

Radar Rainfall Analysis

January 2019 Summary Report



Prepared for 3 Rivers Wet Weather

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Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Overview

Vieux & Associates, Inc. (Vieux) processes radar and rain gauge data for 3 Rivers Wet Weather (3RWW). During each month, radar and rain gauge data are quality controlled (QC). To produce QC gauge-adjusted radar rainfall (GARR), both radar and rain gauge data are reviewed manually to remove inconsistent data. Only rainfall events that qualified for gauge-adjustment of the radar are included in this report.

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 Q1 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 II 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 fifteen-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.

Rain gauge data from as many as 38 gauges were used to adjust the radar. 3RWW provided rain data in 15-minute increments for 33 stations. In addition, rain gauge data were obtained from three 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 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.

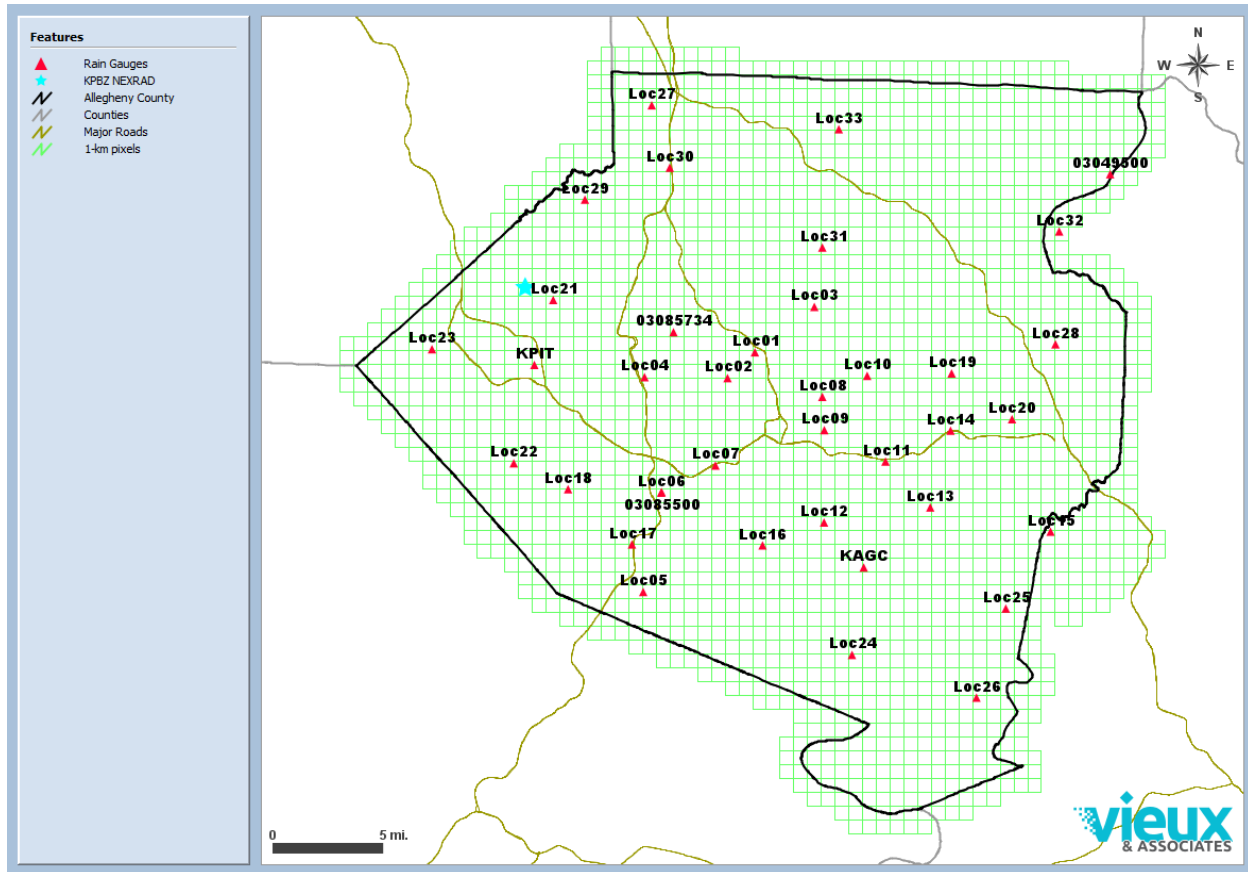


Figure 1. Spatial Distribution of the Rain Gauge Network, KPBZ NEXRAD and 1-km² Pixels

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
Loc14	Churchill Munic Bldg	3RWW

Gauge ID	Gauge Name	Source
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
03085500	Chartiers Creek at Carnegie	USGS
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	USGS

The 38 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

Statistical control of the data makes radar rainfall measurements more accurate. By statistical comparison between the radar and rain gauge accumulations during a calibration interval, statistical outliers may be identified. 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. Qualified rainfall events are defined based on a storm event definition where, for any given hour, at least 50% of all working 3RWW gauges have an accumulation of 0.05 inches.

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 or outlier check, 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. The 1-km² pixels are then filtered spatially from the final adjusted radar bins 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-km² pixels for all events. The data is provided in CSV format. The data file documentation follows:

CSV metadata:

- Single CSV file for each 1-km² pixel in 15-minute intervals.
- Comma-delimited text file, first five columns represent the month, day, year, hour and minute, respectively.
- The sixth and last column represents the rainfall depth in inches.
- Data values represent 15-min accumulation (inches) at end of interval.
- Time zone is in Eastern local time (e.g. EST/EDT).
- The 1-km² pixel ID is contained in the filename.

Gauge-Adjusted Radar Rainfall (GARR)

GARR was processed continuously at fifteen-minute increments for each qualified rainfall event. Four rainfall events were identified as having met the storm definition during January 2019. The GARR statistics for each event are listed in Table 2. Four of the events were split into multiple sub-event periods to improve gauge-adjustment of the radar, resulting in a total of nineteen 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 four 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 nineteen event and sub-event periods, the event CAD averaged 3.1%, indicating that the mean GARR agrees with the mean gauge accumulation to within $\pm 1.5\%$.

Table 2. Storm Events and GARR Statistics

Event #	Source	Event Date	Gauges Used (38)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E1a	KPBZ LII	2019-01-05	9	0.053	0.969	13.5	1.2
E1b	Gauge Only	2019-01-05	31	0.235	---	---	---
E2a	KPBZ LII	2019-01-08	25	0.064	0.665	64.4	9.0
E2b	KPBZ LII	2019-01-08	10	0.037	0.832	20.6	1.5
E3a	KPBZ LII	2019-01-19	28	0.070	0.712	42.9	3.2
E3b	KPBZ LII	2019-01-19	25	0.094	1.574	36.2	2.5
E3c	KPBZ LII	2019-01-19	33	0.133	1.111	13.3	2.7
E3d	KPBZ LII	2019-01-19	33	0.271	1.304	23.5	2.5
E3e	KPBZ LII	2019-01-19	33	0.118	1.221	18.5	2.2
E3f	Gauge Only	2019-01-19	30	0.227	---	---	---
E3g	KPBZ LII	2019-01-19	24	0.089	1.123	15.2	4.7
E3h	KPBZ LII	2019-01-19	12	0.089	0.793	33.9	1.7
E4a	KPBZ LII	2019-01-23	32	0.163	1.011	9.5	3.1
E4b	KPBZ LII	2019-01-23	34	0.109	0.925	18.7	3.5
E4c	KPBZ LII	2019-01-23	33	0.161	1.407	28.0	2.2

Event #	Source	Event Date	Gauges Used (38)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E4d	Gauge Only	2019-01-23	30	0.137	---	---	---
E4e	KPBZ LII	2019-01-23	32	0.134	1.302	22.9	2.8
E4f	KPBZ LII	2019-01-23	31	0.115	1.086	12.7	3.1
E4g	KPBZ LII	2019-01-23	10	0.069	0.696	57.5	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 B - E. CDPs are useful for visualizing rain gauge performance. Figure 2 shows the rainfall accumulation at the Marshall TWP (Loc27) gauge during the 2019-01-23 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.

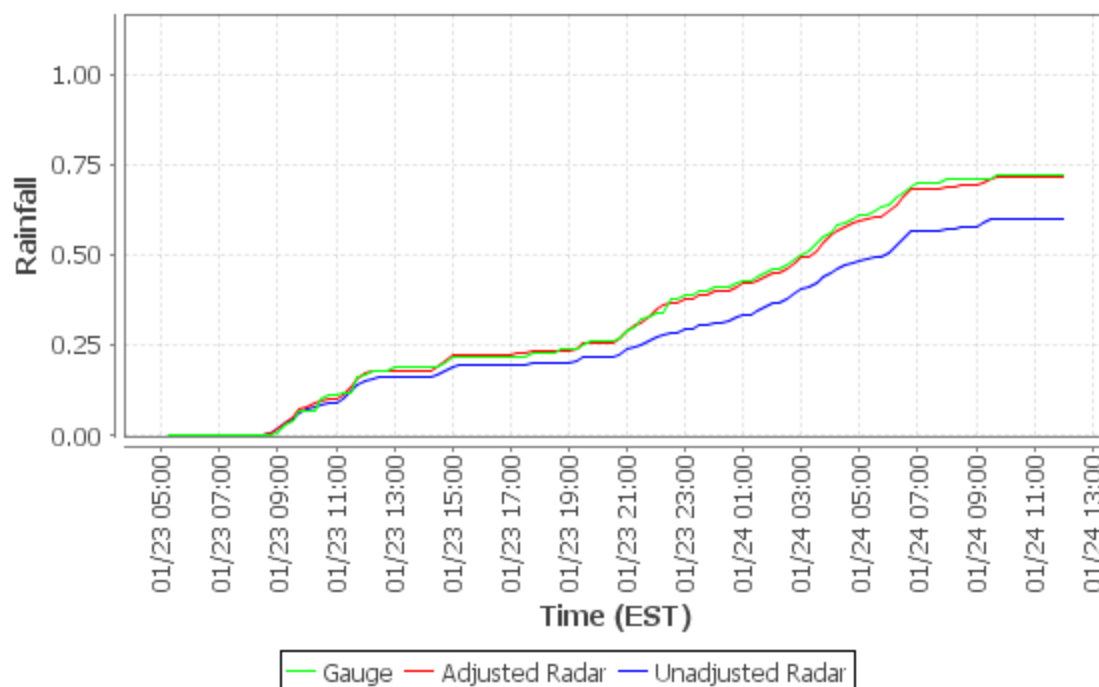


Figure 2. CDP Showing Rain Gauge Versus Unadjusted Radar Versus GARR

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 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.

Table 3. List of Possible Reasons for Exclusion of Rain Gauges

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

Reason	Explanation
No Data (ND)	Gauge reported "no data" for a significant amount of time

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: 2019-01-05

The analysis period was from 2019-01-04 19:00 EST to 2019-01-05 10:00 EST. The event was then split into two sub-event periods at 2019-01-04 23:00 EST to improve gauge adjustment of the radar. Gauge Only was used during Event 1b since all radar sources were either unavailable or provided insufficient rainfall information.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event. Gauges Loc03, Loc04, Loc06, Loc07, Loc08, Loc09, Loc10, Loc11, Loc12, Loc13, Loc14, Loc15, Loc16, Loc19, Loc21, Loc23, Loc27, Loc28, Loc29, Loc30, Loc31, Loc32, Loc33, KAGC, KPIT, 03049500 and 03085734 did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar during Event 1a.

The Eastern U.S. cool season stratiform Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 4 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 5 - 6 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. Figure 3 shows the scatter plot of the gauge-adjusted RG pairs. Figure 4 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.2 - 0.4 inches with a mean of 0.3 inches. Table 7 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 4. GARR Statistics for Event 1

Event #	Radar	Event Date	Gauges Used (38)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E1a	KPBZ LII	2019-01-05	9	0.053	0.969	13.5	1.2
E1b	Gauge Only	2019-01-05	31	0.235	---	---	---

Table 5. Summary of Individual RG Pairs for Event 1a

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	Diff* (in)	Diff* (%)
Loc02	ALCOSAN WWTP Lab	0.05	0.05	0.05	0.00	0.0
Loc05	Upper St. Clair	0.09	0.10	0.09	0.00	0.0

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc17	Chartiers Pump Station	0.05	0.05	0.05	0.00	0.0
Loc18	Oakdale Pump Station	0.05	0.06	0.05	0.00	0.0
Loc20	Gascola Eq Facility	0.05	0.06	0.05	0.00	0.0
Loc22	North Fayette TWP	0.08	0.10	0.08	0.00	0.0
Loc24	Jefferson Hills	0.07	0.08	0.07	0.00	0.0
Loc25	White Oak Public Works Bldg	0.07	0.07	0.07	0.00	0.0
Loc26	Elizabeth TWP Municipal Bldg	0.12	0.09	0.12	0.00	0.0

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc13	M-59 Access Shaft	0.10	---	---	---	---
Loc24	Jefferson Hills	0.11	---	---	---	---
Loc14	Churchill Munic Bldg	0.14	---	---	---	---
Loc19	Sandy Creek Eq Facility	0.16	---	---	---	---
Loc25	White Oak Public Works Bldg	0.19	---	---	---	---
Loc27	Marshall TWP	0.19	---	---	---	---
Loc15	Trafford Maint Bldg	0.20	---	---	---	---
Loc02	ALCOSAN WWTP Lab	0.21	---	---	---	---
Loc12	Baldwin	0.21	---	---	---	---
Loc26	Elizabeth TWP Municipal Bldg	0.21	---	---	---	---
Loc28	Plum Municipal Bldg	0.21	---	---	---	---
Loc09	Univ of Pittsburgh	0.22	---	---	---	---
Loc20	Gascola Eq Facility	0.22	---	---	---	---
Loc30	McCandless Twn Hall	0.22	---	---	---	---
Loc08	AC Health Dept Bldg	0.23	---	---	---	---
Loc11	M-46 Access Shaft	0.23	---	---	---	---
Loc16	Castle Shannon	0.23	---	---	---	---
Loc32	Arnold	0.23	---	---	---	---
Loc07	Greentree Munic Bldg	0.24	---	---	---	---
Loc10	PWSA-Highland Park	0.24	---	---	---	---
Loc03	Shaler Munic Bldg	0.25	---	---	---	---
Loc04	Kennedy Twp PS	0.26	---	---	---	---
Loc06	Carnegie Transit Time	0.26	---	---	---	---
Loc05	Upper St. Clair	0.27	---	---	---	---
Loc29	Bell Acres Munic Bldg	0.27	---	---	---	---
Loc17	Chartiers Pump Station	0.28	---	---	---	---

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc18	Oakdale Pump Station	0.28	---	---	---	---
Loc31	Hampton Municipal Bldg	0.28	---	---	---	---
Loc21	Moon TWP	0.29	---	---	---	---
Loc22	North Fayette TWP	0.33	---	---	---	---
Loc33	Richland TWP	0.34	---	---	---	---

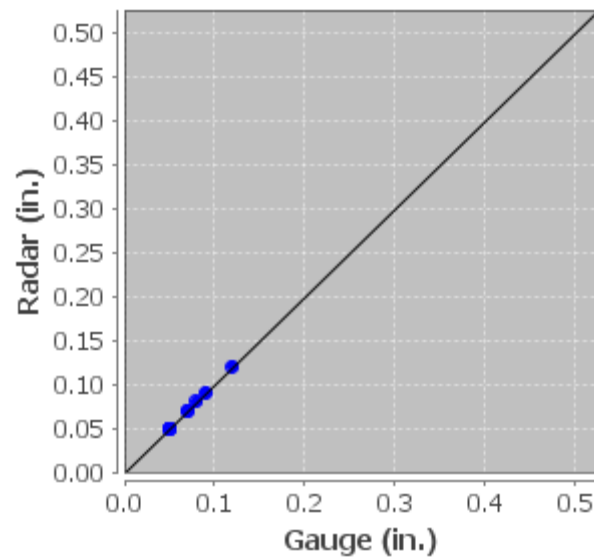


Figure 3. Scatter Plot of Gauge-Adjusted RG Pairs for Event 1a

statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar during Event 2a. Gauges Loc05, Loc06, Loc08, Loc09, Loc10, Loc11, Loc13, Loc14, Loc15, Loc16, Loc17, Loc18, Loc19, Loc20, Loc21, Loc22, Loc24, Loc25, Loc26, Loc28, Loc29, Loc30, KAGC and KPIT did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar during Event 2b.

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. Tables 9 - 10 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. Figures 5 - 6 show the scatter plots of the gauge-adjusted RG pairs. 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 - 0.3 inches with a mean of 0.1 inches. Table 11 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 8. GARR Statistics for Event 2

Event #	Radar	Event Date	Gauges Used (38)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E2a	KPBZ LII	2019-01-08	25	0.064	0.665	64.4	9.0
E2b	KPBZ LII	2019-01-08	10	0.037	0.832	20.6	1.5

Table 9. Summary of Individual RG Pairs for Event 2a

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	Diff* (in)	Diff* (%)
Loc09	Univ of Pittsburgh	0.06	0.15	0.09	-0.03	-50.0
Loc07	Greentree Munic Bldg	0.05	0.10	0.07	-0.02	-40.0
Loc14	Churchill Munic Bldg	0.06	0.15	0.08	-0.02	-33.3
Loc28	Plum Municipal Bldg	0.07	0.20	0.08	-0.01	-14.3
Loc13	M-59 Access Shaft	0.08	0.16	0.09	-0.01	-12.5
KAGC	Pittsburgh Allegheny Cty	0.08	0.09	0.08	0.00	0.0
Loc04	Kennedy Twp PS	0.09	0.08	0.09	0.00	0.0
Loc05	Upper St. Clair	0.09	0.11	0.09	0.00	0.0
Loc12	Baldwin	0.12	0.14	0.12	0.00	0.0
Loc15	Trafford Maint Bldg	0.06	0.15	0.06	0.00	0.0
Loc17	Chartiers Pump Station	0.10	0.11	0.10	0.00	0.0
Loc18	Oakdale Pump Station	0.06	0.06	0.06	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.08	0.15	0.08	0.00	0.0
Loc22	North Fayette TWP	0.05	0.06	0.05	0.00	0.0
Loc24	Jefferson Hills	0.19	0.17	0.19	0.00	0.0
Loc25	White Oak Public Works Bldg	0.09	0.14	0.09	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.08	0.15	0.08	0.00	0.0
Loc30	McCandless Twn Hall	0.05	0.12	0.05	0.00	0.0

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc33	Richland TWP	0.11	0.22	0.11	0.00	0.0
Loc16	Castle Shannon	0.13	0.12	0.12	0.01	7.7
Loc08	AC Health Dept Bldg	0.12	0.18	0.11	0.01	8.3
Loc20	Gascola Eq Facility	0.11	0.18	0.10	0.01	9.1
Loc11	M-46 Access Shaft	0.10	0.15	0.09	0.01	10.0
Loc06	Carnegie Transit Time	0.09	0.09	0.08	0.01	11.1
Loc10	PWSA-Highland Park	0.15	0.17	0.12	0.03	20.0

Table 10. Summary of Individual RG Pairs for Event 2b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc02	ALCOSAN WWTP Lab	0.05	0.06	0.05	0.00	0.0
Loc03	Shaler Munic Bldg	0.06	0.07	0.06	0.00	0.0
Loc04	Kennedy Twp PS	0.05	0.06	0.05	0.00	0.0
Loc07	Greentree Munic Bldg	0.05	0.06	0.05	0.00	0.0
Loc12	Baldwin	0.05	0.05	0.05	0.00	0.0
Loc23	Clinton Munic Bldg	0.05	0.05	0.05	0.00	0.0
Loc27	Marshall TWP	0.05	0.06	0.05	0.00	0.0
Loc31	Hampton Municipal Bldg	0.05	0.07	0.05	0.00	0.0
Loc32	Arnold	0.06	0.06	0.06	0.00	0.0
Loc33	Richland TWP	0.05	0.07	0.05	0.00	0.0

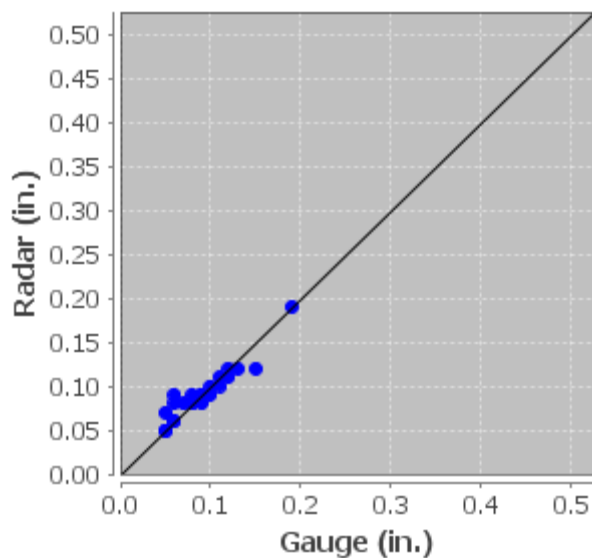


Figure 5. Scatter Plot of Gauge-Adjusted RG Pairs for Event 2a

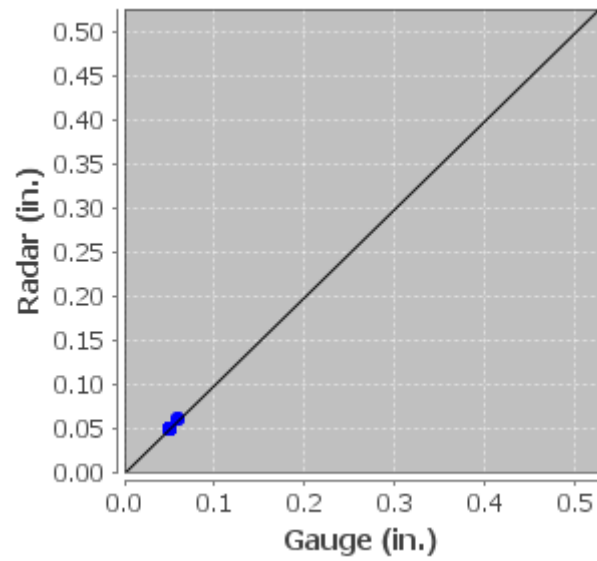


Figure 6. Scatter Plot of Gauge-Adjusted RG Pairs for Event 2b

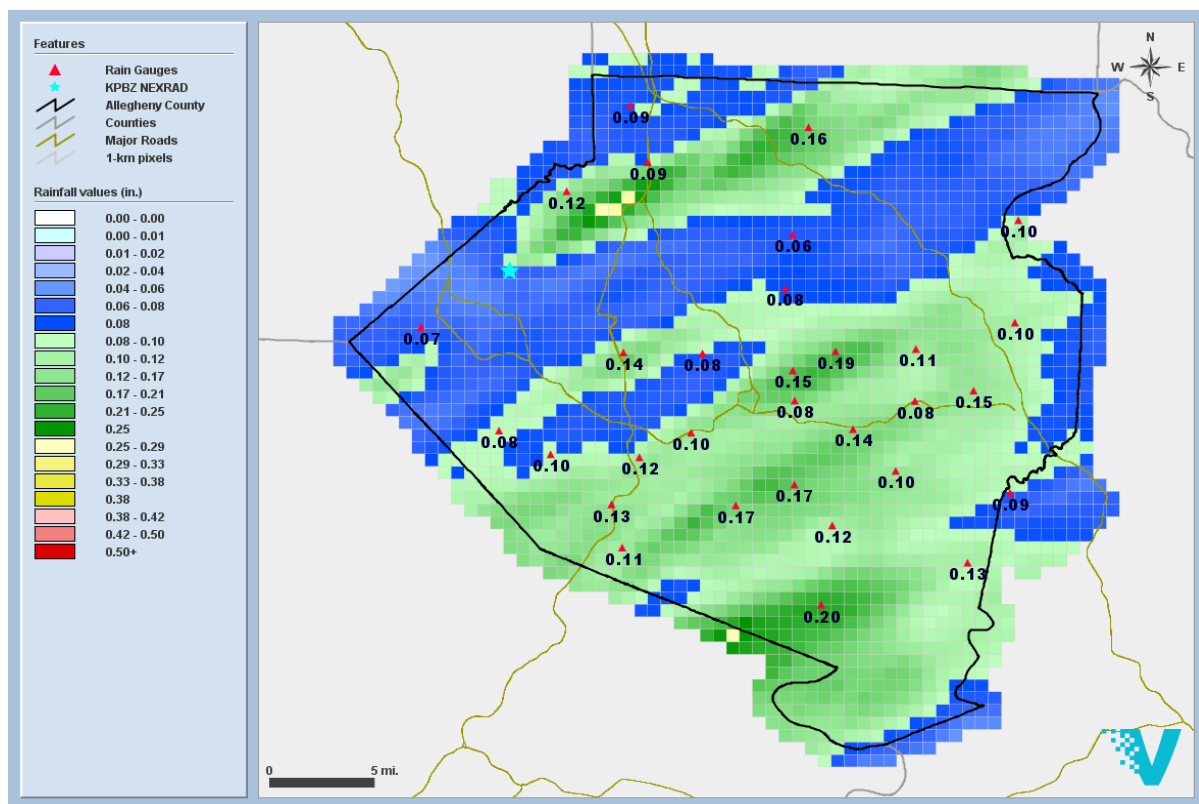


Figure 7. GARR Storm Total for Event 2

Table 11. Depth Duration Frequency Analyses for Event 2

Duration	Depth (in)	Pixel	Time (EST)	Frequency
15 minutes	0.190	136123	2019-01-08 17:00	<1 yr.
30 minutes	0.199	136123	2019-01-08 17:15	<1 yr.
1 hour	0.206	146156	2019-01-08 17:45	<1 yr.
2 hour	0.224	145157	2019-01-08 18:00	<1 yr.
3 hour	0.224	145157	2019-01-08 18:00	<1 yr.
6 hour	0.268	136123	2019-01-08 21:00	<1 yr.
12 hour	0.268	136123	2019-01-09 02:00	<1 yr.

Event 3: 2019-01-19

The analysis period was from 2019-01-19 09:00 EST to 2019-01-20 09:00 EST. The event was then split into eight sub-event periods at 2019-01-19 17:00 EST, 2019-01-19 18:15 EST, 2019-01-19 20:00 EST, 2019-01-19 22:15 EST, 2019-01-19 23:45 EST, 2019-01-20 02:45 EST and 2019-01-20 03:30 EST to improve gauge adjustment of the radar. Gauge Only was used during Event 3f since all radar sources were either unavailable or provided insufficient rainfall information.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event. Gauges Loc02, Loc27, Loc28, Loc30, Loc31, Loc32, 03049500 and 03085734 did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar during Event 3a. Gauges Loc05, Loc06, Loc16, Loc17, Loc18, Loc22, Loc23, KPIT and 03085734 did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar during Event 3b. Gauges Loc24, Loc25, Loc26 and Loc27 did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar during Event 3g. Gauges Loc24 and Loc26 did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar during Event 3h.

The Eastern U.S. cool season stratiform Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 12 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 13 - 20 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. Figures 8 - 14 show the scatter plots of the gauge-adjusted RG pairs. Figure 15 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.9 - 1.3 inches with a mean of 1.1 inches. Table 21 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 12. GARR Statistics for Event 3

Event #	Radar	Event Date	Gauges Used (38)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E3a	KPBZ LII	2019-01-19	28	0.070	0.712	42.9	3.2
E3b	KPBZ LII	2019-01-19	25	0.094	1.574	36.2	2.5
E3c	KPBZ LII	2019-01-19	33	0.133	1.111	13.3	2.7
E3d	KPBZ LII	2019-01-19	33	0.271	1.304	23.5	2.5
E3e	KPBZ LII	2019-01-19	33	0.118	1.221	18.5	2.2
E3f	Gauge Only	2019-01-19	30	0.227	---	---	---
E3g	KPBZ LII	2019-01-19	24	0.089	1.123	15.2	4.7
E3h	KPBZ LII	2019-01-19	12	0.089	0.793	33.9	1.7

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

Gauge ID	Name	Gi (in)	Ri (in)	Ri* (in)	Diff* (in)	Diff* (%)
Loc18	Oakdale Pump Station	0.06	0.09	0.07	-0.01	-16.7
Loc07	Greentree Munic Bldg	0.07	0.09	0.08	-0.01	-14.3
KAGC	Pittsburgh Allegheny Cty	0.10	0.15	0.10	0.00	0.0
KPIT	Greater Pittsburgh Int'l	0.07	0.07	0.07	0.00	0.0
Loc04	Kennedy Twp PS	0.07	0.07	0.07	0.00	0.0
Loc05	Upper St. Clair	0.09	0.10	0.09	0.00	0.0
Loc08	AC Health Dept Bldg	0.06	0.09	0.06	0.00	0.0
Loc09	Univ of Pittsburgh	0.07	0.09	0.07	0.00	0.0
Loc10	PWSA-Highland Park	0.06	0.09	0.06	0.00	0.0
Loc11	M-46 Access Shaft	0.07	0.12	0.07	0.00	0.0
Loc12	Baldwin	0.08	0.12	0.08	0.00	0.0
Loc13	M-59 Access Shaft	0.08	0.16	0.08	0.00	0.0
Loc14	Churchill Munic Bldg	0.07	0.13	0.07	0.00	0.0
Loc15	Trafford Maint Bldg	0.08	0.13	0.08	0.00	0.0
Loc16	Castle Shannon	0.08	0.10	0.08	0.00	0.0
Loc17	Chartiers Pump Station	0.09	0.10	0.09	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.06	0.12	0.06	0.00	0.0
Loc20	Gascola Eq Facility	0.07	0.14	0.07	0.00	0.0
Loc21	Moon TWP	0.06	0.07	0.06	0.00	0.0
Loc22	North Fayette TWP	0.06	0.08	0.06	0.00	0.0
Loc23	Clinton Munic Bldg	0.08	0.08	0.08	0.00	0.0
Loc24	Jefferson Hills	0.09	0.17	0.09	0.00	0.0
Loc25	White Oak Public Works Bldg	0.11	0.16	0.11	0.00	0.0

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc26	Elizabeth TWP Municipal Bldg	0.10	0.16	0.10	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.05	0.06	0.05	0.00	0.0
Loc33	Richland TWP	0.05	0.07	0.05	0.00	0.0
Loc06	Carnegie Transit Time	0.10	0.09	0.09	0.01	10.0
Loc03	Shaler Munic Bldg	0.07	0.06	0.06	0.01	14.3

Table 14. Summary of Individual RG Pairs for Event 3b

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc11	M-46 Access Shaft	0.08	0.05	0.09	-0.01	-12.5
03049500	Allegheny River at Natrona	0.09	0.08	0.09	0.00	0.0
Loc02	ALCOSAN WWTP Lab	0.08	0.05	0.08	0.00	0.0
Loc03	Shaler Munic Bldg	0.09	0.05	0.09	0.00	0.0
Loc04	Kennedy Twp PS	0.10	0.05	0.10	0.00	0.0
Loc09	Univ of Pittsburgh	0.09	0.05	0.09	0.00	0.0
Loc10	PWSA-Highland Park	0.10	0.05	0.10	0.00	0.0
Loc12	Baldwin	0.10	0.05	0.10	0.00	0.0
Loc13	M-59 Access Shaft	0.10	0.05	0.10	0.00	0.0
Loc14	Churchill Munic Bldg	0.09	0.05	0.09	0.00	0.0
Loc15	Trafford Maint Bldg	0.10	0.07	0.10	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.09	0.05	0.09	0.00	0.0
Loc20	Gascola Eq Facility	0.10	0.06	0.10	0.00	0.0
Loc21	Moon TWP	0.08	0.06	0.08	0.00	0.0
Loc24	Jefferson Hills	0.11	0.07	0.11	0.00	0.0
Loc25	White Oak Public Works Bldg	0.10	0.08	0.10	0.00	0.0
Loc26	Elizabeth TWP Municipal Bldg	0.14	0.10	0.14	0.00	0.0
Loc27	Marshall TWP	0.09	0.05	0.09	0.00	0.0
Loc28	Plum Municipal Bldg	0.08	0.06	0.08	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.10	0.06	0.10	0.00	0.0
Loc31	Hampton Municipal Bldg	0.09	0.05	0.09	0.00	0.0
Loc32	Arnold	0.09	0.07	0.09	0.00	0.0
Loc33	Richland TWP	0.08	0.06	0.08	0.00	0.0
KAGC	Pittsburgh Allegheny Cty	0.11	0.06	0.10	0.01	9.1
Loc08	AC Health Dept Bldg	0.10	0.05	0.09	0.01	10.0

