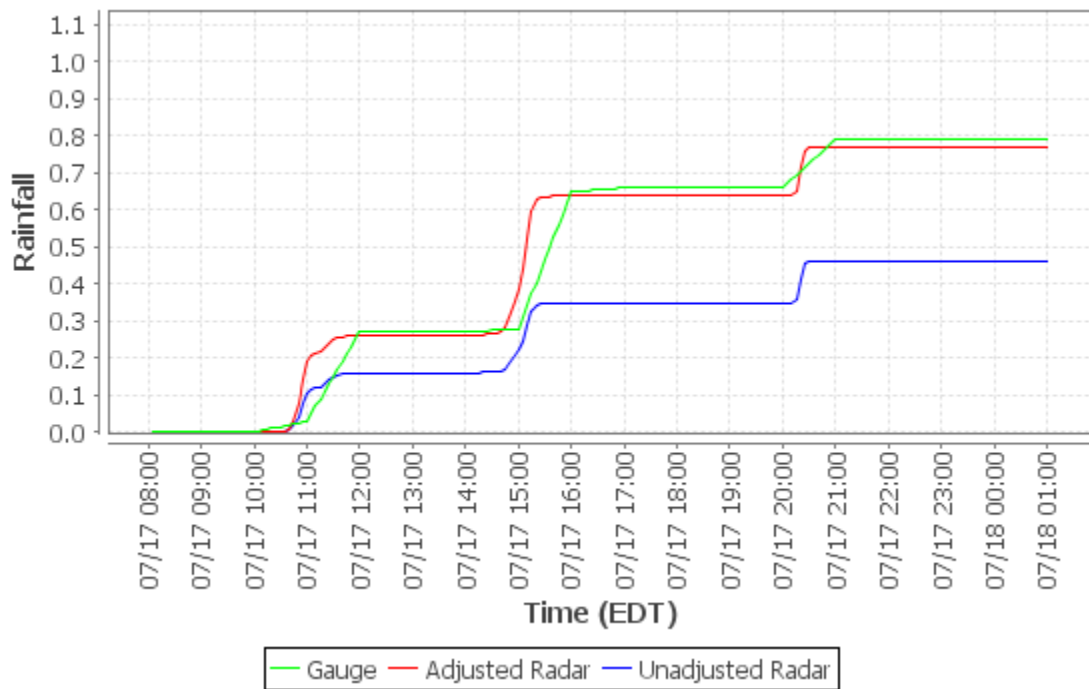
Cumulative Distribution Plot - Richland TWP (Loc33)



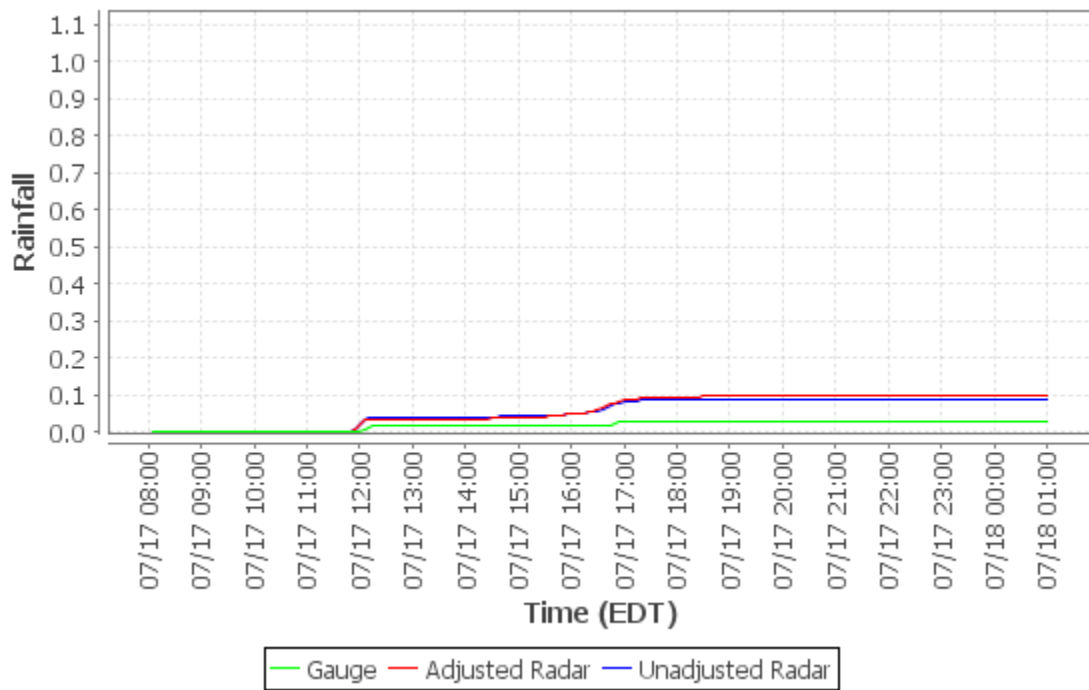
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



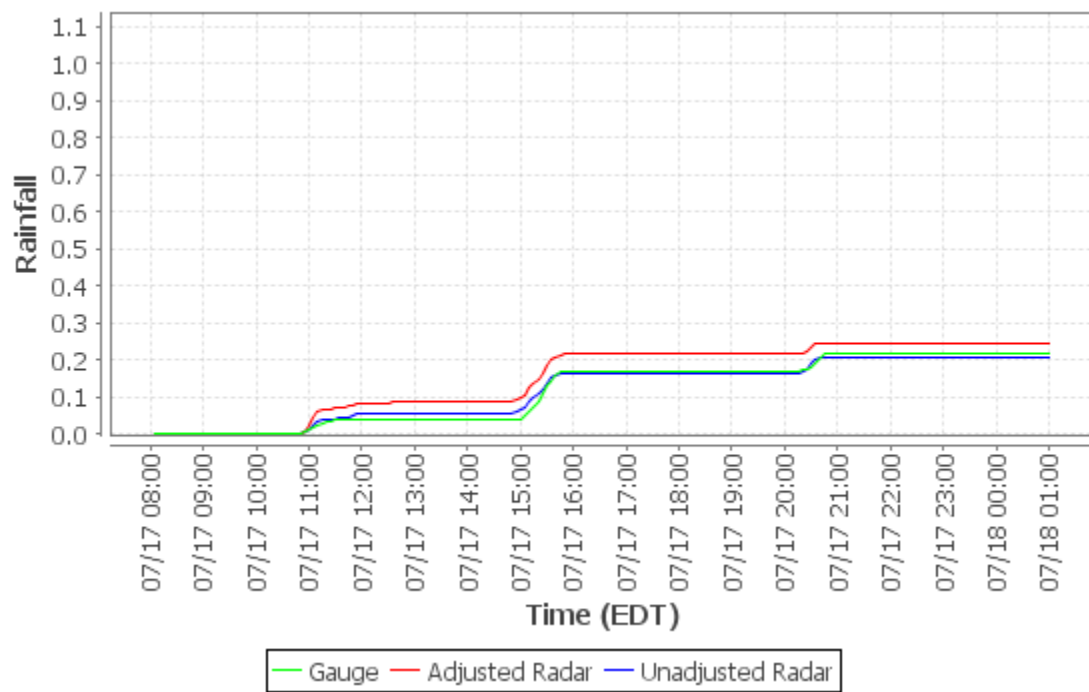
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

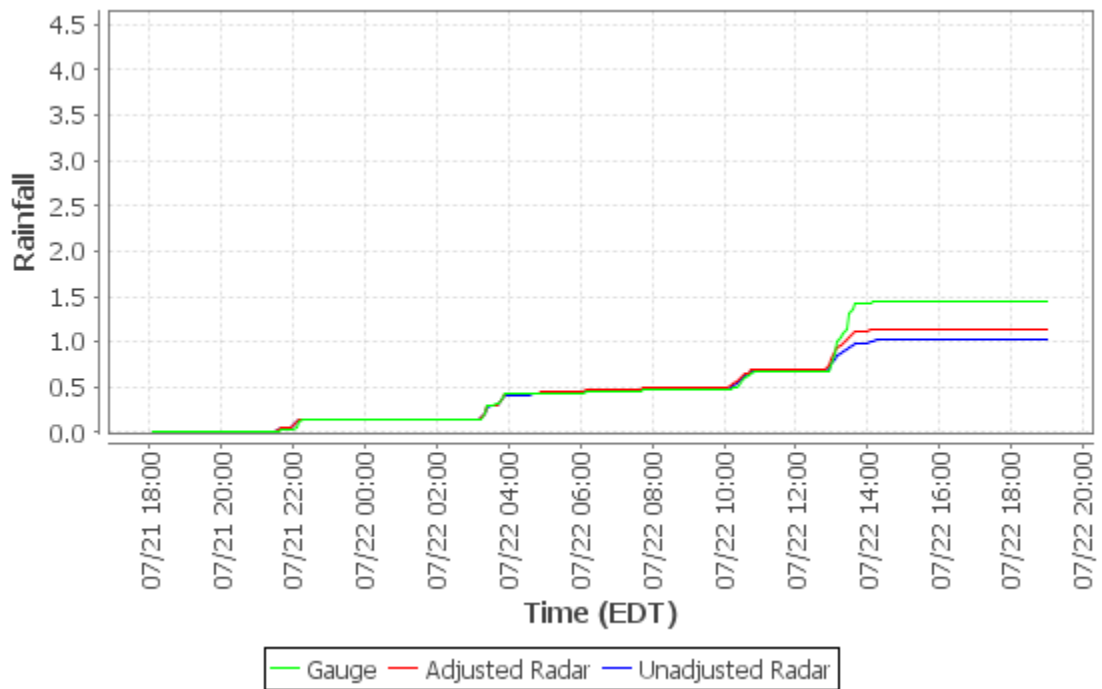


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

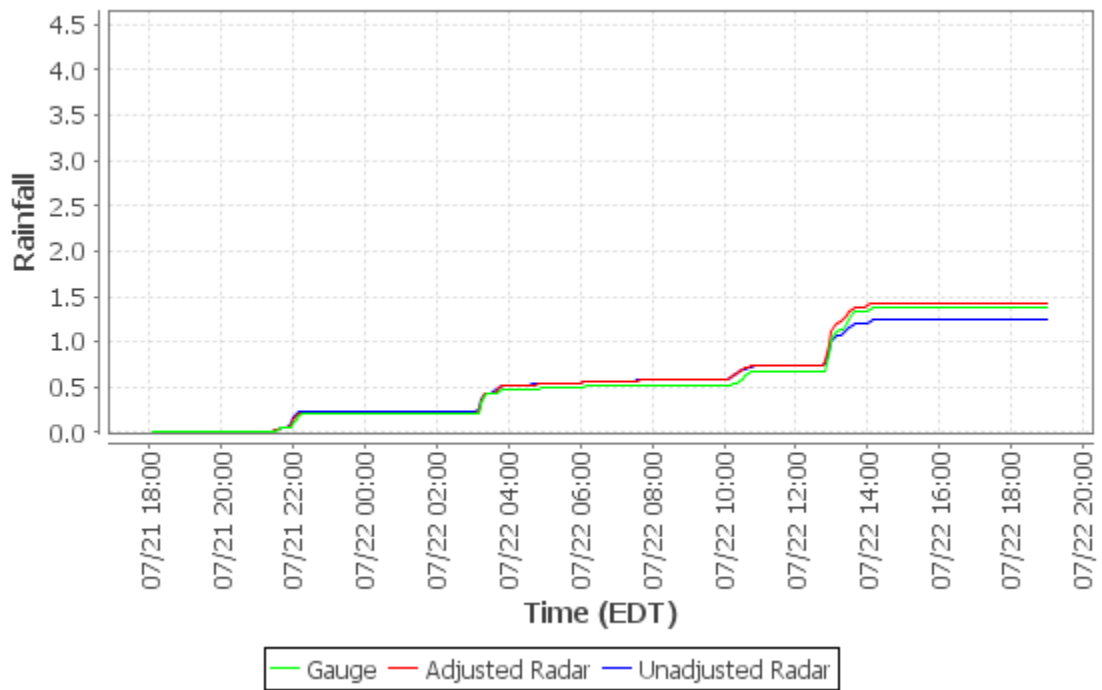


Appendix H - Event 6 (2019-07-22) CDPs

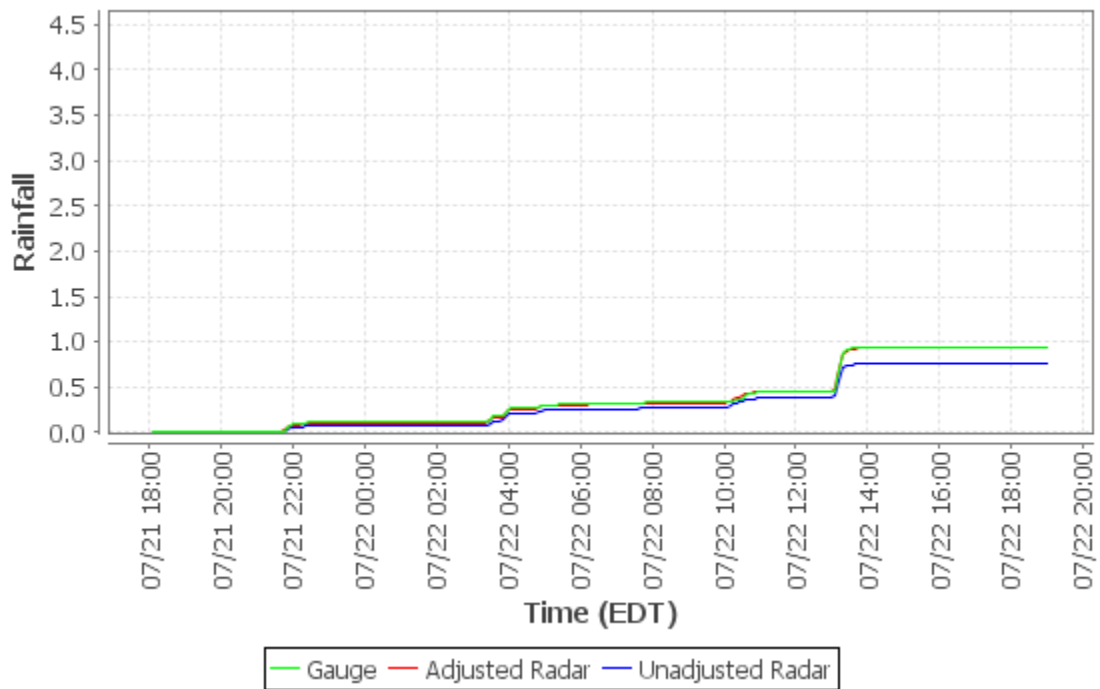
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



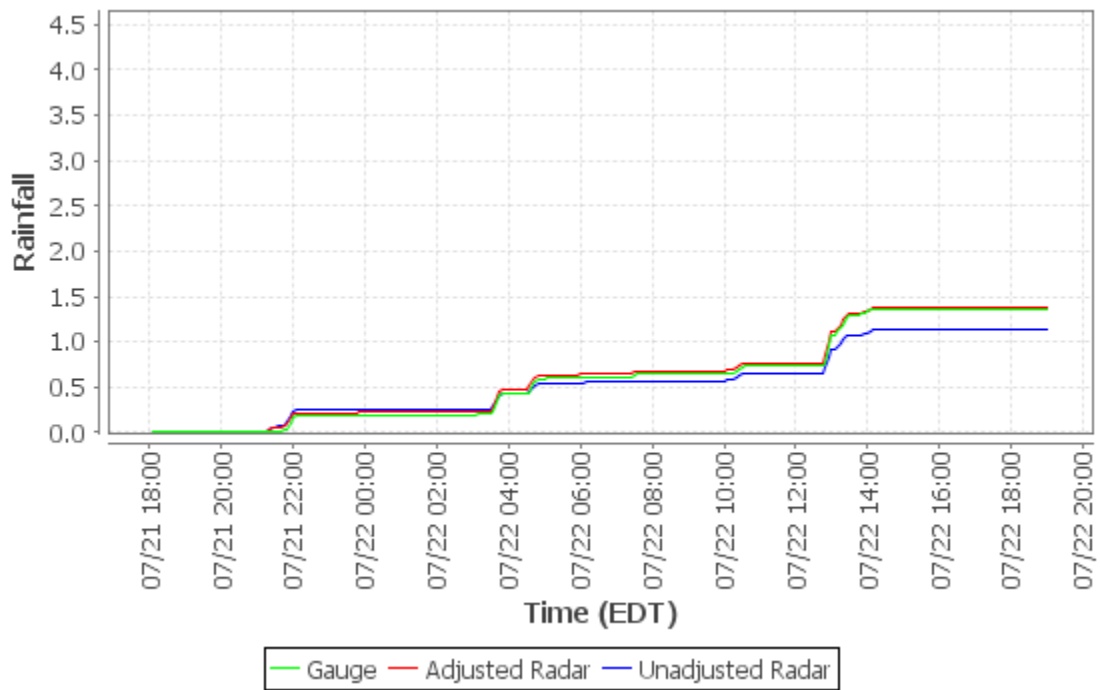
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



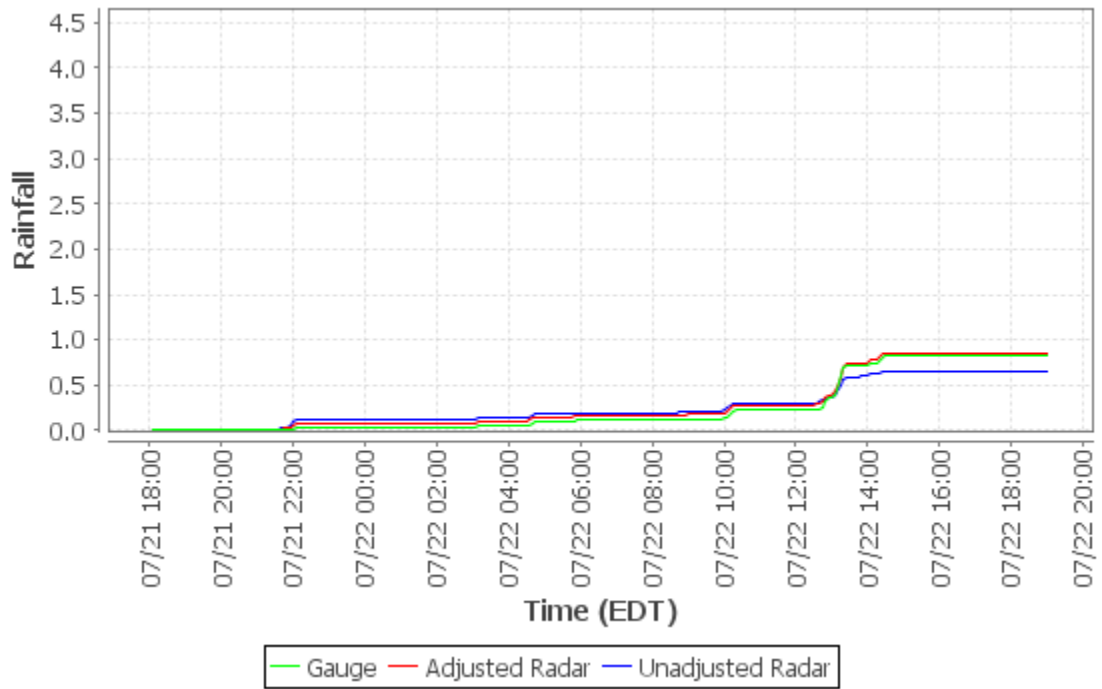
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



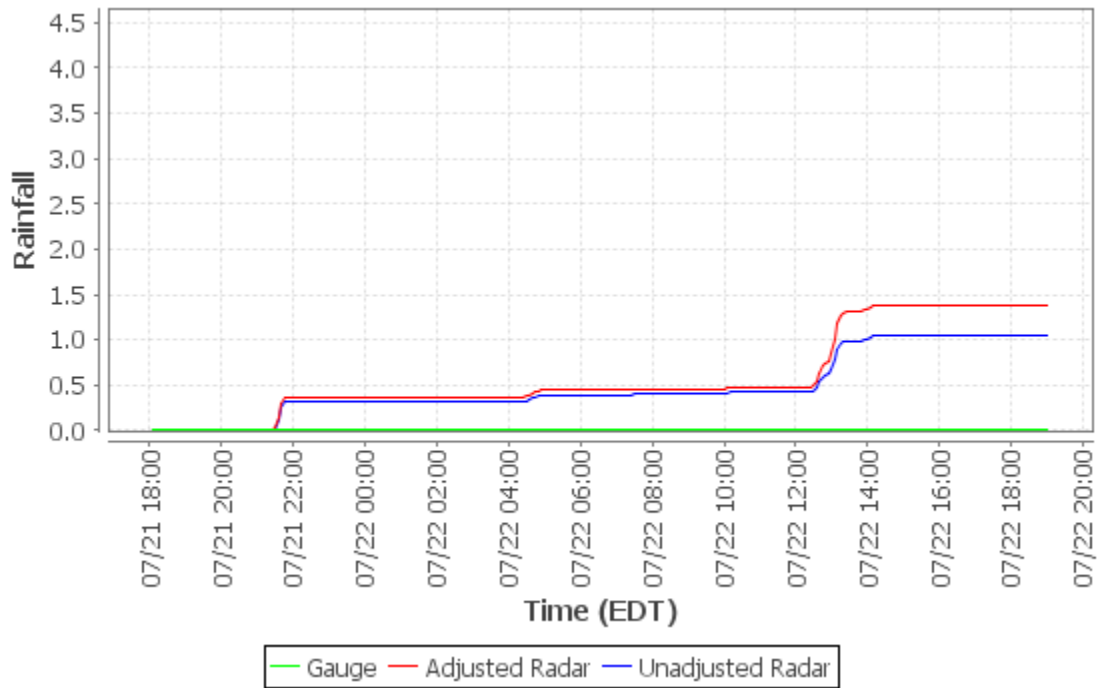
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