Table 15. Summary of Individual RG Pairs for Event 3c

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.11	0.11	0.12	-0.01	-9.1
Loc07	Greentree Munic Bldg	0.13	0.13	0.14	-0.01	-7.7
Loc22	North Fayette TWP	0.14	0.15	0.15	-0.01	-7.1
03049500	Allegheny River at Natrona	0.12	0.11	0.12	0.00	0.0
KAGC	Pittsburgh Allegheny Cty	0.13	0.12	0.13	0.00	0.0
KPIT	Greater Pittsburgh Int'l	0.14	0.13	0.14	0.00	0.0
Loc02	ALCOSAN WWTP Lab	0.13	0.12	0.13	0.00	0.0
Loc03	Shaler Munic Bldg	0.12	0.10	0.12	0.00	0.0
Loc05	Upper St. Clair	0.14	0.13	0.14	0.00	0.0
Loc08	AC Health Dept Bldg	0.13	0.11	0.13	0.00	0.0
Loc09	Univ of Pittsburgh	0.13	0.11	0.13	0.00	0.0
Loc10	PWSA-Highland Park	0.13	0.10	0.13	0.00	0.0
Loc11	M-46 Access Shaft	0.12	0.10	0.12	0.00	0.0
Loc12	Baldwin	0.11	0.11	0.11	0.00	0.0
Loc13	M-59 Access Shaft	0.12	0.11	0.12	0.00	0.0
Loc14	Churchill Munic Bldg	0.11	0.09	0.11	0.00	0.0
Loc15	Trafford Maint Bldg	0.12	0.16	0.12	0.00	0.0
Loc16	Castle Shannon	0.12	0.11	0.12	0.00	0.0
Loc17	Chartiers Pump Station	0.16	0.14	0.16	0.00	0.0
Loc18	Oakdale Pump Station	0.16	0.14	0.16	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.11	0.09	0.11	0.00	0.0
Loc20	Gascola Eq Facility	0.12	0.10	0.12	0.00	0.0
Loc21	Moon TWP	0.15	0.12	0.15	0.00	0.0
Loc24	Jefferson Hills	0.13	0.14	0.13	0.00	0.0
Loc25	White Oak Public Works Bldg	0.15	0.16	0.15	0.00	0.0
Loc26	Elizabeth TWP Municipal Bldg	0.19	0.19	0.19	0.00	0.0
Loc27	Marshall TWP	0.11	0.09	0.11	0.00	0.0
Loc28	Plum Municipal Bldg	0.09	0.10	0.09	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.15	0.10	0.15	0.00	0.0
Loc31	Hampton Municipal Bldg	0.12	0.10	0.12	0.00	0.0
Loc32	Arnold	0.12	0.10	0.12	0.00	0.0
Loc04	Kennedy Twp PS	0.16	0.12	0.15	0.01	6.3
Loc06	Carnegie Transit Time	0.19	0.14	0.17	0.02	10.5

Table 16. Summary of Individual RG Pairs for Event 3d

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)
<u>Loc07</u>	Greentree Munic Bldg	0.21	0.19	0.23	-0.02	-9.5
<u>Loc11</u>	M-46 Access Shaft	0.21	0.17	0.22	-0.01	-4.8
<u>Loc09</u>	Univ of Pittsburgh	0.22	0.18	0.23	-0.01	-4.5
<u>Loc28</u>	Plum Municipal Bldg	0.22	0.23	0.23	-0.01	-4.5
<u>Loc02</u>	ALCOSAN WWTP Lab	0.23	0.20	0.24	-0.01	-4.3
<u>Loc18</u>	Oakdale Pump Station	0.23	0.20	0.24	-0.01	-4.3
<u>03049500</u>	Allegheny River at Natrona	0.24	0.26	0.25	-0.01	-4.2
<u>Loc31</u>	Hampton Municipal Bldg	0.24	0.19	0.25	-0.01	-4.2
<u>Loc20</u>	Gascola Eq Facility	0.25	0.22	0.26	-0.01	-4.0
<u>KAGC</u>	Pittsburgh Allegheny Cty	0.26	0.18	0.26	0.00	0.0
<u>KPIT</u>	Greater Pittsburgh Int'l	0.29	0.22	0.29	0.00	0.0
<u>Loc03</u>	Shaler Munic Bldg	0.26	0.19	0.26	0.00	0.0
<u>Loc05</u>	Upper St. Clair	0.21	0.17	0.21	0.00	0.0
<u>Loc12</u>	Baldwin	0.23	0.16	0.23	0.00	0.0
<u>Loc14</u>	Churchill Munic Bldg	0.24	0.18	0.24	0.00	0.0
<u>Loc15</u>	Trafford Maint Bldg	0.29	0.23	0.29	0.00	0.0
<u>Loc16</u>	Castle Shannon	0.22	0.17	0.22	0.00	0.0
<u>Loc17</u>	Chartiers Pump Station	0.23	0.18	0.23	0.00	0.0
<u>Loc23</u>	Clinton Munic Bldg	0.30	0.21	0.30	0.00	0.0
<u>Loc24</u>	Jefferson Hills	0.29	0.19	0.29	0.00	0.0
<u>Loc25</u>	White Oak Public Works Bldg	0.32	0.22	0.32	0.00	0.0
<u>Loc26</u>	Elizabeth TWP Municipal Bldg	0.37	0.25	0.37	0.00	0.0
<u>Loc27</u>	Marshall TWP	0.31	0.21	0.31	0.00	0.0
<u>Loc29</u>	Bell Acres Munic Bldg	0.31	0.22	0.31	0.00	0.0
<u>Loc33</u>	Richland TWP	0.30	0.20	0.30	0.00	0.0
<u>Loc04</u>	Kennedy Twp PS	0.28	0.20	0.27	0.01	3.6
<u>Loc22</u>	North Fayette TWP	0.28	0.21	0.27	0.01	3.6
<u>Loc13</u>	M-59 Access Shaft	0.27	0.18	0.26	0.01	3.7
<u>Loc10</u>	PWSA-Highland Park	0.26	0.18	0.25	0.01	3.8
<u>Loc08</u>	AC Health Dept Bldg	0.25	0.18	0.24	0.01	4.0
<u>Loc32</u>	Arnold	0.25	0.24	0.24	0.01	4.0
<u>Loc19</u>	Sandy Creek Eq Facility	0.24	0.17	0.23	0.01	4.2
<u>Loc06</u>	Carnegie Transit Time	0.28	0.19	0.25	0.03	10.7

Table 17. Summary of Individual RG Pairs for Event 3e

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)
<u>03049500</u>	Allegheny River at Natrona	0.12	0.14	0.13	-0.01	-8.3
<u>Loc09</u>	Univ of Pittsburgh	0.12	0.11	0.13	-0.01	-8.3
<u>Loc11</u>	M-46 Access Shaft	0.12	0.10	0.13	-0.01	-8.3
<u>KAGC</u>	Pittsburgh Allegheny Cty	0.15	0.10	0.15	0.00	0.0
<u>KPIT</u>	Greater Pittsburgh Int'l	0.10	0.10	0.10	0.00	0.0
<u>Loc02</u>	ALCOSAN WWTP Lab	0.10	0.08	0.10	0.00	0.0
<u>Loc03</u>	Shaler Munic Bldg	0.09	0.08	0.09	0.00	0.0
<u>Loc04</u>	Kennedy Twp PS	0.10	0.08	0.10	0.00	0.0
<u>Loc05</u>	Upper St. Clair	0.11	0.09	0.11	0.00	0.0
<u>Loc06</u>	Carnegie Transit Time	0.11	0.09	0.11	0.00	0.0
<u>Loc08</u>	AC Health Dept Bldg	0.12	0.10	0.12	0.00	0.0
<u>Loc10</u>	PWSA-Highland Park	0.12	0.10	0.12	0.00	0.0
<u>Loc12</u>	Baldwin	0.14	0.10	0.14	0.00	0.0
<u>Loc14</u>	Churchill Munic Bldg	0.14	0.10	0.14	0.00	0.0
<u>Loc15</u>	Trafford Maint Bldg	0.15	0.11	0.15	0.00	0.0
<u>Loc16</u>	Castle Shannon	0.12	0.10	0.12	0.00	0.0
<u>Loc17</u>	Chartiers Pump Station	0.11	0.09	0.11	0.00	0.0
<u>Loc18</u>	Oakdale Pump Station	0.09	0.08	0.09	0.00	0.0
<u>Loc19</u>	Sandy Creek Eq Facility	0.13	0.10	0.13	0.00	0.0
<u>Loc21</u>	Moon TWP	0.10	0.10	0.10	0.00	0.0
<u>Loc22</u>	North Fayette TWP	0.10	0.09	0.10	0.00	0.0
<u>Loc23</u>	Clinton Munic Bldg	0.10	0.10	0.10	0.00	0.0
<u>Loc24</u>	Jefferson Hills	0.12	0.09	0.12	0.00	0.0
<u>Loc25</u>	White Oak Public Works Bldg	0.15	0.10	0.15	0.00	0.0
<u>Loc26</u>	Elizabeth TWP Municipal Bldg	0.13	0.09	0.13	0.00	0.0
<u>Loc27</u>	Marshall TWP	0.11	0.09	0.11	0.00	0.0
<u>Loc28</u>	Plum Municipal Bldg	0.12	0.11	0.12	0.00	0.0
<u>Loc29</u>	Bell Acres Munic Bldg	0.12	0.10	0.12	0.00	0.0
<u>Loc31</u>	Hampton Municipal Bldg	0.10	0.08	0.10	0.00	0.0
<u>Loc32</u>	Arnold	0.12	0.11	0.12	0.00	0.0
<u>Loc33</u>	Richland TWP	0.11	0.09	0.11	0.00	0.0
<u>Loc13</u>	M-59 Access Shaft	0.15	0.10	0.14	0.01	6.7
<u>Loc20</u>	Gascola Eq Facility	0.15	0.10	0.14	0.01	6.7

Table 18. Summary of Individual RG Pairs for Event 3f

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)
Loc26	Elizabeth TWP Municipal Bldg	0.08	---	---	---	---
Loc15	Trafford Maint Bldg	0.09	---	---	---	---
Loc25	White Oak Public Works Bldg	0.10	---	---	---	---
Loc13	M-59 Access Shaft	0.11	---	---	---	---
Loc24	Jefferson Hills	0.12	---	---	---	---
Loc20	Gascola Eq Facility	0.14	---	---	---	---
Loc14	Churchill Munic Bldg	0.17	---	---	---	---
Loc28	Plum Municipal Bldg	0.17	---	---	---	---
Loc09	Univ of Pittsburgh	0.22	---	---	---	---
Loc19	Sandy Creek Eq Facility	0.22	---	---	---	---
Loc22	North Fayette TWP	0.22	---	---	---	---
Loc08	AC Health Dept Bldg	0.23	---	---	---	---
Loc06	Carnegie Transit Time	0.24	---	---	---	---
Loc17	Chartiers Pump Station	0.24	---	---	---	---
Loc11	M-46 Access Shaft	0.25	---	---	---	---
Loc32	Arnold	0.25	---	---	---	---
Loc18	Oakdale Pump Station	0.26	---	---	---	---
Loc23	Clinton Munic Bldg	0.26	---	---	---	---
Loc02	ALCOSAN WWTP Lab	0.27	---	---	---	---
Loc04	Kennedy Twp PS	0.27	---	---	---	---
Loc10	PWSA-Highland Park	0.27	---	---	---	---
Loc12	Baldwin	0.27	---	---	---	---
Loc21	Moon TWP	0.27	---	---	---	---
Loc29	Bell Acres Munic Bldg	0.27	---	---	---	---
Loc05	Upper St. Clair	0.28	---	---	---	---
Loc16	Castle Shannon	0.28	---	---	---	---
Loc31	Hampton Municipal Bldg	0.28	---	---	---	---
Loc03	Shaler Munic Bldg	0.30	---	---	---	---
Loc33	Richland TWP	0.33	---	---	---	---
Loc27	Marshall TWP	0.35	---	---	---	---

Table 19. Summary of Individual RG Pairs for Event 3g

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)
Loc22	North Fayette TWP	0.07	0.10	0.08	-0.01	-14.3
Loc04	Kennedy Twp PS	0.09	0.12	0.10	-0.01	-11.1

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc06	Carnegie Transit Time	0.10	0.11	0.11	-0.01	-10.0
Loc09	Univ of Pittsburgh	0.11	0.11	0.12	-0.01	-9.1
Loc31	Hampton Municipal Bldg	0.12	0.10	0.13	-0.01	-8.3
03049500	Allegheny River at Natrona	0.12	0.12	0.12	0.00	0.0
KAGC	Pittsburgh Allegheny Cty	0.06	0.06	0.06	0.00	0.0
Loc02	ALCOSAN WWTP Lab	0.13	0.12	0.13	0.00	0.0
Loc05	Upper St. Clair	0.09	0.09	0.09	0.00	0.0
Loc07	Greentree Munic Bldg	0.11	0.11	0.11	0.00	0.0
Loc11	M-46 Access Shaft	0.10	0.09	0.10	0.00	0.0
Loc13	M-59 Access Shaft	0.07	0.07	0.07	0.00	0.0
Loc14	Churchill Munic Bldg	0.11	0.08	0.11	0.00	0.0
Loc15	Trafford Maint Bldg	0.06	0.05	0.06	0.00	0.0
Loc16	Castle Shannon	0.12	0.10	0.12	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.13	0.10	0.13	0.00	0.0
Loc20	Gascola Eq Facility	0.12	0.09	0.12	0.00	0.0
Loc28	Plum Municipal Bldg	0.13	0.10	0.13	0.00	0.0
Loc32	Arnold	0.12	0.12	0.12	0.00	0.0
Loc03	Shaler Munic Bldg	0.16	0.12	0.15	0.01	6.3
Loc18	Oakdale Pump Station	0.13	0.12	0.12	0.01	7.7
Loc12	Baldwin	0.12	0.09	0.11	0.01	8.3
Loc17	Chartiers Pump Station	0.12	0.10	0.11	0.01	8.3
Loc10	PWSA-Highland Park	0.18	0.12	0.16	0.02	11.1

Table 20. Summary of Individual RG Pairs for Event 3h

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc06	Carnegie Transit Time	0.09	0.13	0.09	0.00	0.0
Loc09	Univ of Pittsburgh	0.11	0.15	0.11	0.00	0.0
Loc11	M-46 Access Shaft	0.12	0.15	0.12	0.00	0.0
Loc12	Baldwin	0.11	0.12	0.11	0.00	0.0
Loc15	Trafford Maint Bldg	0.08	0.08	0.08	0.00	0.0
Loc16	Castle Shannon	0.10	0.12	0.10	0.00	0.0
Loc18	Oakdale Pump Station	0.07	0.12	0.07	0.00	0.0
Loc20	Gascola Eq Facility	0.12	0.12	0.12	0.00	0.0
Loc25	White Oak Public Works Bldg	0.08	0.06	0.08	0.00	0.0
Loc27	Marshall TWP	0.06	0.14	0.06	0.00	0.0
Loc28	Plum Municipal Bldg	0.12	0.14	0.12	0.00	0.0

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc32	Arnold	0.13	0.18	0.13	0.00	0.0

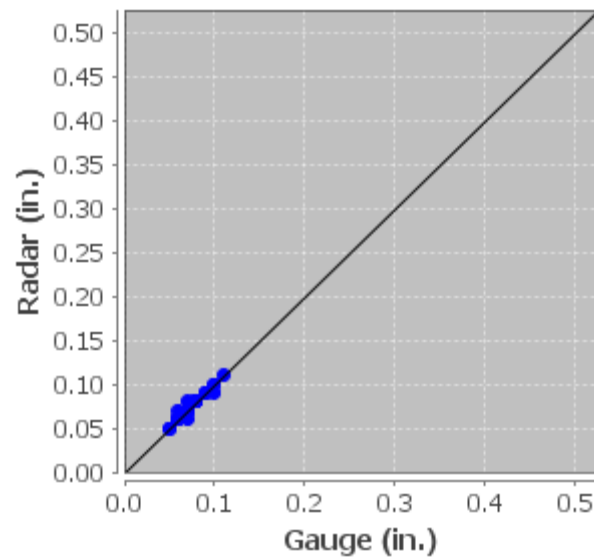


Figure 8. Scatter Plot of Gauge-Adjusted RG Pairs for Event 3a

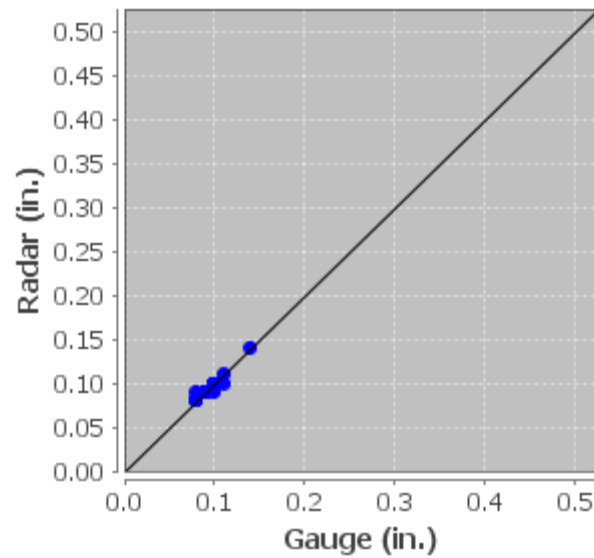


Figure 9. Scatter Plot of Gauge-Adjusted RG Pairs for Event 3b

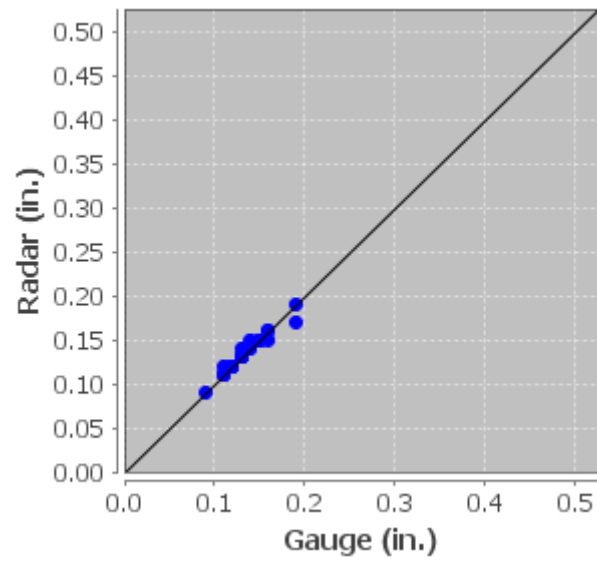


Figure 10. Scatter Plot of Gauge-Adjusted RG Pairs for Event 3c

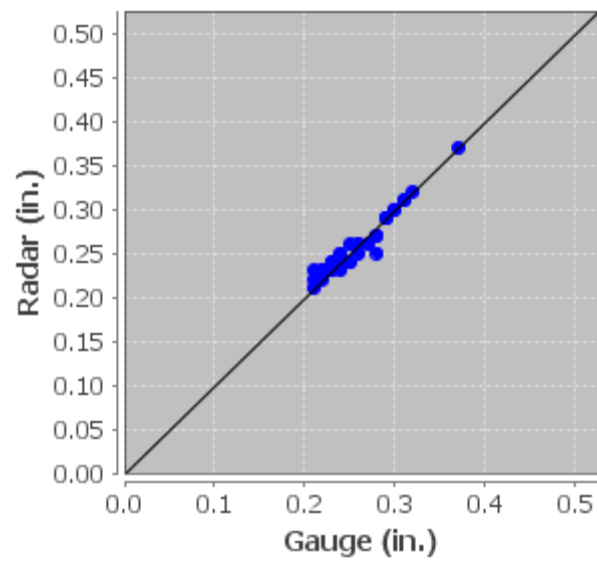


Figure 11. Scatter Plot of Gauge-Adjusted RG Pairs for Event 3d

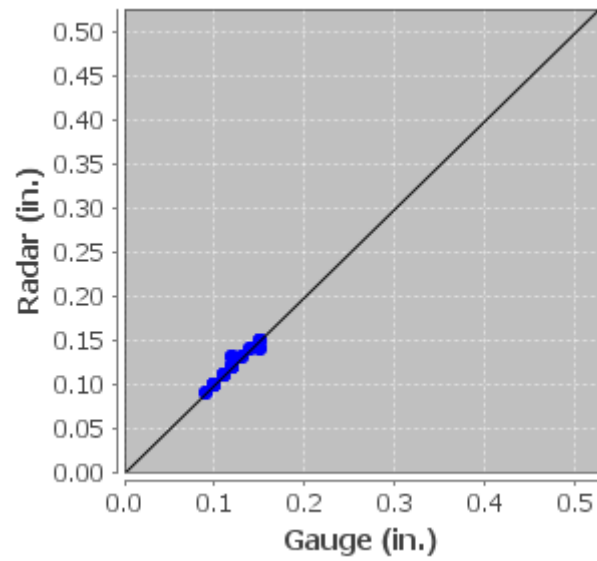


Figure 12. Scatter Plot of Gauge-Adjusted RG Pairs for Event 3e

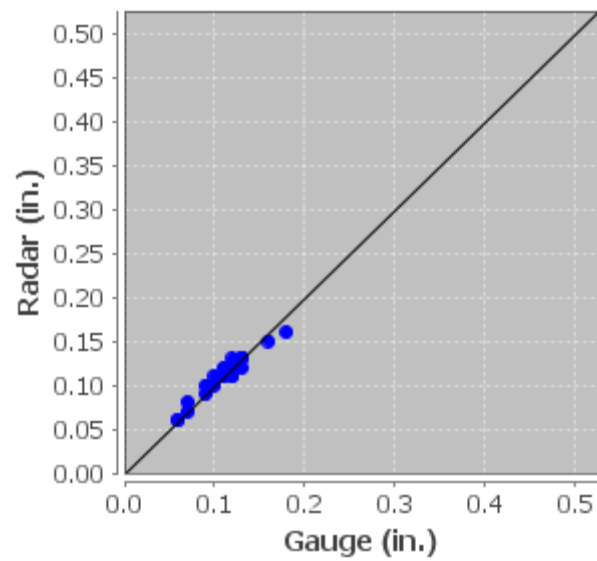


Figure 13. Scatter Plot of Gauge-Adjusted RG Pairs for Event 3g

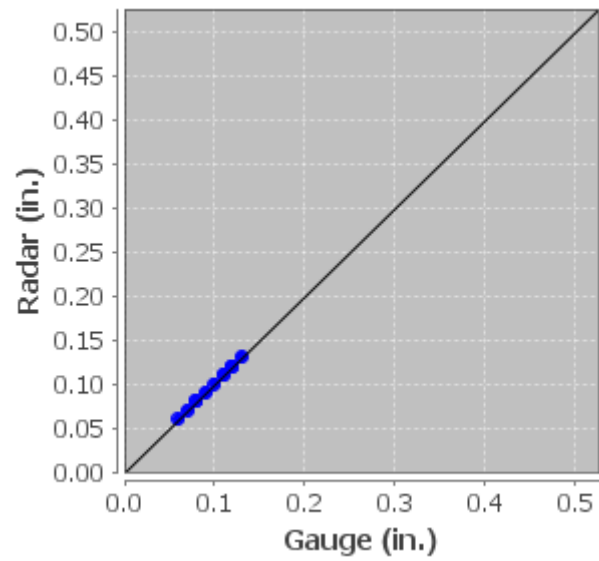


Figure 14. Scatter Plot of Gauge-Adjusted RG Pairs for Event 3h

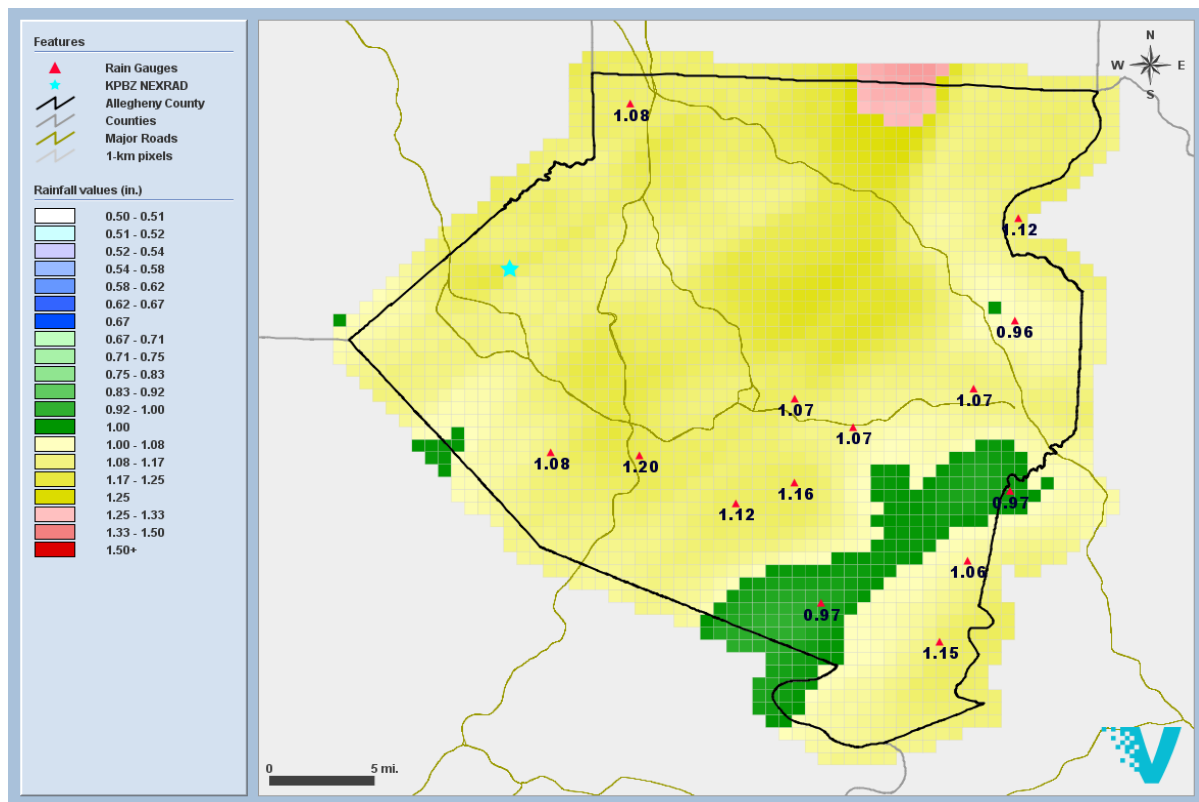


Figure 15. GARR Storm Total for Event 3

Table 21. Depth Duration Frequency Analyses for Event 3

Duration	Depth (in)	Pixel	Time (EST)	Frequency
15 minutes	0.065	154133	2019-01-20 03:30	<1 yr.
30 minutes	0.115	150130	2019-01-20 03:15	<1 yr.
1 hour	0.197	153134	2019-01-20 03:45	<1 yr.
2 hour	0.340	161158	2019-01-19 21:30	<1 yr.
3 hour	0.474	161158	2019-01-19 22:15	<1 yr.
6 hour	0.813	165162	2019-01-19 23:15	<1 yr.
12 hour	1.215	160112	2019-01-20 04:15	<1 yr.
24 hour	1.302	160112	2019-01-20 09:00	<1 yr.

Event 4: 2019-01-23

The analysis period was from 2019-01-23 05:00 EST to 2019-01-24 12:00 EST. The event was then split into seven sub-event periods at 2019-01-23 12:45 EST, 2019-01-23 20:30 EST, 2019-01-23 22:45 EST, 2019-01-24 02:45 EST, 2019-01-24 05:00 EST and 2019-01-24 07:15 EST to improve gauge adjustment of the radar. Gauge Only was used during Event 4d since all radar sources were either unavailable or provided insufficient rainfall information.

The gauges listed in [Appendix A](#) were not used to adjust the radar due to inconsistencies between the gauge and the radar or surrounding gauges, or they did not have data available for this event. Gauge Loc24 did not meet statistical criteria for gauge-adjustment of the radar and was not used to adjust the radar during Event 4a. Gauge Loc30 did not meet statistical criteria for gauge-adjustment of the radar and was not used to adjust the radar during Event 4f. Gauges Loc02, Loc03, Loc06, Loc07, Loc17, Loc18, Loc22, Loc23, Loc27 and Loc30 did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar during Event 4g.

The Eastern U.S. cool season stratiform Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 22 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 23 - 29 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. Figures 16 - 21 show the scatter plots of the gauge-adjusted RG pairs. Figure 22 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 2313 1-km² pixels range from 0.6 - 1.3 inches with a mean of 0.9 inches. Table 30 shows the Depth Duration Frequency (DDF) maximum values for the 1-km² pixels.