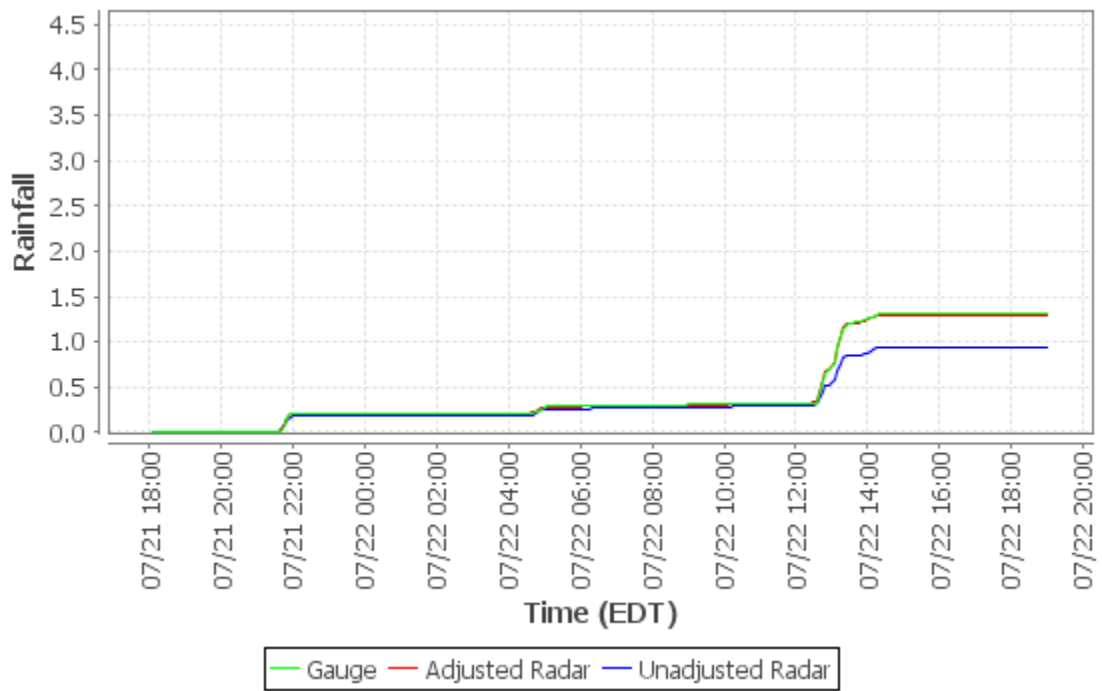
Cumulative Distribution Plot - Upper St. Clair (Loc05)



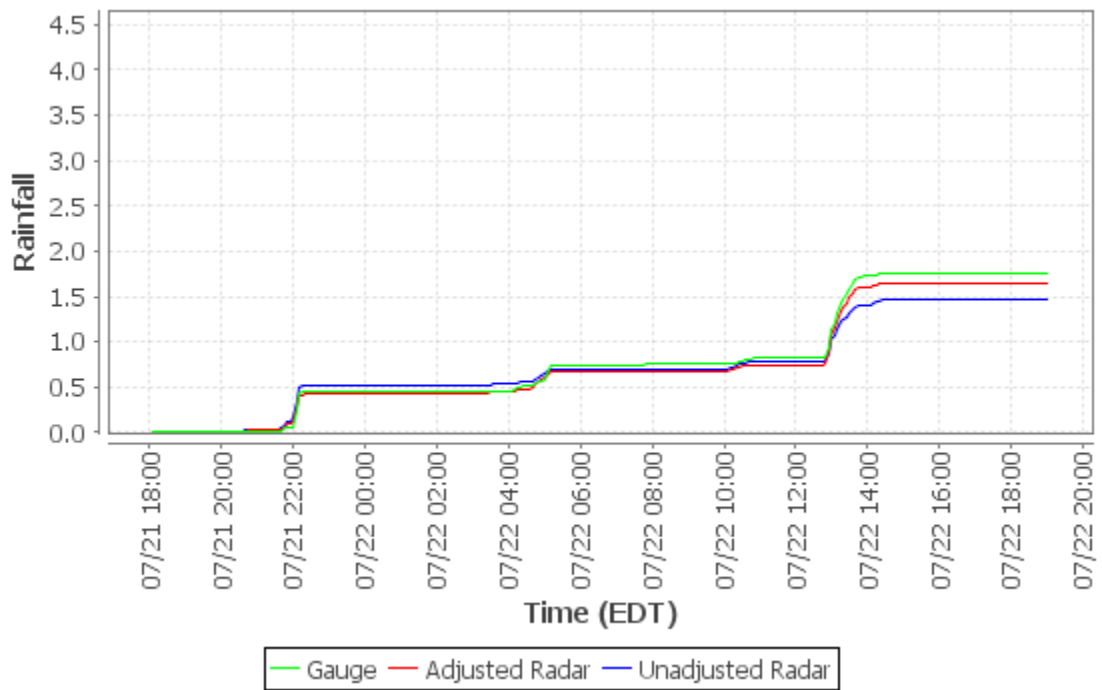
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



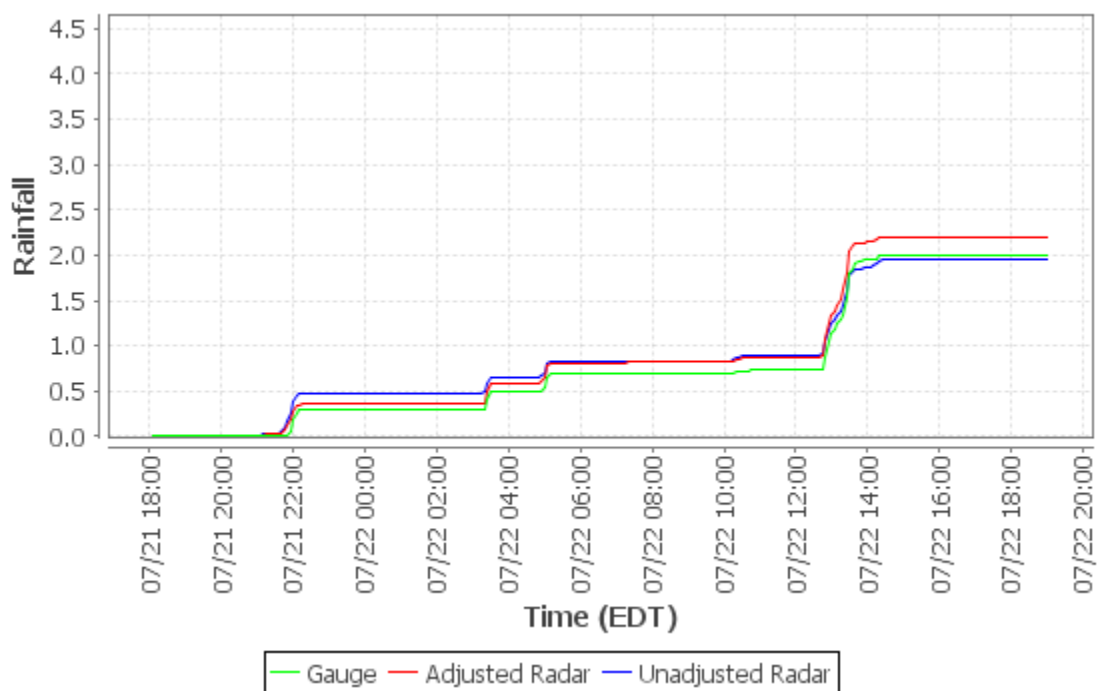
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



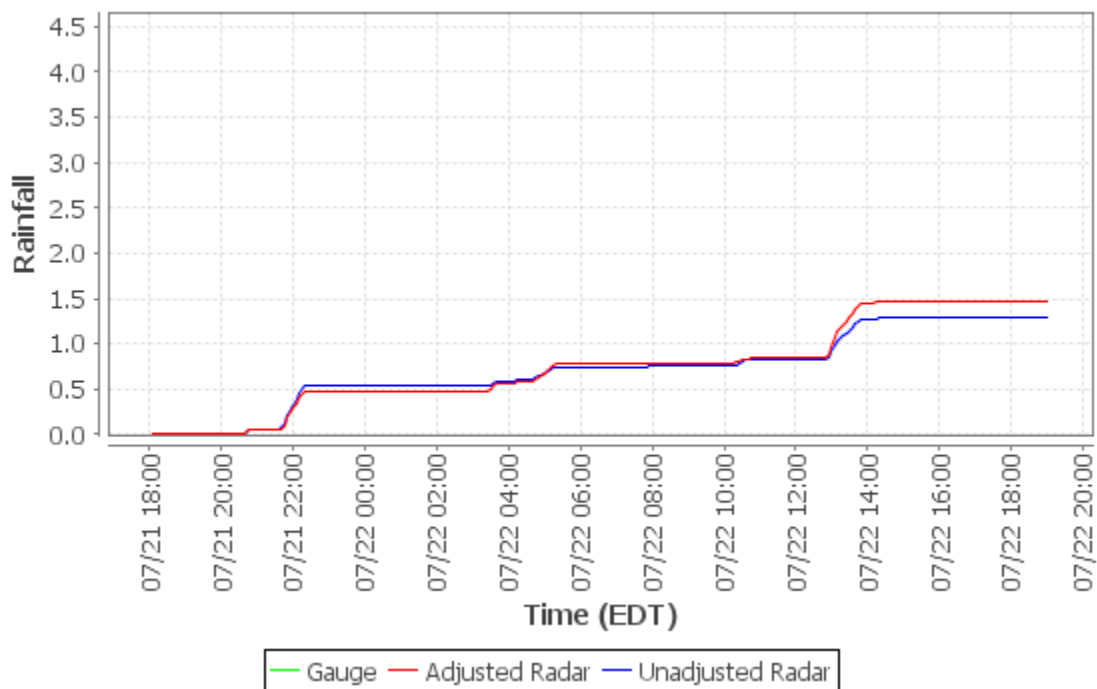
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



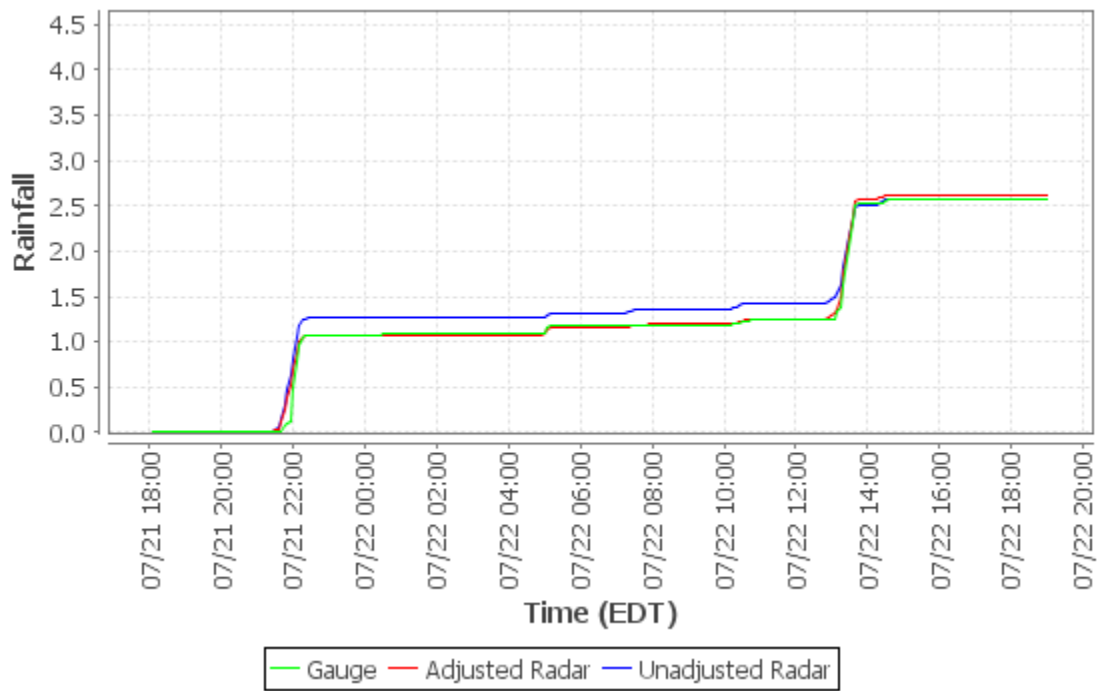
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



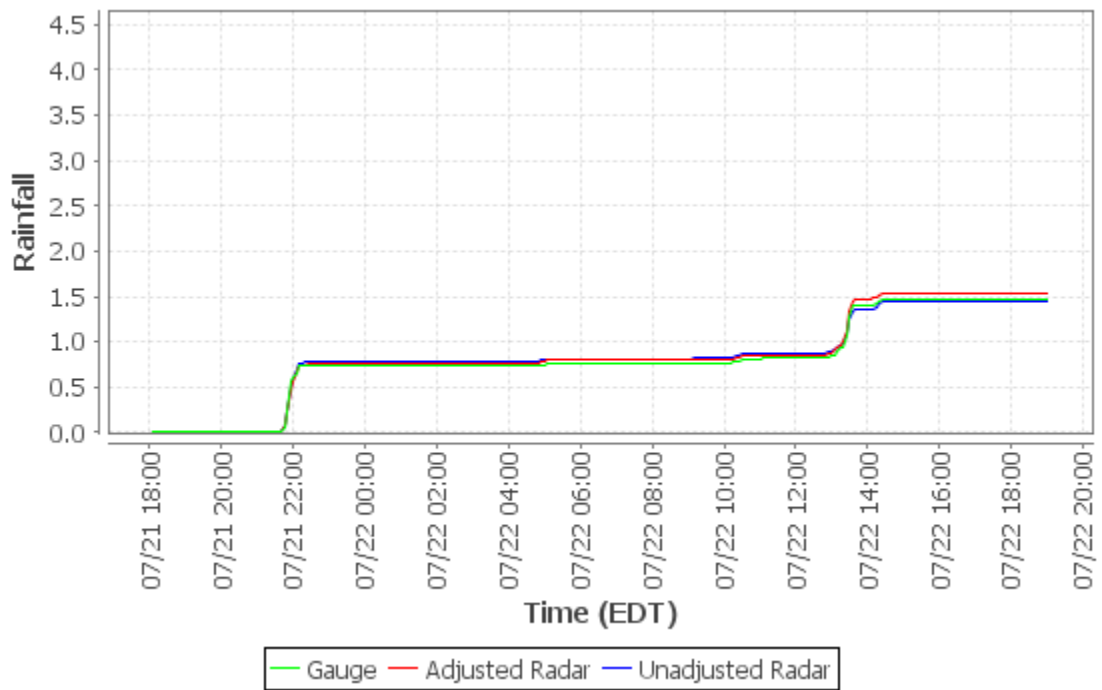
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



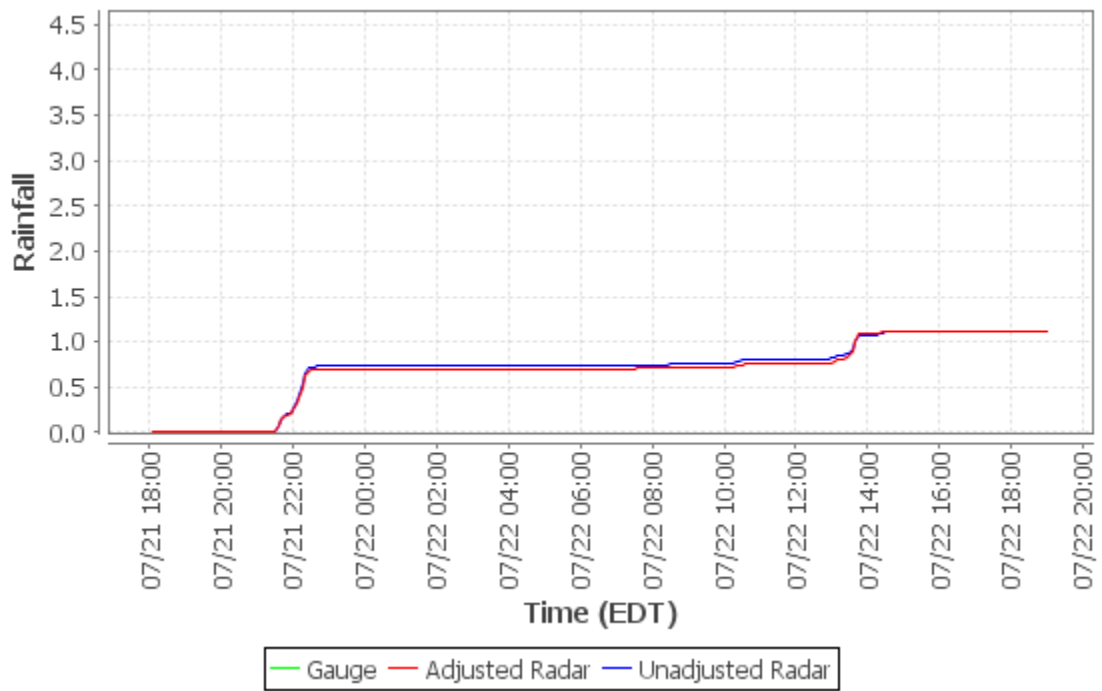
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



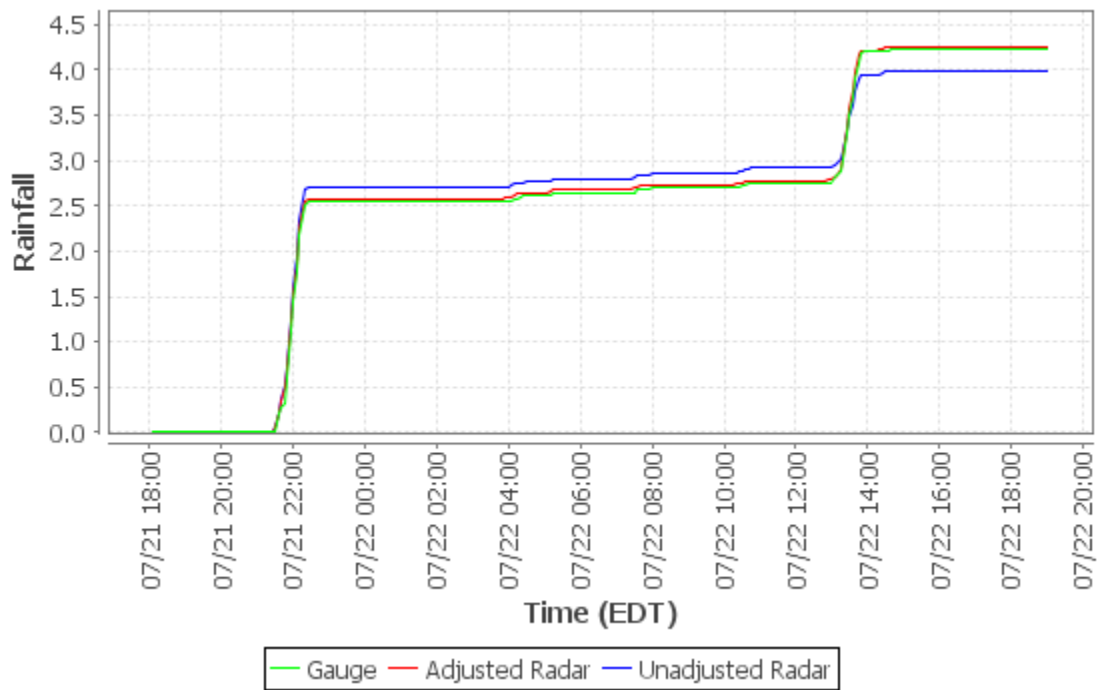
Cumulative Distribution Plot - Baldwin (Loc12)



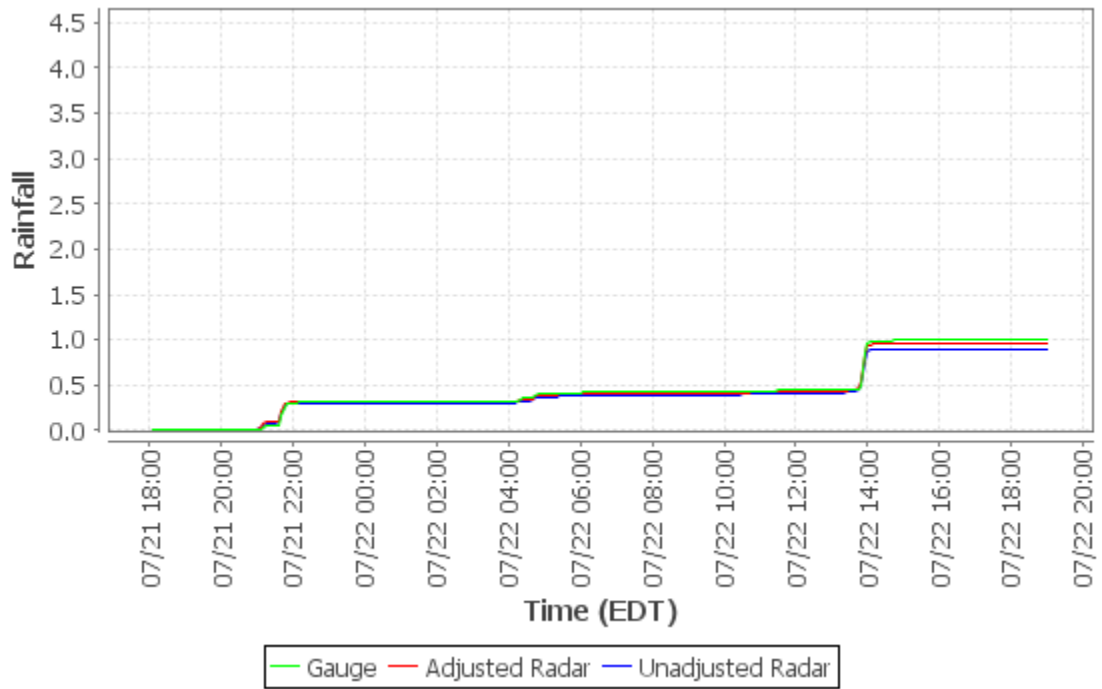
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



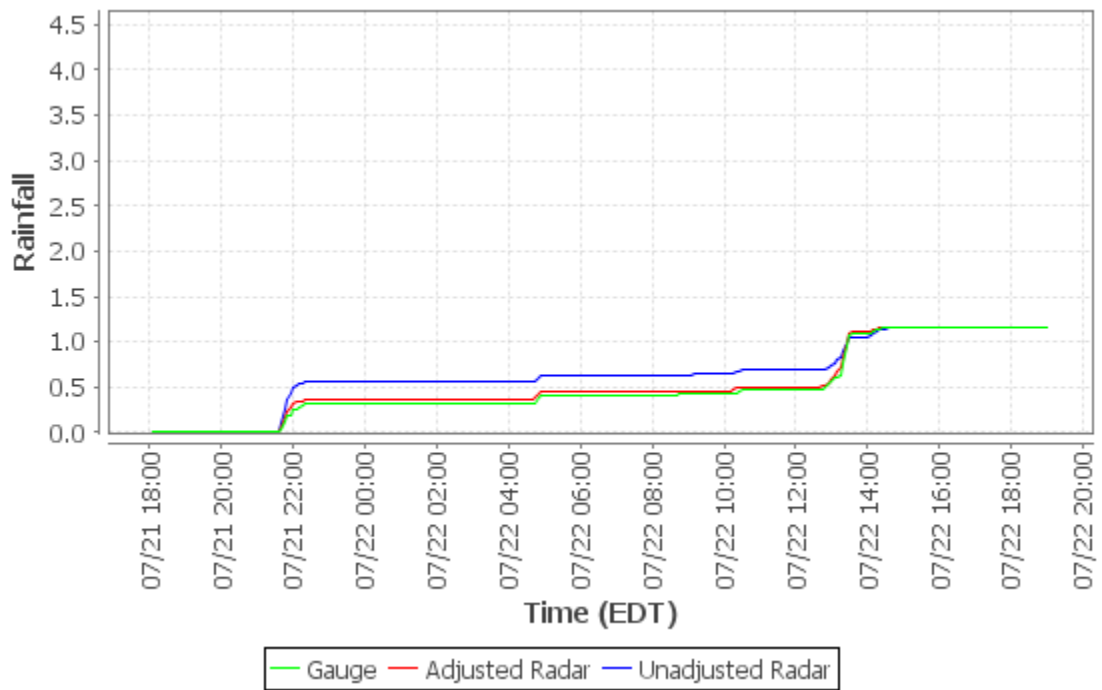
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