Table 22. GARR Statistics for Event 4

Event #	Radar	Event Date	Gauges Used (38)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E4a	KPBZ LII	2019-01-23	32	0.163	1.011	9.5	3.1
E4b	KPBZ LII	2019-01-23	34	0.109	0.925	18.7	3.5

Event #	Radar	Event Date	Gauges Used (38)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E4c	KPBZ LII	2019-01-23	33	0.161	1.407	28.0	2.2
E4d	Gauge Only	2019-01-23	30	0.137	---	---	---
E4e	KPBZ LII	2019-01-23	32	0.134	1.302	22.9	2.8
E4f	KPBZ LII	2019-01-23	31	0.115	1.086	12.7	3.1
E4g	KPBZ LII	2019-01-23	10	0.069	0.696	57.5	3.5

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc02	ALCOSAN WWTP Lab	0.12	0.15	0.13	-0.01	-8.3
Loc11	M-46 Access Shaft	0.13	0.15	0.14	-0.01	-7.7
Loc16	Castle Shannon	0.13	0.15	0.14	-0.01	-7.7
Loc21	Moon TWP	0.14	0.14	0.15	-0.01	-7.1
Loc09	Univ of Pittsburgh	0.15	0.16	0.16	-0.01	-6.7
Loc14	Churchill Munic Bldg	0.15	0.16	0.16	-0.01	-6.7
Loc17	Chartiers Pump Station	0.15	0.15	0.16	-0.01	-6.7
Loc31	Hampton Municipal Bldg	0.16	0.19	0.17	-0.01	-6.3
KAGC	Pittsburgh Allegheny Cty	0.15	0.15	0.15	0.00	0.0
Loc03	Shaler Munic Bldg	0.17	0.17	0.17	0.00	0.0
Loc05	Upper St. Clair	0.15	0.16	0.15	0.00	0.0
Loc12	Baldwin	0.14	0.15	0.14	0.00	0.0
Loc13	M-59 Access Shaft	0.13	0.14	0.13	0.00	0.0
Loc15	Trafford Maint Bldg	0.15	0.16	0.15	0.00	0.0
Loc18	Oakdale Pump Station	0.13	0.13	0.13	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.17	0.17	0.17	0.00	0.0
Loc22	North Fayette TWP	0.14	0.13	0.14	0.00	0.0
Loc23	Clinton Munic Bldg	0.16	0.14	0.16	0.00	0.0
Loc25	White Oak Public Works Bldg	0.14	0.15	0.14	0.00	0.0
Loc26	Elizabeth TWP Municipal Bldg	0.11	0.13	0.11	0.00	0.0
Loc27	Marshall TWP	0.18	0.16	0.18	0.00	0.0
Loc28	Plum Municipal Bldg	0.22	0.20	0.22	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.18	0.17	0.18	0.00	0.0
Loc30	McCandless Twn Hall	0.18	0.16	0.18	0.00	0.0
Loc32	Arnold	0.21	0.19	0.21	0.00	0.0
Loc33	Richland TWP	0.19	0.19	0.19	0.00	0.0
Loc06	Carnegie Transit Time	0.19	0.16	0.18	0.01	5.3

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc10	PWSA-Highland Park	0.19	0.16	0.18	0.01	5.3
Loc08	AC Health Dept Bldg	0.18	0.16	0.17	0.01	5.6
Loc20	Gascola Eq Facility	0.18	0.17	0.17	0.01	5.6
Loc04	Kennedy Twp PS	0.17	0.14	0.16	0.01	5.9
KPIT	Greater Pittsburgh Int'l	0.15	0.12	0.14	0.01	6.7

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc07	Greentree Munic Bldg	0.07	0.10	0.08	-0.01	-14.3
Loc09	Univ of Pittsburgh	0.08	0.11	0.09	-0.01	-12.5
Loc12	Baldwin	0.09	0.12	0.10	-0.01	-11.1
Loc18	Oakdale Pump Station	0.09	0.11	0.10	-0.01	-11.1
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.09	0.09	0.09	0.00	0.0
KAGC	Pittsburgh Allegheny Cty	0.13	0.14	0.13	0.00	0.0
Loc02	ALCOSAN WWTP Lab	0.07	0.09	0.07	0.00	0.0
Loc03	Shaler Munic Bldg	0.08	0.09	0.08	0.00	0.0
Loc05	Upper St. Clair	0.10	0.12	0.10	0.00	0.0
Loc06	Carnegie Transit Time	0.08	0.11	0.08	0.00	0.0
Loc08	AC Health Dept Bldg	0.09	0.11	0.09	0.00	0.0
Loc11	M-46 Access Shaft	0.10	0.12	0.10	0.00	0.0
Loc13	M-59 Access Shaft	0.12	0.14	0.12	0.00	0.0
Loc14	Churchill Munic Bldg	0.11	0.13	0.11	0.00	0.0
Loc15	Trafford Maint Bldg	0.18	0.20	0.18	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.12	0.12	0.12	0.00	0.0
Loc21	Moon TWP	0.11	0.08	0.11	0.00	0.0
Loc22	North Fayette TWP	0.11	0.11	0.11	0.00	0.0
Loc23	Clinton Munic Bldg	0.12	0.09	0.12	0.00	0.0
Loc24	Jefferson Hills	0.15	0.16	0.15	0.00	0.0
Loc25	White Oak Public Works Bldg	0.16	0.19	0.16	0.00	0.0
Loc26	Elizabeth TWP Municipal Bldg	0.13	0.16	0.13	0.00	0.0
Loc27	Marshall TWP	0.08	0.06	0.08	0.00	0.0
Loc28	Plum Municipal Bldg	0.12	0.16	0.12	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.08	0.07	0.08	0.00	0.0
Loc30	McCandless Twn Hall	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* (%)
Loc31	Hampton Municipal Bldg	0.07	0.09	0.07	0.00	0.0
Loc32	Arnold	0.13	0.14	0.13	0.00	0.0
Loc33	Richland TWP	0.08	0.06	0.08	0.00	0.0
KPIT	Greater Pittsburgh Int'l	0.12	0.08	0.11	0.01	8.3
Loc16	Castle Shannon	0.12	0.12	0.11	0.01	8.3
Loc04	Kennedy Twp PS	0.11	0.10	0.10	0.01	9.1
Loc10	PWSA-Highland Park	0.11	0.11	0.10	0.01	9.1
Loc17	Chartiers Pump Station	0.10	0.11	0.09	0.01	10.0

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

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)
KAGC	Pittsburgh Allegheny Cty	0.13	0.11	0.14	-0.01	-7.7
Loc30	McCandless Twn Hall	0.13	0.10	0.14	-0.01	-7.7
03085734	Ohio River at Emsworth Dam Lower Pool at Emsworth	0.15	0.12	0.16	-0.01	-6.7
Loc09	Univ of Pittsburgh	0.18	0.13	0.19	-0.01	-5.6
KPIT	Greater Pittsburgh Int'l	0.15	0.11	0.15	0.00	0.0
Loc02	ALCOSAN WWTP Lab	0.17	0.13	0.17	0.00	0.0
Loc03	Shaler Munic Bldg	0.18	0.13	0.18	0.00	0.0
Loc05	Upper St. Clair	0.23	0.14	0.23	0.00	0.0
Loc07	Greentree Munic Bldg	0.19	0.14	0.19	0.00	0.0
Loc11	M-46 Access Shaft	0.16	0.11	0.16	0.00	0.0
Loc12	Baldwin	0.17	0.13	0.17	0.00	0.0
Loc13	M-59 Access Shaft	0.14	0.10	0.14	0.00	0.0
Loc14	Churchill Munic Bldg	0.15	0.11	0.15	0.00	0.0
Loc15	Trafford Maint Bldg	0.11	0.11	0.11	0.00	0.0
Loc17	Chartiers Pump Station	0.22	0.14	0.22	0.00	0.0
Loc18	Oakdale Pump Station	0.18	0.12	0.18	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.16	0.11	0.16	0.00	0.0
Loc21	Moon TWP	0.18	0.12	0.18	0.00	0.0
Loc22	North Fayette TWP	0.17	0.11	0.17	0.00	0.0
Loc23	Clinton Munic Bldg	0.16	0.12	0.16	0.00	0.0
Loc24	Jefferson Hills	0.15	0.11	0.15	0.00	0.0
Loc25	White Oak Public Works Bldg	0.11	0.11	0.11	0.00	0.0

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc26	Elizabeth TWP Municipal Bldg	0.12	0.13	0.12	0.00	0.0
Loc28	Plum Municipal Bldg	0.13	0.10	0.13	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.17	0.10	0.17	0.00	0.0
Loc31	Hampton Municipal Bldg	0.16	0.12	0.16	0.00	0.0
Loc32	Arnold	0.16	0.11	0.16	0.00	0.0
Loc33	Richland TWP	0.17	0.10	0.17	0.00	0.0
Loc10	PWSA-Highland Park	0.22	0.14	0.21	0.01	4.5
Loc08	AC Health Dept Bldg	0.21	0.14	0.20	0.01	4.8
Loc16	Castle Shannon	0.19	0.13	0.18	0.01	5.3
Loc04	Kennedy Twp PS	0.18	0.12	0.17	0.01	5.6
Loc27	Marshall TWP	0.12	0.07	0.11	0.01	8.3

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc06	Carnegie Transit Time	0.08	---	---	---	---
Loc02	ALCOSAN WWTP Lab	0.09	---	---	---	---
Loc07	Greentree Munic Bldg	0.09	---	---	---	---
Loc09	Univ of Pittsburgh	0.10	---	---	---	---
Loc18	Oakdale Pump Station	0.10	---	---	---	---
Loc30	McCandless Twn Hall	0.10	---	---	---	---
Loc31	Hampton Municipal Bldg	0.10	---	---	---	---
Loc03	Shaler Munic Bldg	0.11	---	---	---	---
Loc08	AC Health Dept Bldg	0.11	---	---	---	---
Loc16	Castle Shannon	0.11	---	---	---	---
Loc17	Chartiers Pump Station	0.11	---	---	---	---
Loc27	Marshall TWP	0.11	---	---	---	---
Loc29	Bell Acres Munic Bldg	0.11	---	---	---	---
Loc05	Upper St. Clair	0.12	---	---	---	---
Loc11	M-46 Access Shaft	0.12	---	---	---	---
Loc19	Sandy Creek Eq Facility	0.12	---	---	---	---
Loc22	North Fayette TWP	0.12	---	---	---	---
Loc23	Clinton Munic Bldg	0.12	---	---	---	---
Loc33	Richland TWP	0.12	---	---	---	---
Loc10	PWSA-Highland Park	0.13	---	---	---	---
Loc12	Baldwin	0.13	---	---	---	---

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc21	Moon TWP	0.13	---	---	---	---
Loc14	Churchill Munic Bldg	0.15	---	---	---	---
Loc13	M-59 Access Shaft	0.16	---	---	---	---
Loc32	Arnold	0.16	---	---	---	---
Loc24	Jefferson Hills	0.17	---	---	---	---
Loc28	Plum Municipal Bldg	0.18	---	---	---	---
Loc15	Trafford Maint Bldg	0.20	---	---	---	---
Loc25	White Oak Public Works Bldg	0.21	---	---	---	---
Loc26	Elizabeth TWP Municipal Bldg	0.22	---	---	---	---

Table 27. Summary of Individual RG Pairs for Event 4e

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc06	Carnegie Transit Time	0.09	0.09	0.10	-0.01	-11.1
Loc09	Univ of Pittsburgh	0.11	0.10	0.12	-0.01	-9.1
Loc08	AC Health Dept Bldg	0.12	0.11	0.13	-0.01	-8.3
Loc11	M-46 Access Shaft	0.12	0.11	0.13	-0.01	-8.3
Loc14	Churchill Munic Bldg	0.13	0.13	0.14	-0.01	-7.7
KAGC	Pittsburgh Allegheny Cty	0.13	0.11	0.13	0.00	0.0
KPIT	Greater Pittsburgh Int'l	0.10	0.06	0.10	0.00	0.0
Loc02	ALCOSAN WWTP Lab	0.13	0.09	0.13	0.00	0.0
Loc03	Shaler Munic Bldg	0.14	0.10	0.14	0.00	0.0
Loc04	Kennedy Twp PS	0.11	0.08	0.11	0.00	0.0
Loc05	Upper St. Clair	0.11	0.08	0.11	0.00	0.0
Loc12	Baldwin	0.12	0.11	0.12	0.00	0.0
Loc15	Trafford Maint Bldg	0.16	0.12	0.16	0.00	0.0
Loc16	Castle Shannon	0.11	0.10	0.11	0.00	0.0
Loc17	Chartiers Pump Station	0.11	0.08	0.11	0.00	0.0
Loc18	Oakdale Pump Station	0.11	0.07	0.11	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.15	0.12	0.15	0.00	0.0
Loc21	Moon TWP	0.10	0.08	0.10	0.00	0.0
Loc22	North Fayette TWP	0.10	0.05	0.10	0.00	0.0
Loc23	Clinton Munic Bldg	0.11	0.07	0.11	0.00	0.0
Loc24	Jefferson Hills	0.17	0.12	0.17	0.00	0.0
Loc25	White Oak Public Works Bldg	0.13	0.10	0.13	0.00	0.0
Loc26	Elizabeth TWP Municipal Bldg	0.16	0.10	0.16	0.00	0.0
Loc27	Marshall TWP	0.12	0.09	0.12	0.00	0.0

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc28	Plum Municipal Bldg	0.19	0.14	0.19	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.11	0.09	0.11	0.00	0.0
Loc30	McCandless Twn Hall	0.12	0.10	0.12	0.00	0.0
Loc31	Hampton Municipal Bldg	0.14	0.10	0.14	0.00	0.0
Loc32	Arnold	0.16	0.13	0.16	0.00	0.0
Loc33	Richland TWP	0.13	0.09	0.13	0.00	0.0
Loc13	M-59 Access Shaft	0.15	0.11	0.14	0.01	6.7
Loc10	PWSA-Highland Park	0.16	0.11	0.14	0.02	12.5

Table 28. Summary of Individual RG Pairs for Event 4f

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc08	AC Health Dept Bldg	0.09	0.11	0.11	-0.02	-22.2
Loc07	Greentree Munic Bldg	0.09	0.11	0.10	-0.01	-11.1
Loc09	Univ of Pittsburgh	0.09	0.10	0.10	-0.01	-11.1
KAGC	Pittsburgh Allegheny Cty	0.12	0.11	0.12	0.00	0.0
KPIT	Greater Pittsburgh Int'l	0.07	0.08	0.07	0.00	0.0
Loc02	ALCOSAN WWTP Lab	0.10	0.10	0.10	0.00	0.0
Loc03	Shaler Munic Bldg	0.12	0.10	0.12	0.00	0.0
Loc04	Kennedy Twp PS	0.09	0.08	0.09	0.00	0.0
Loc05	Upper St. Clair	0.11	0.09	0.11	0.00	0.0
Loc06	Carnegie Transit Time	0.11	0.10	0.11	0.00	0.0
Loc14	Churchill Munic Bldg	0.13	0.11	0.13	0.00	0.0
Loc15	Trafford Maint Bldg	0.14	0.13	0.14	0.00	0.0
Loc16	Castle Shannon	0.10	0.10	0.10	0.00	0.0
Loc17	Chartiers Pump Station	0.11	0.10	0.11	0.00	0.0
Loc18	Oakdale Pump Station	0.08	0.08	0.08	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.14	0.11	0.14	0.00	0.0
Loc21	Moon TWP	0.07	0.09	0.07	0.00	0.0
Loc22	North Fayette TWP	0.08	0.08	0.08	0.00	0.0
Loc23	Clinton Munic Bldg	0.08	0.08	0.08	0.00	0.0
Loc24	Jefferson Hills	0.12	0.12	0.12	0.00	0.0
Loc25	White Oak Public Works Bldg	0.15	0.12	0.15	0.00	0.0
Loc26	Elizabeth TWP Municipal Bldg	0.14	0.13	0.14	0.00	0.0
Loc27	Marshall TWP	0.09	0.08	0.09	0.00	0.0
Loc28	Plum Municipal Bldg	0.15	0.12	0.15	0.00	0.0
Loc29	Bell Acres Munic Bldg	0.07	0.09	0.07	0.00	0.0

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc31	Hampton Municipal Bldg	0.11	0.10	0.11	0.00	0.0
Loc32	Arnold	0.15	0.13	0.15	0.00	0.0
Loc33	Richland TWP	0.10	0.09	0.10	0.00	0.0
Loc11	M-46 Access Shaft	0.14	0.11	0.13	0.01	7.1
Loc12	Baldwin	0.12	0.10	0.11	0.01	8.3
Loc10	PWSA-Highland Park	0.14	0.11	0.12	0.02	14.3

Table 29. Summary of Individual RG Pairs for Event 4g

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)
Loc04	Kennedy Twp PS	0.06	0.07	0.06	0.00	0.0
Loc09	Univ of Pittsburgh	0.05	0.11	0.05	0.00	0.0
Loc10	PWSA-Highland Park	0.06	0.10	0.06	0.00	0.0
Loc11	M-46 Access Shaft	0.07	0.12	0.07	0.00	0.0
Loc15	Trafford Maint Bldg	0.14	0.15	0.14	0.00	0.0
Loc19	Sandy Creek Eq Facility	0.05	0.11	0.05	0.00	0.0
Loc25	White Oak Public Works Bldg	0.12	0.16	0.12	0.00	0.0
Loc26	Elizabeth TWP Municipal Bldg	0.14	0.15	0.14	0.00	0.0
Loc28	Plum Municipal Bldg	0.09	0.12	0.09	0.00	0.0
Loc32	Arnold	0.06	0.12	0.06	0.00	0.0

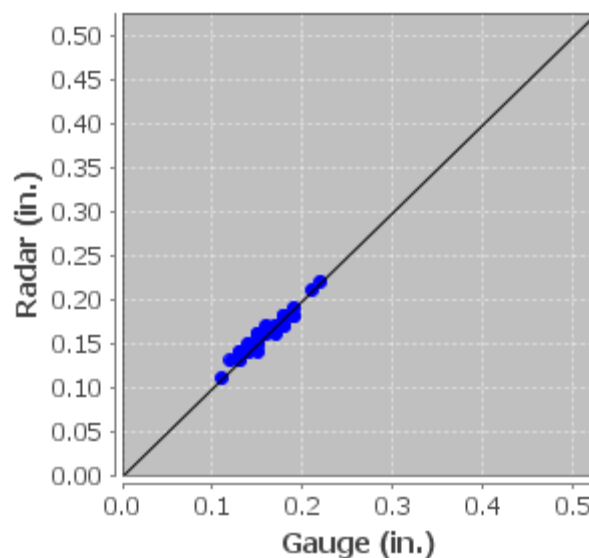


Figure 16. Scatter Plot of Gauge-Adjusted RG Pairs for Event 4a

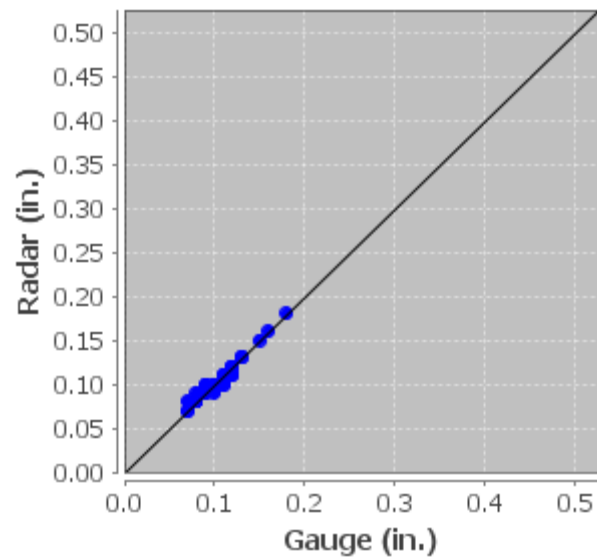


Figure 17. Scatter Plot of Gauge-Adjusted RG Pairs for Event 4b

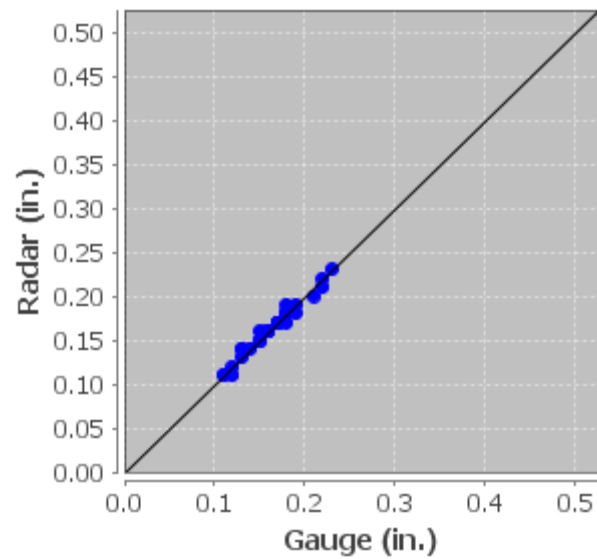


Figure 18. Scatter Plot of Gauge-Adjusted RG Pairs for Event 4c

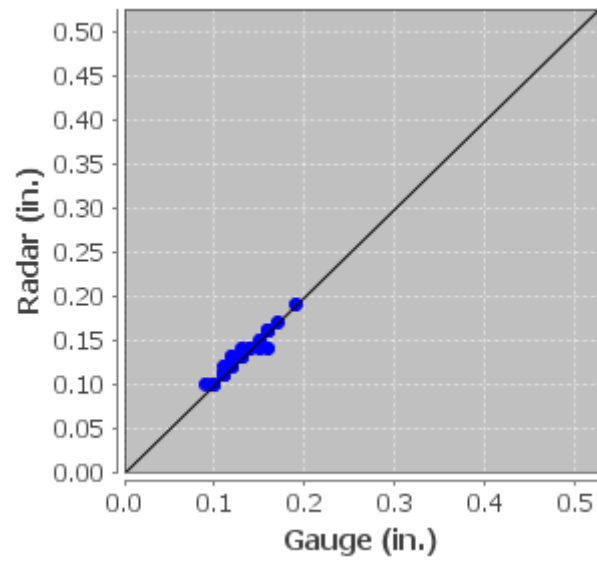


Figure 19. Scatter Plot of Gauge-Adjusted RG Pairs for Event 4e

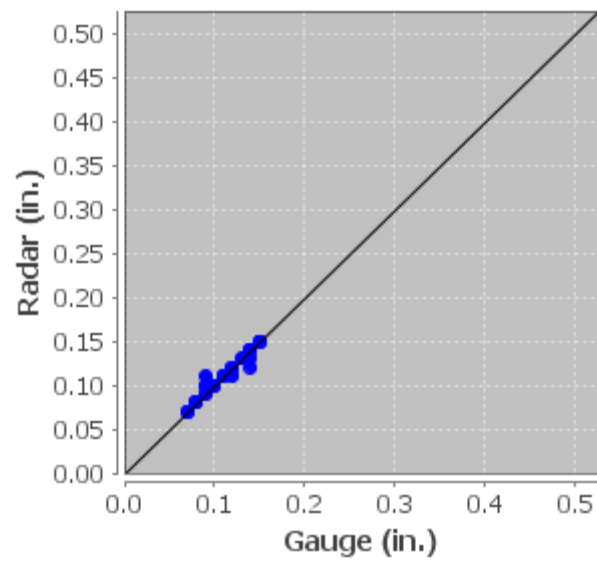


Figure 20. Scatter Plot of Gauge-Adjusted RG Pairs for Event 4f

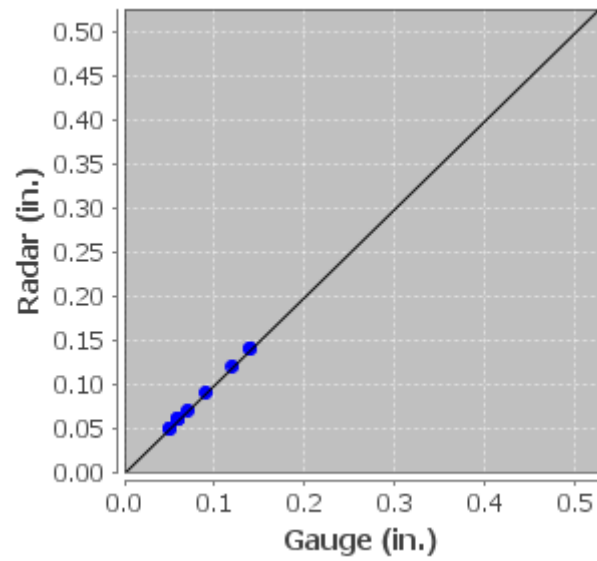


Figure 21. Scatter Plot of Gauge-Adjusted RG Pairs for Event 4g

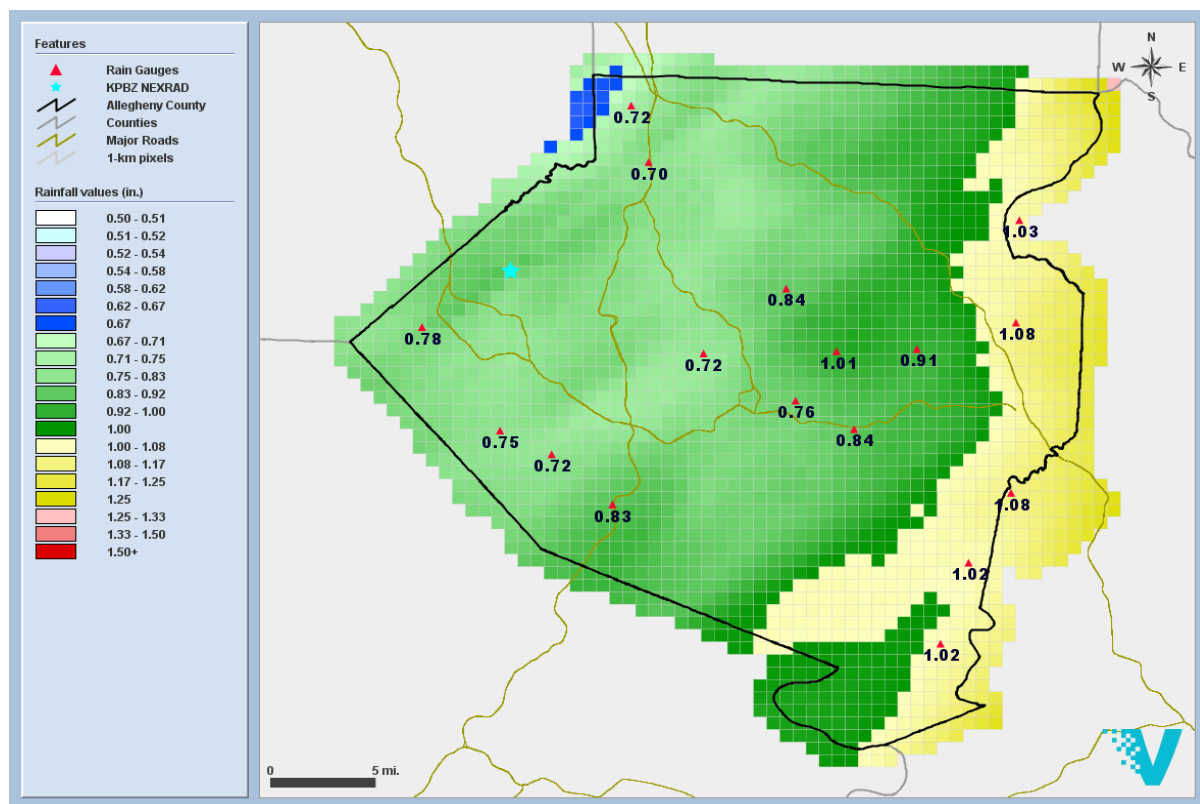


Figure 22. GARR Storm Total for Event 4

Table 30. Depth Duration Frequency Analyses for Event 4

Duration	Depth (in)	Pixel	Time (EST)	Frequency
15 minutes	0.045	152135	2019-01-23 22:15	<1 yr.
30 minutes	0.078	152135	2019-01-23 22:15	<1 yr.
1 hour	0.133	173134	2019-01-24 07:15	<1 yr.
2 hour	0.226	174118	2019-01-24 04:30	<1 yr.
3 hour	0.293	174118	2019-01-24 05:15	<1 yr.
6 hour	0.551	174113	2019-01-24 07:15	<1 yr.
12 hour	0.876	165164	2019-01-24 07:30	<1 yr.
24 hour	1.213	174113	2019-01-24 09:15	<1 yr.

Appendices

[Appendix A](#) - Gauge Summary Table
[Appendix B](#) - Event 1 (2019-01-05) CDPs
[Appendix C](#) - Event 2 (2019-01-08) CDPs
[Appendix D](#) - Event 3 (2019-01-19) CDPs
[Appendix E](#) - Event 4 (2019-01-23) CDPs

Appendix A - Gauge Summary 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

	<u>E1a</u>	<u>E1b</u>	<u>E2a</u>	<u>E2b</u>	<u>E3a</u>	<u>E3b</u>
Gauge	2019-01-05	2019-01-05	2019-01-08	2019-01-08	2019-01-19	2019-01-19
Loc01	U	U	U	U	ND	ND
Loc02						
Loc03						
Loc04						
Loc05						
Loc06						
Loc07						U
Loc08						
Loc09						
Loc10						
Loc11						
Loc12						
Loc13						
Loc14						
Loc15						
Loc16						
Loc17						
Loc18						
Loc19						
Loc20						
Loc21						
Loc22						
Loc23		O				
Loc24						
Loc25						
Loc26						
Loc27						
Loc28						

	<u>E1a</u>	<u>E1b</u>	<u>E2a</u>	<u>E2b</u>	<u>E3a</u>	<u>E3b</u>
Gauge	2019-01-05	2019-01-05	2019-01-08	2019-01-08	2019-01-19	2019-01-19
Loc29						
Loc30						U
Loc31						
Loc32						
Loc33						
KAGC		T				
KPIT		T				
03049500		U	Z	U		
03085500	ND	ND	ND	ND	ND	ND
03085734		T	Z	U		

	<u>E3c</u>	<u>E3d</u>	<u>E3e</u>	<u>E3f</u>	<u>E3g</u>	<u>E3h</u>
Gauge	2019-01-19	2019-01-19	2019-01-19	2019-01-19	2019-01-19	2019-01-19
Loc01	ND	ND	ND	ND	ND	ND
Loc02						F/M
Loc03						F/M
Loc04						F/M
Loc05						F/M
Loc06						
Loc07			U	U		U
Loc08					F/M	F/M
Loc09						
Loc10						F/M
Loc11						
Loc12						
Loc13						F/M
Loc14						F/M
Loc15						
Loc16						
Loc17						F/M
Loc18						
Loc19						F/M
Loc20						
Loc21		U			F/M	F/M
Loc22						F/M
Loc23	S				F/M	F/M
Loc24						
Loc25						
Loc26						
Loc27						

	<u>E3c</u>	<u>E3d</u>	<u>E3e</u>	<u>E3f</u>	<u>E3g</u>	<u>E3h</u>
Gauge	2019-01-19	2019-01-19	2019-01-19	2019-01-19	2019-01-19	2019-01-19
Loc28						
Loc29					F/M	F/M
Loc30	U	U	U	O	F/M	F/M
Loc31						F/M
Loc32						
Loc33	O				F/M	F/M
KAGC				T		F/M
KPIT				T	F/M	F/M
03049500				U		F/M
03085500	ND	ND	ND	ND	ND	ND
03085734		U	U	U	F/M	F/M

	<u>E4a</u>	<u>E4b</u>	<u>E4c</u>	<u>E4d</u>	<u>E4e</u>	<u>E4f</u>
Gauge	2019-01-23	2019-01-23	2019-01-23	2019-01-23	2019-01-23	2019-01-23
Loc01	ND	ND	ND	ND	ND	ND
Loc02						
Loc03						
Loc04				O		
Loc05						
Loc06			U			
Loc07	U				U	
Loc08						
Loc09						
Loc10						
Loc11						
Loc12						
Loc13						U
Loc14						
Loc15						
Loc16						
Loc17						
Loc18						
Loc19						
Loc20		ND	ND	ND	ND	ND
Loc21						
Loc22						
Loc23						
Loc24						
Loc25						
Loc26						
Loc27						

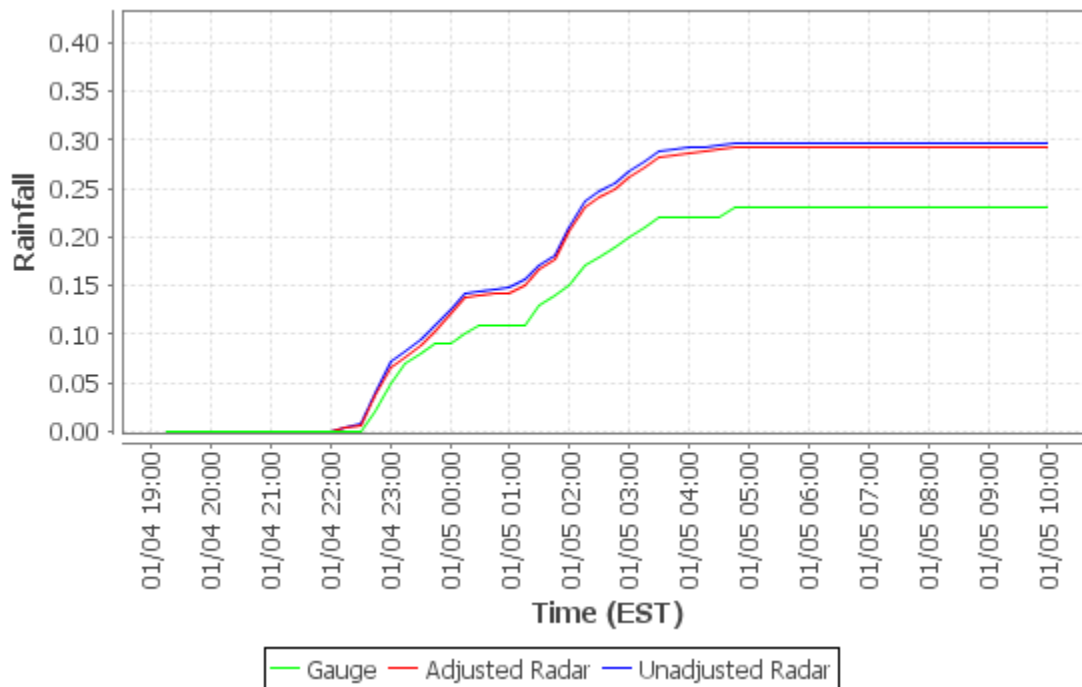
	<u>E4a</u>	<u>E4b</u>	<u>E4c</u>	<u>E4d</u>	<u>E4e</u>	<u>E4f</u>
Gauge	2019-01-23	2019-01-23	2019-01-23	2019-01-23	2019-01-23	2019-01-23
Loc28						
Loc29						
Loc30						
Loc31						
Loc32						
Loc33						
KAGC				T		
KPIT				T		
03049500	S	O	U	S	S	S
03085500	ND	ND	ND	ND	ND	ND
03085734	U			T	U	U

	<u>E4g</u>
Gauge	2019-01-23
Loc01	ND
Loc02	
Loc03	
Loc04	
Loc05	F/M
Loc06	
Loc07	
Loc08	F/M
Loc09	
Loc10	
Loc11	
Loc12	F/M
Loc13	F/M
Loc14	F/M
Loc15	
Loc16	F/M
Loc17	
Loc18	
Loc19	
Loc20	ND
Loc21	F/M
Loc22	
Loc23	
Loc24	F/M
Loc25	
Loc26	
Loc27	