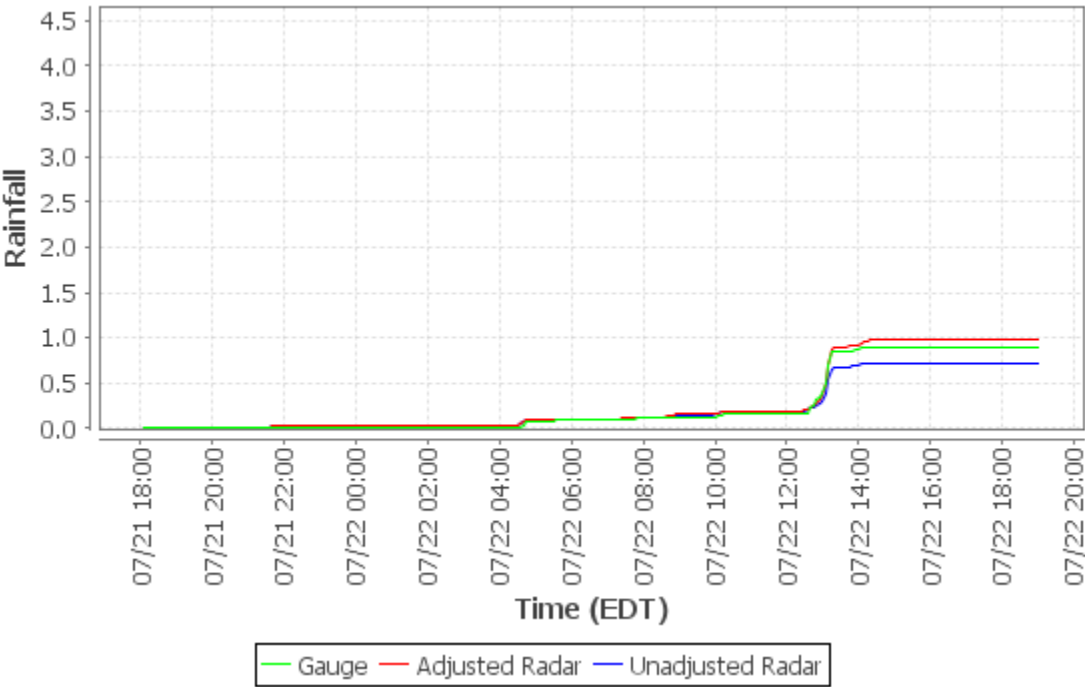
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



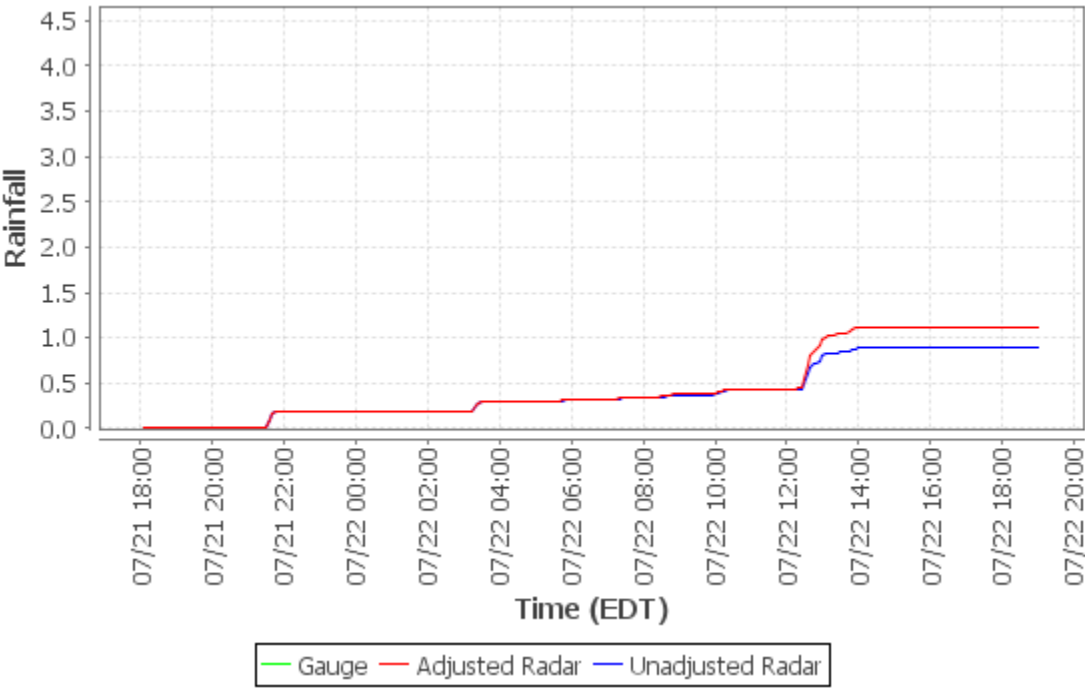
Cumulative Distribution Plot - Castle Shannon (Loc16)



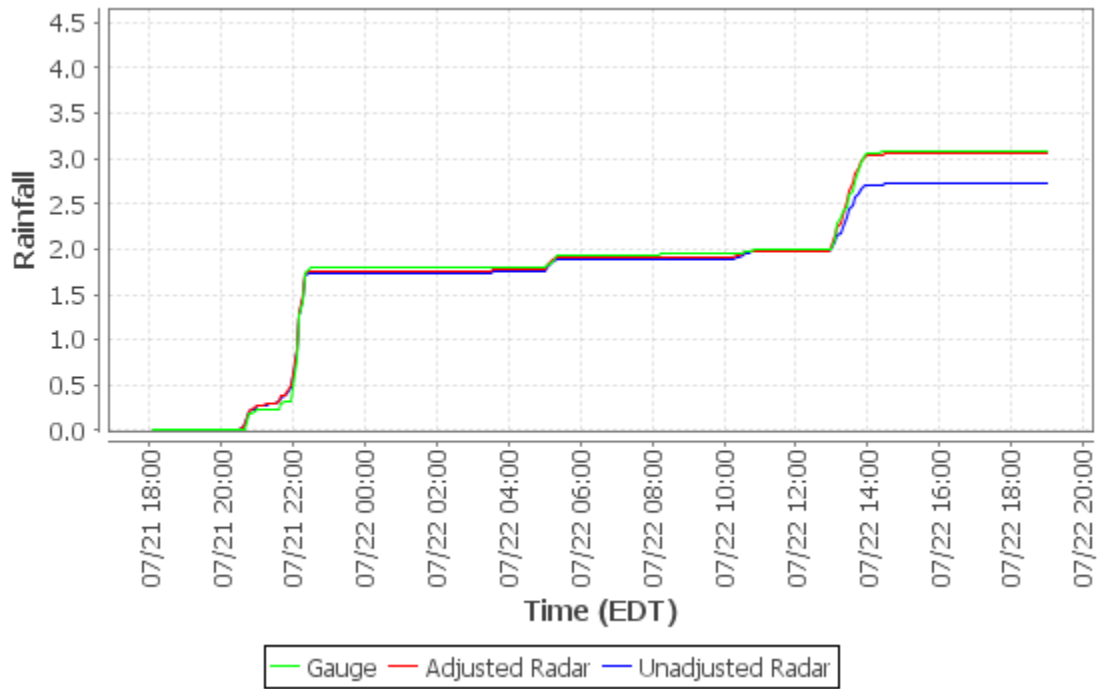
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



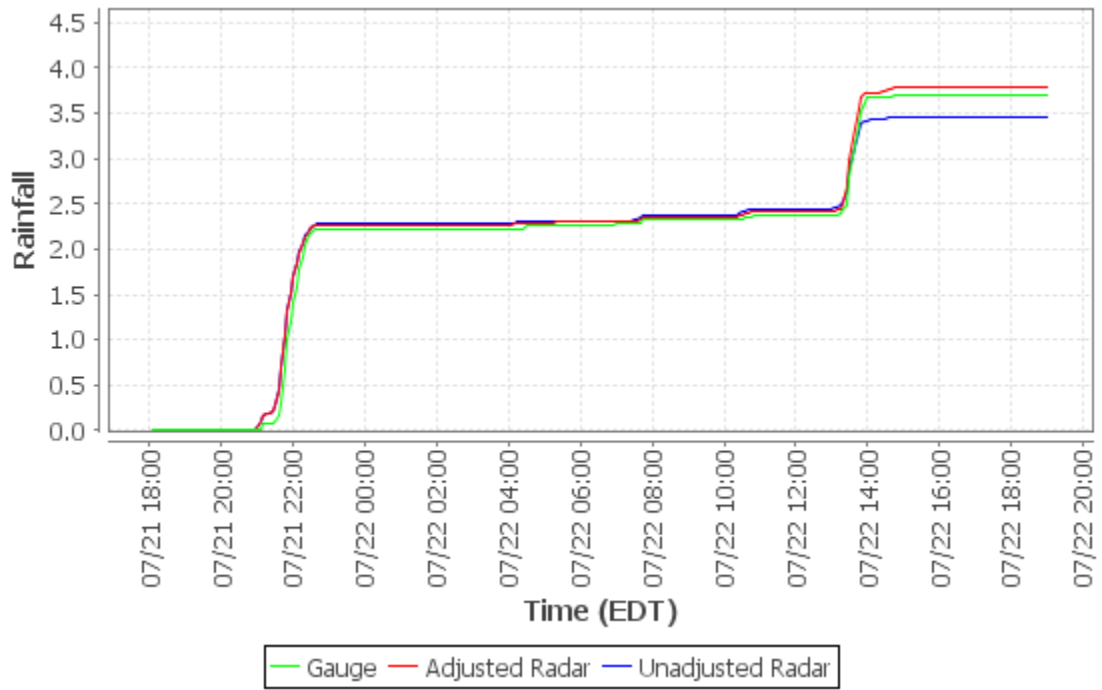
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



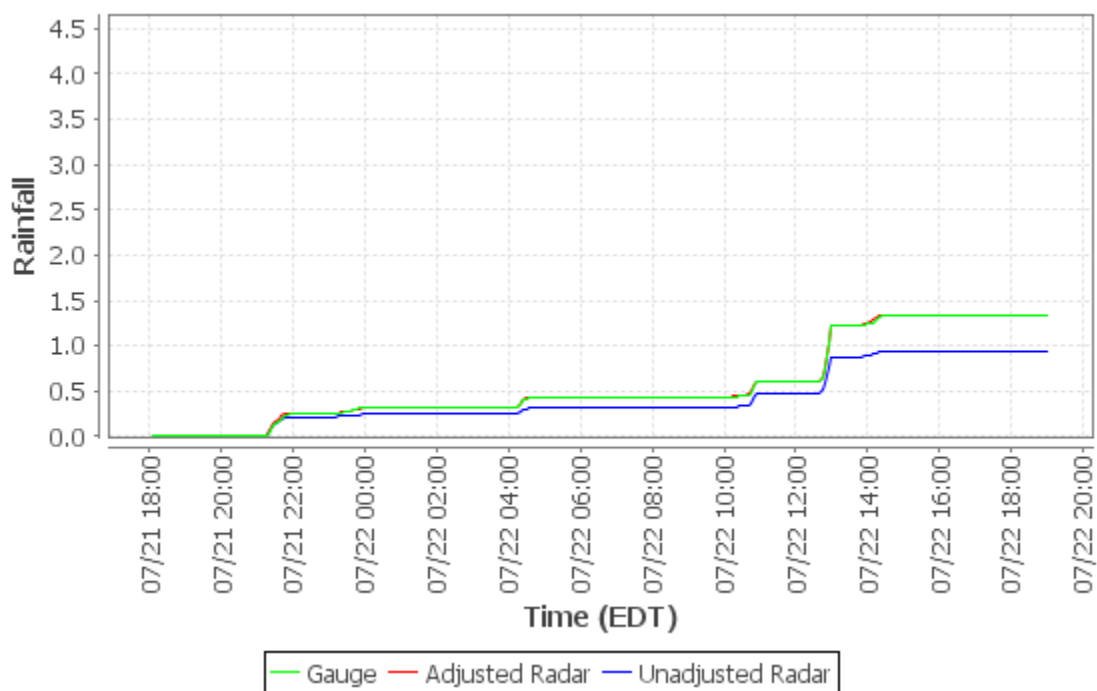
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



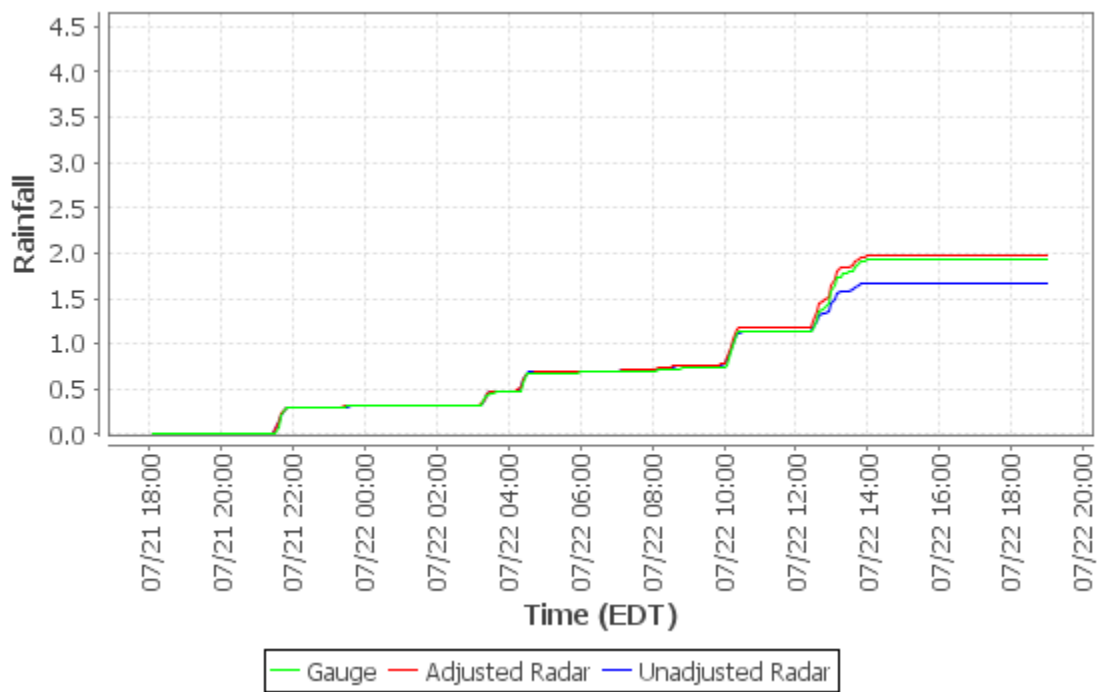
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



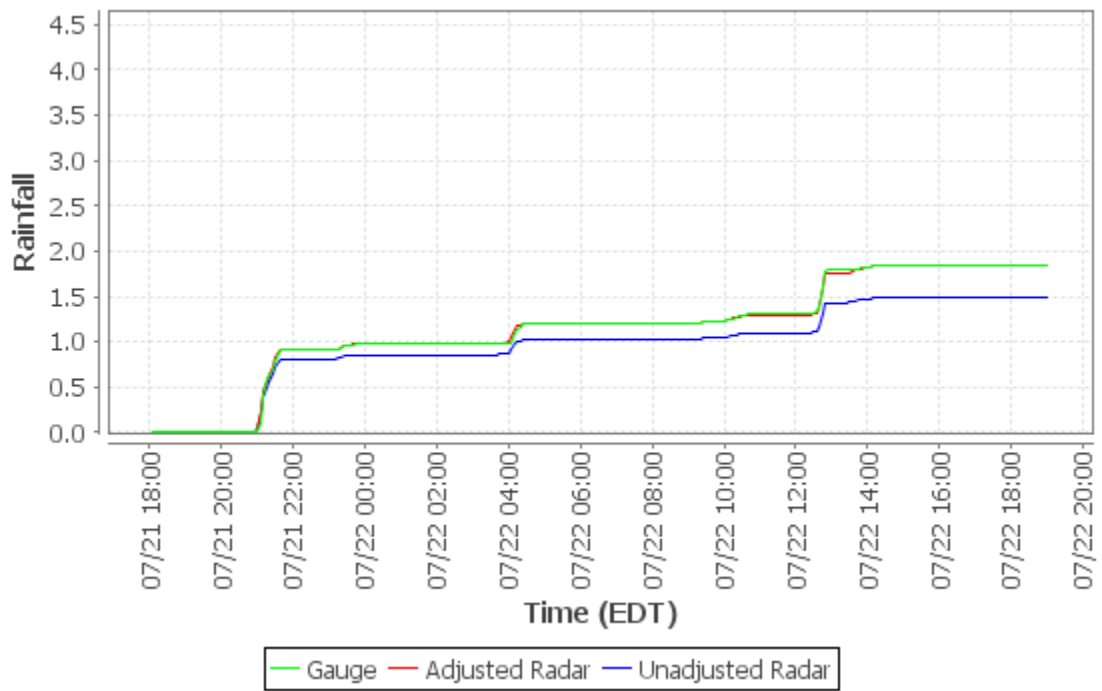
Cumulative Distribution Plot - Moon TWP (Loc21)



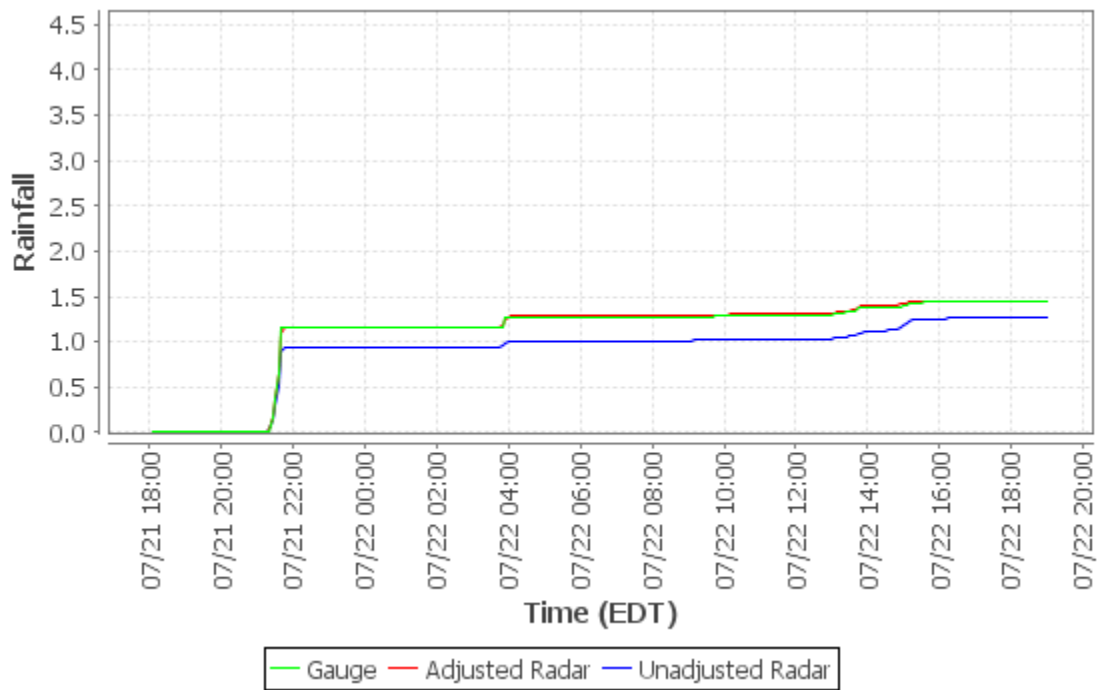
Cumulative Distribution Plot - North Fayette TWP (Loc22)



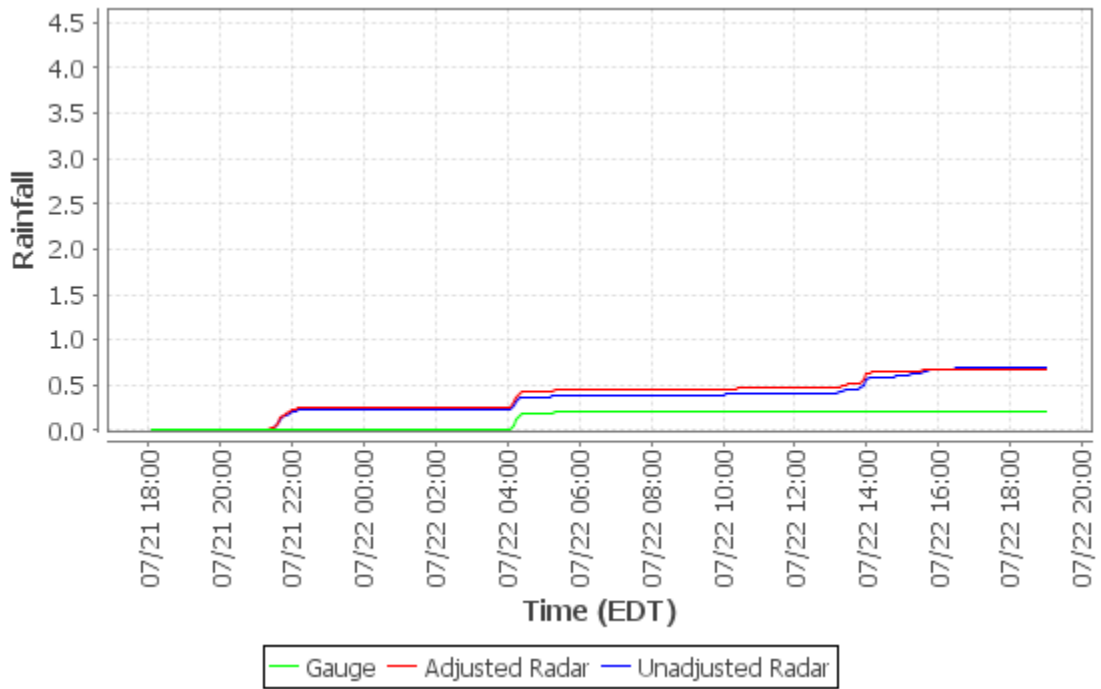
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