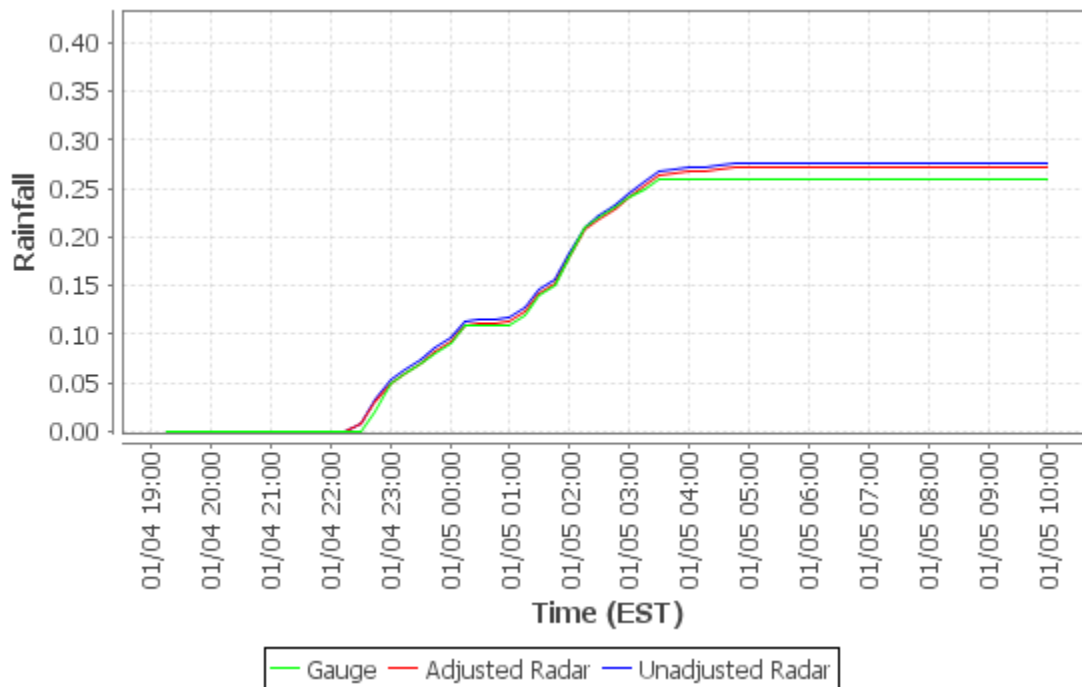
	<u>E4g</u>
Gauge	2019-01-23
Loc28	
Loc29	F/M
Loc30	
Loc31	F/M
Loc32	
Loc33	F/M
KAGC	F/M
KPIT	F/M
03049500	F/M
03085500	ND
03085734	F/M

Appendix B - Event 1 (2019-01-05) CDPs

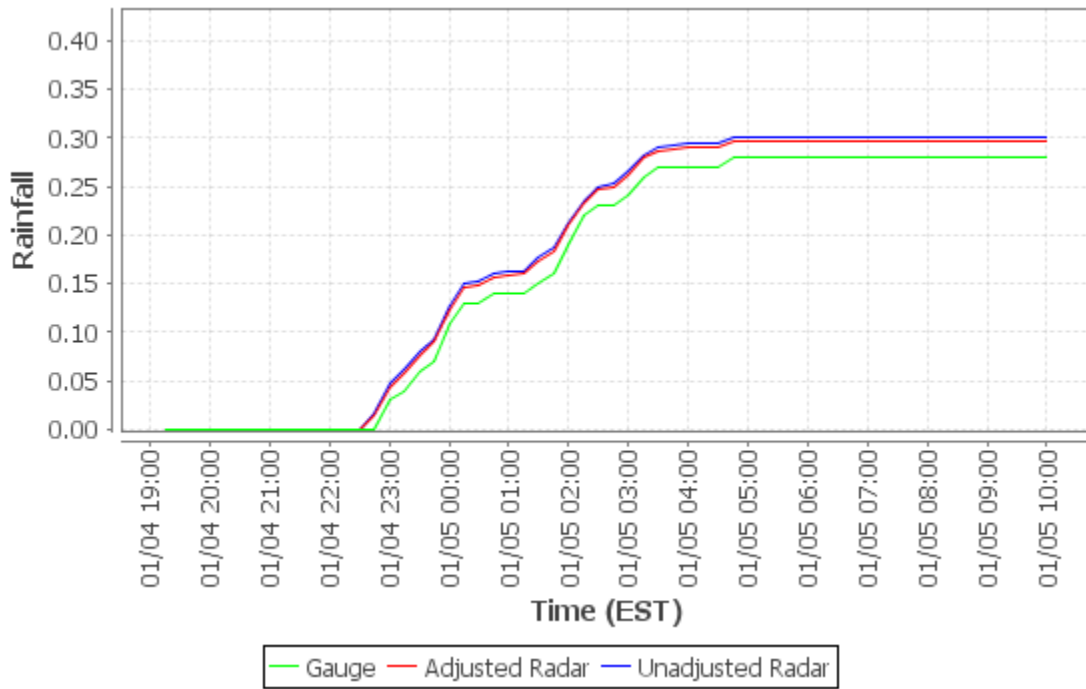
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



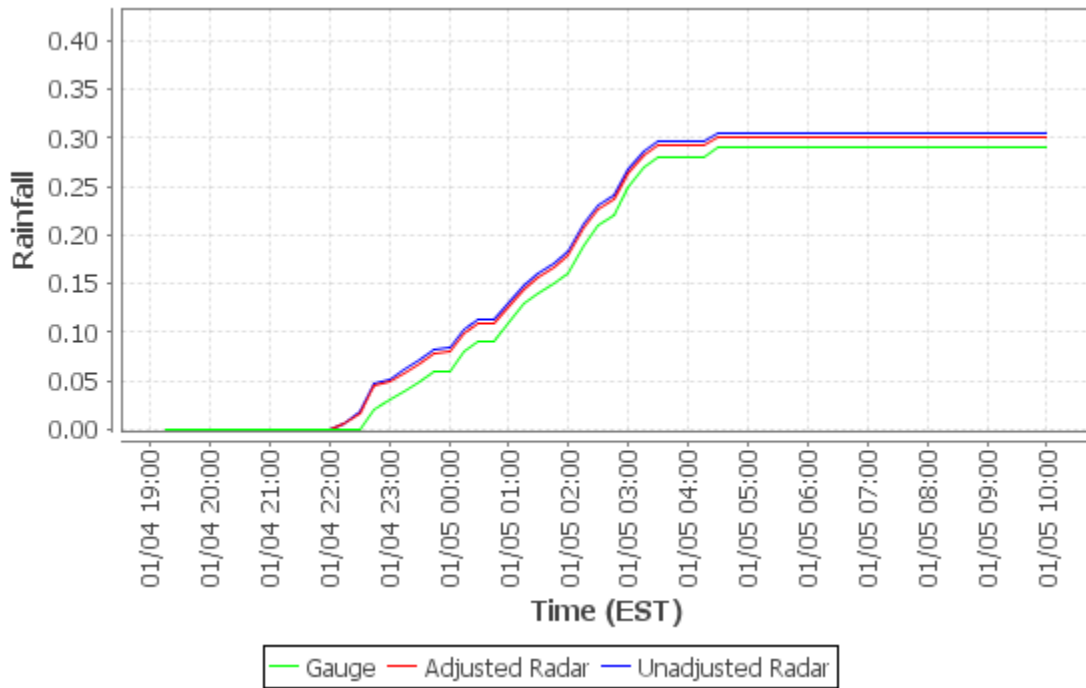
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



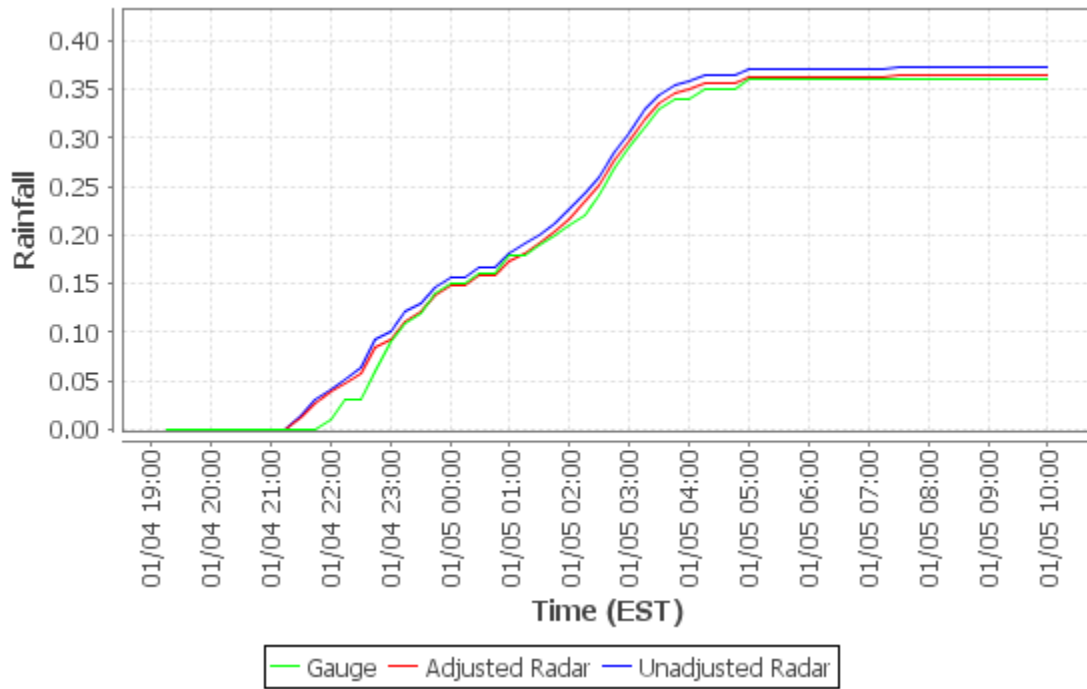
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



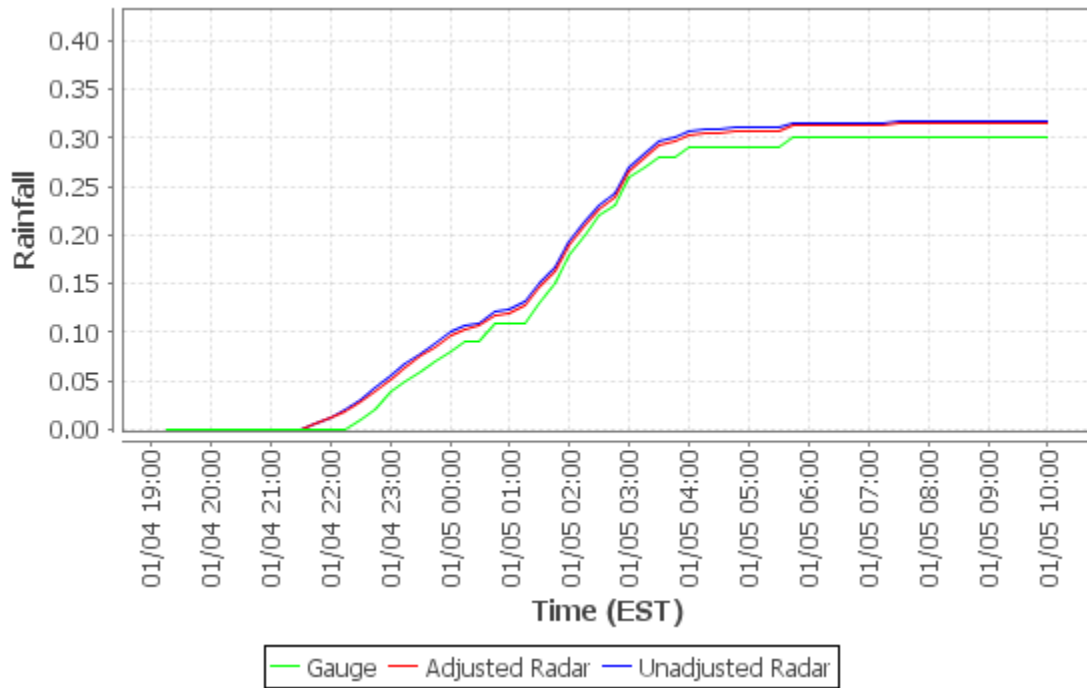
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



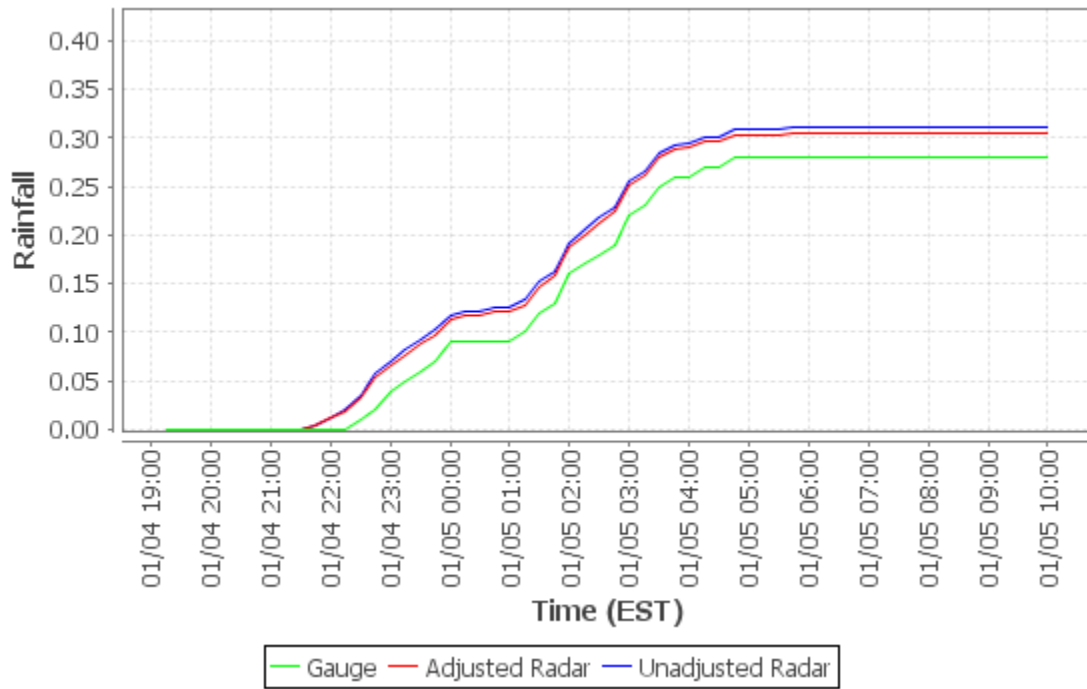
Cumulative Distribution Plot - Upper St. Clair (Loc05)



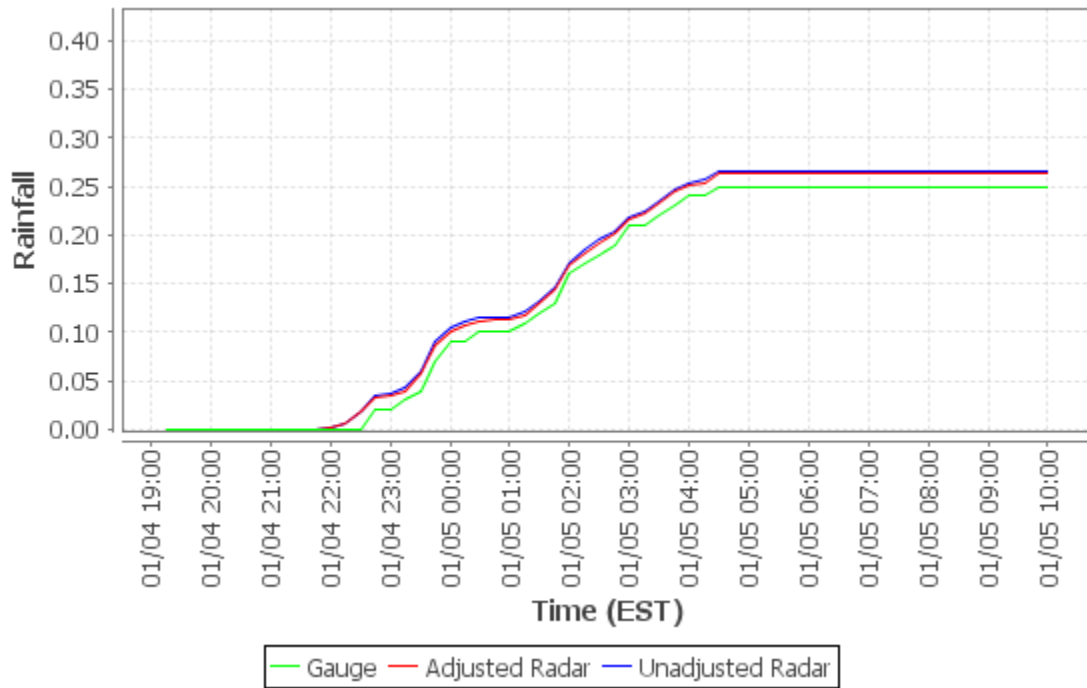
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



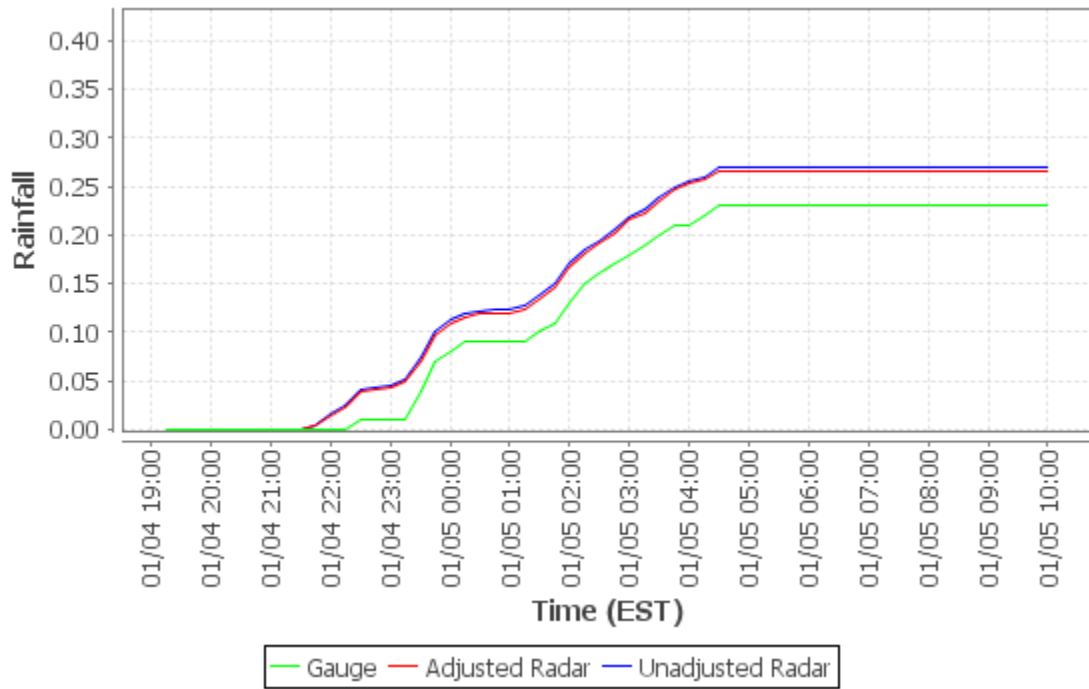
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



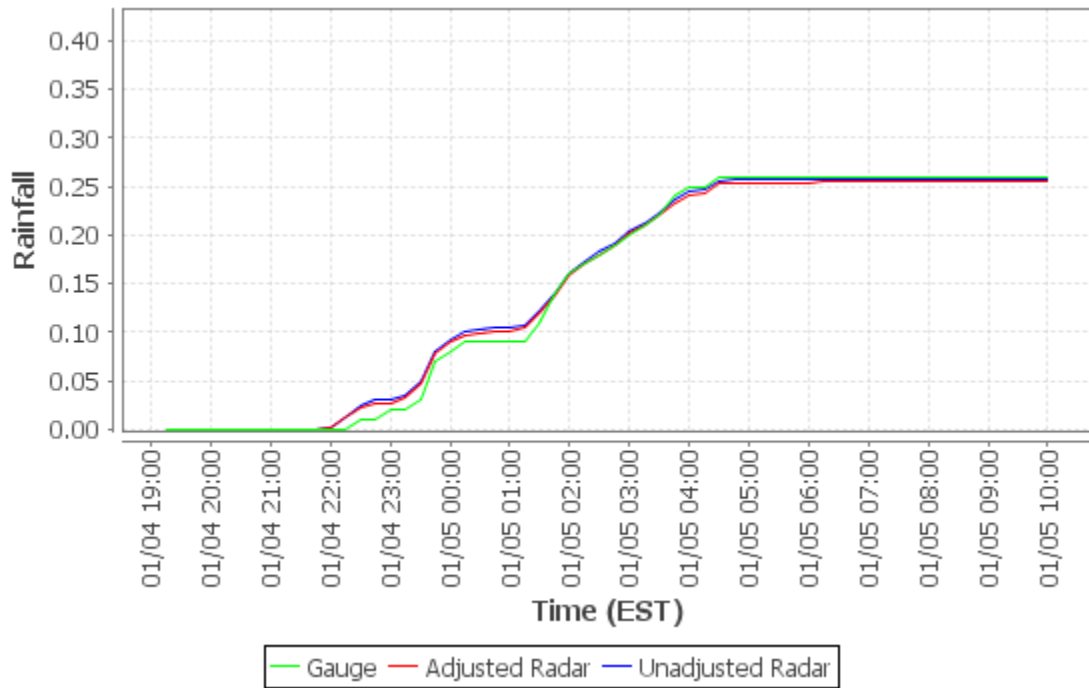
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



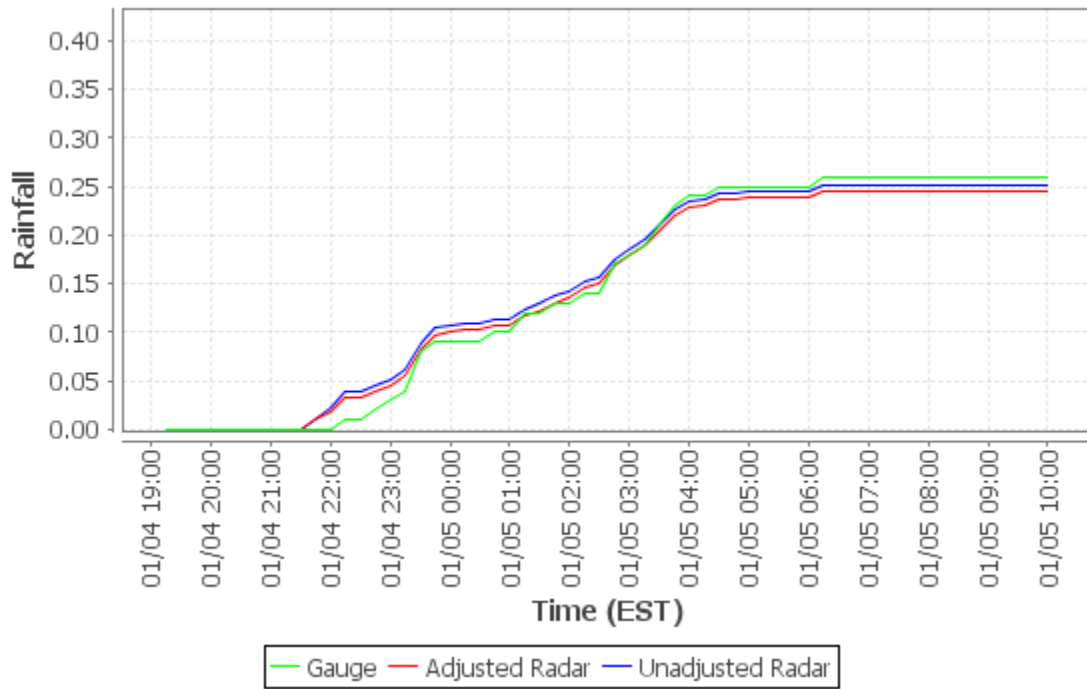
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



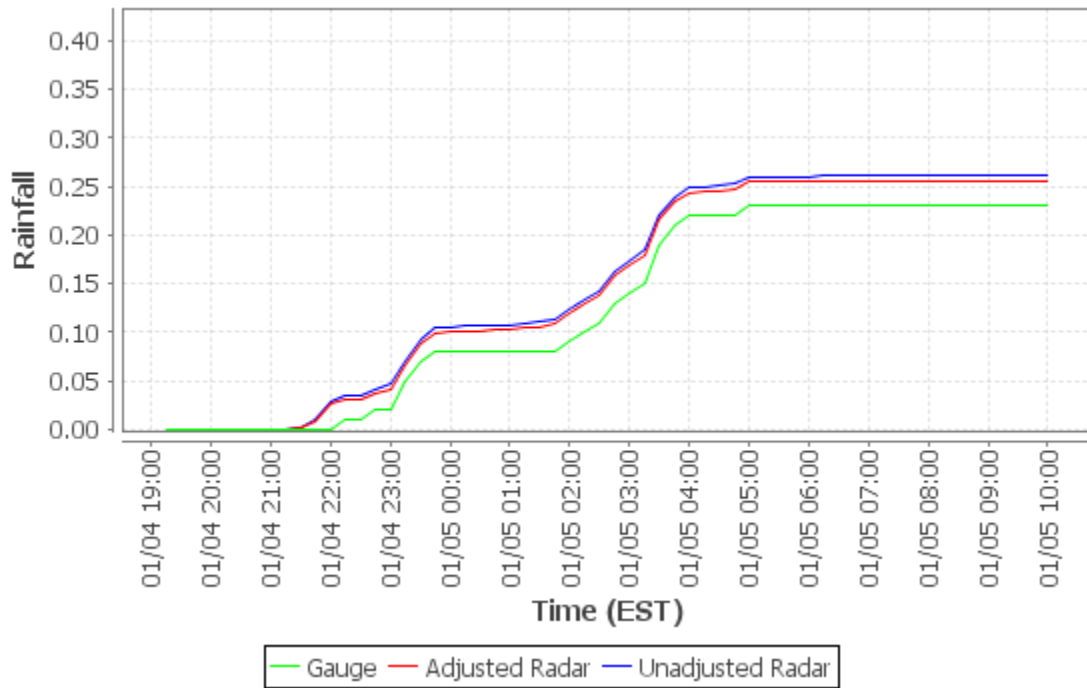
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



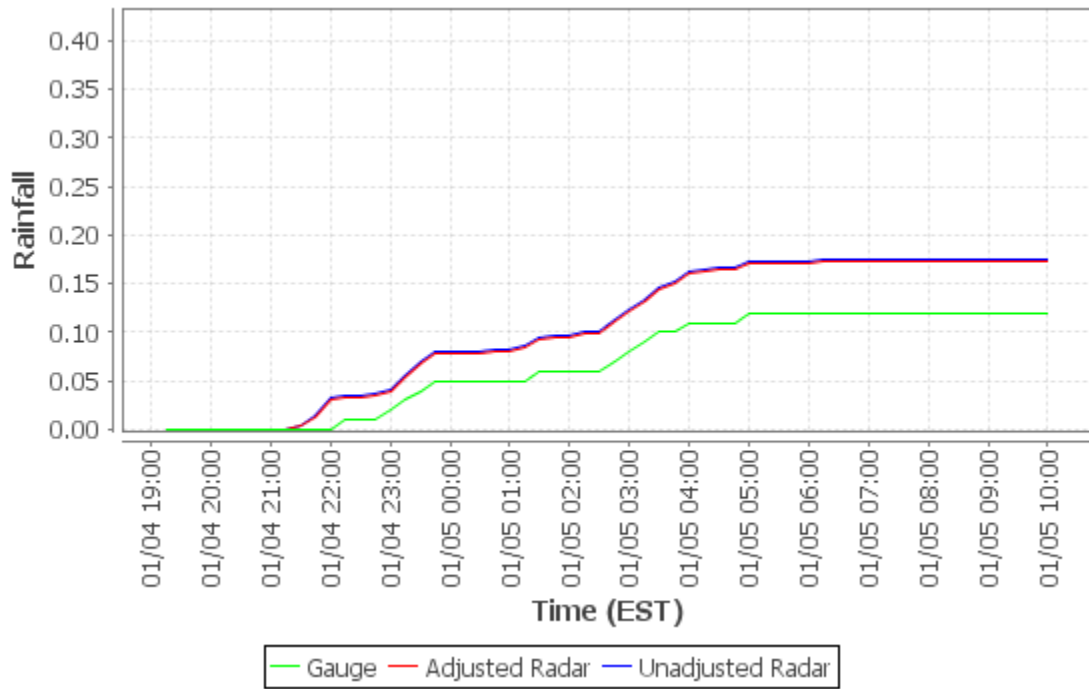
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



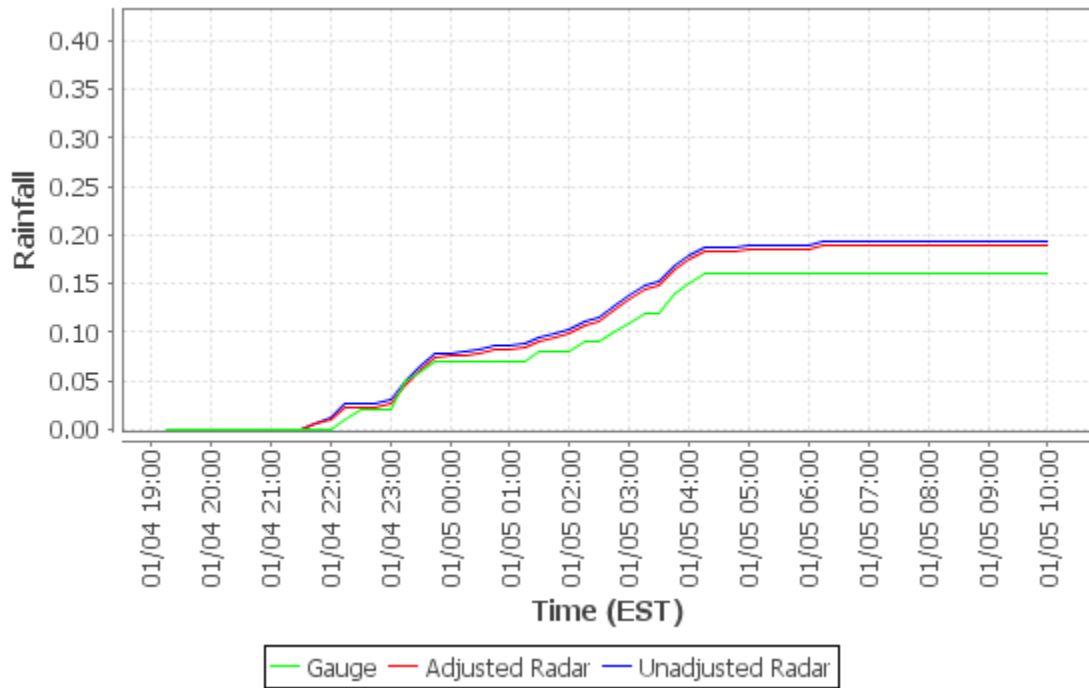
Cumulative Distribution Plot - Baldwin (Loc12)



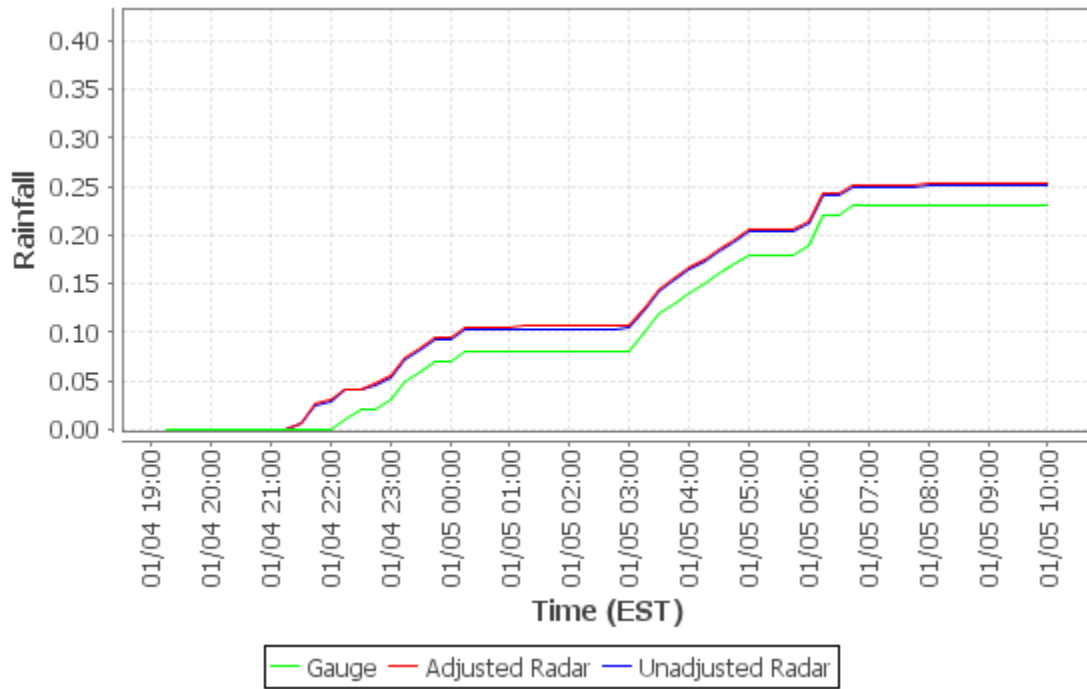
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