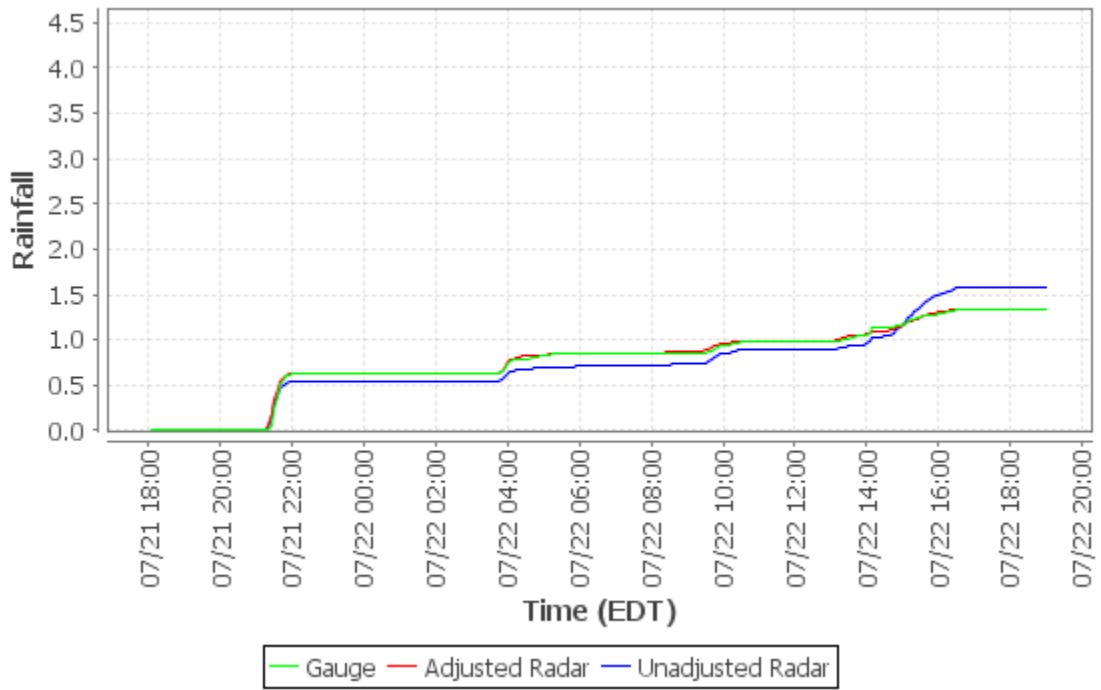
Cumulative Distribution Plot - Jefferson Hills (Loc24)



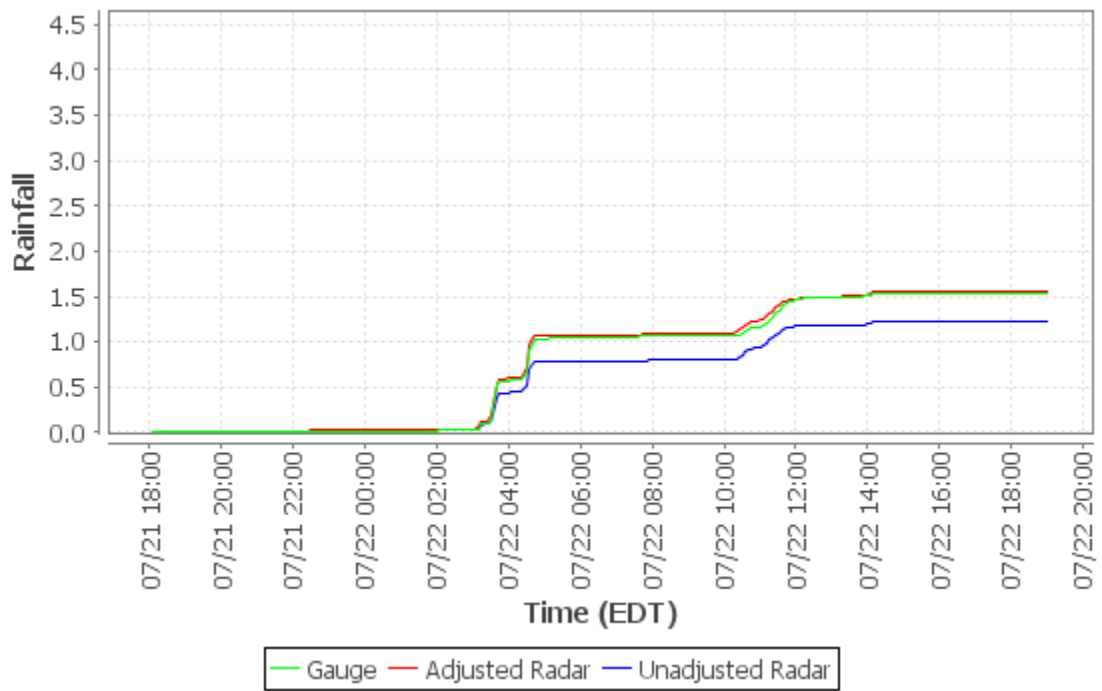
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



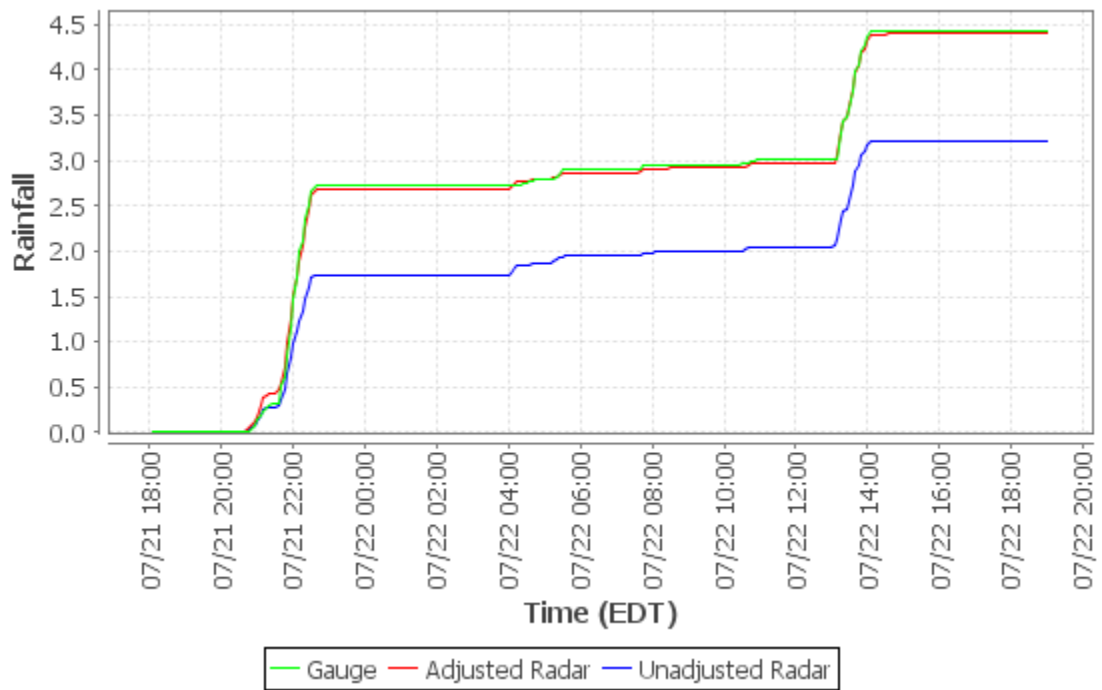
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



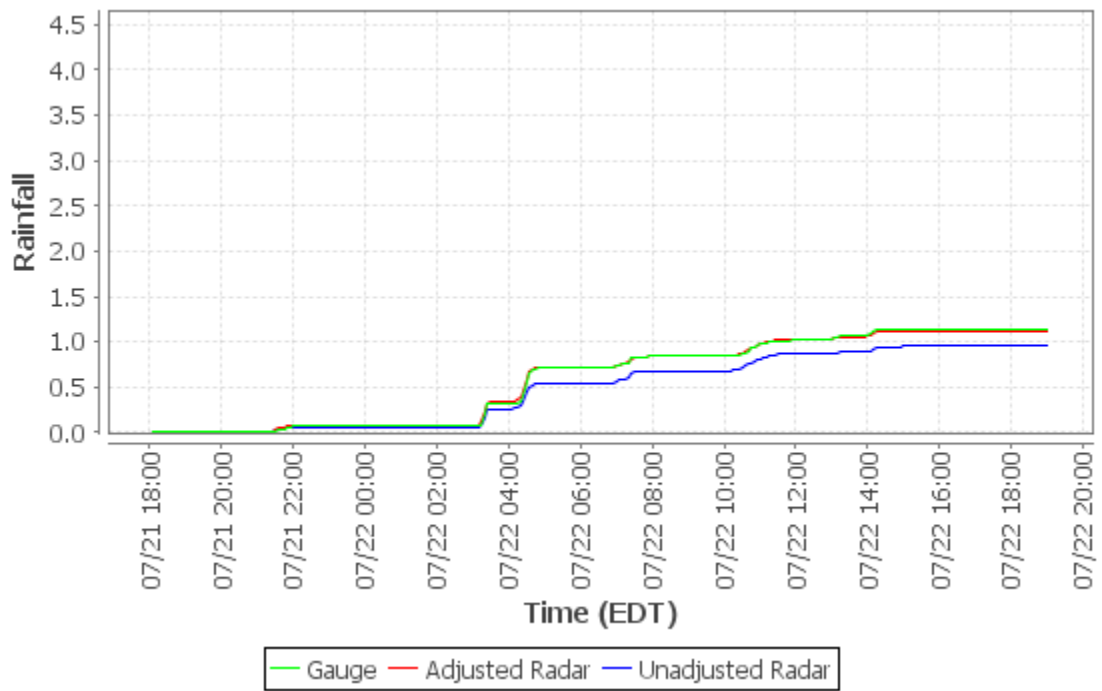
Cumulative Distribution Plot - Marshall TWP (Loc27)



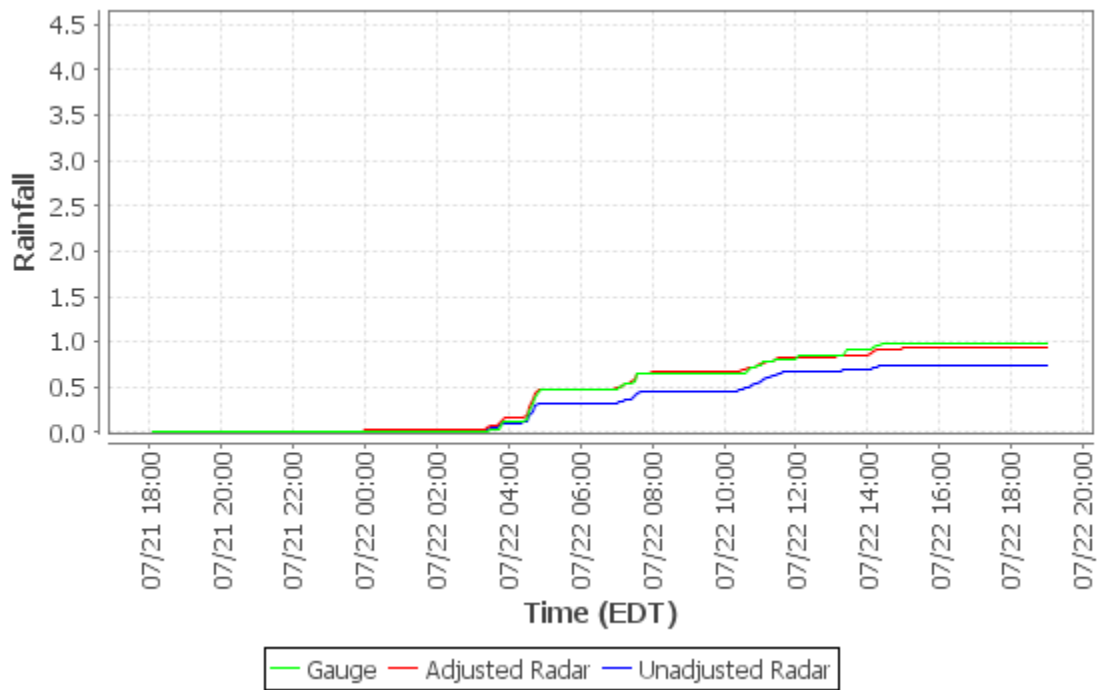
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



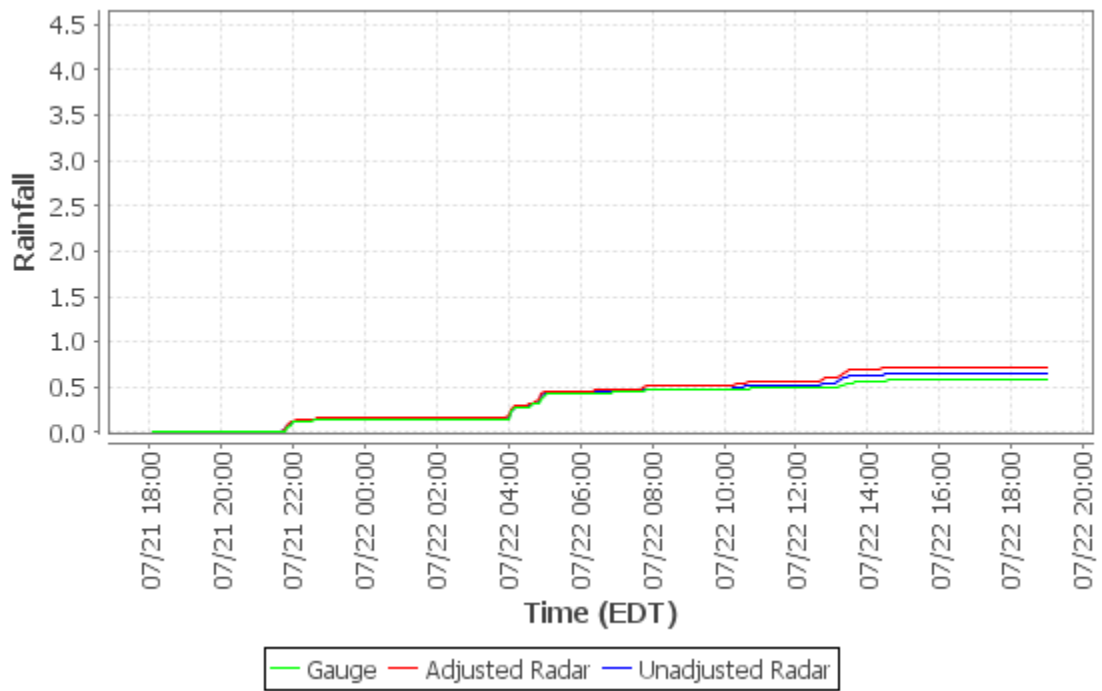
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



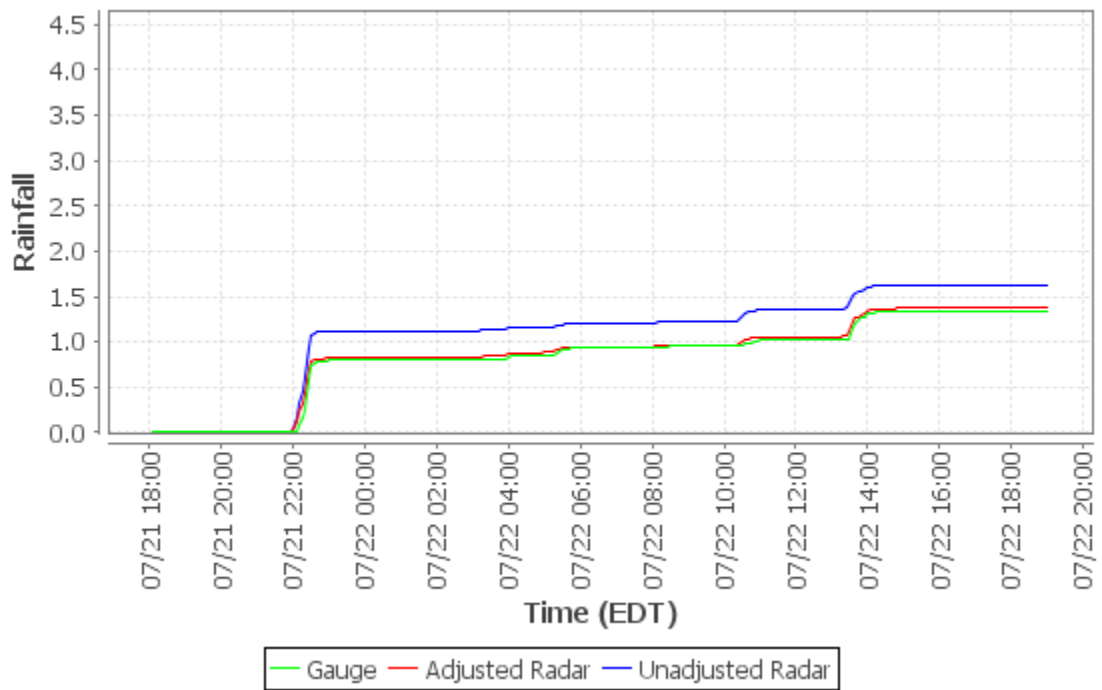
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



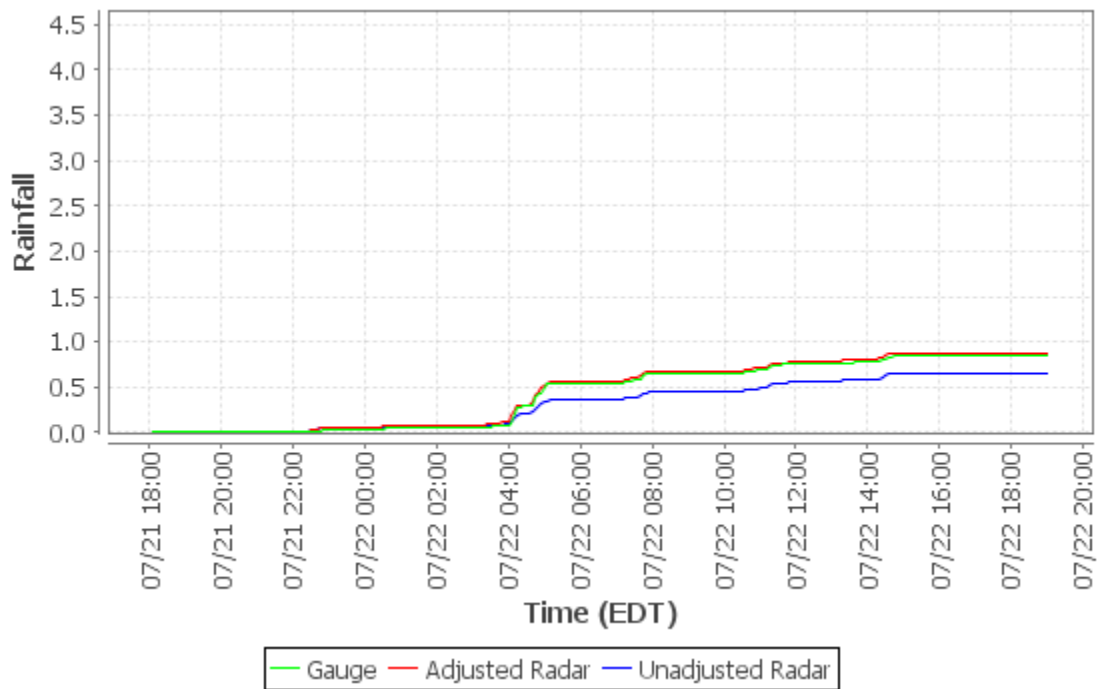
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



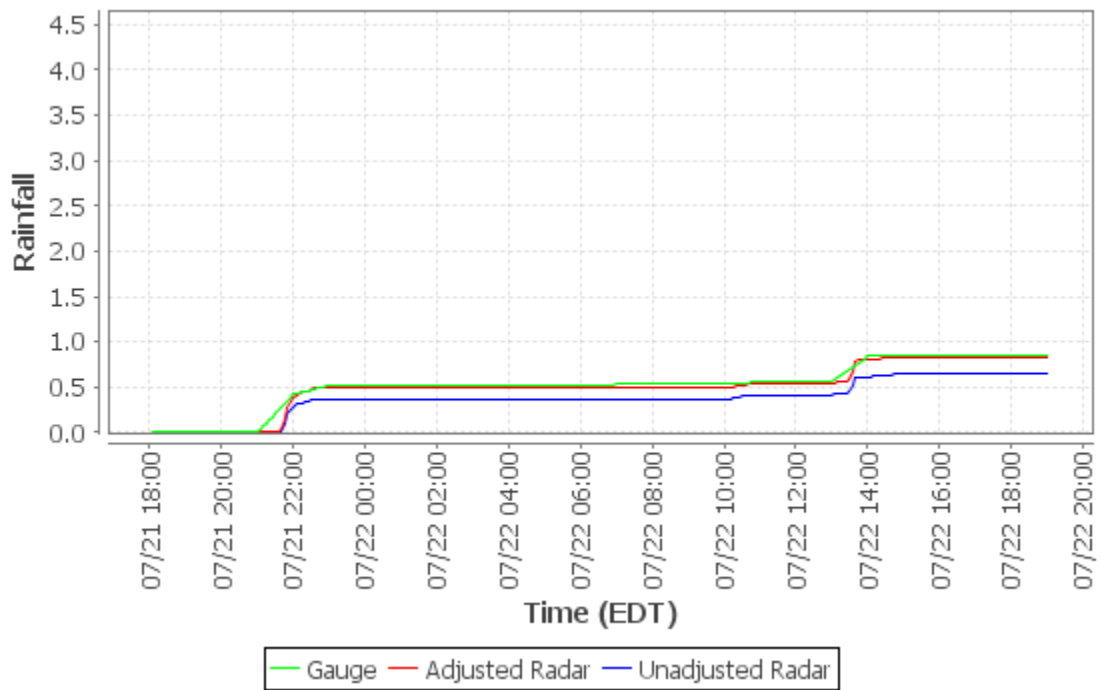
Cumulative Distribution Plot - Arnold (Loc32)



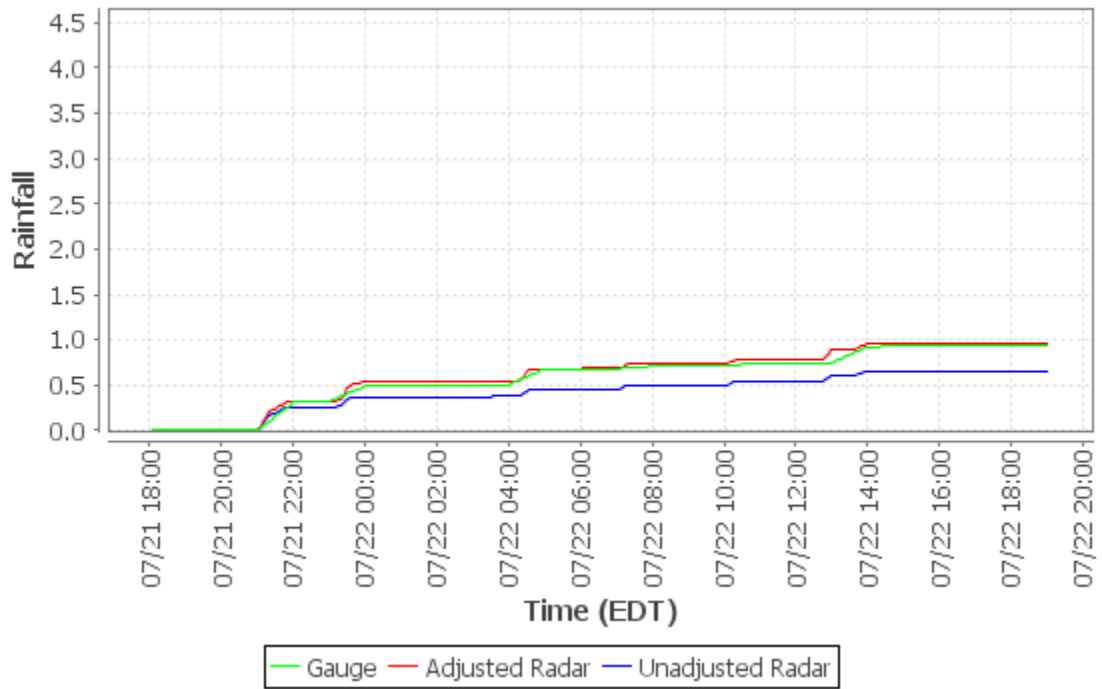
Cumulative Distribution Plot - Richland TWP (Loc33)