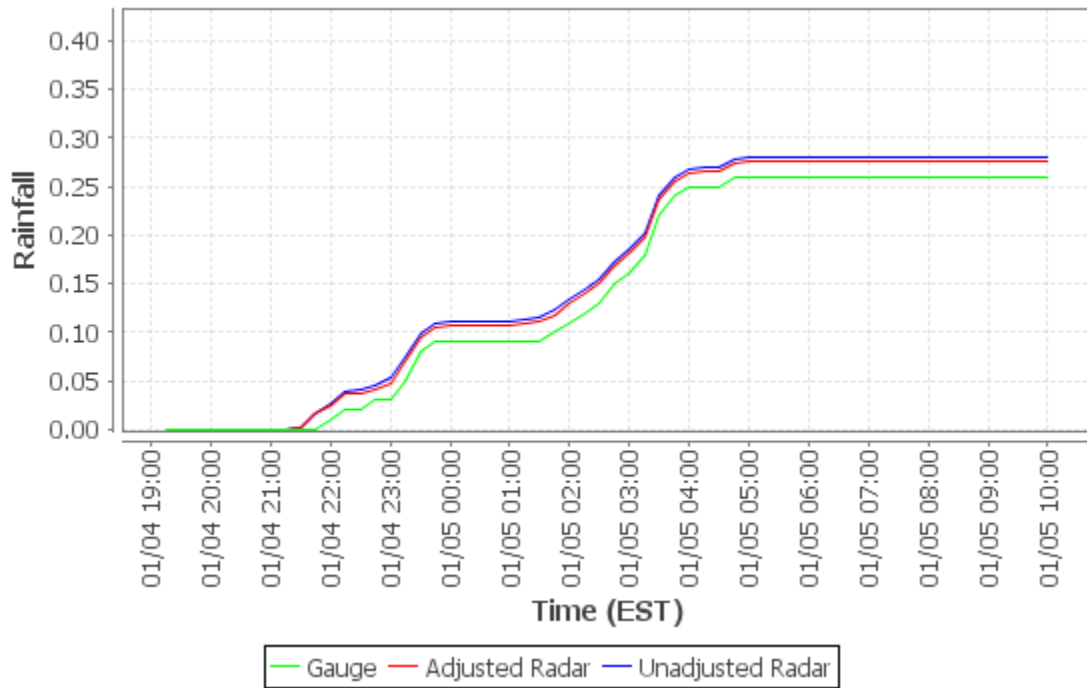
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



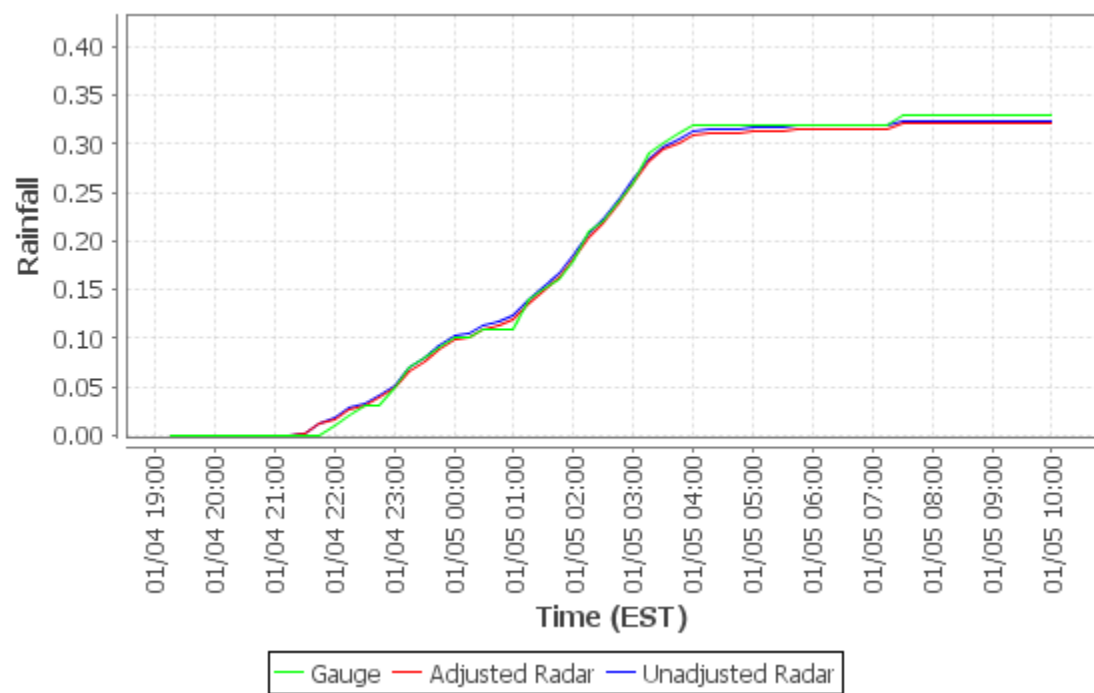
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



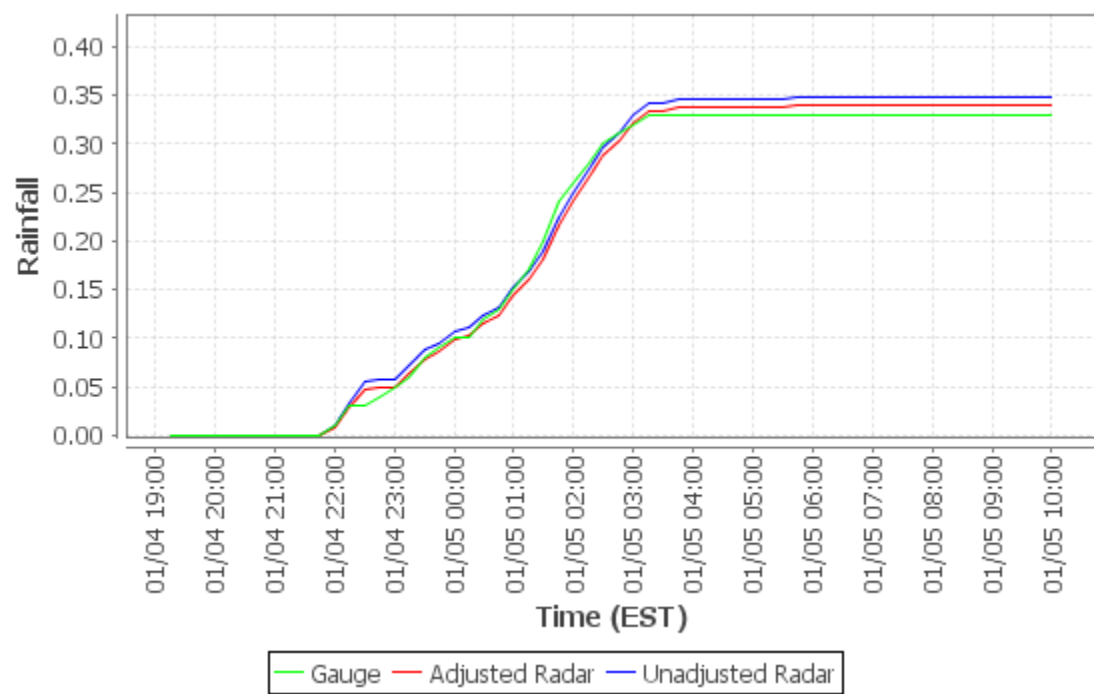
Cumulative Distribution Plot - Castle Shannon (Loc16)



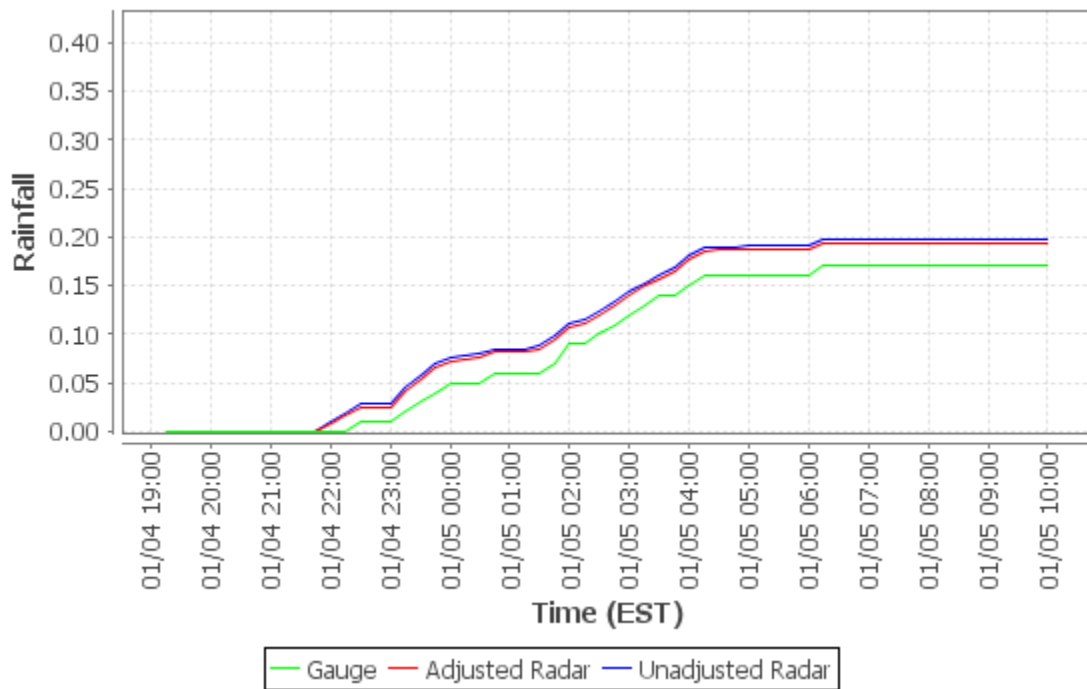
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



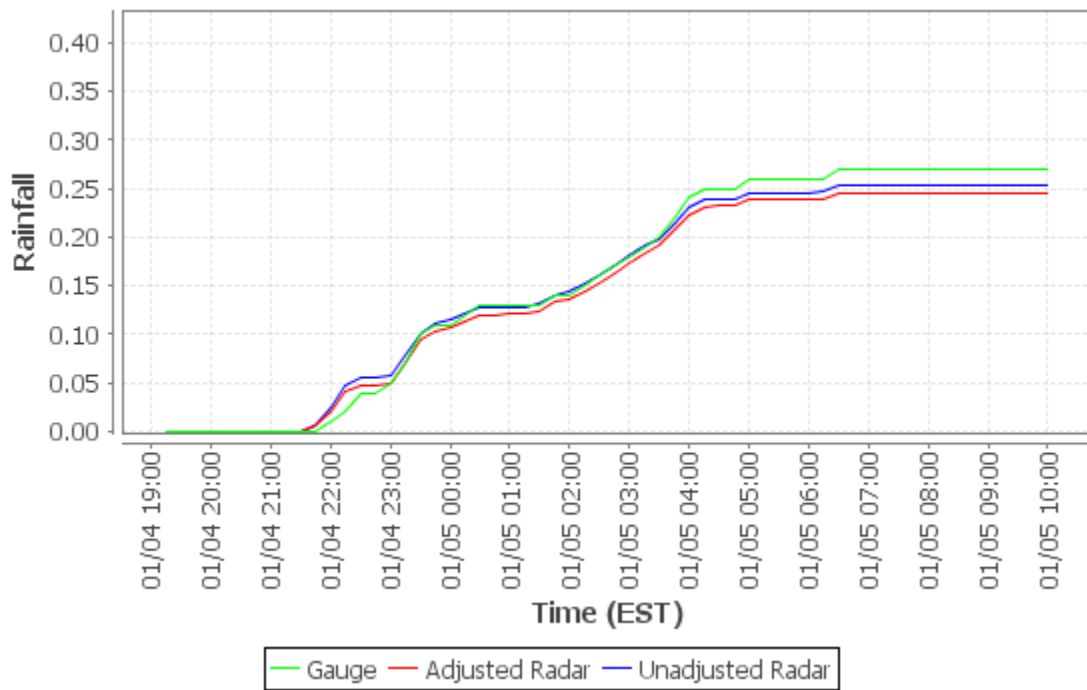
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



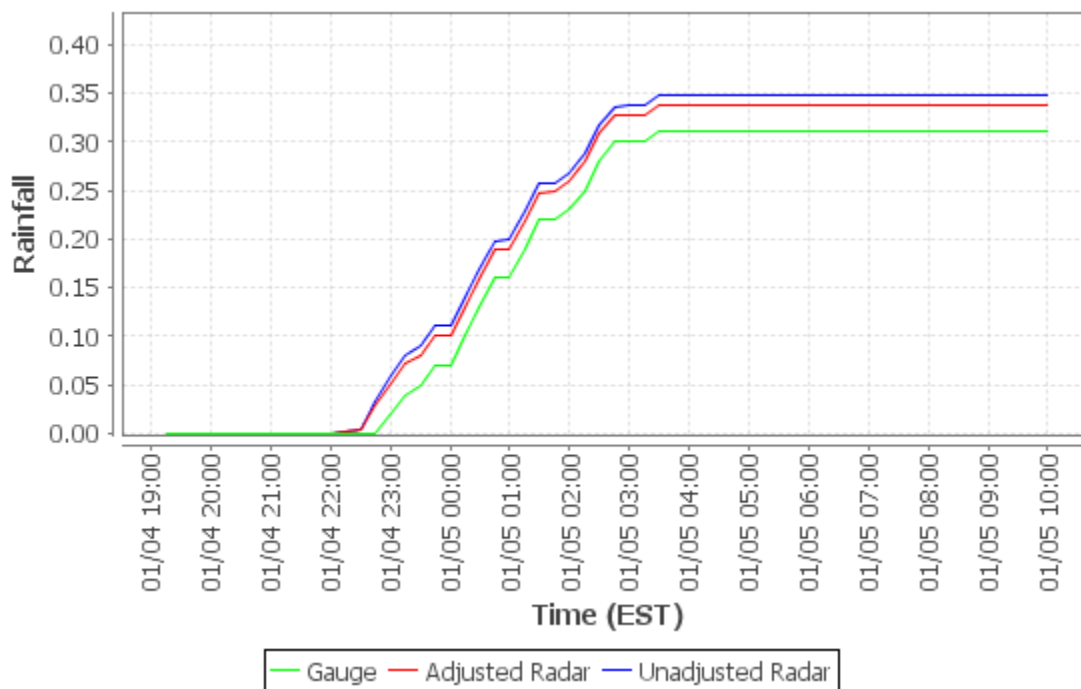
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



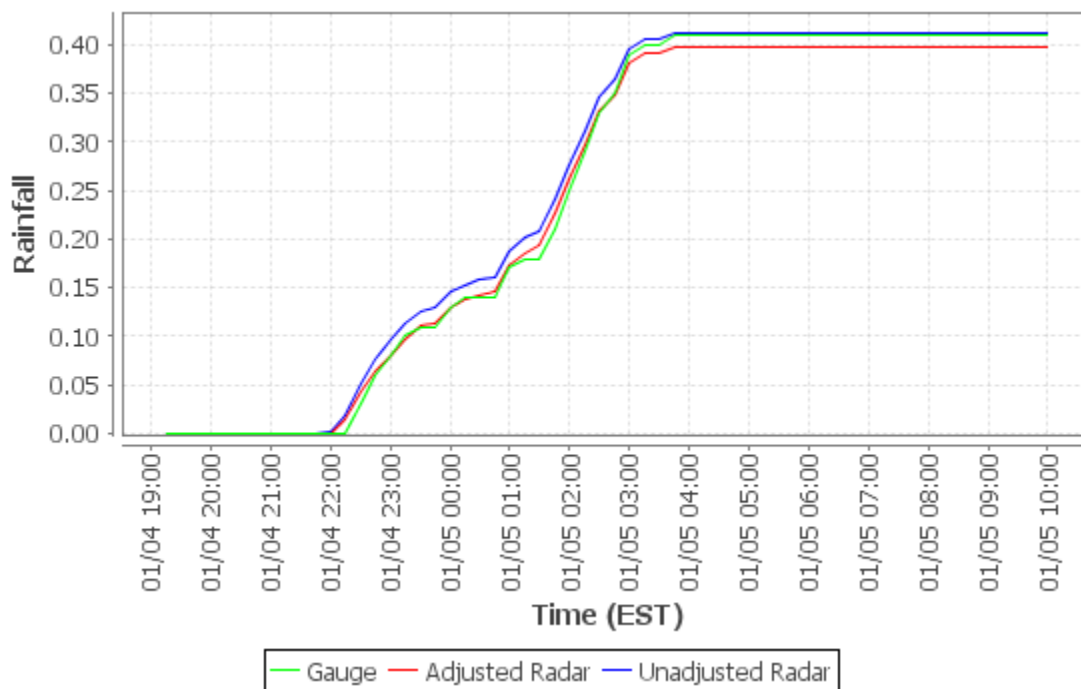
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



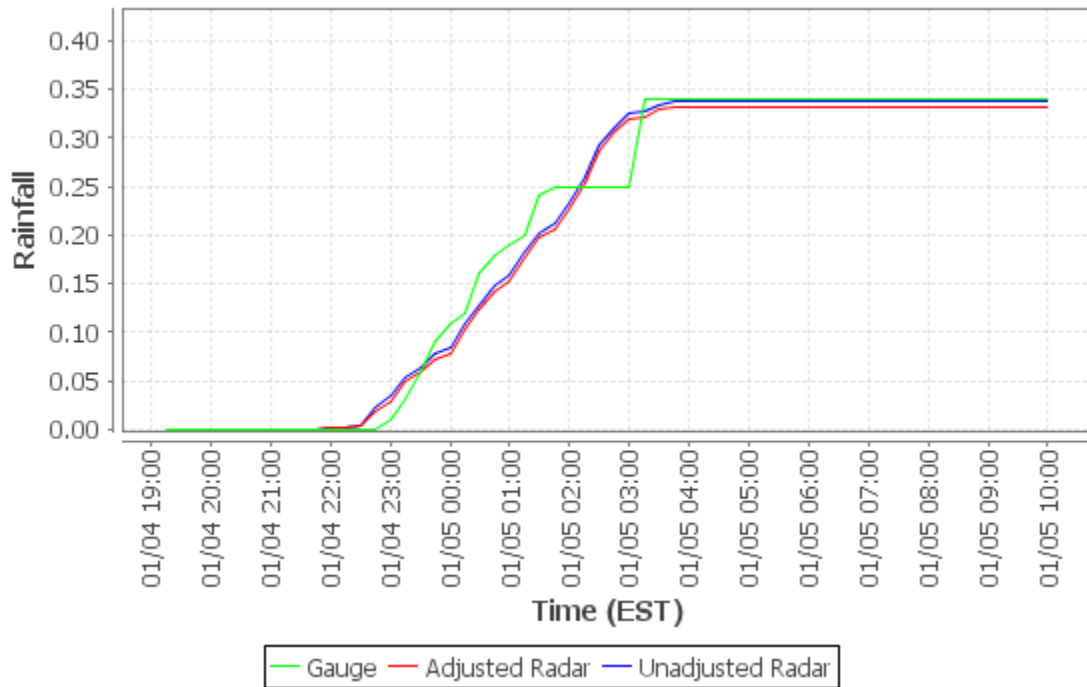
Cumulative Distribution Plot - Moon TWP (Loc21)



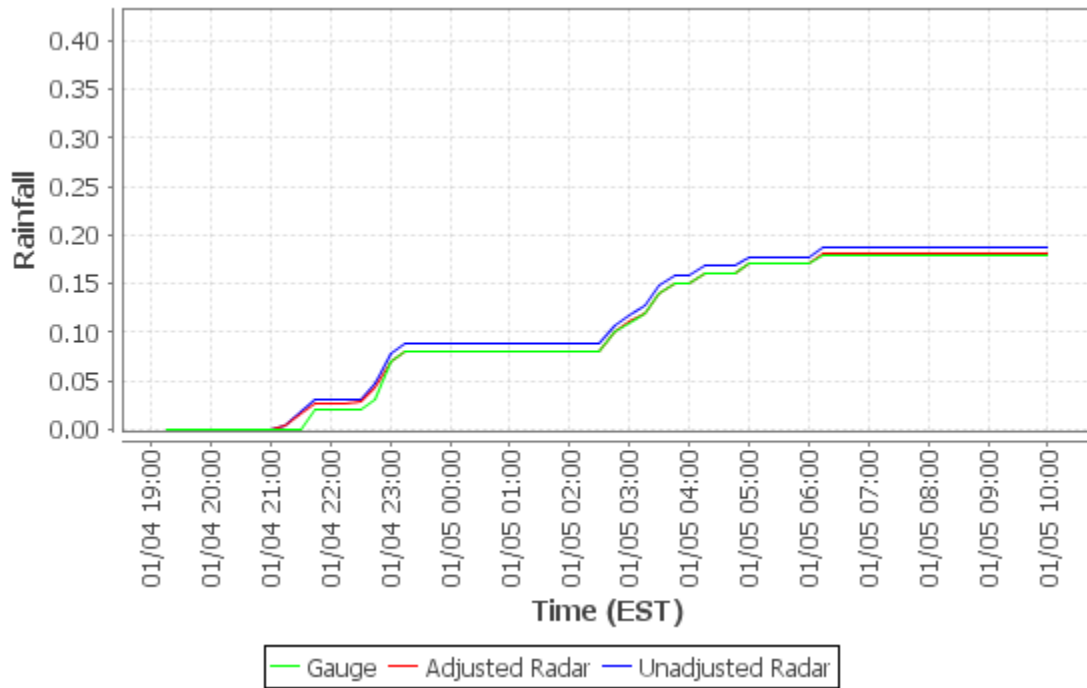
Cumulative Distribution Plot - North Fayette TWP (Loc22)



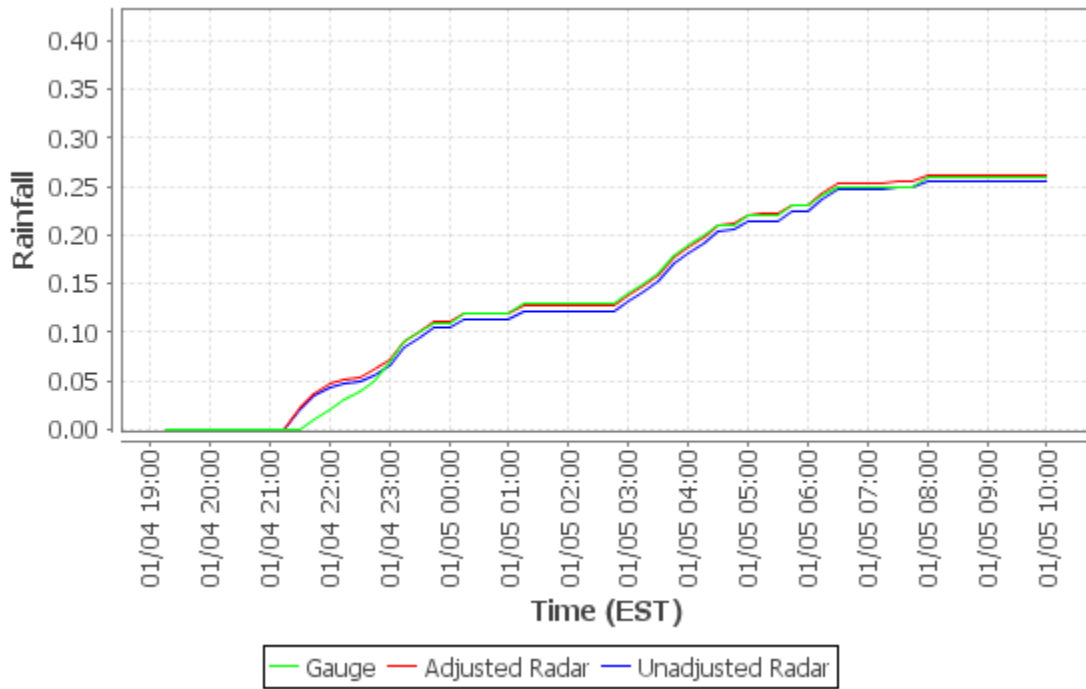
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



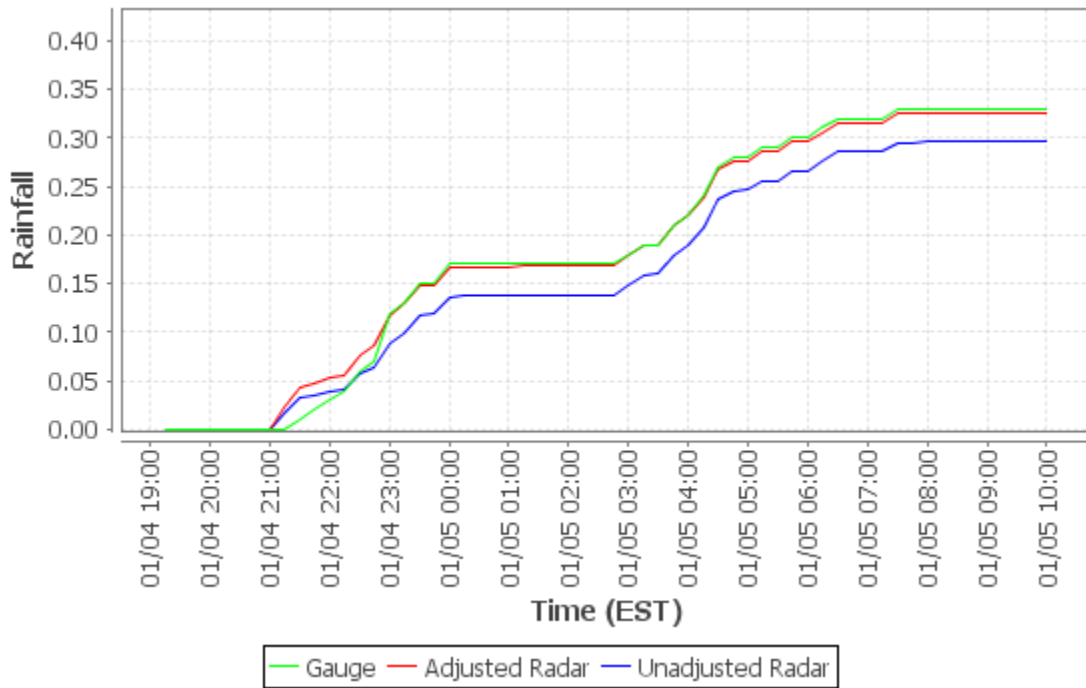
Cumulative Distribution Plot - Jefferson Hills (Loc24)



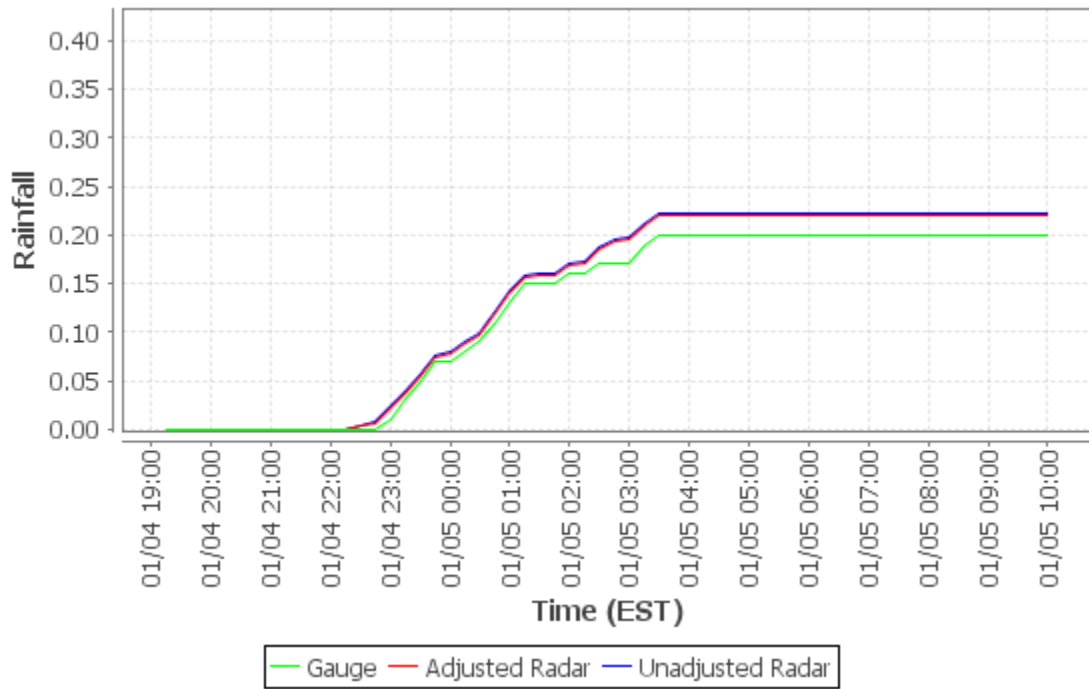
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



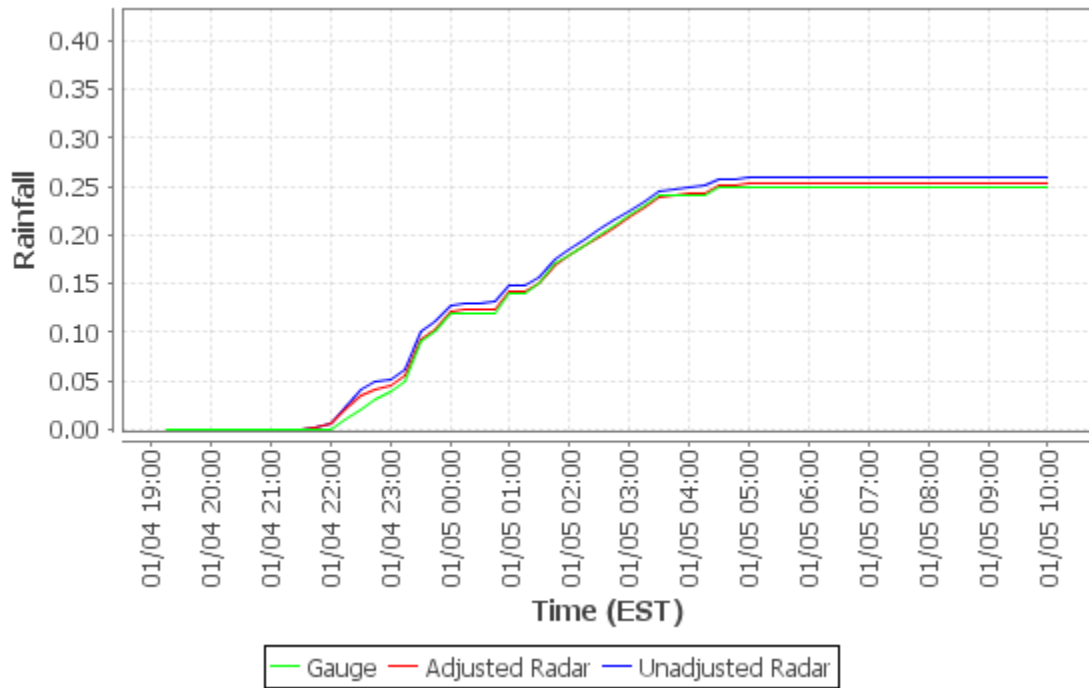
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