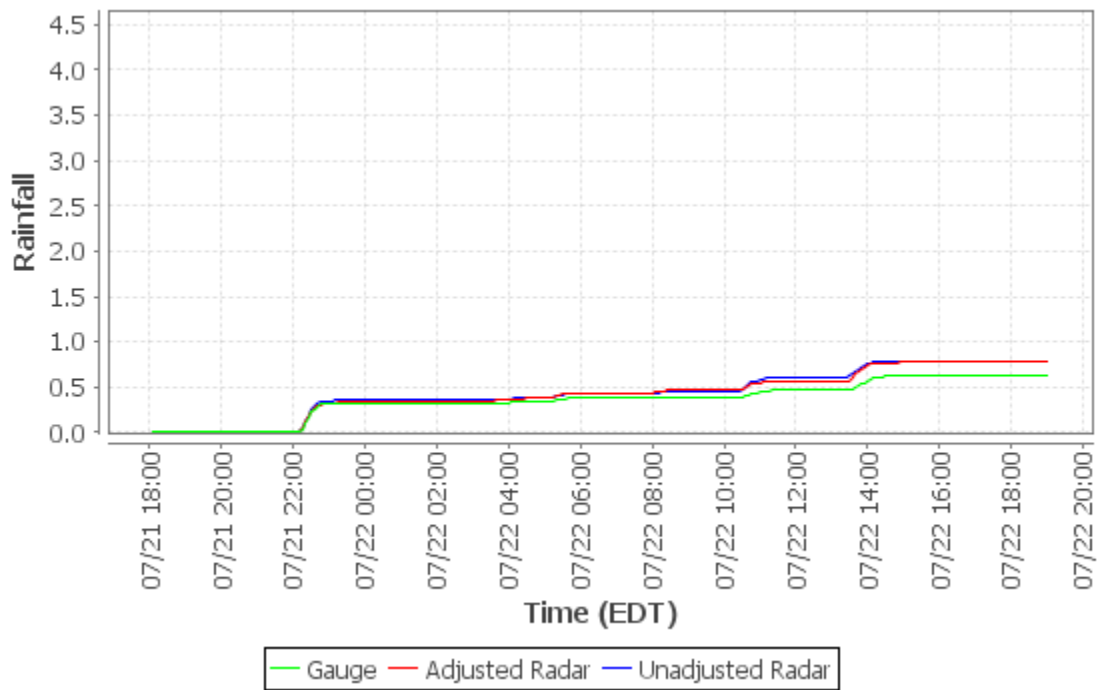
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



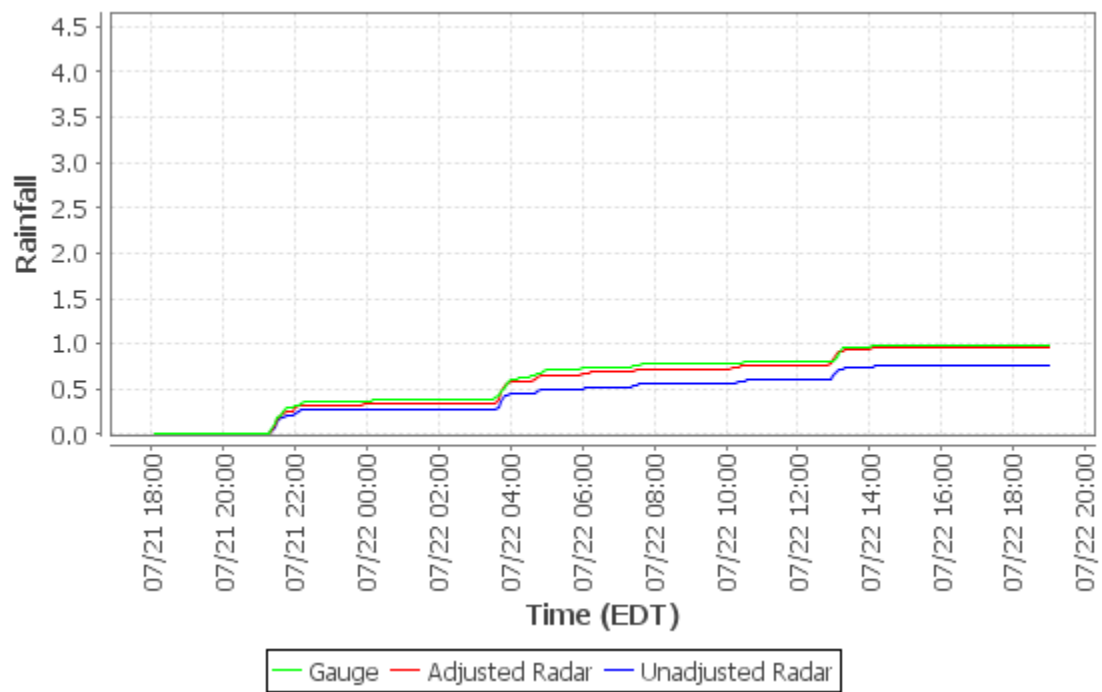
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)

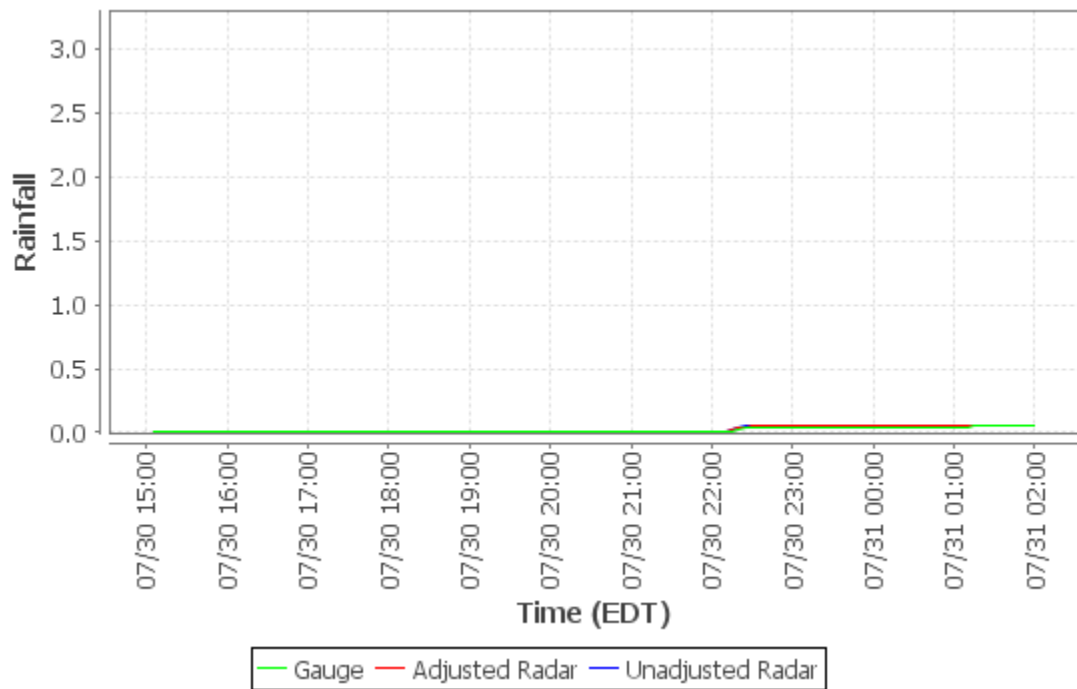


**Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth
(03085734)**

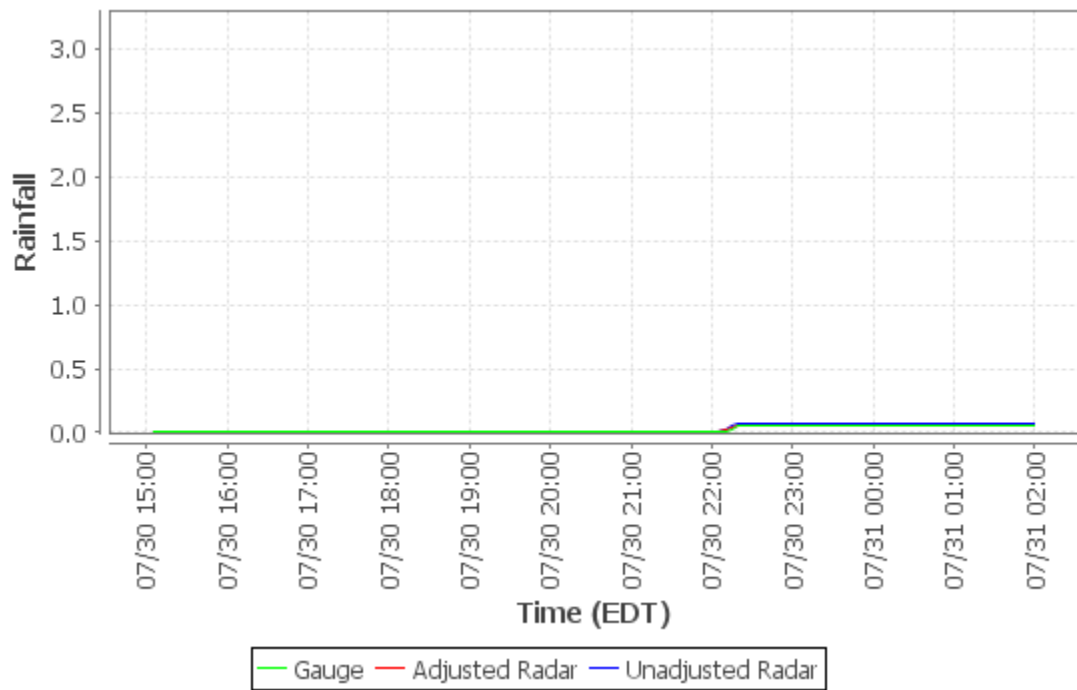


Appendix I - Event 7 (2019-07-30) CDPs

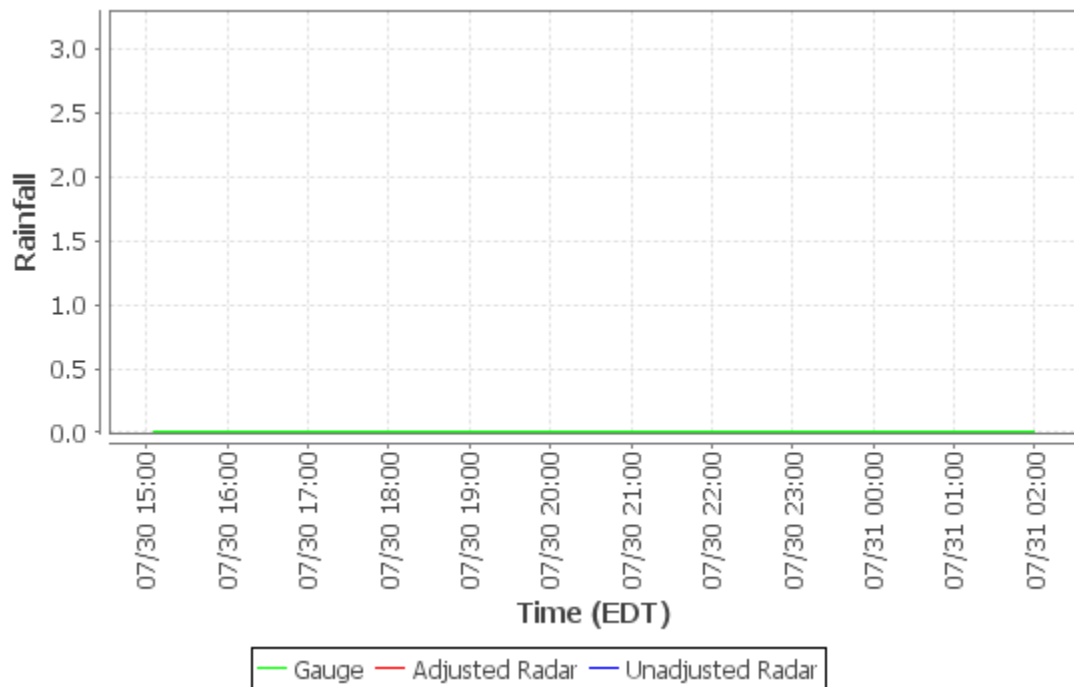
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



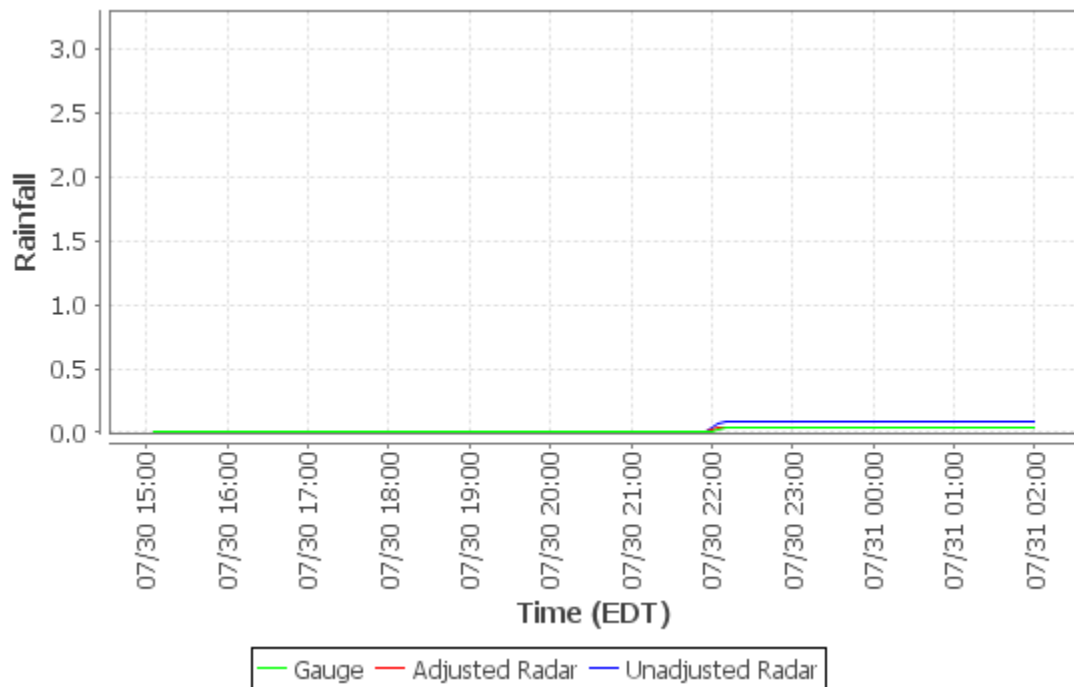
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



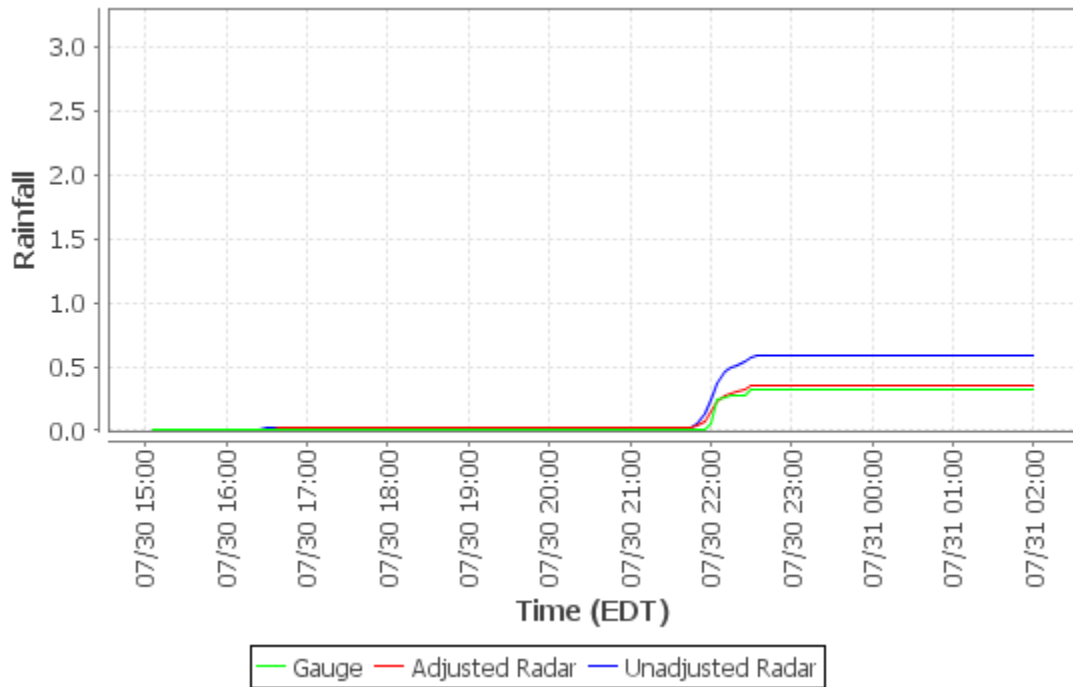
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



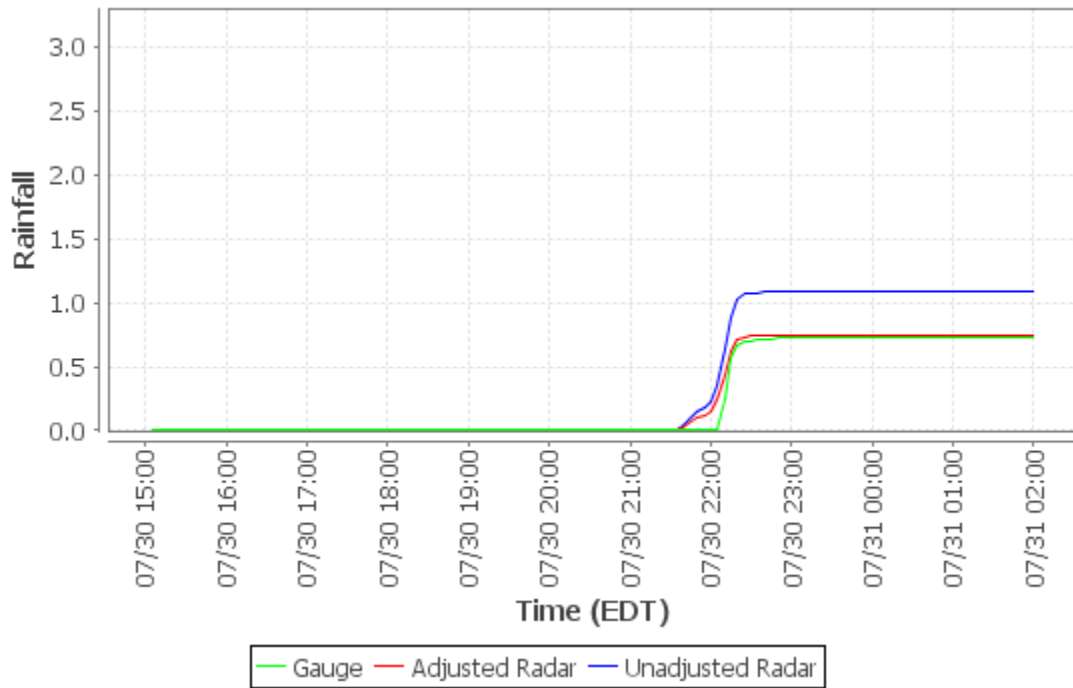
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



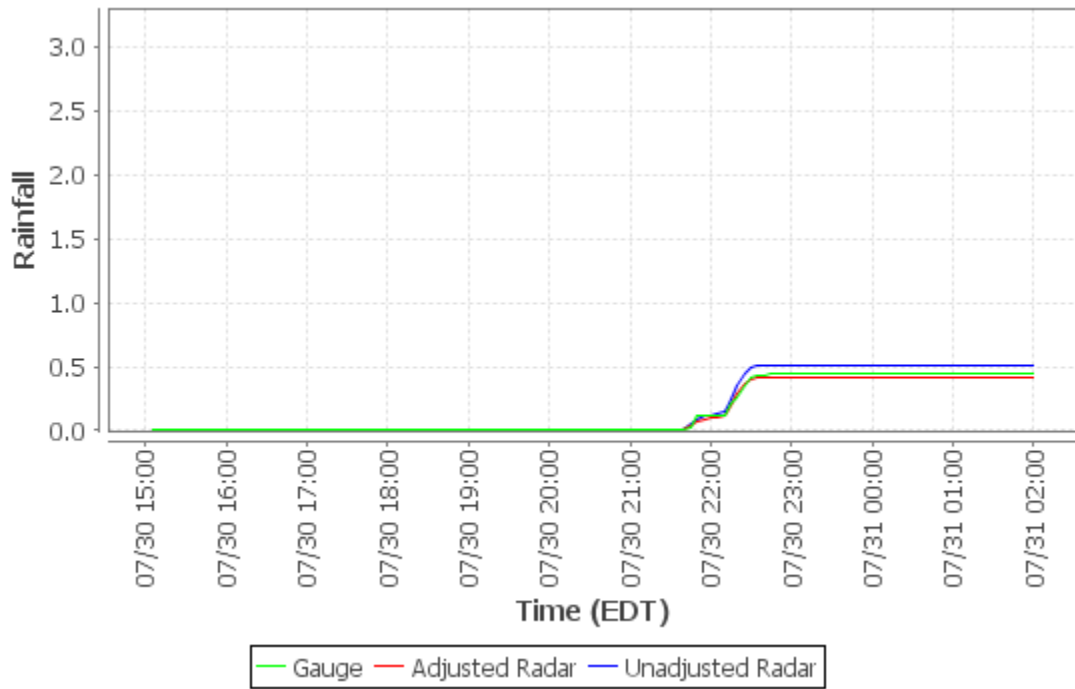
Cumulative Distribution Plot - Upper St. Clair (Loc05)



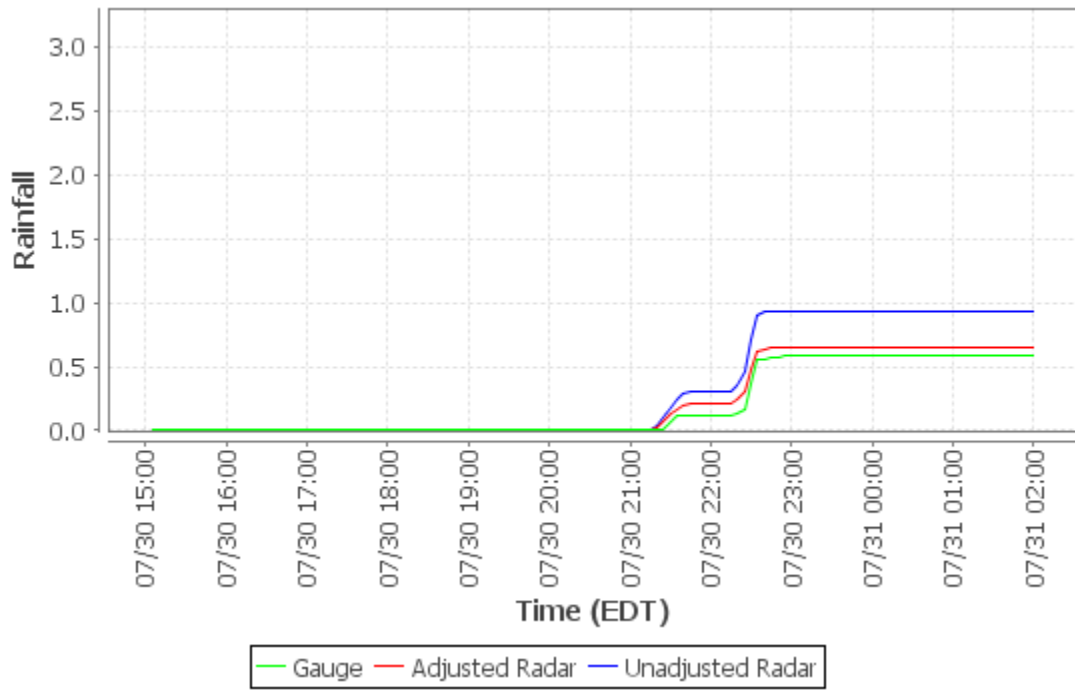
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



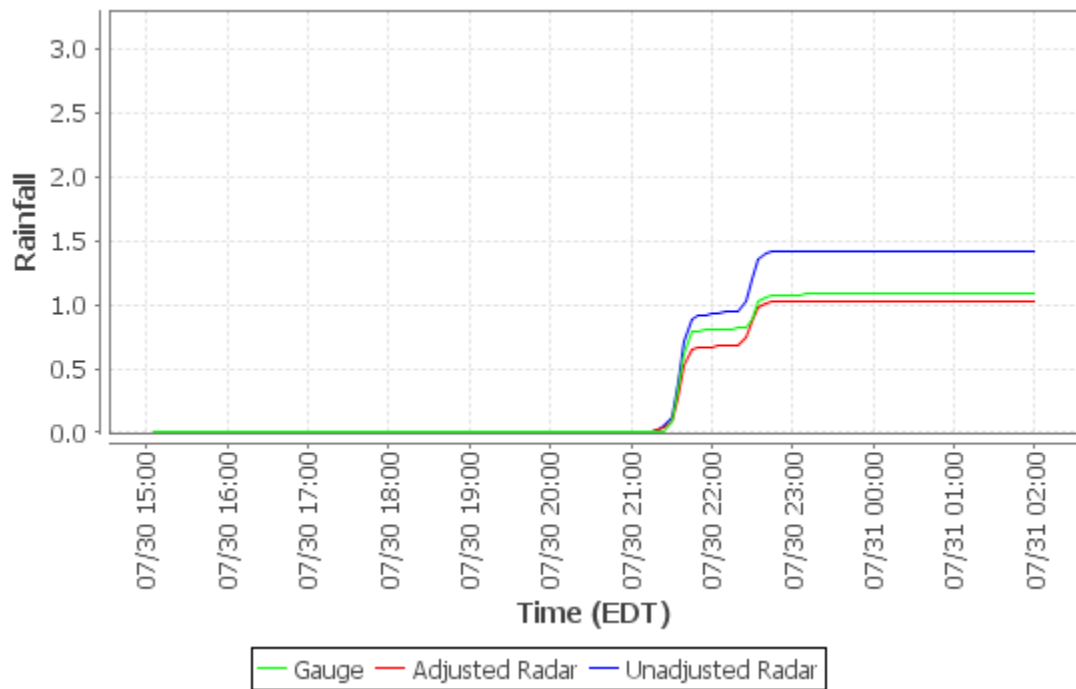
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



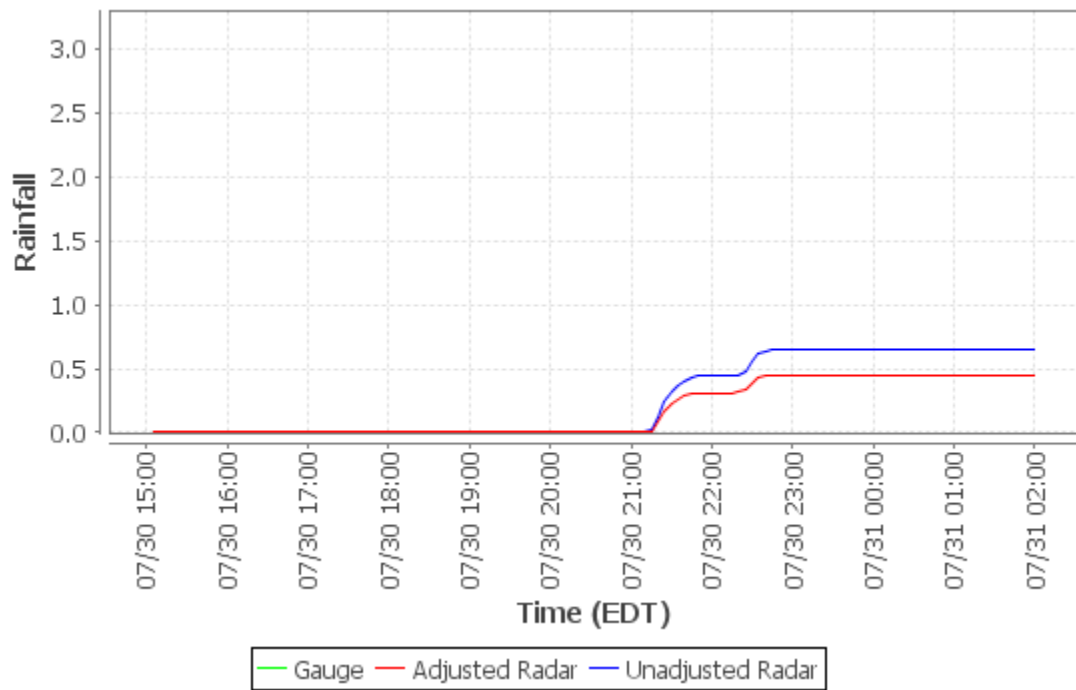
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



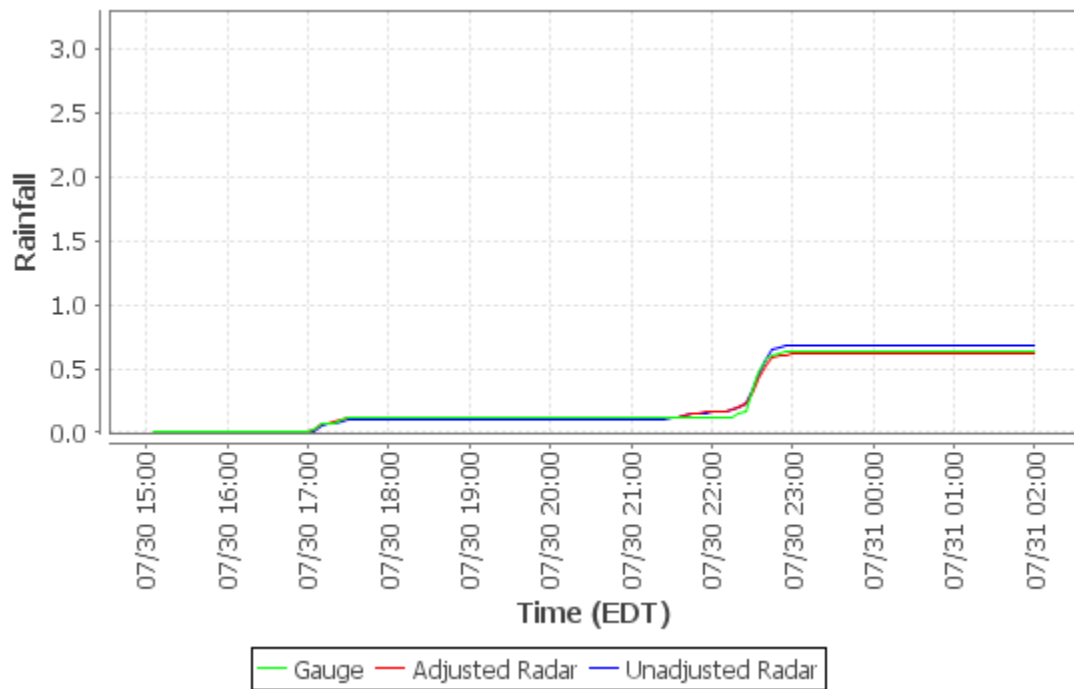
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



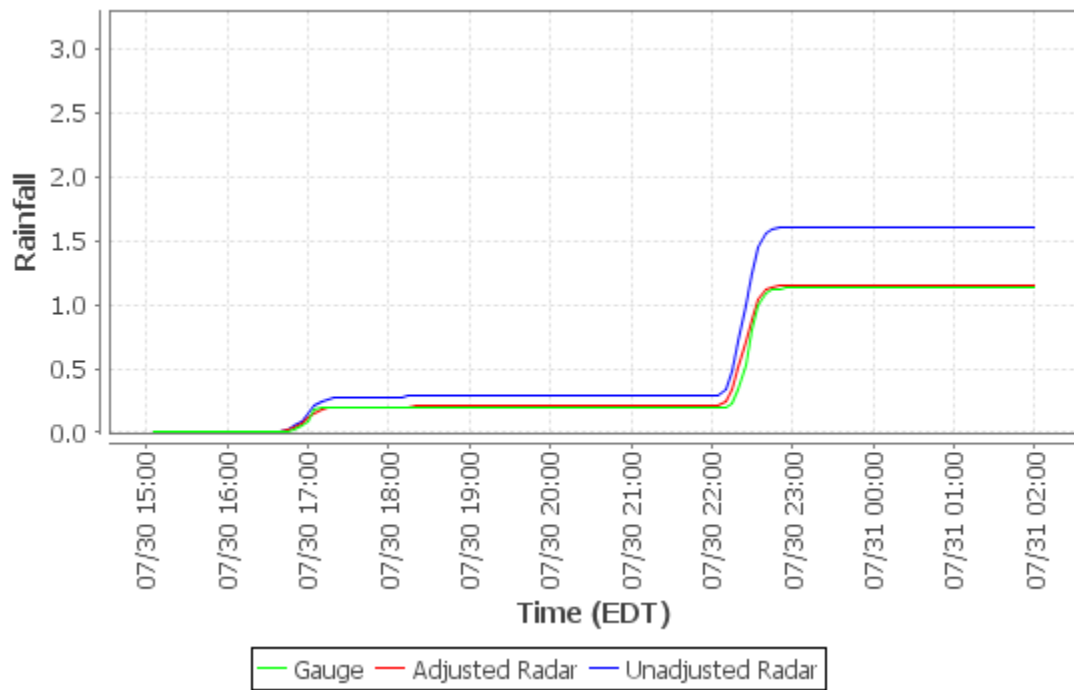
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



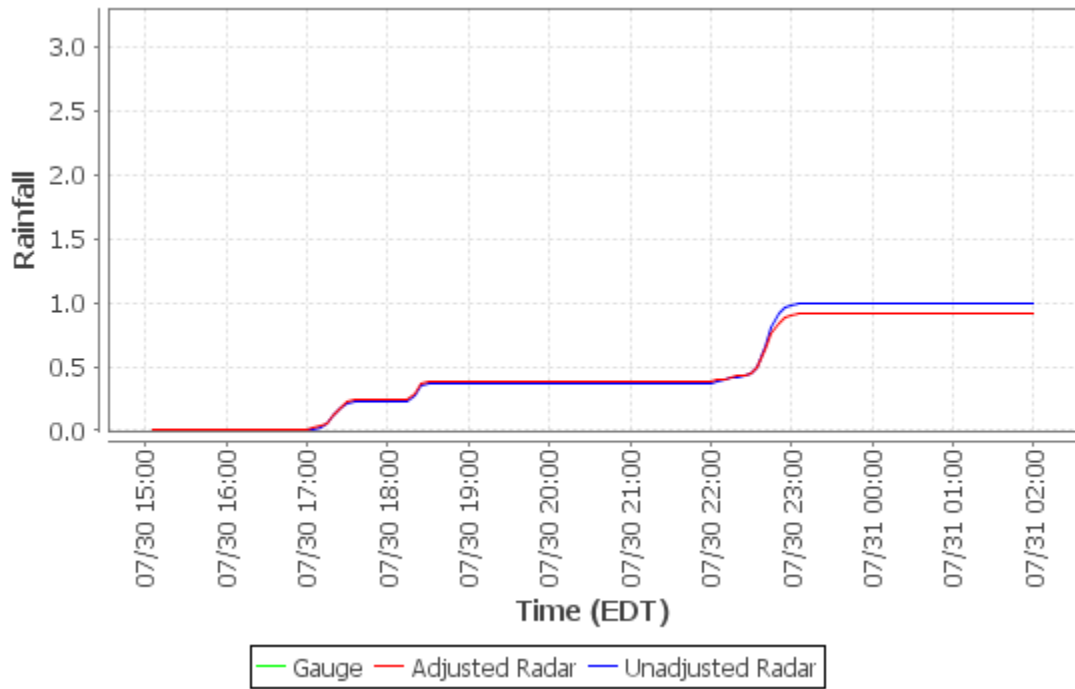
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



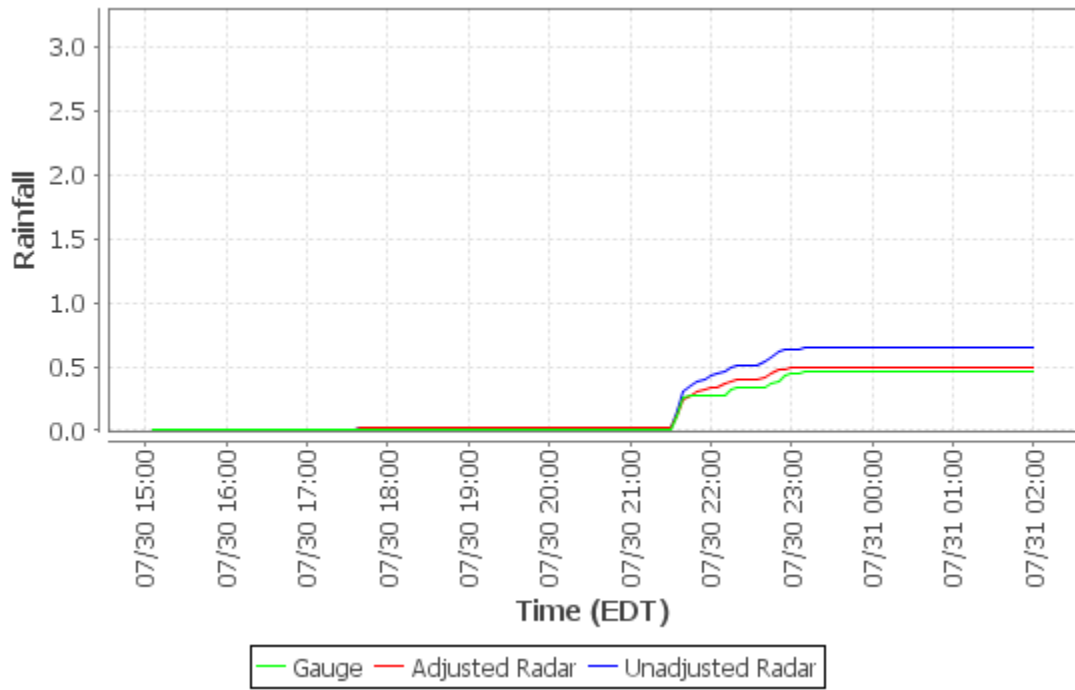
Cumulative Distribution Plot - Baldwin (Loc12)



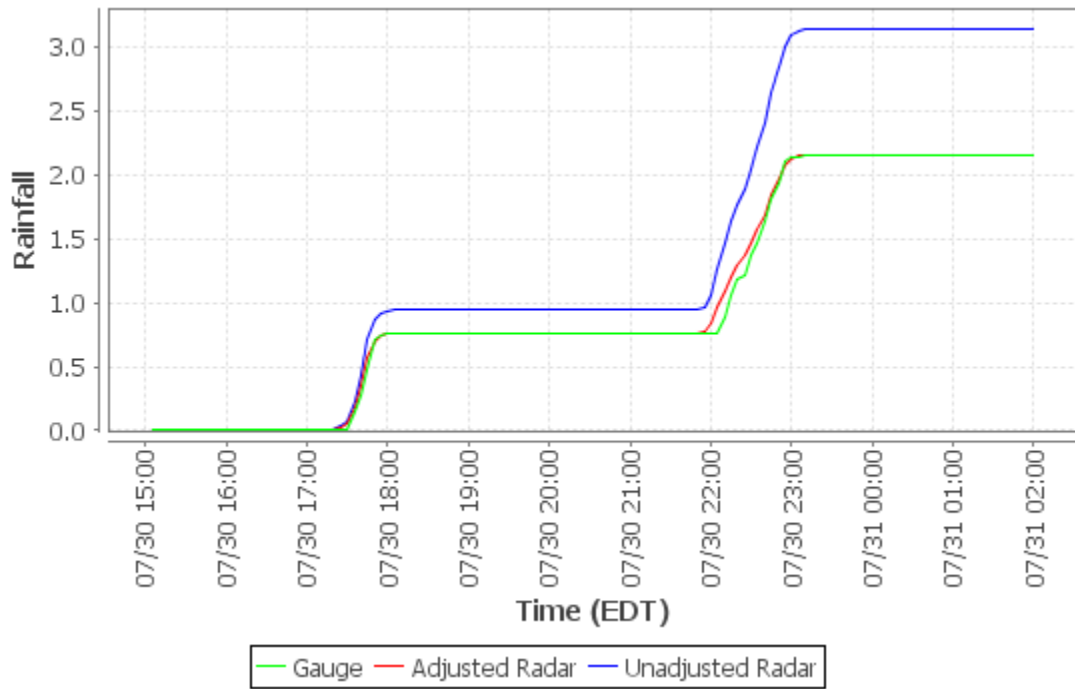
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



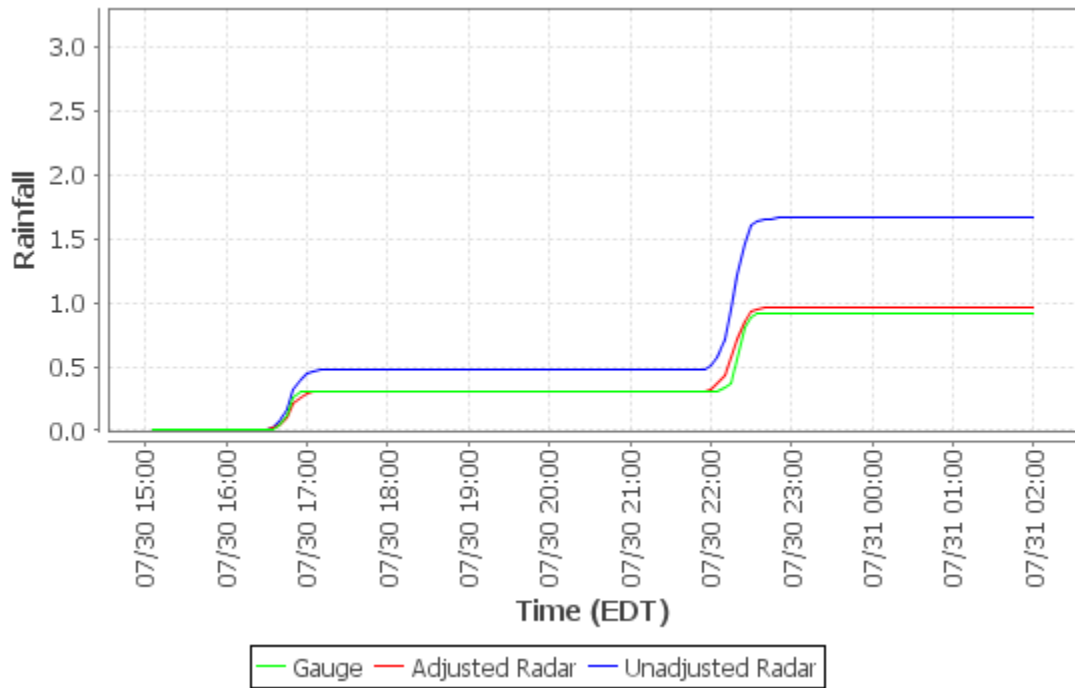
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



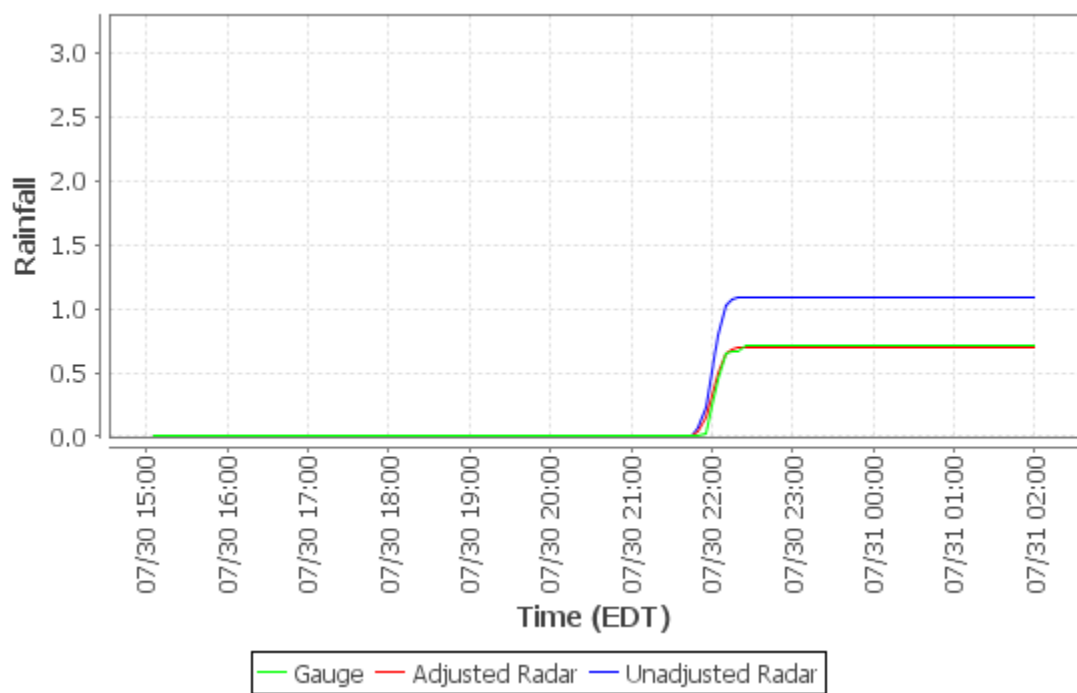
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