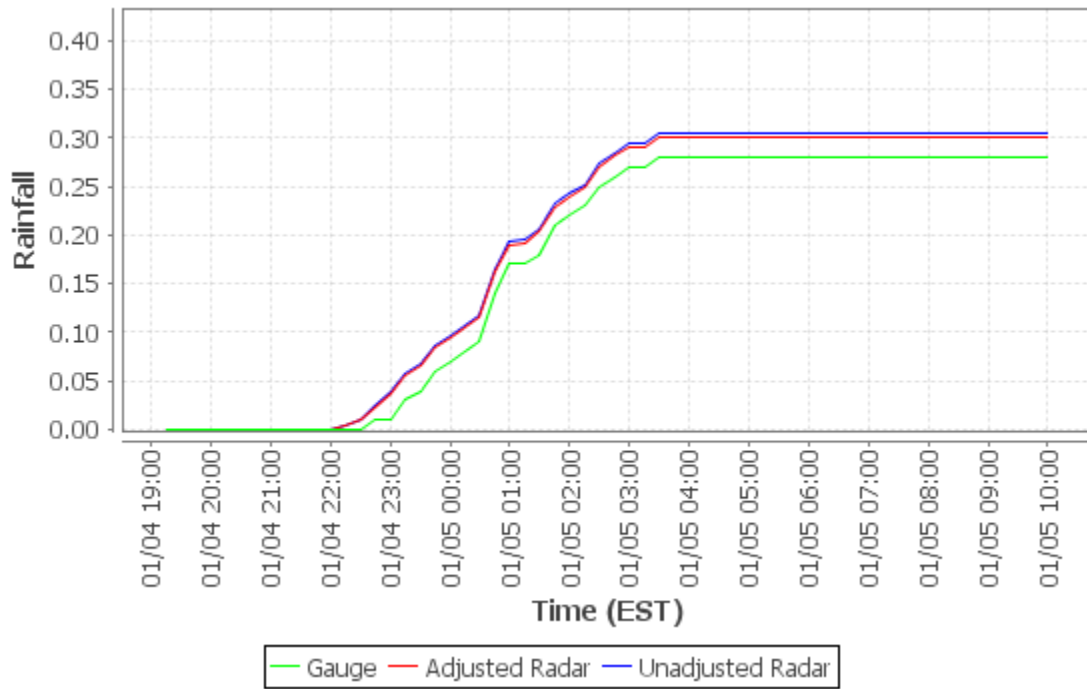
Cumulative Distribution Plot - Marshall TWP (Loc27)



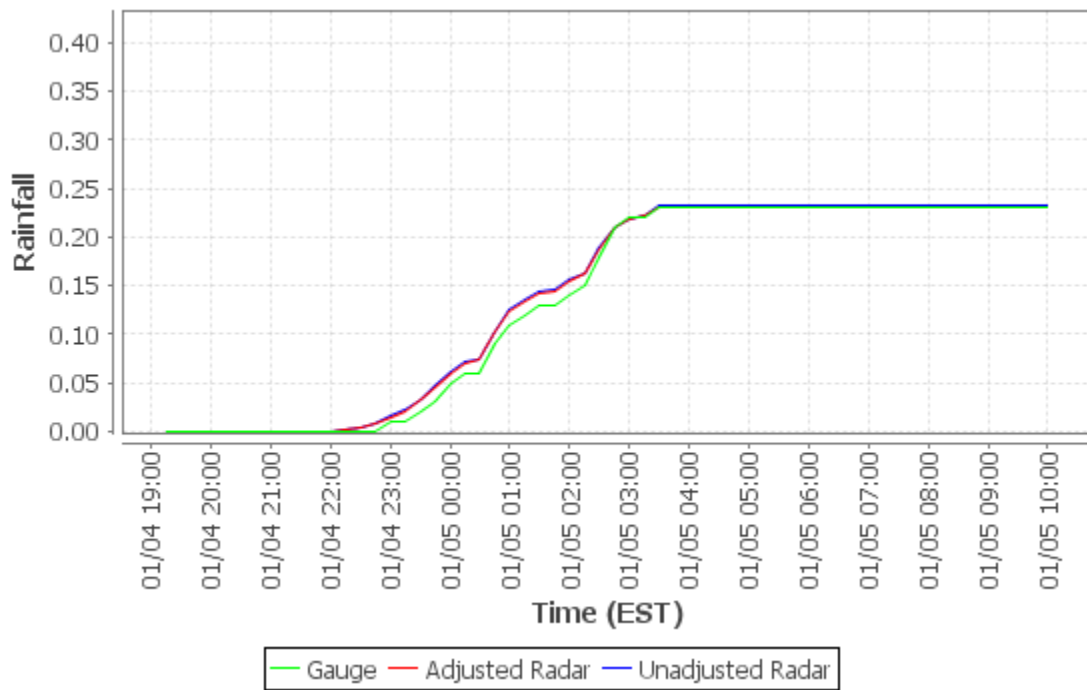
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



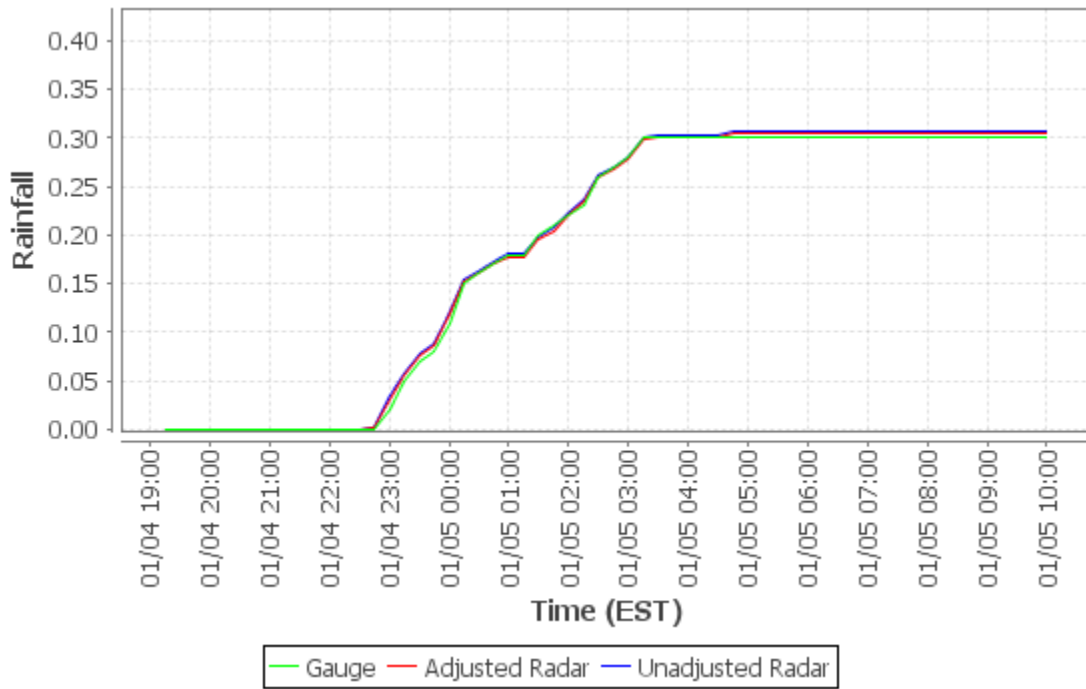
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



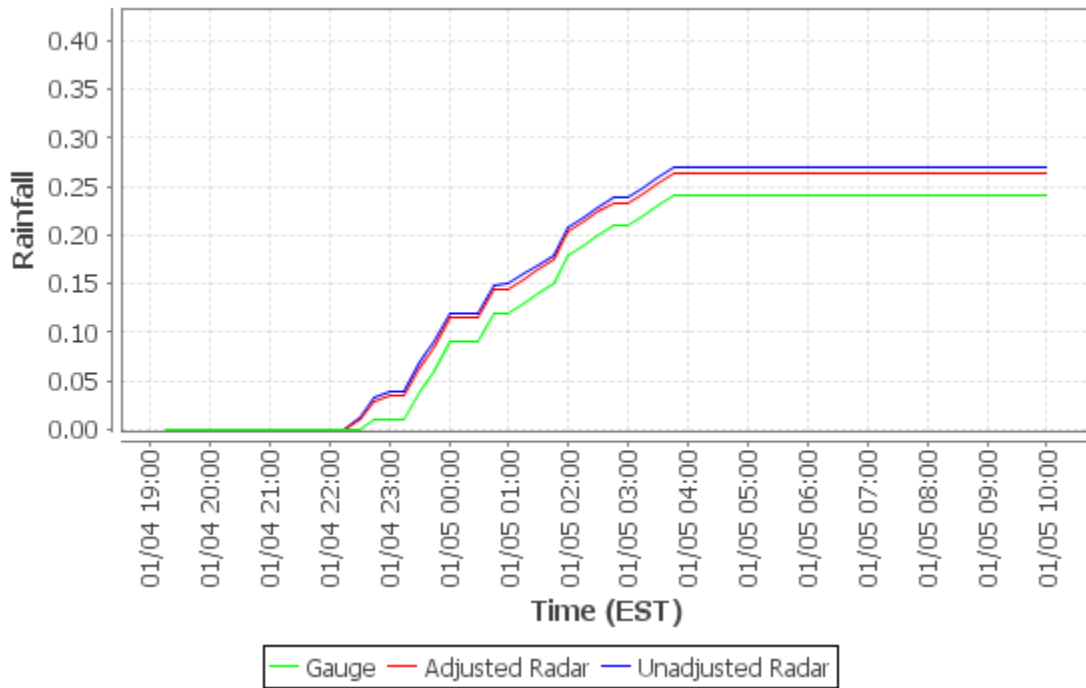
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



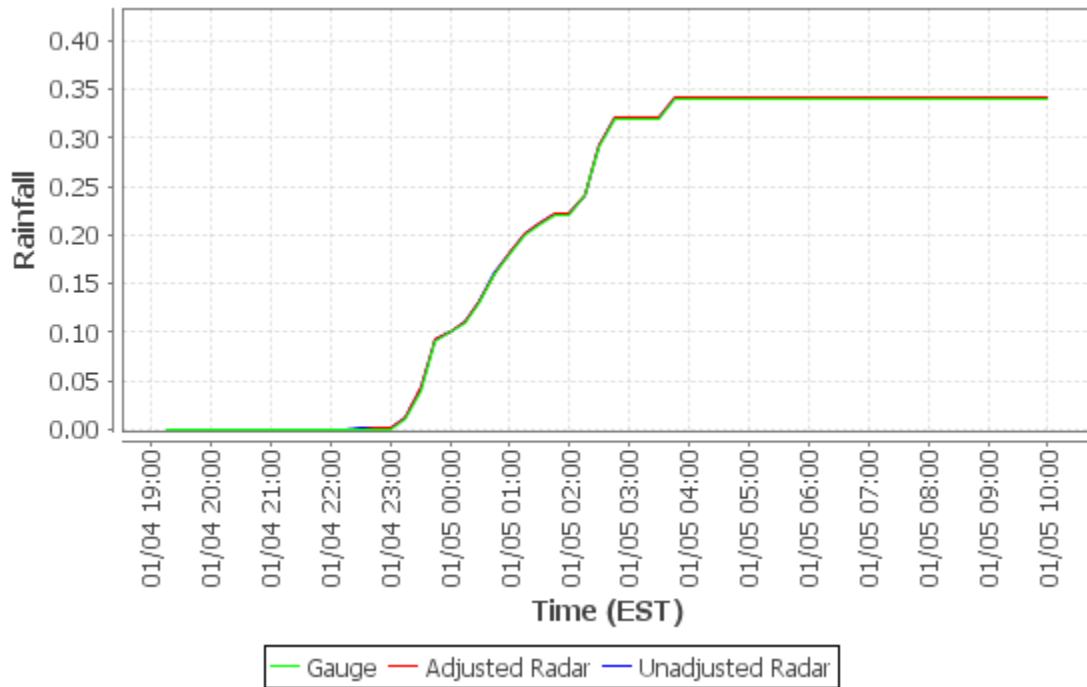
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



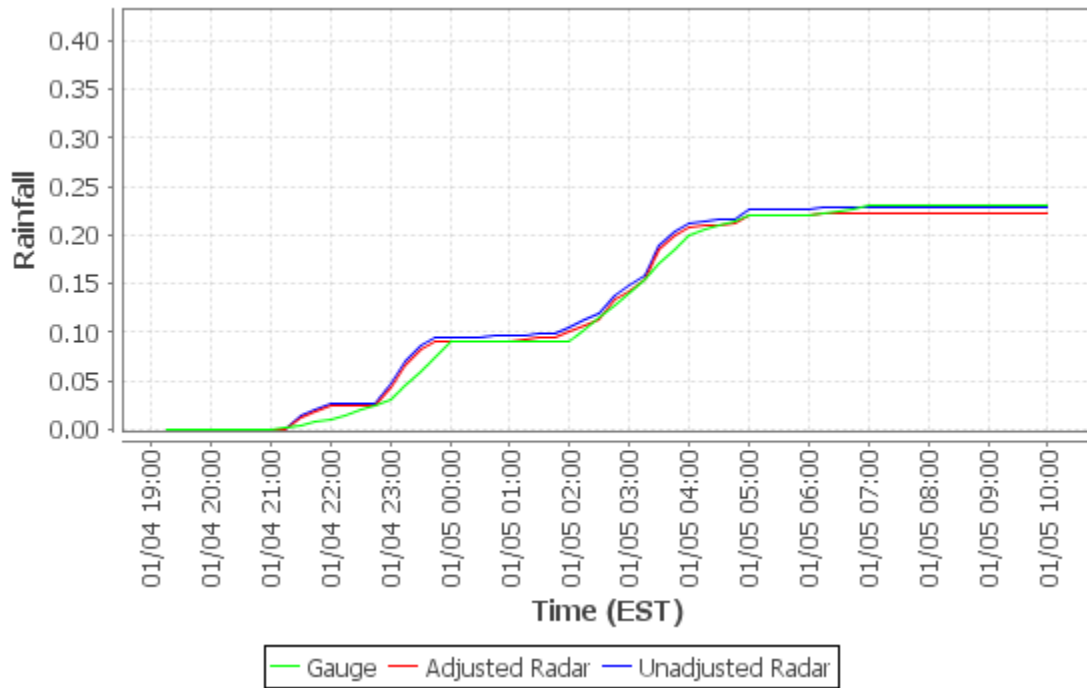
Cumulative Distribution Plot - Arnold (Loc32)



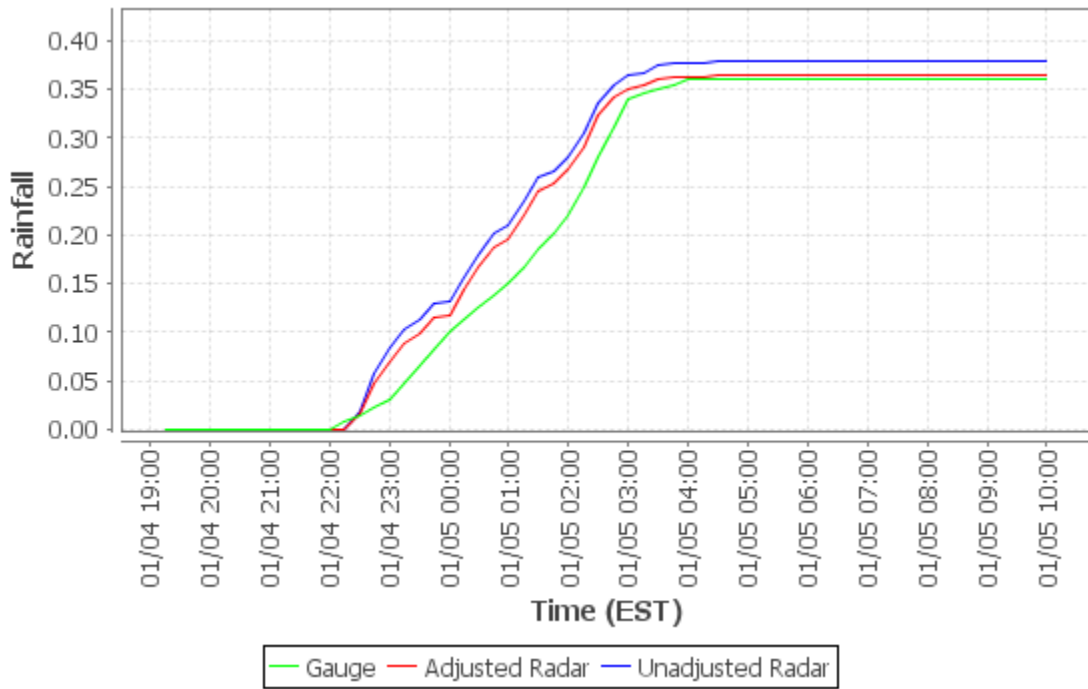
Cumulative Distribution Plot - Richland TWP (Loc33)



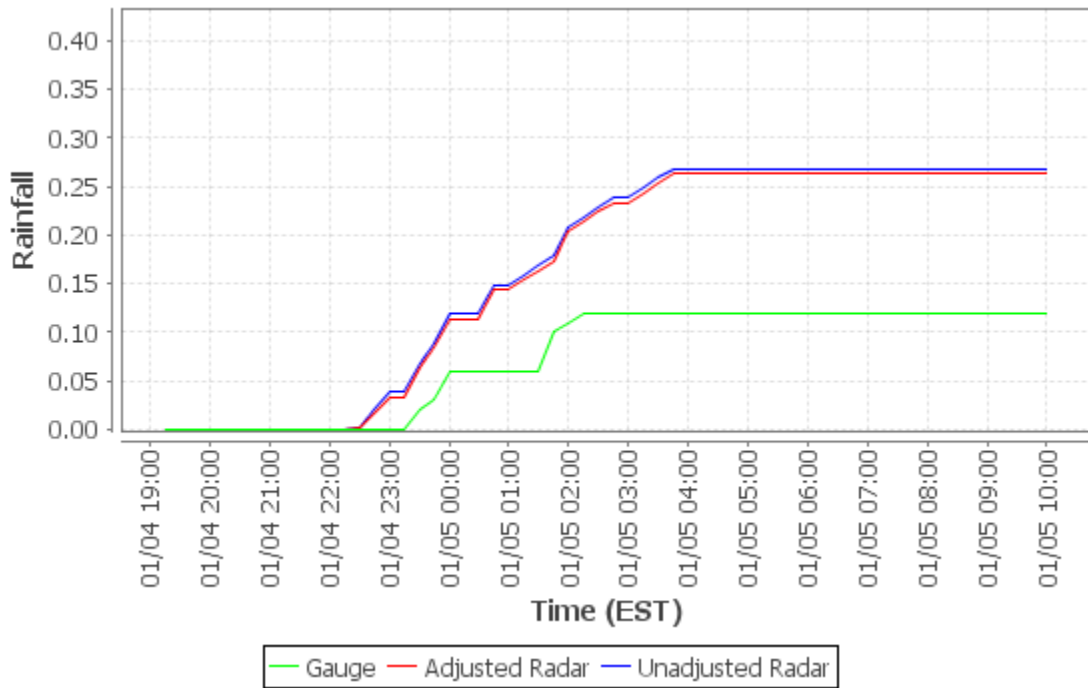
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



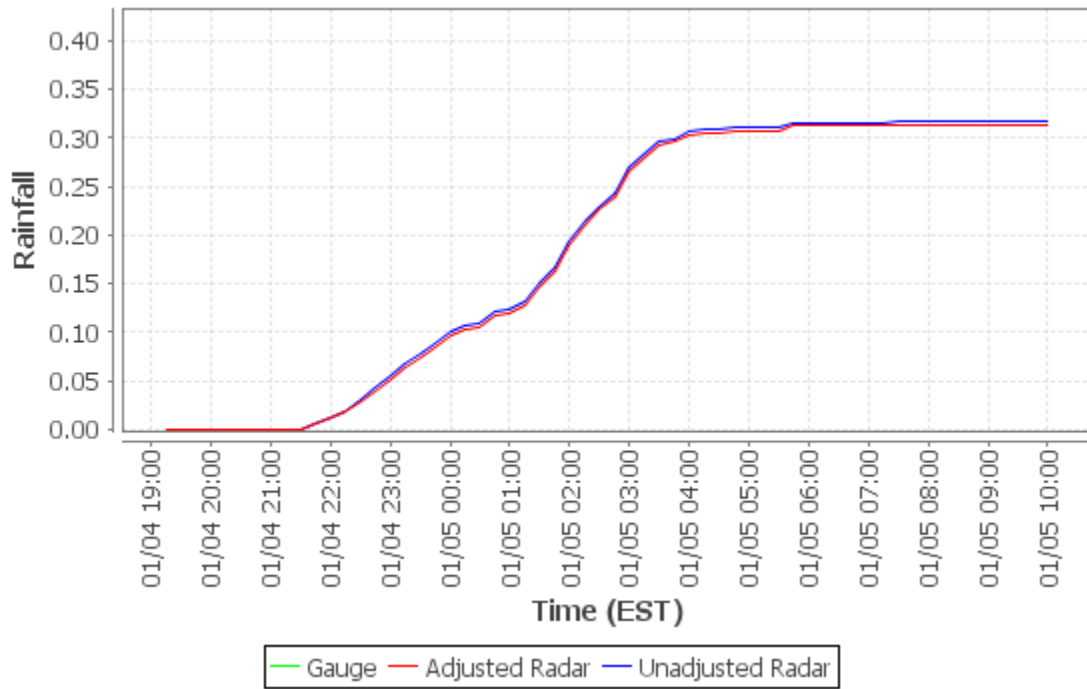
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



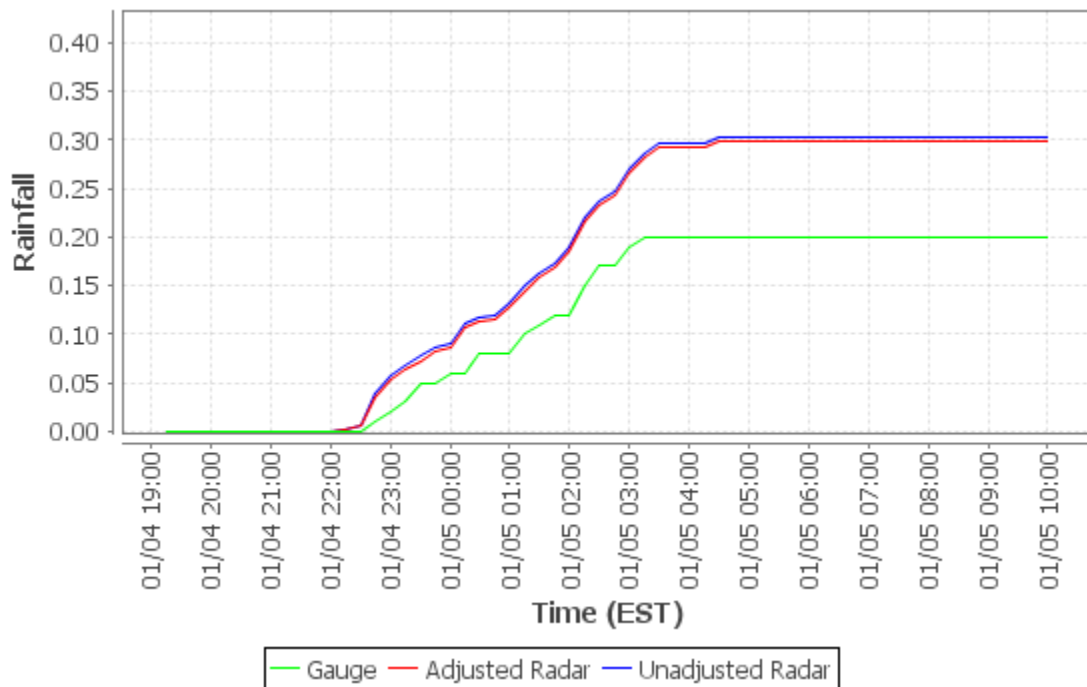
Cumulative Distribution Plot - Allegheny River at Natrona (03049500)



Cumulative Distribution Plot - Chartiers Creek at Carnegie (03085500)

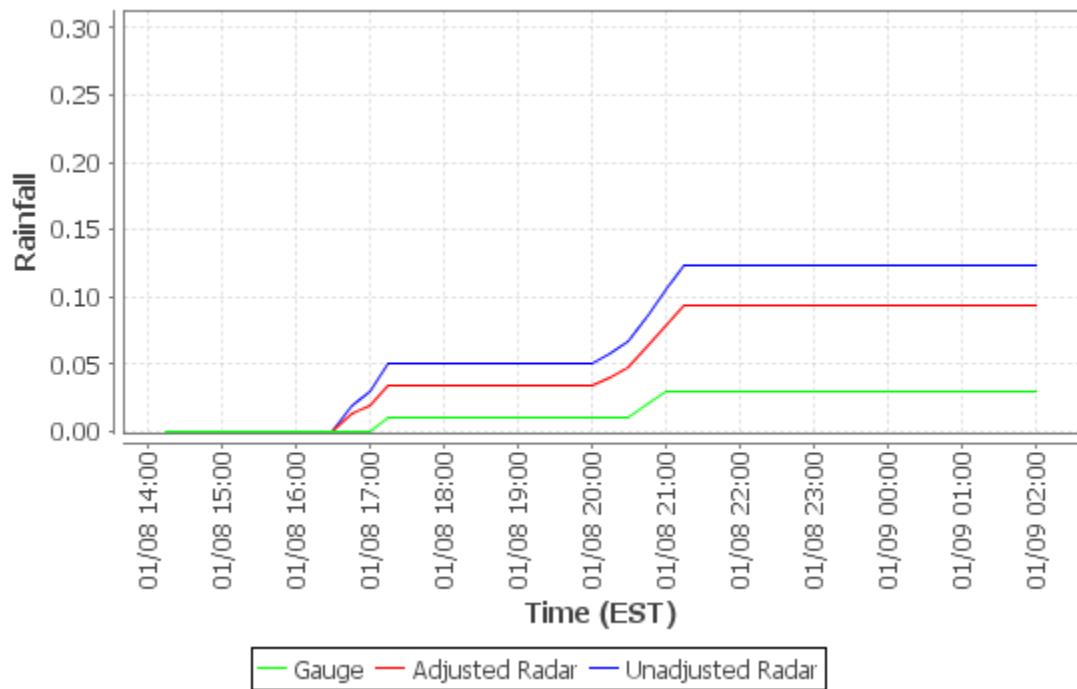


Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth (03085734)

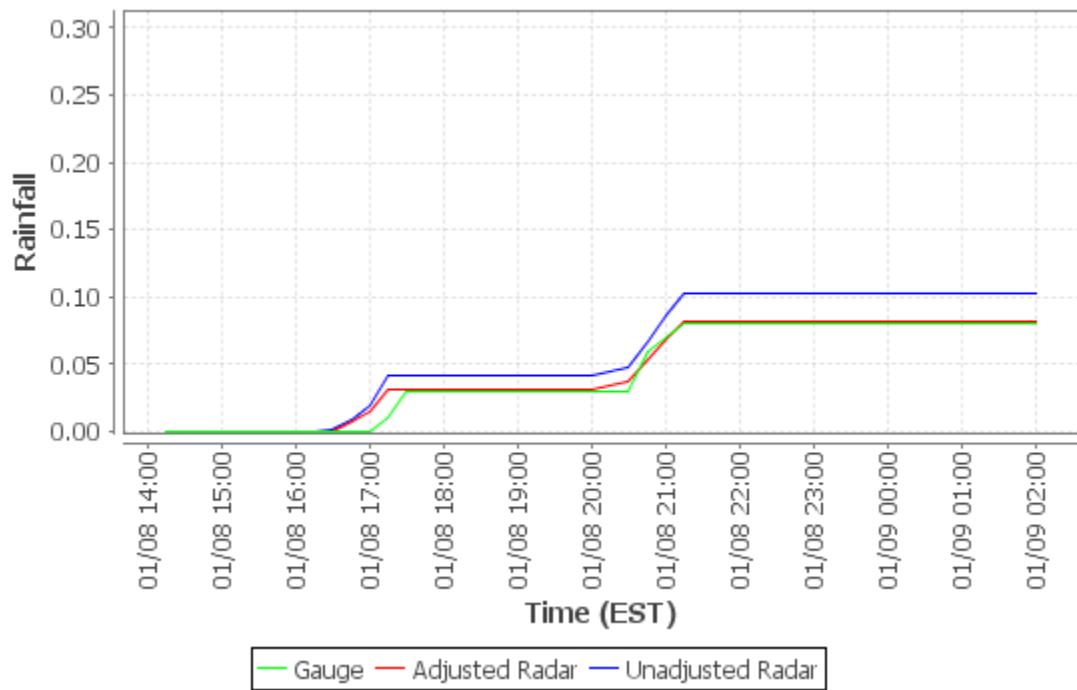


Appendix C - Event 2 (2019-01-08) CDPs

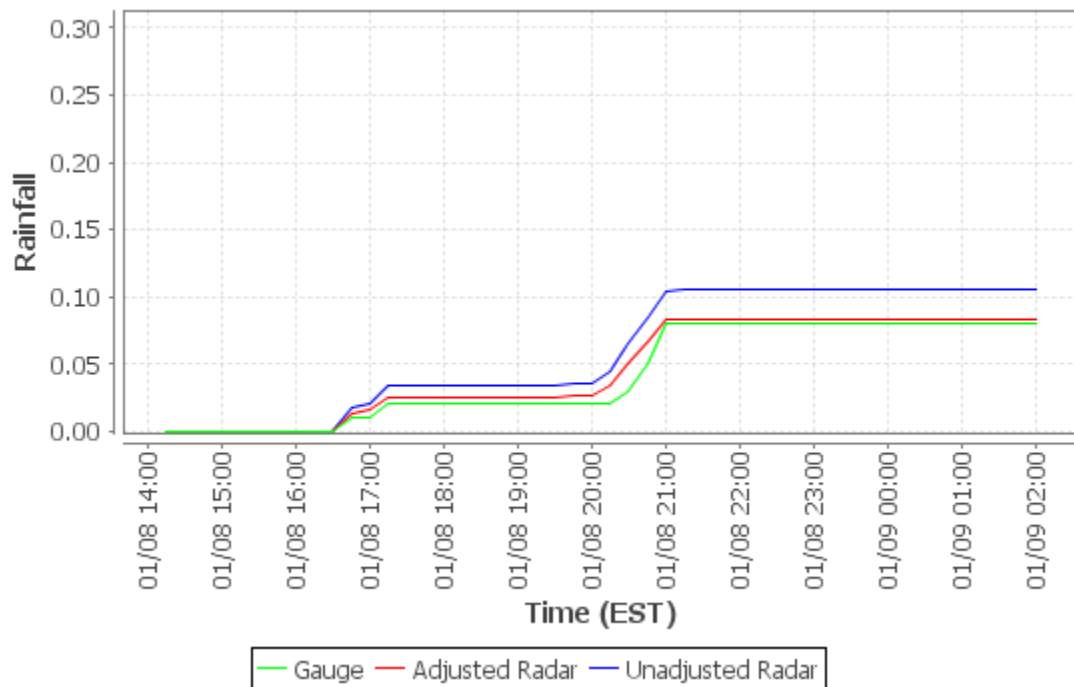
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



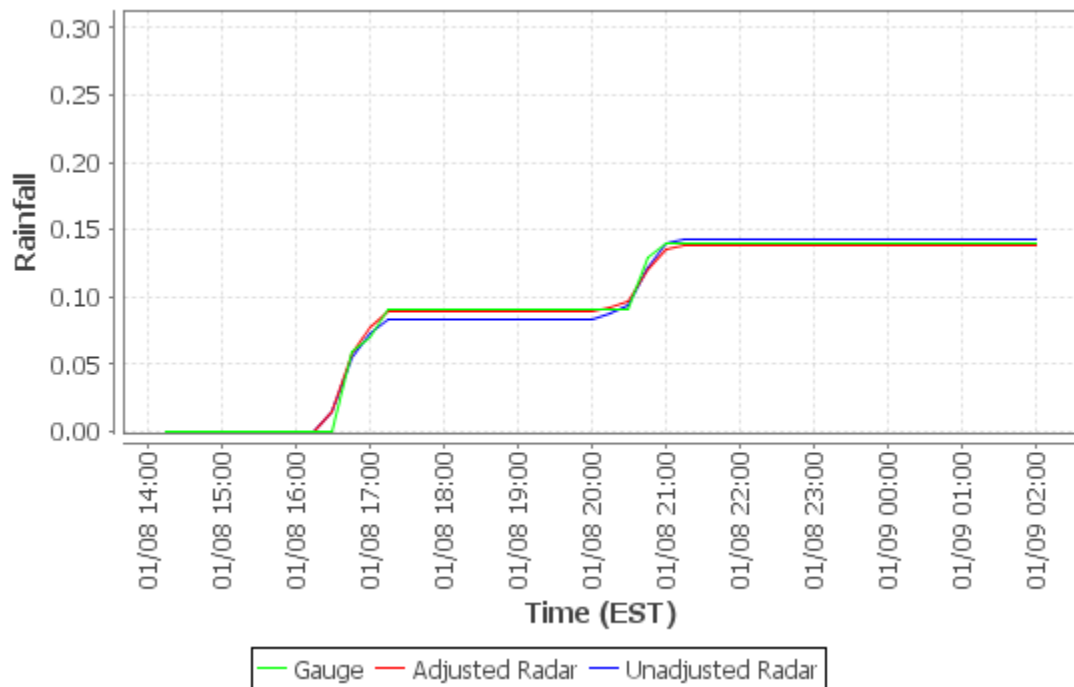
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



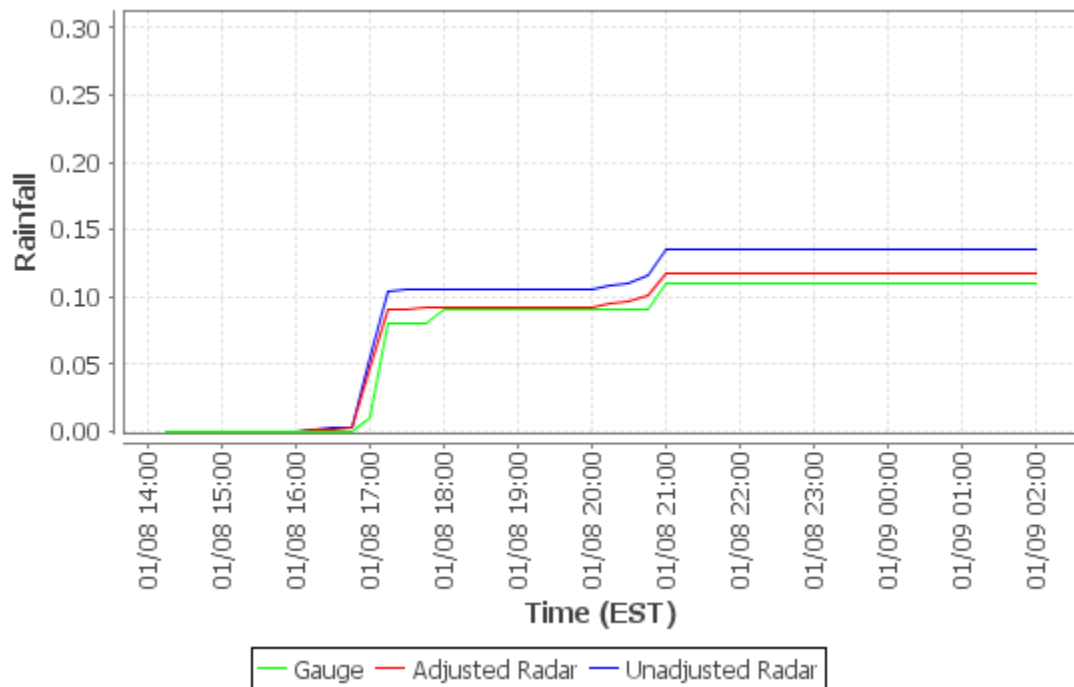
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



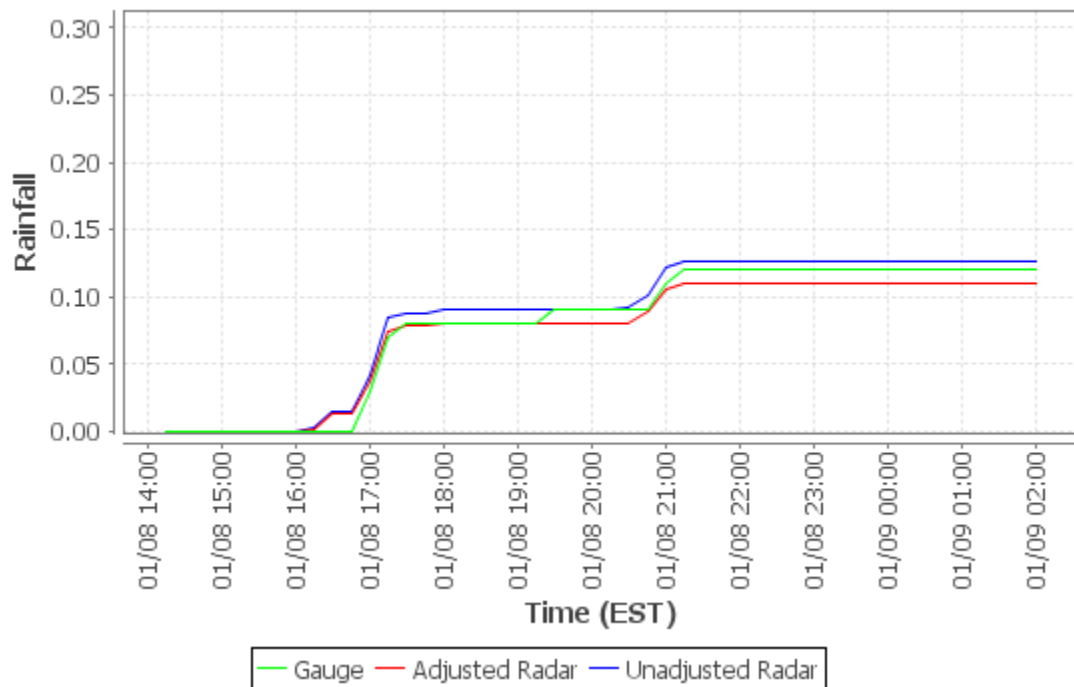
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



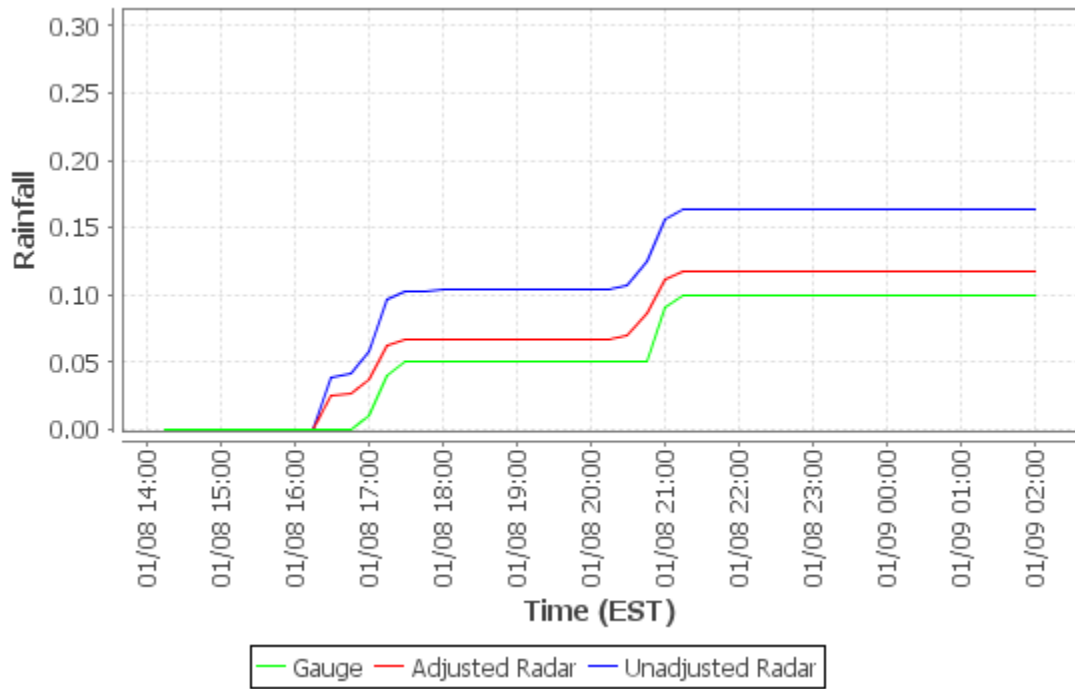
Cumulative Distribution Plot - Upper St. Clair (Loc05)



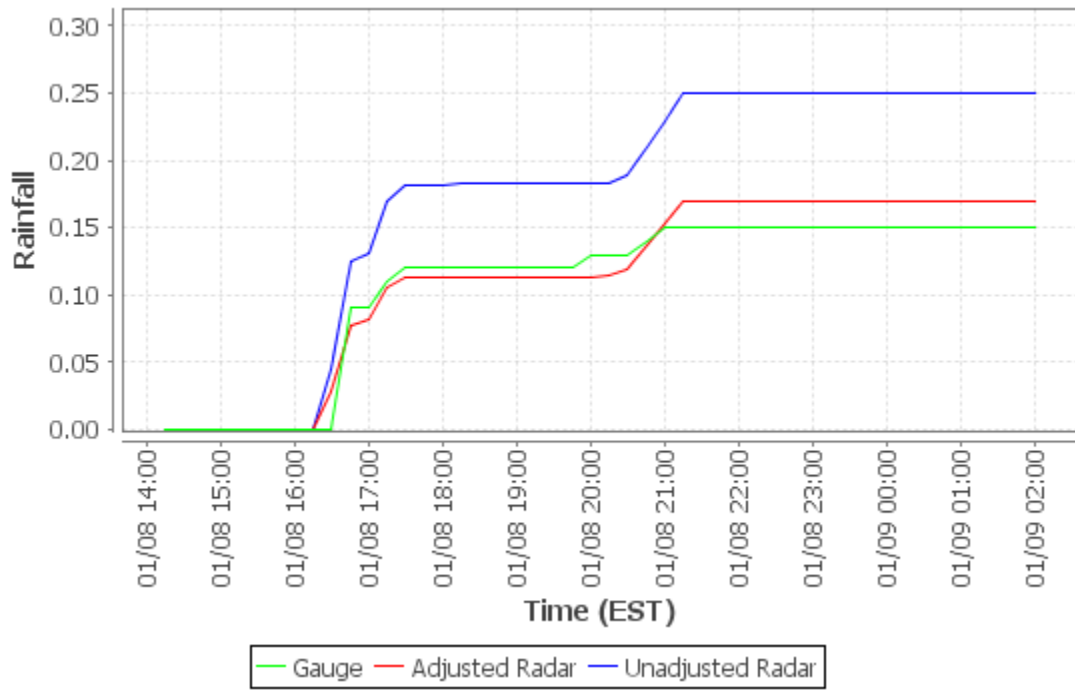
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



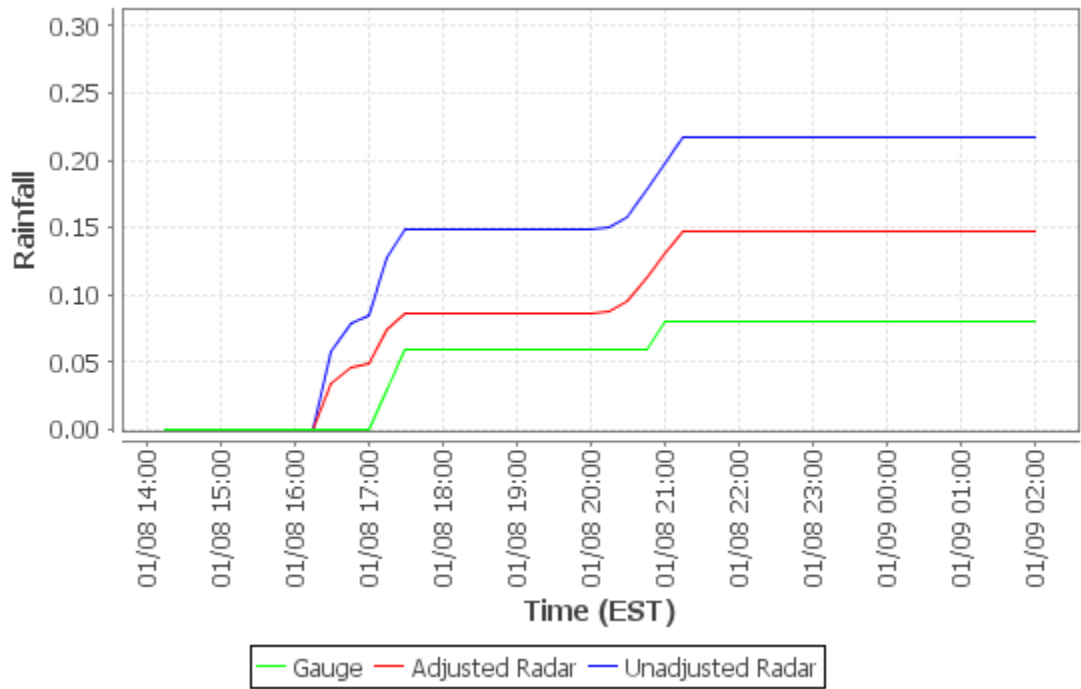
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



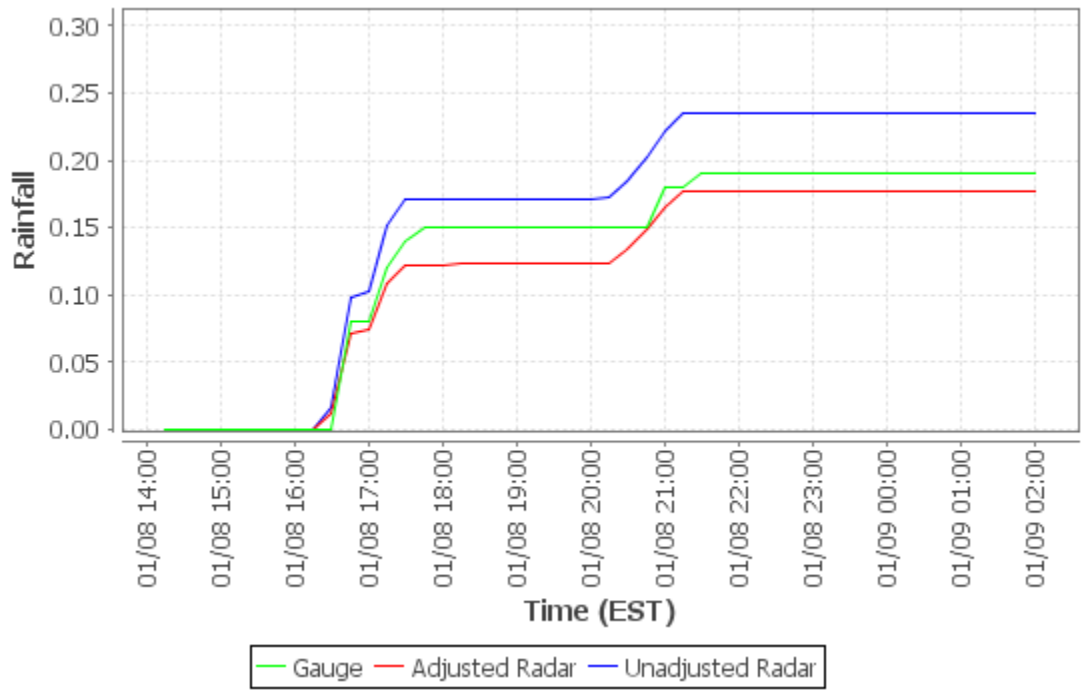
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



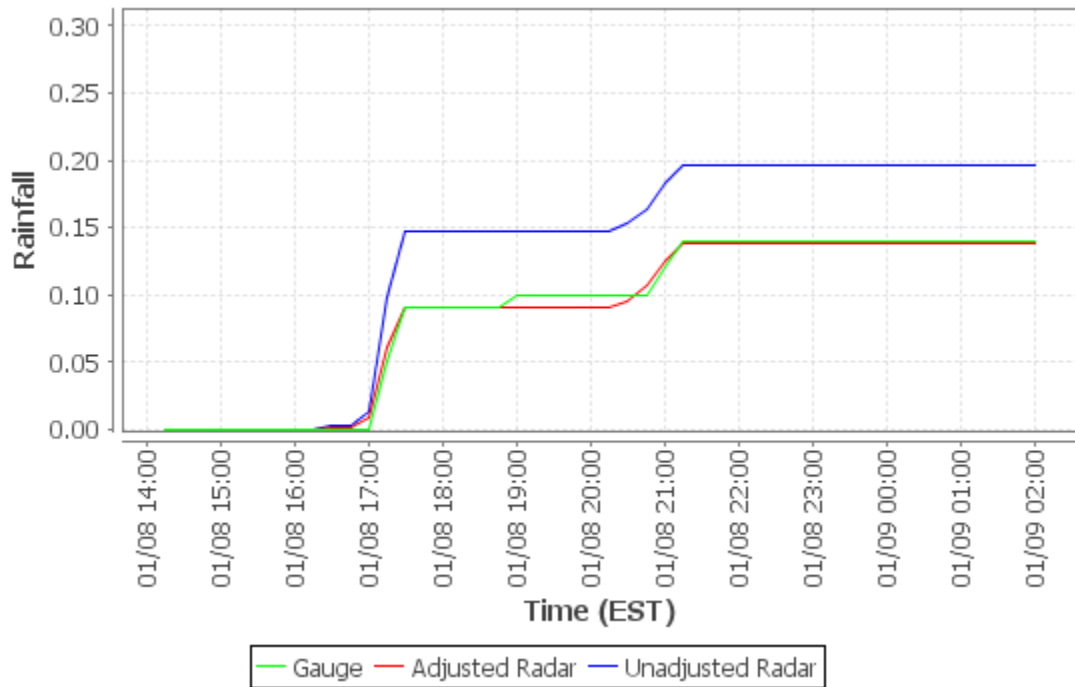
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



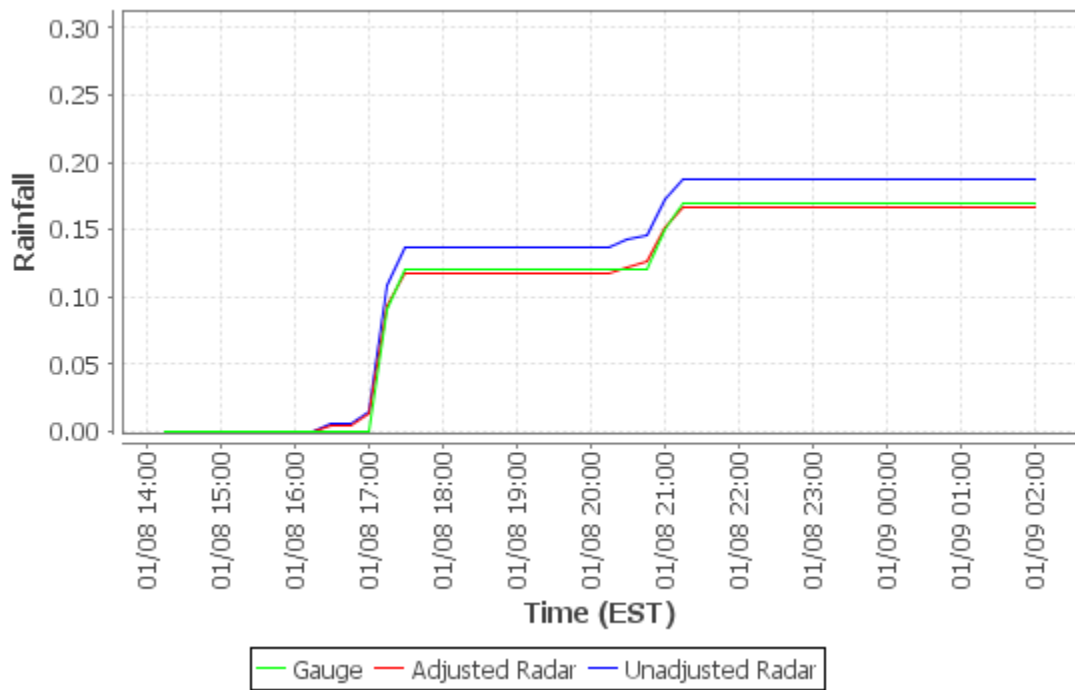
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



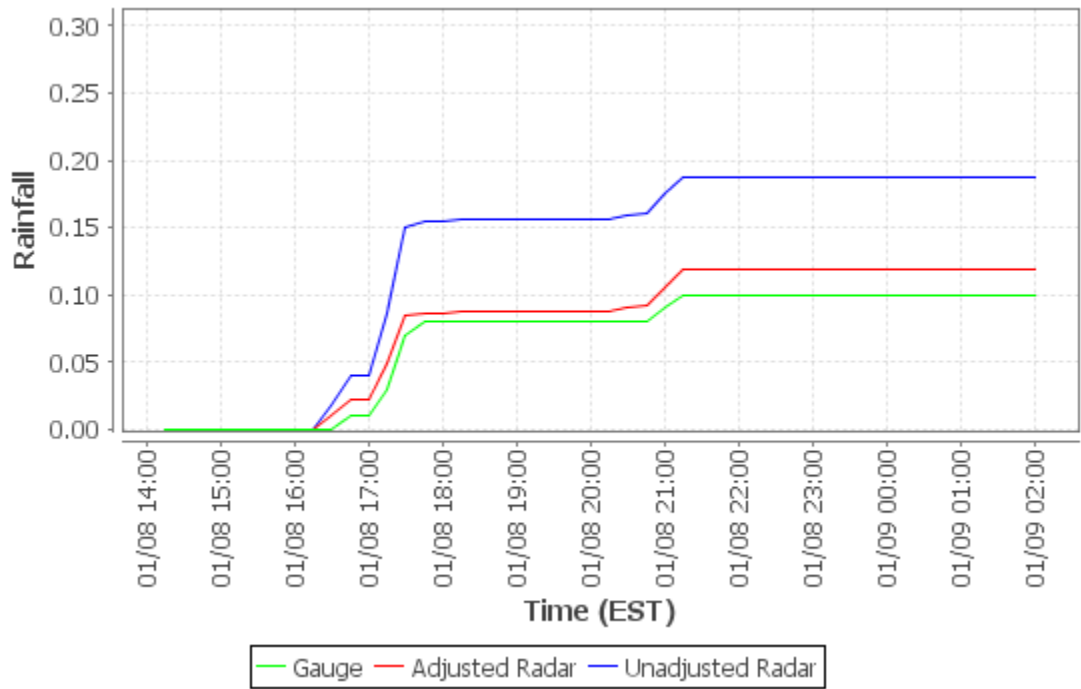
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



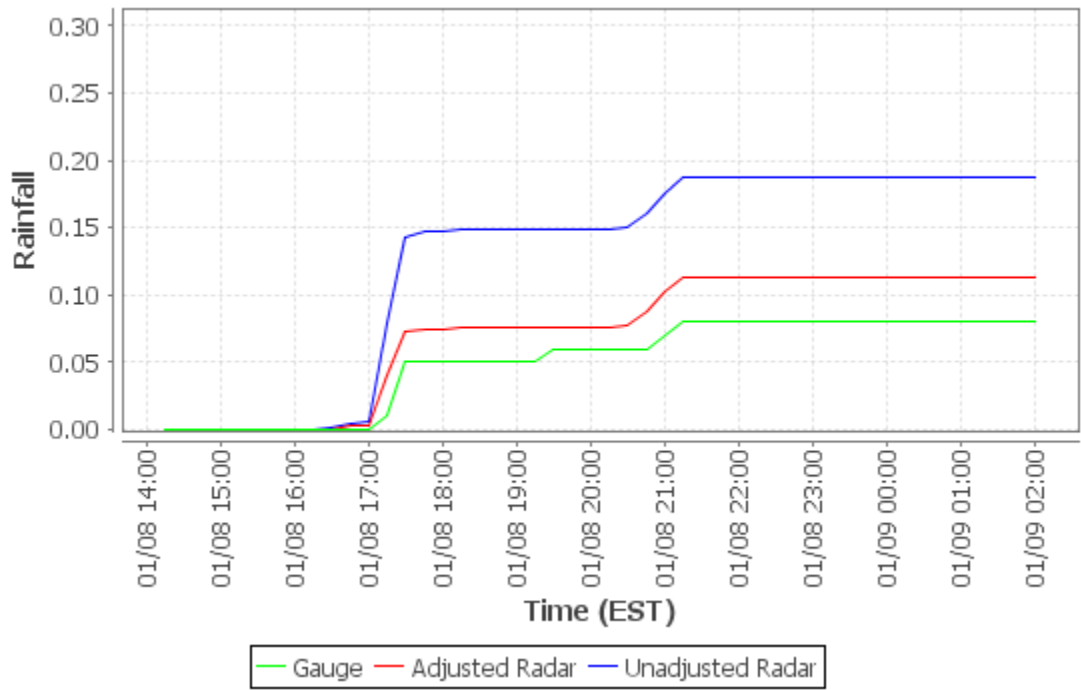
Cumulative Distribution Plot - Baldwin (Loc12)



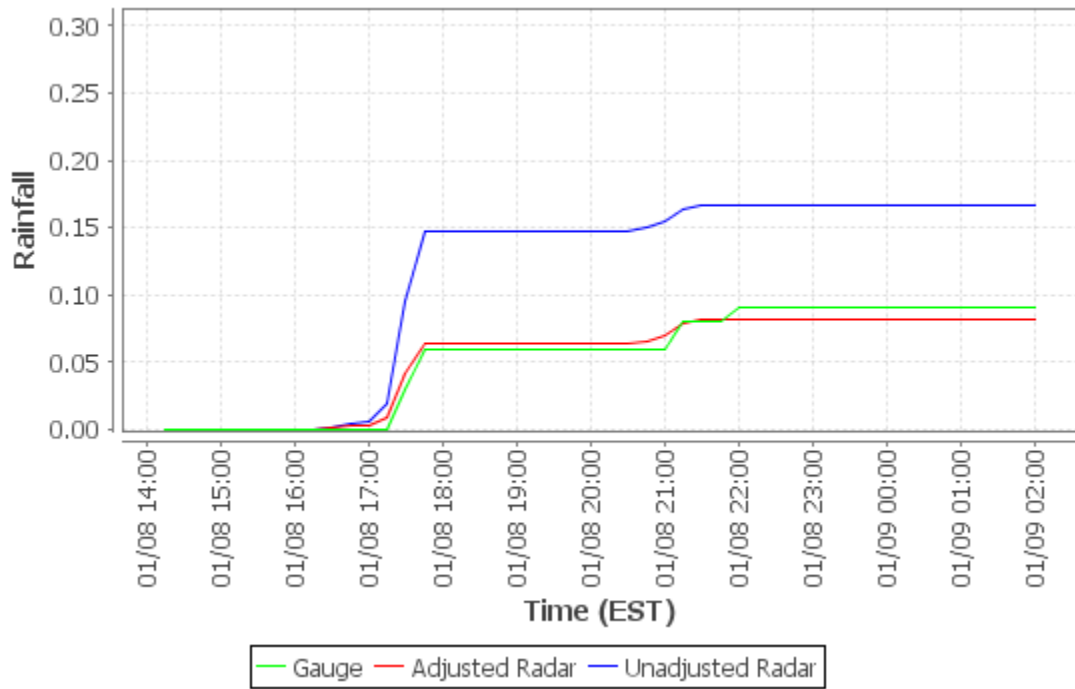
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



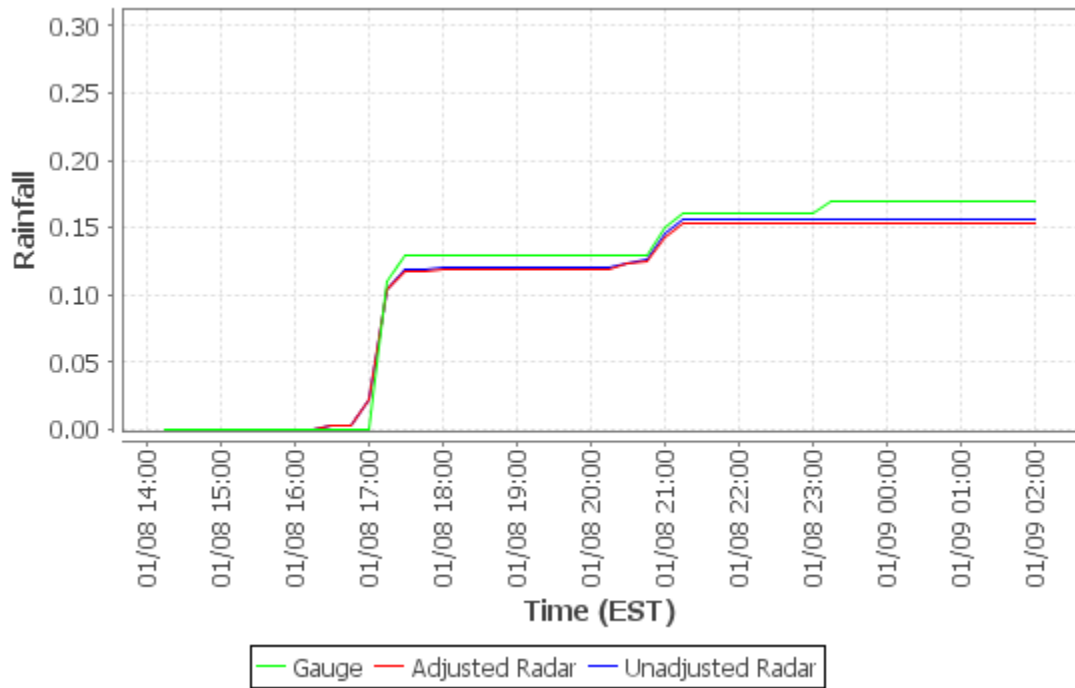
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



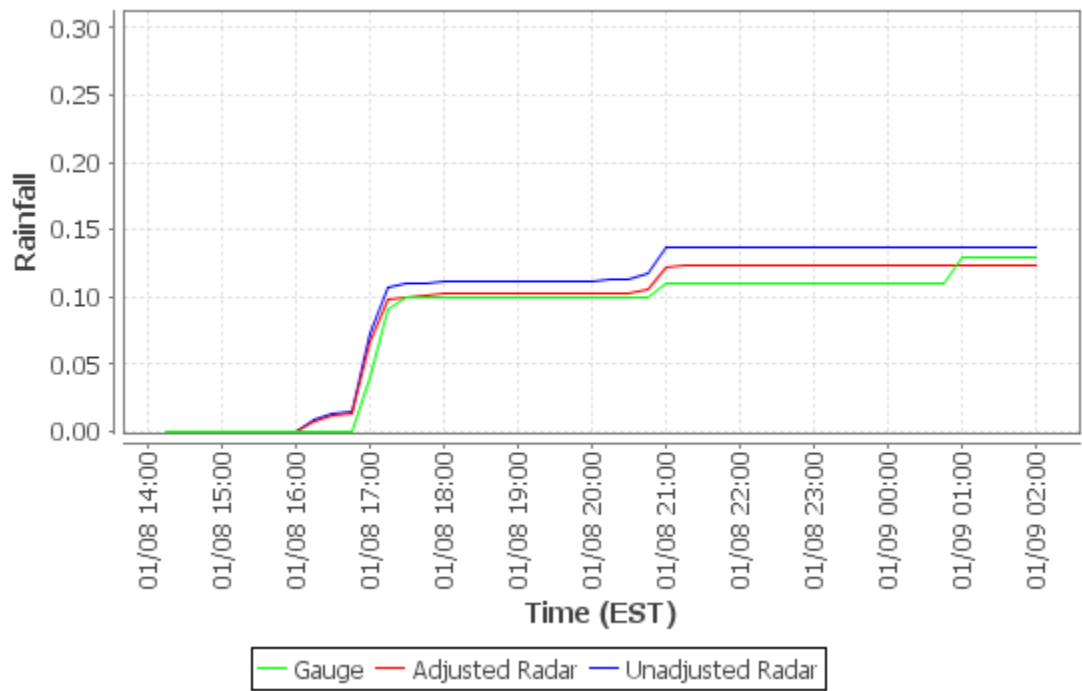
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