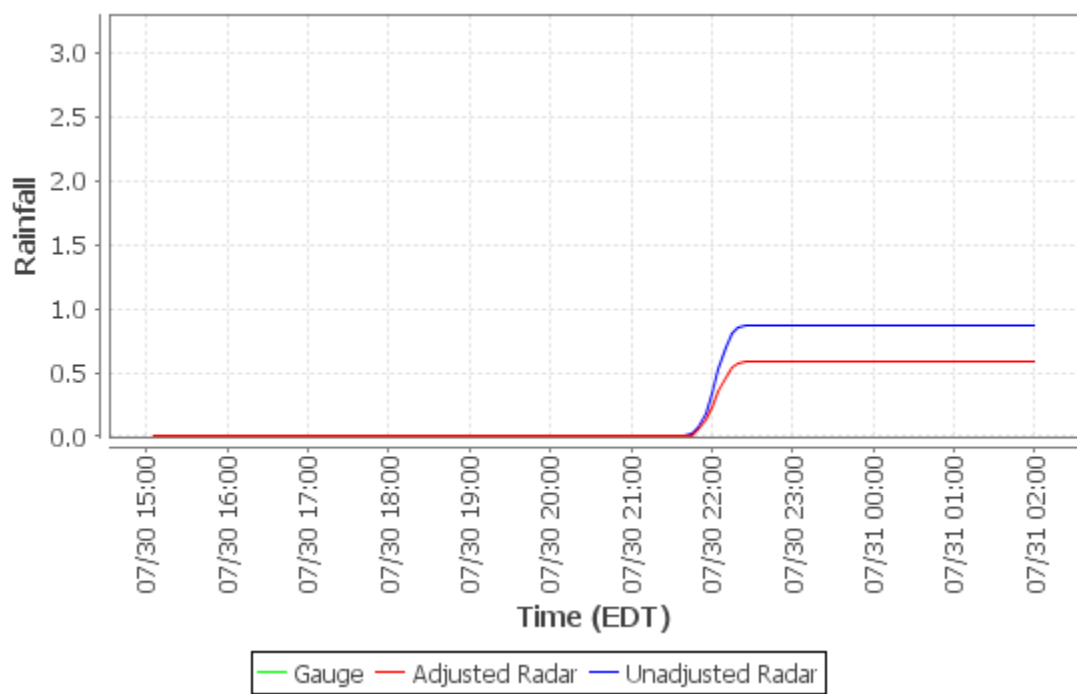
Cumulative Distribution Plot - Castle Shannon (Loc16)



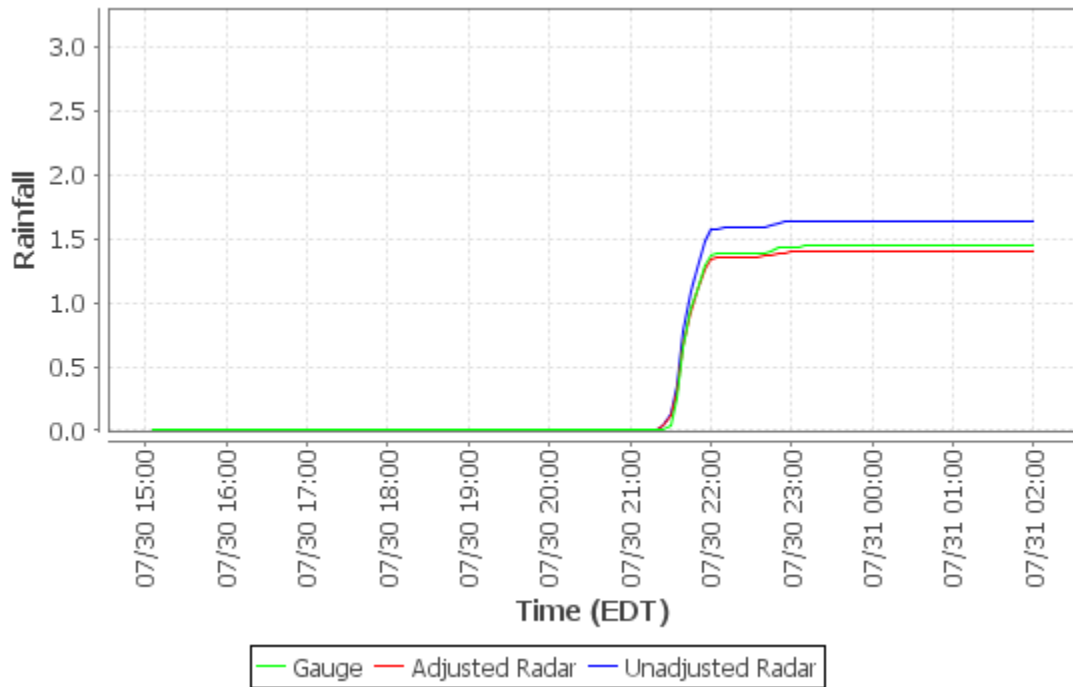
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



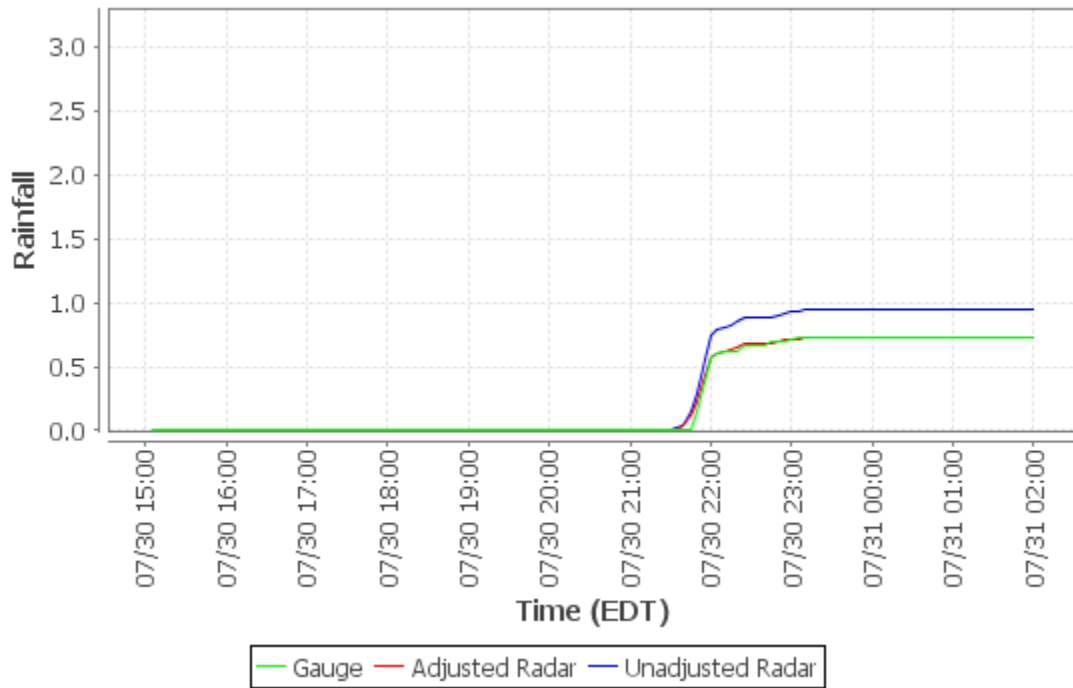
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



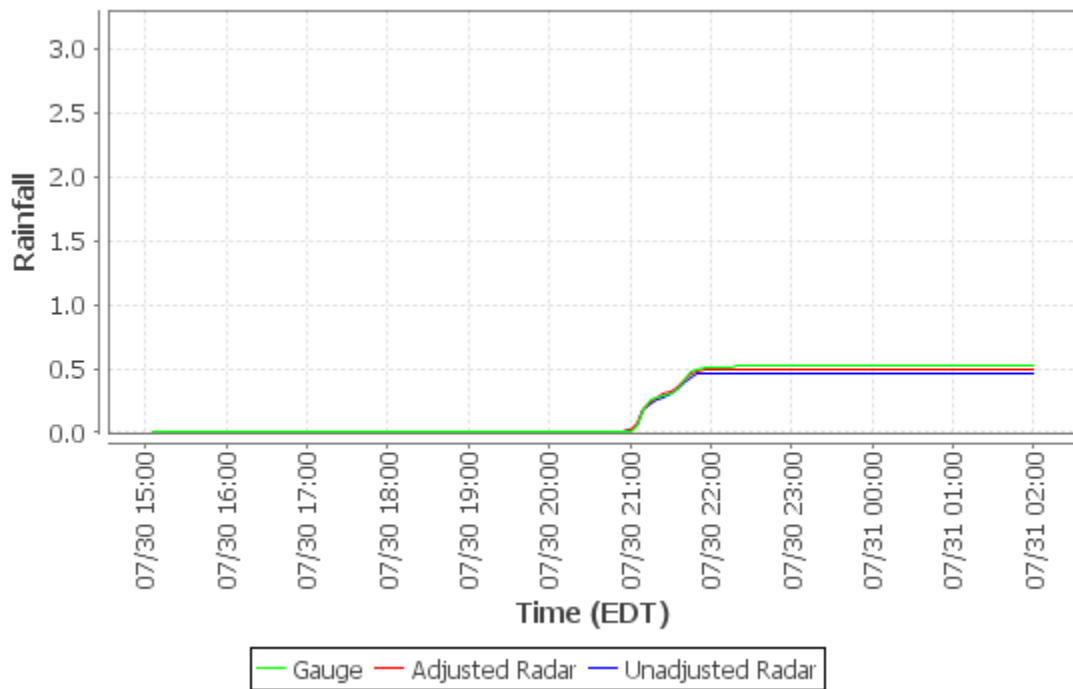
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



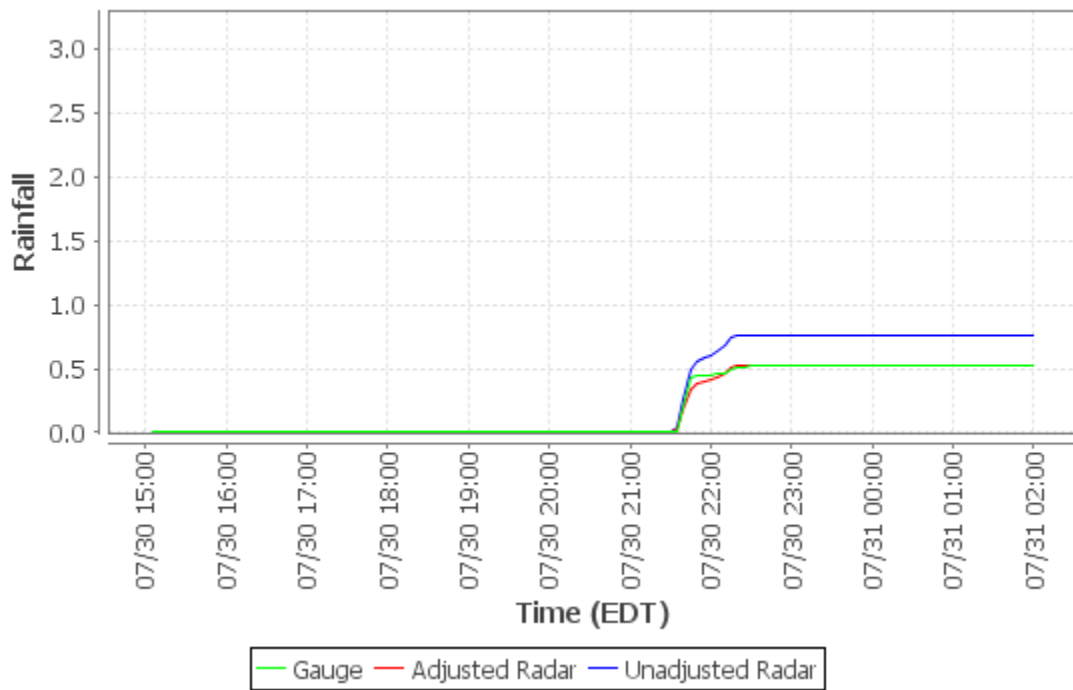
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



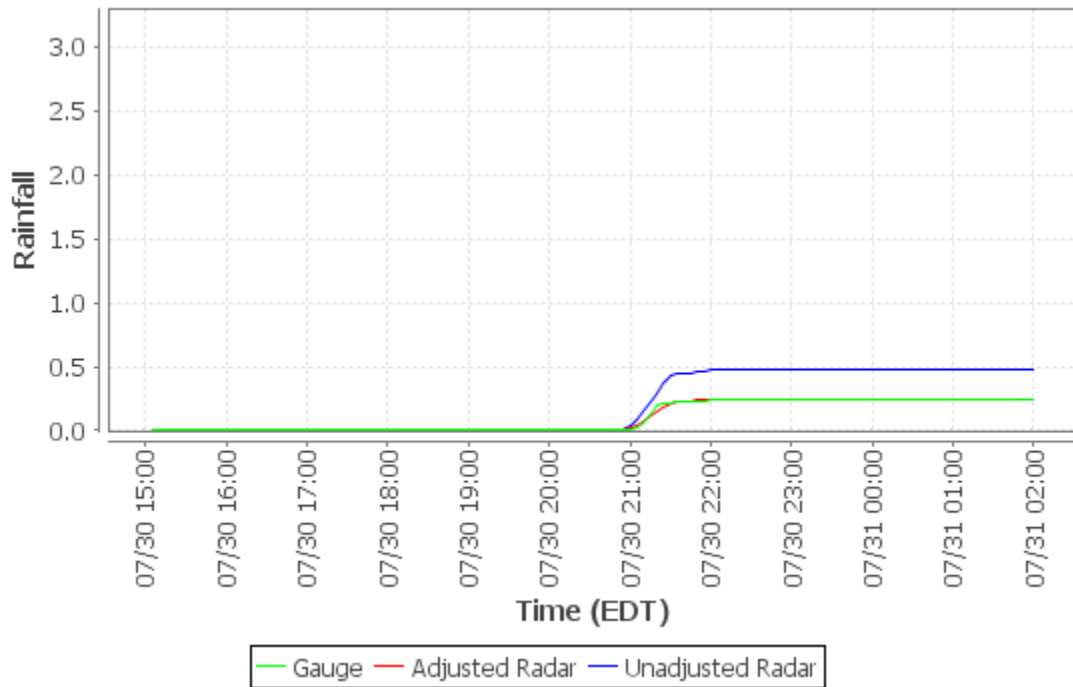
Cumulative Distribution Plot - Moon TWP (Loc21)



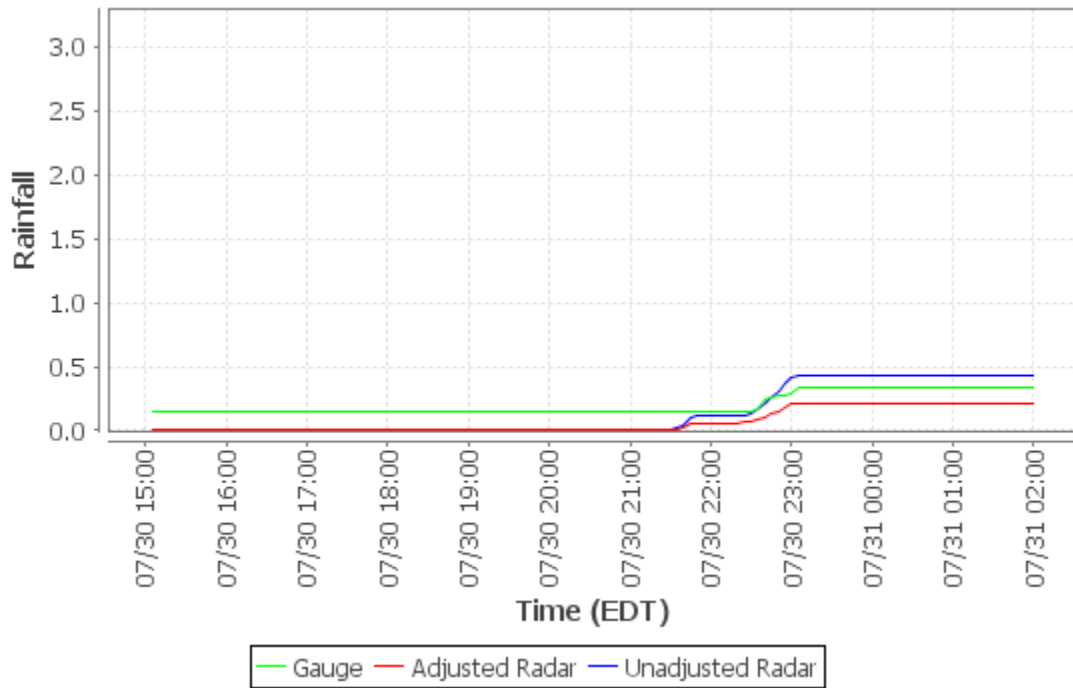
Cumulative Distribution Plot - North Fayette TWP (Loc22)



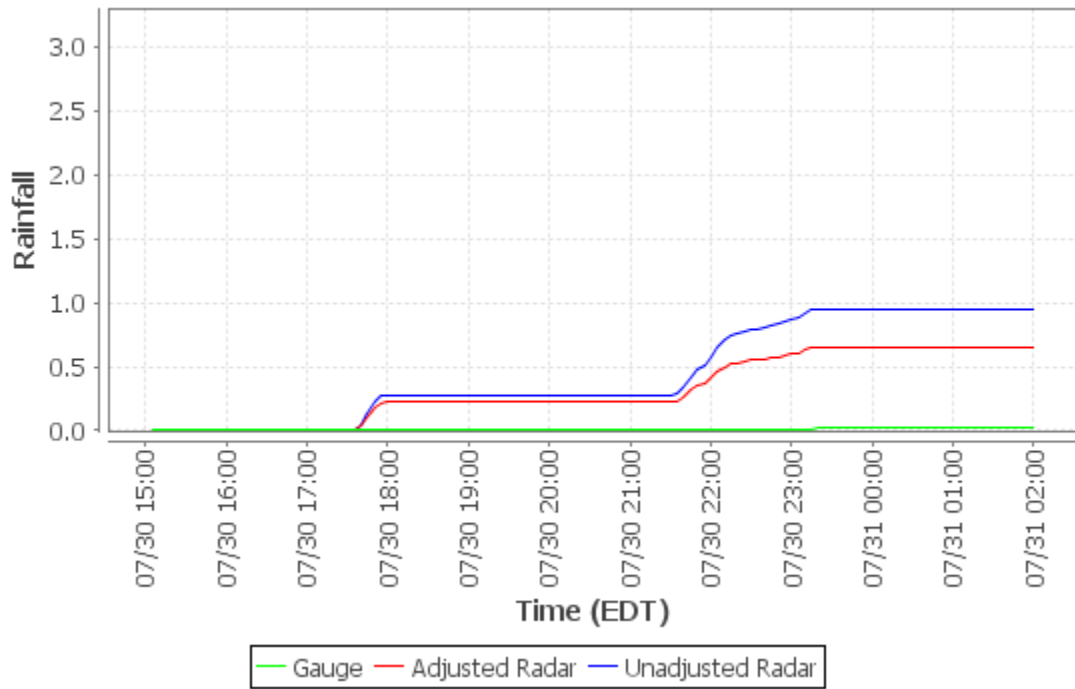
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



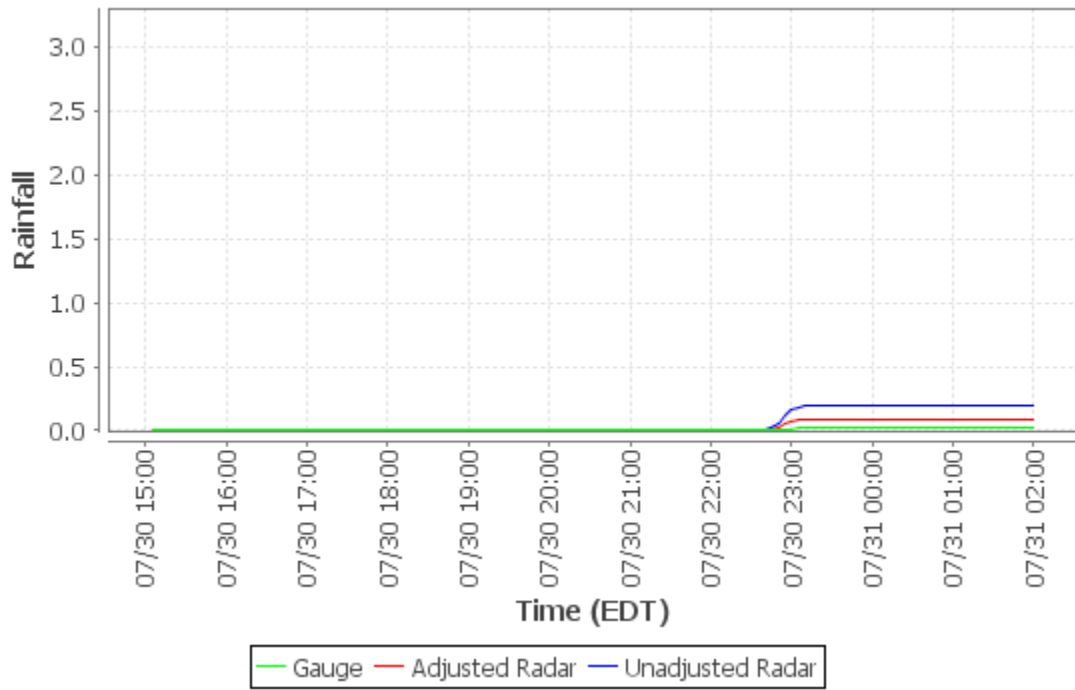
Cumulative Distribution Plot - Jefferson Hills (Loc24)



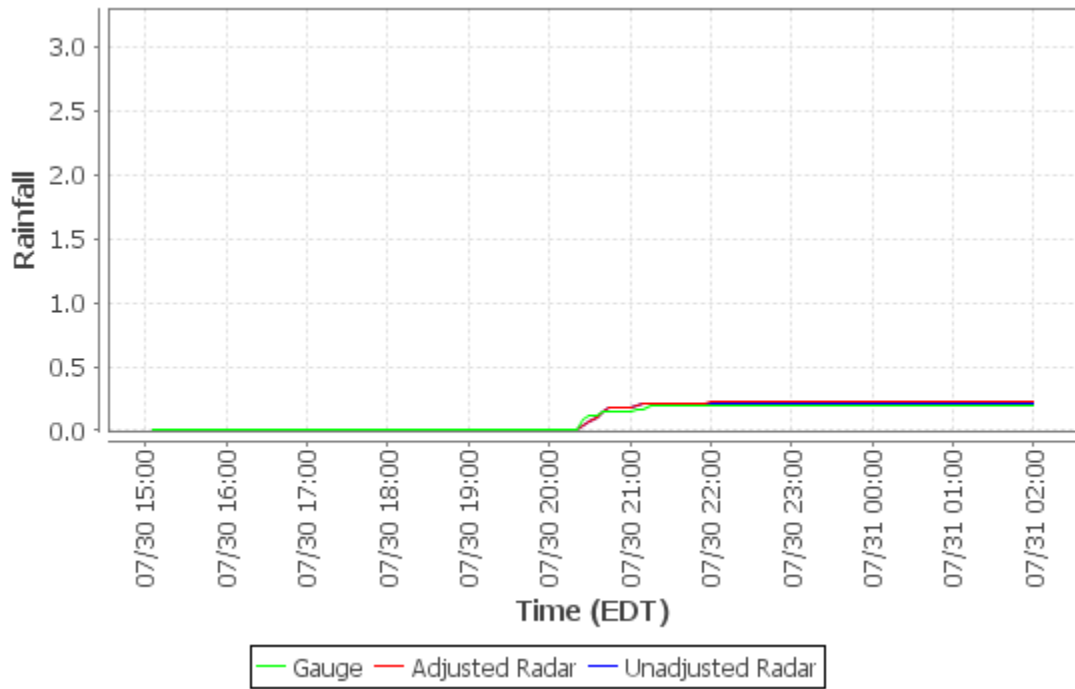
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



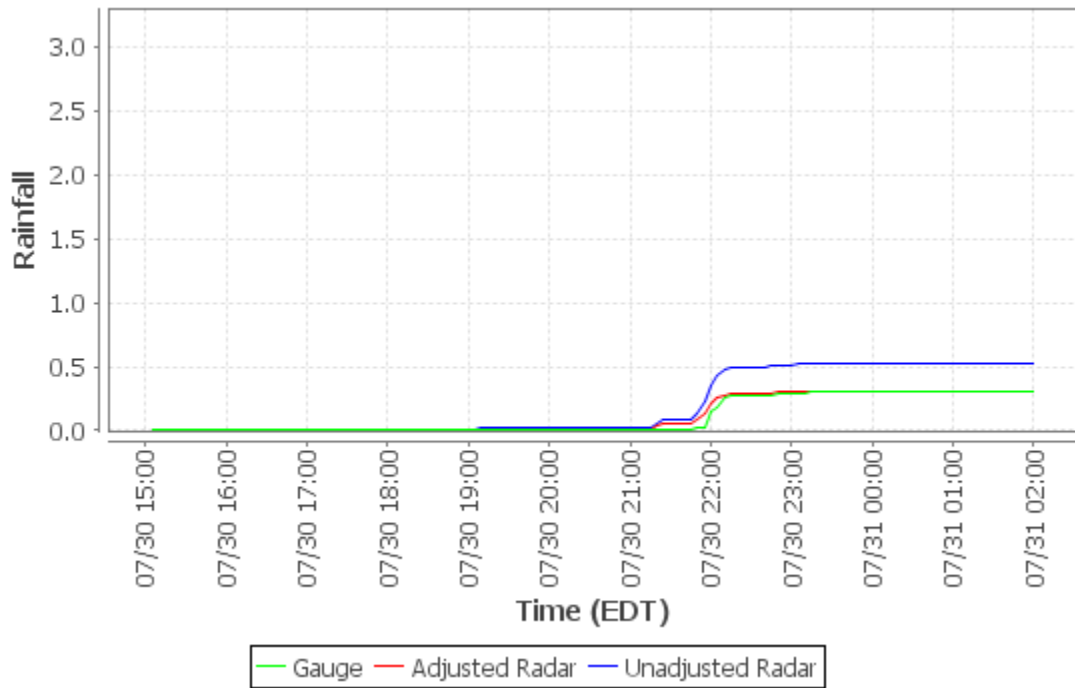
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



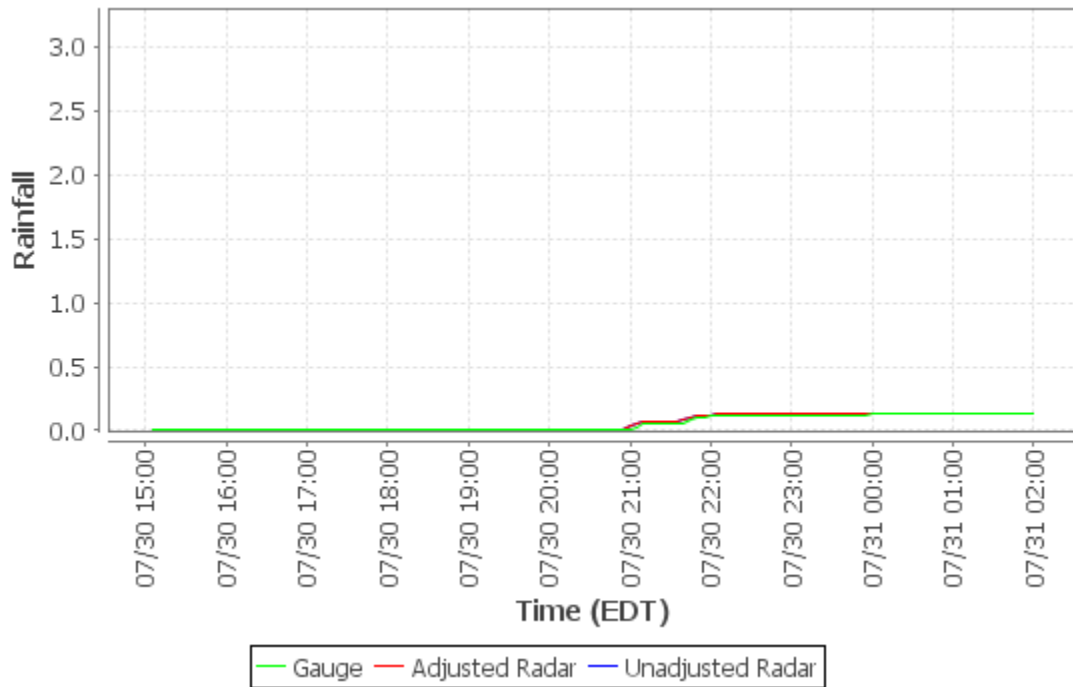
Cumulative Distribution Plot - Marshall TWP (Loc27)



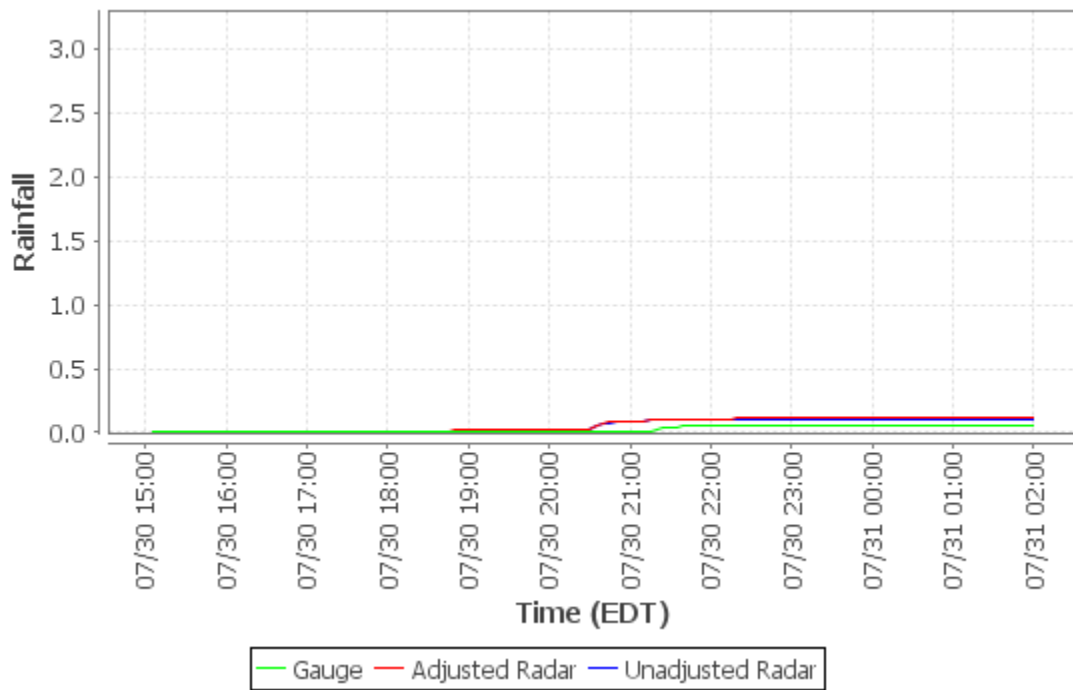
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



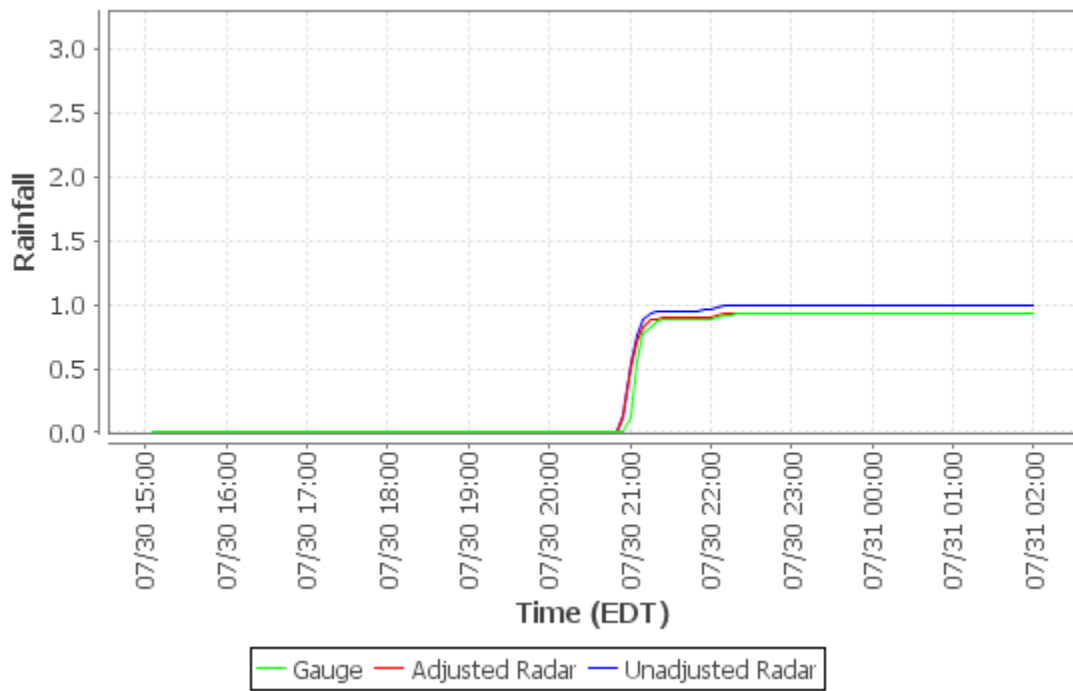
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



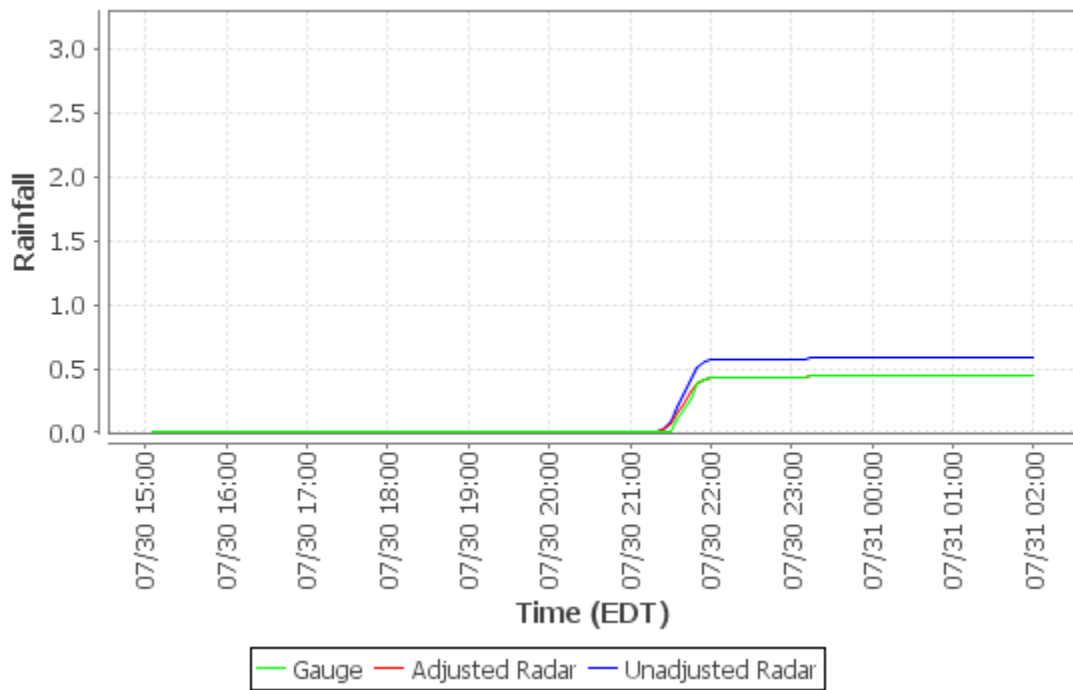
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



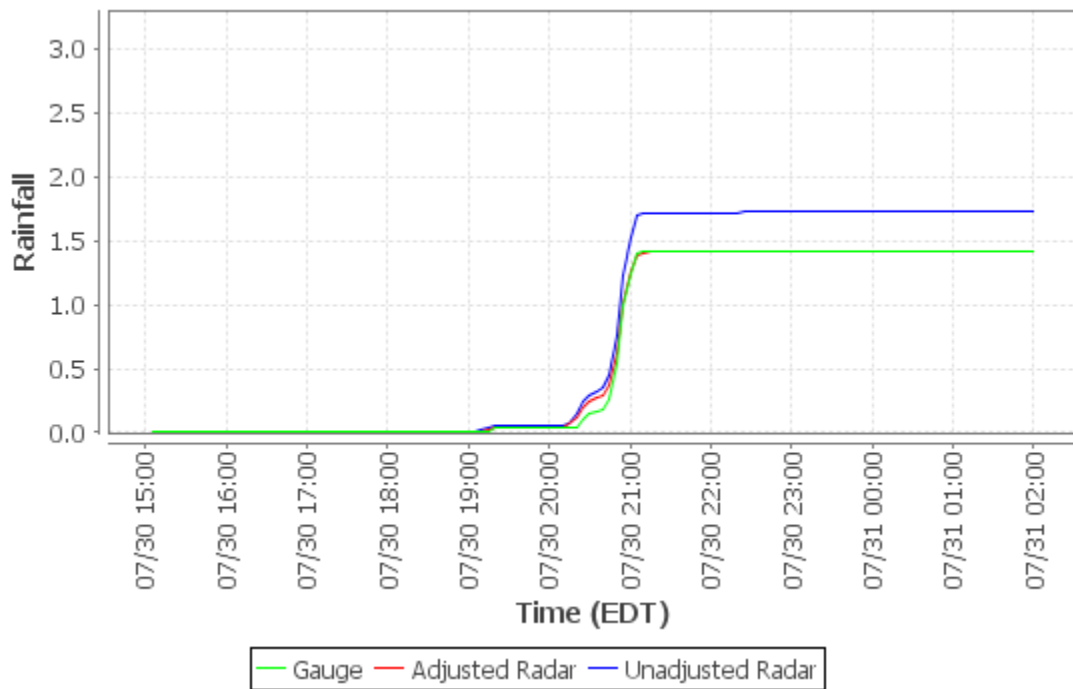
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



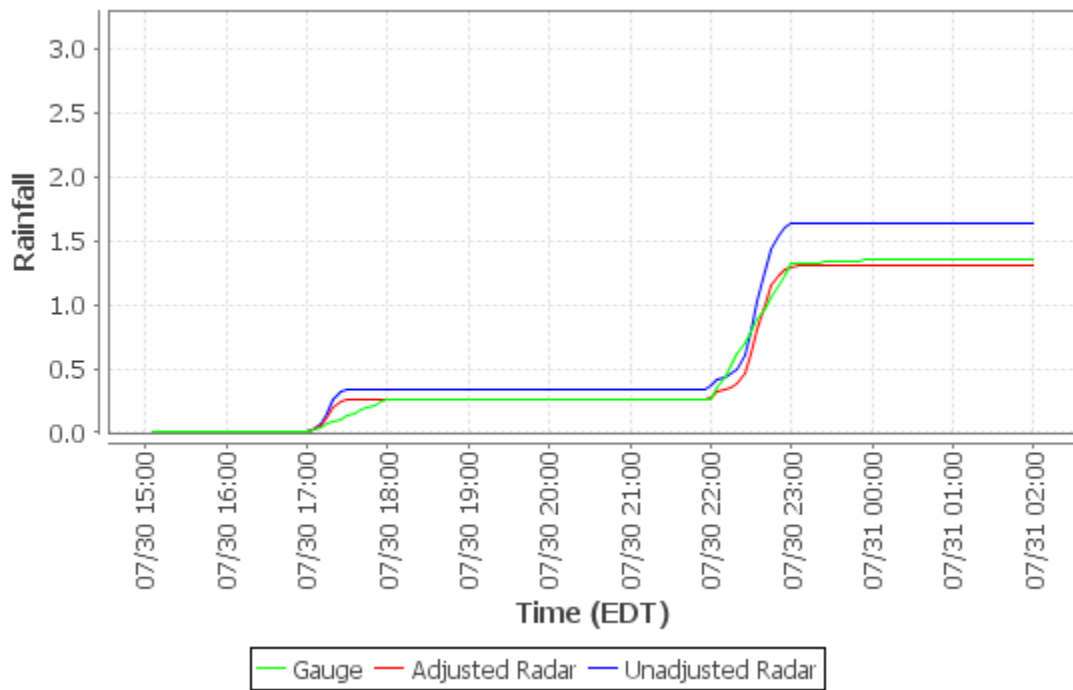
Cumulative Distribution Plot - Arnold (Loc32)



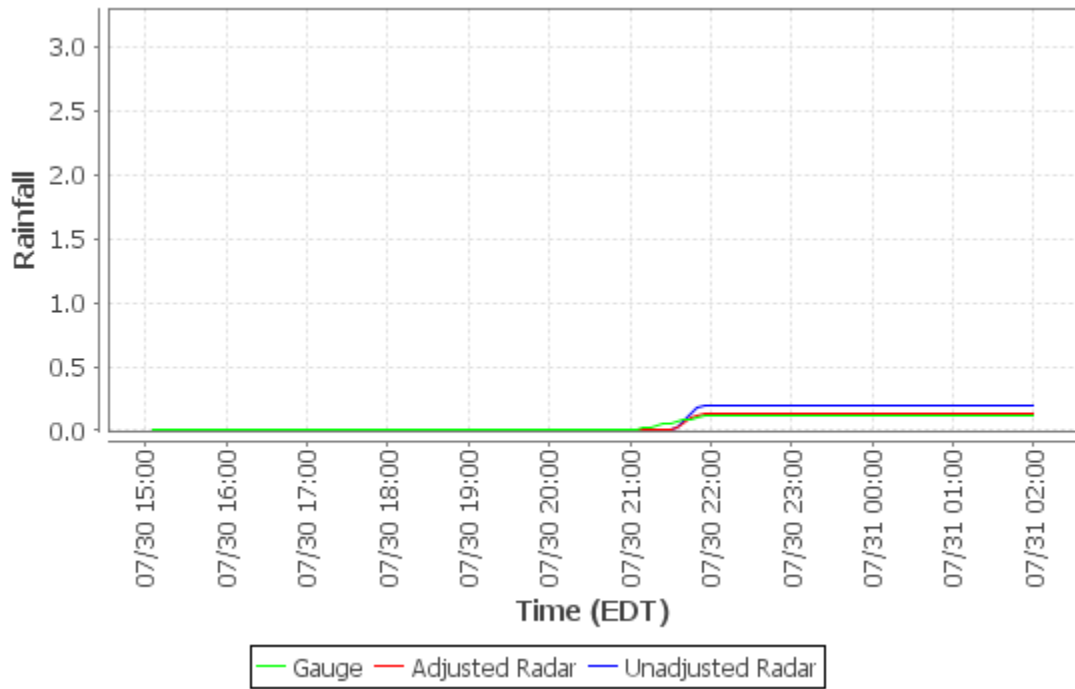
Cumulative Distribution Plot - Richland TWP (Loc33)



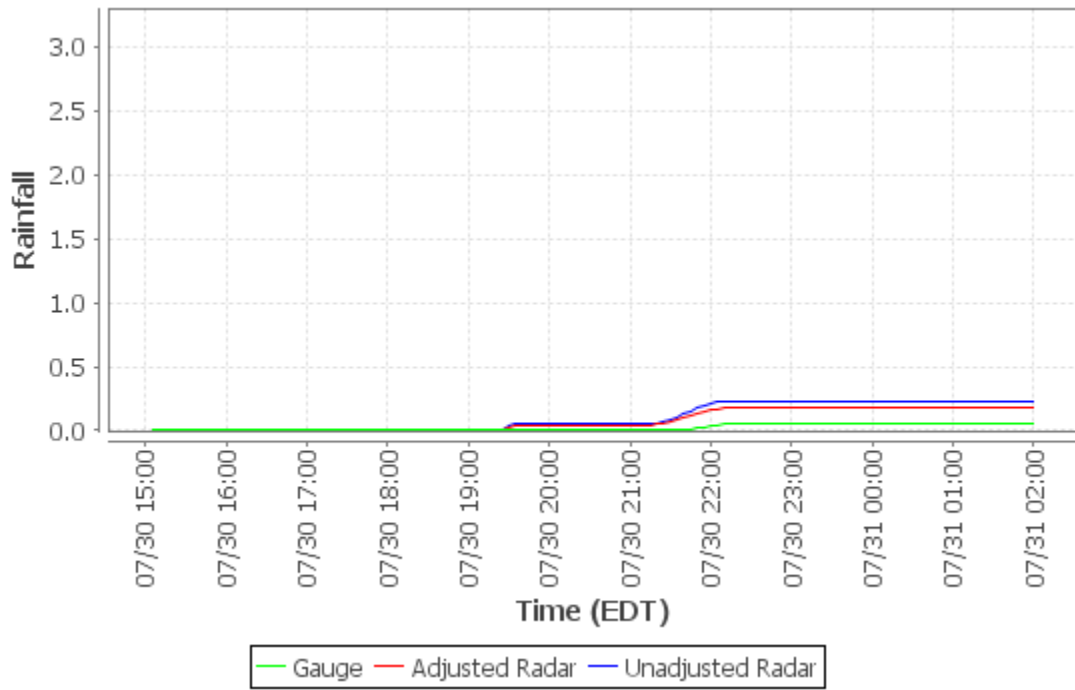
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



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)**