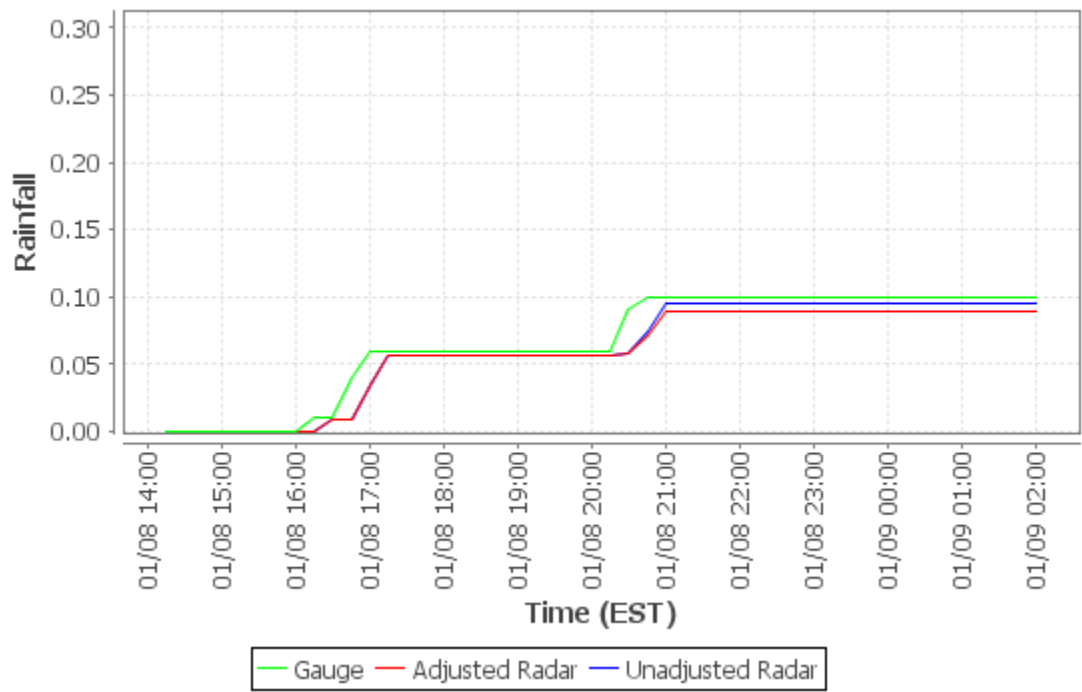
Cumulative Distribution Plot - Castle Shannon (Loc16)



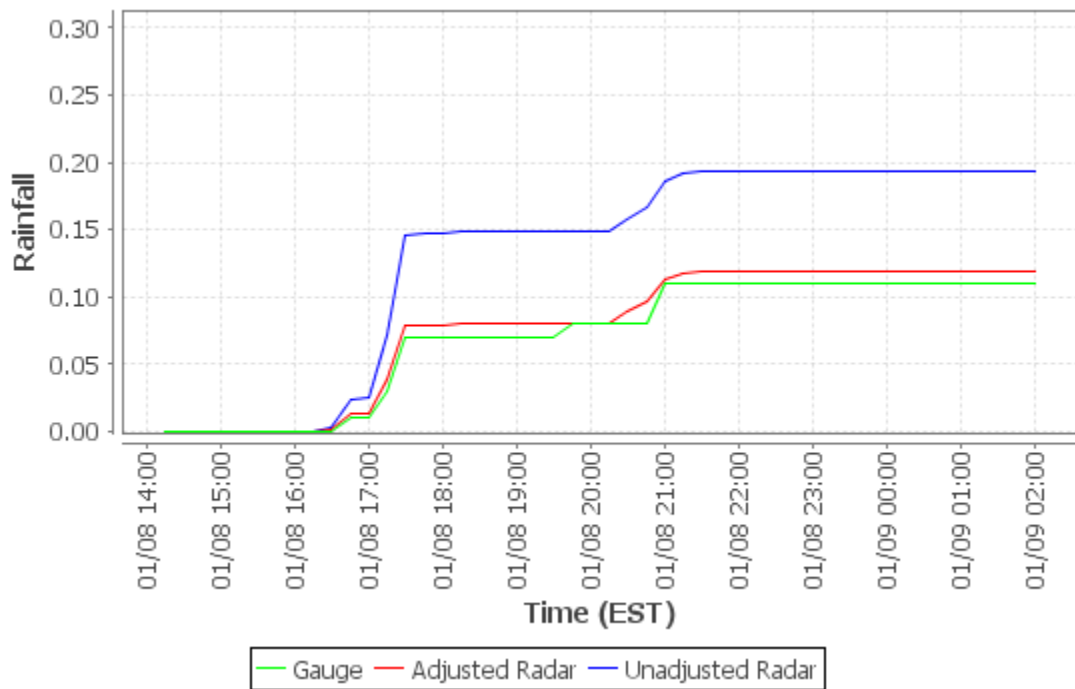
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



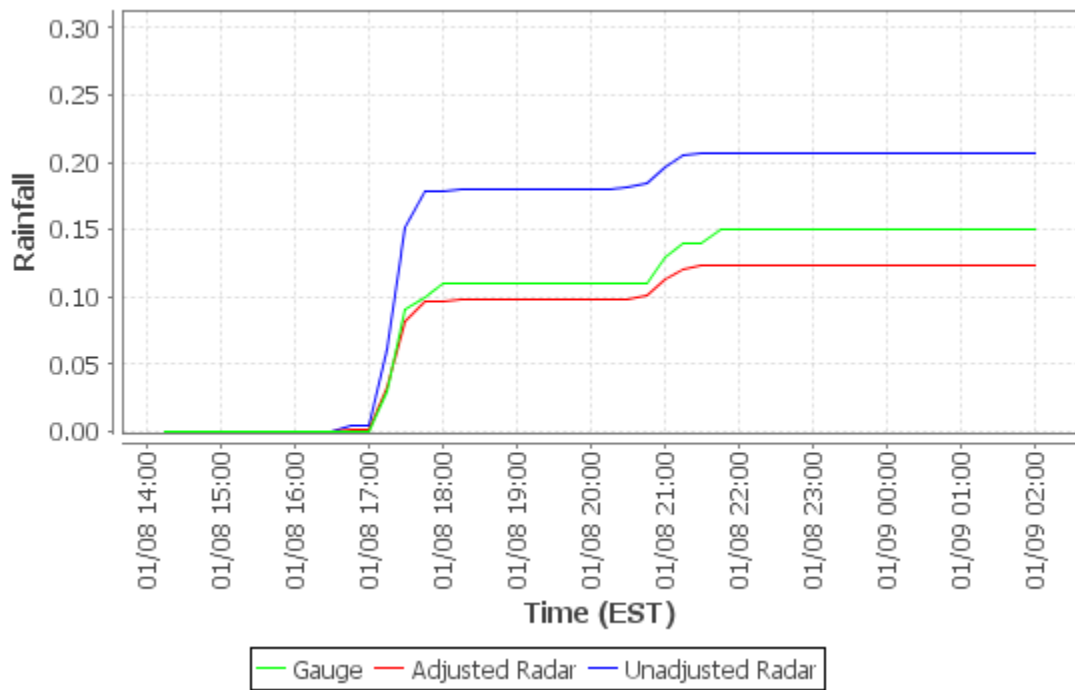
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



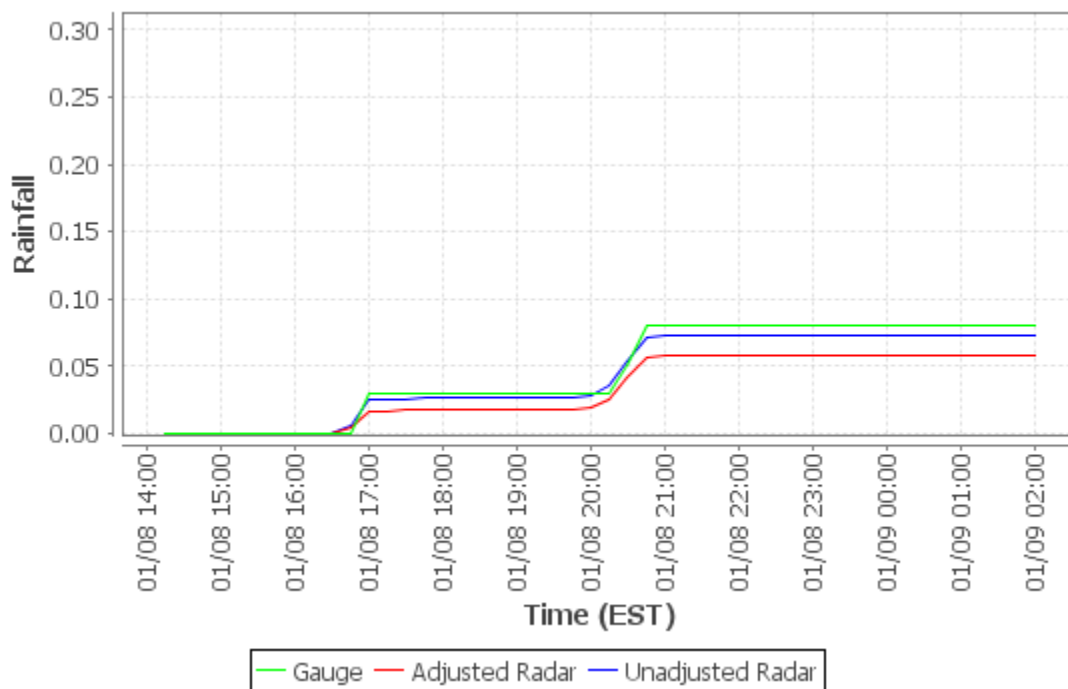
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



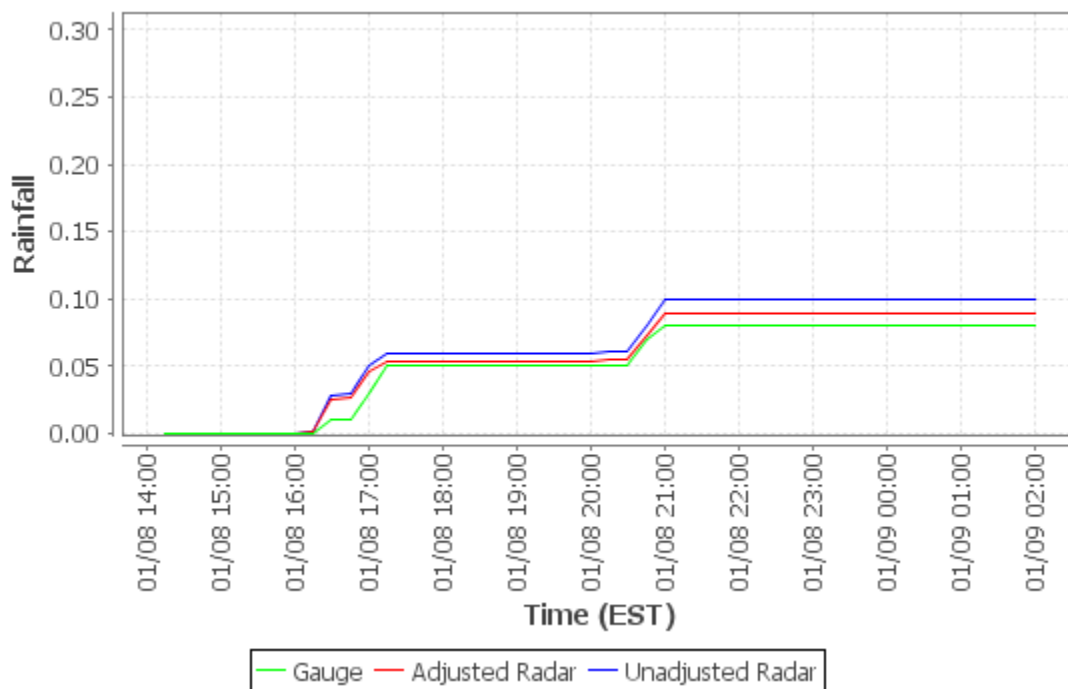
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



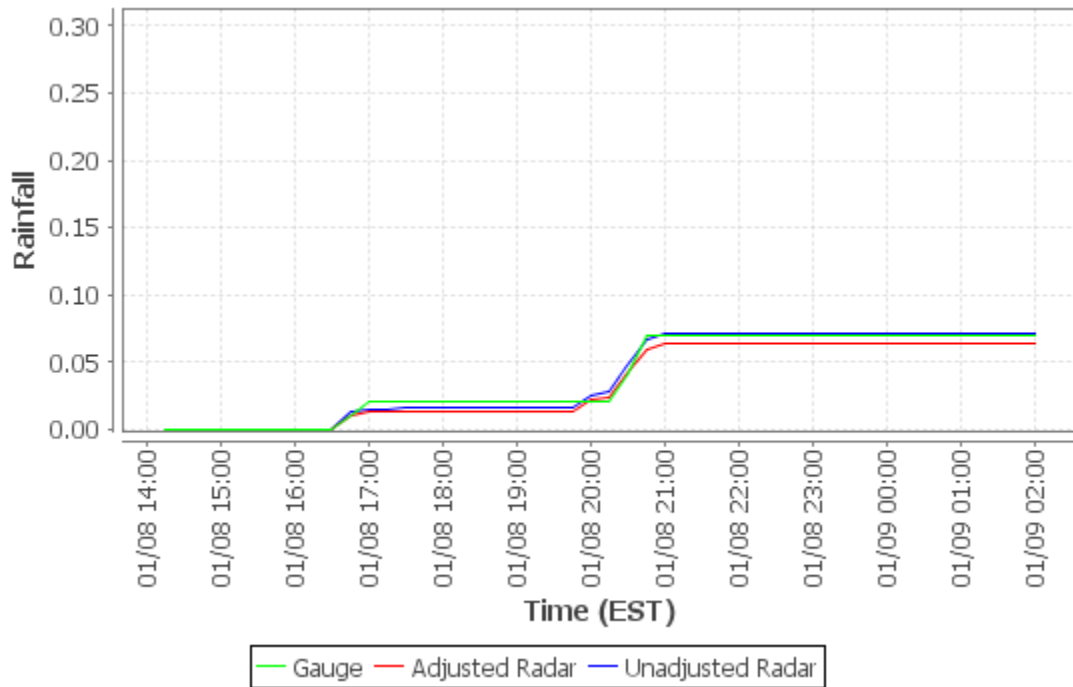
Cumulative Distribution Plot - Moon TWP (Loc21)



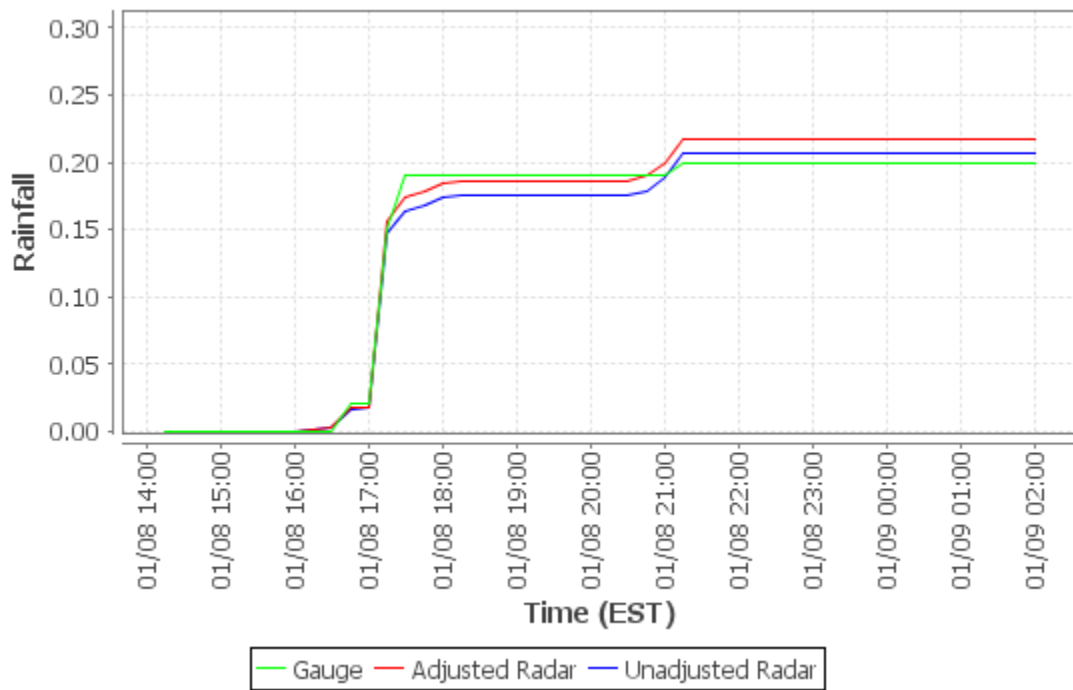
Cumulative Distribution Plot - North Fayette TWP (Loc22)



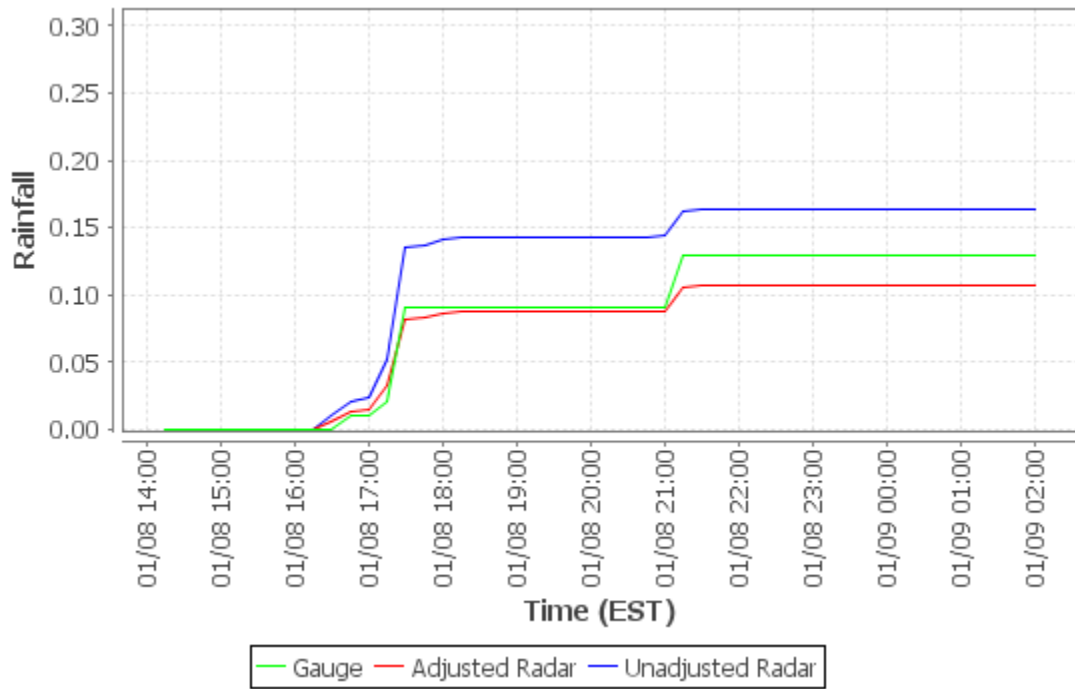
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



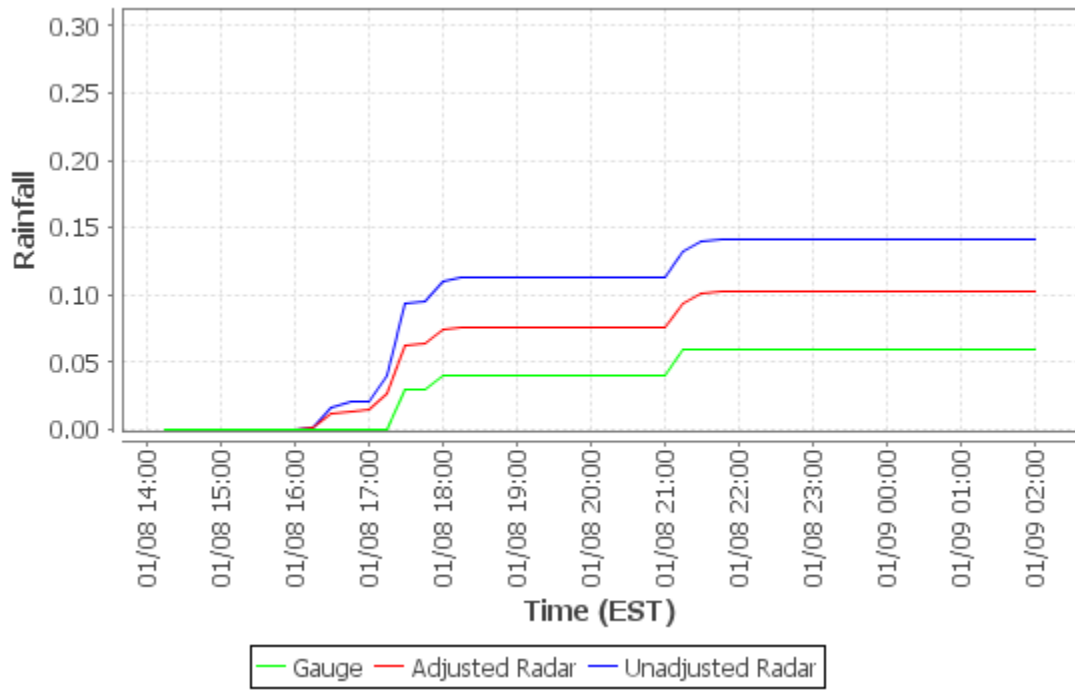
Cumulative Distribution Plot - Jefferson Hills (Loc24)



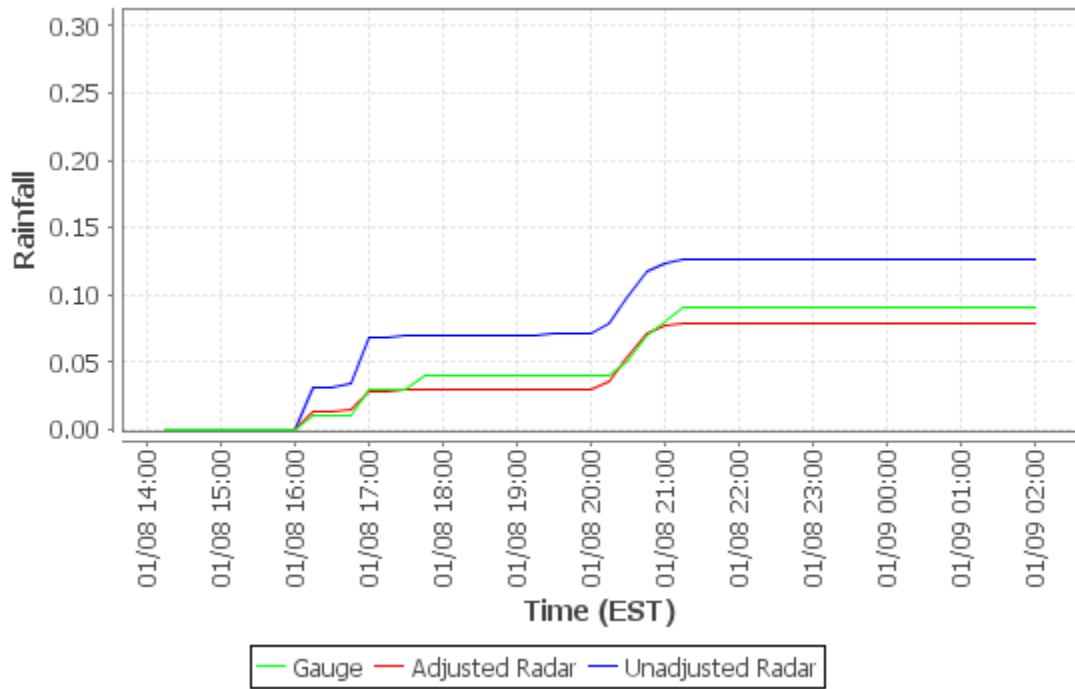
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



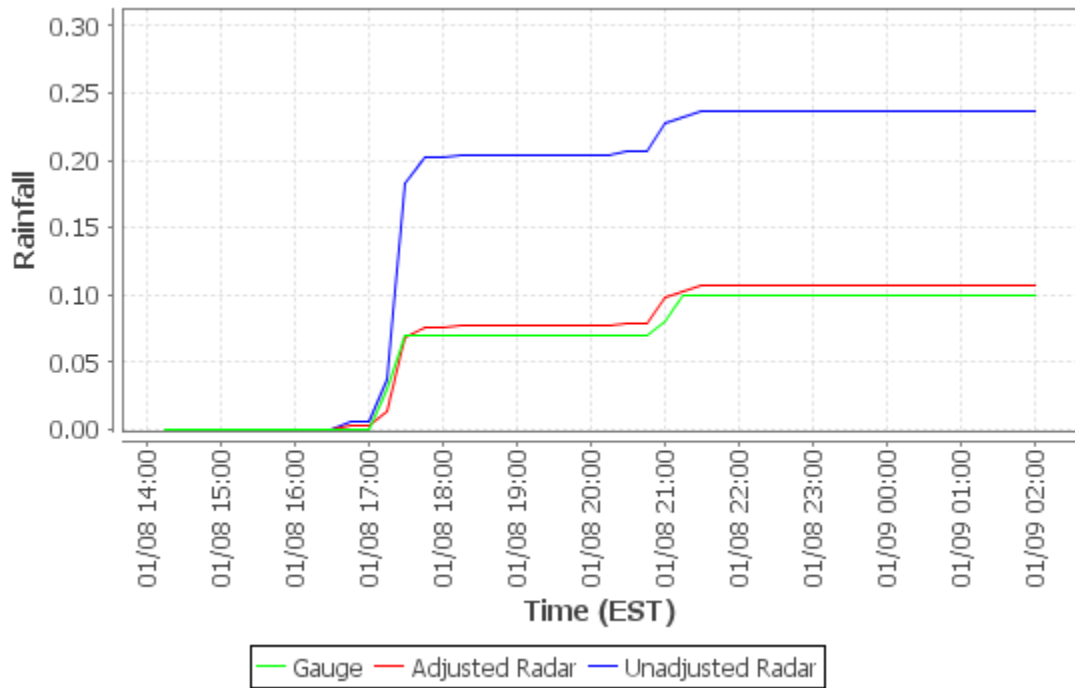
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



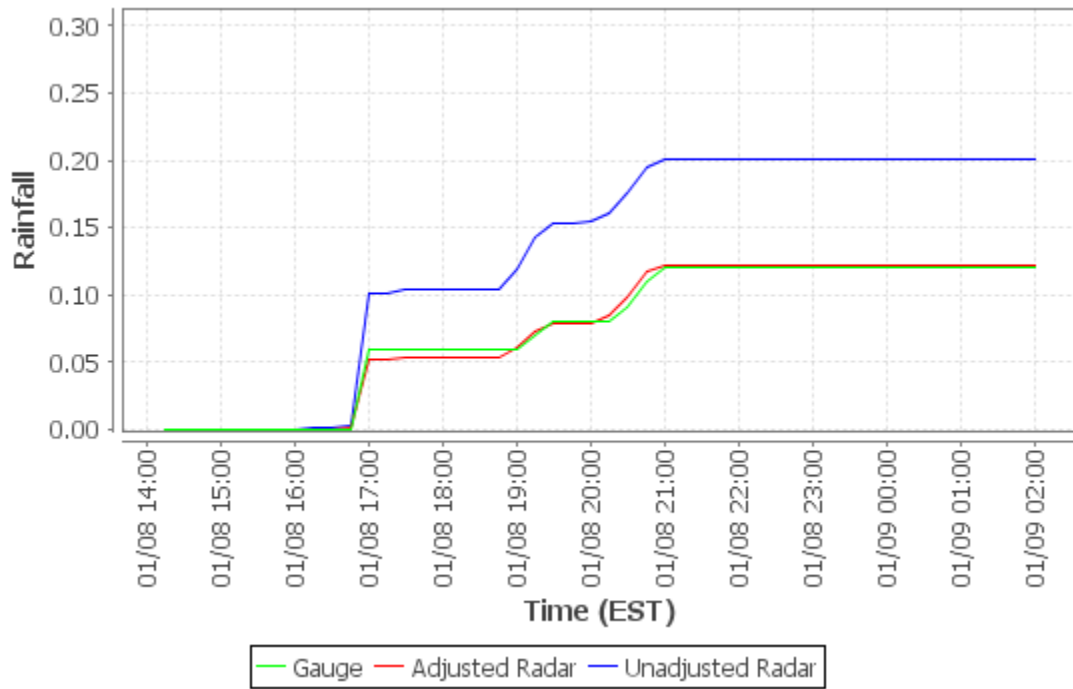
Cumulative Distribution Plot - Marshall TWP (Loc27)



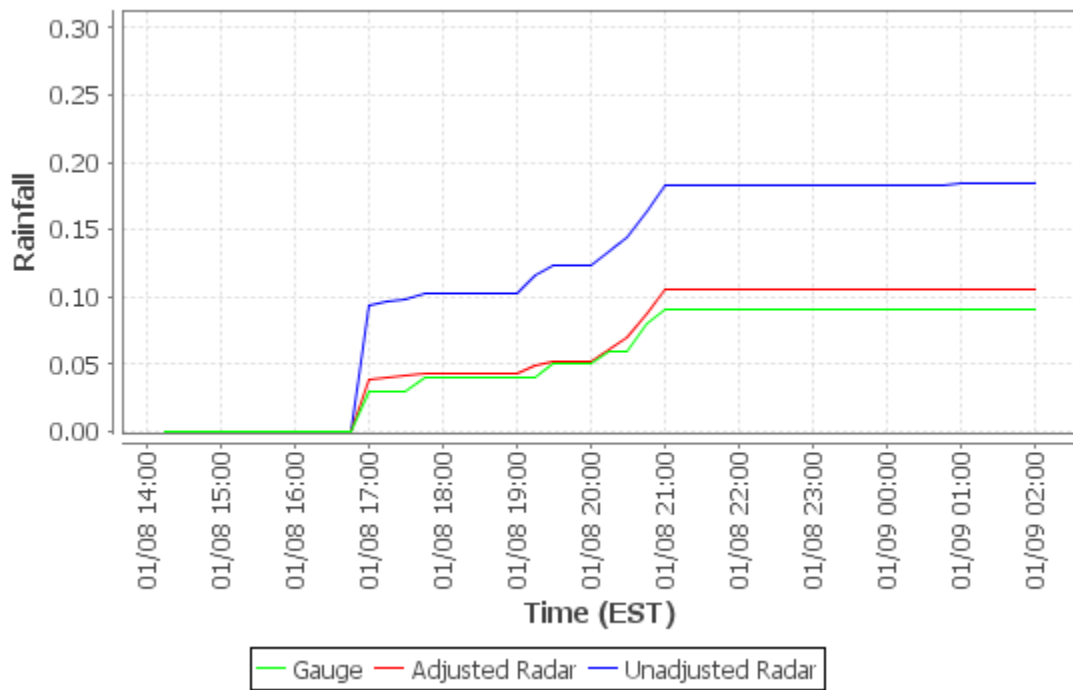
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



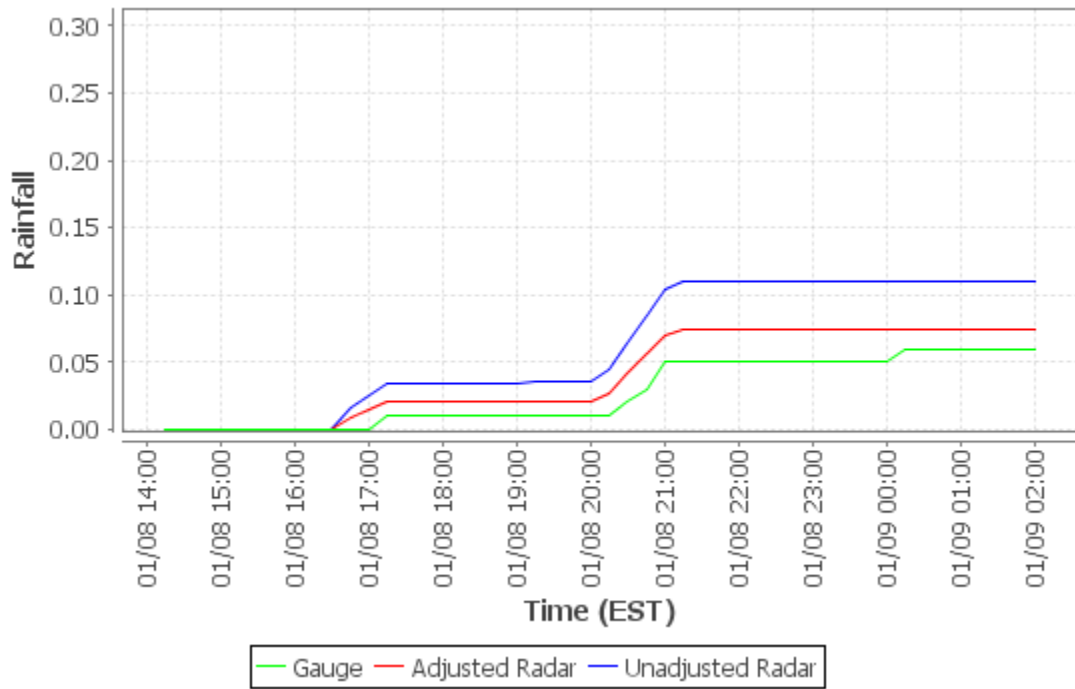
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



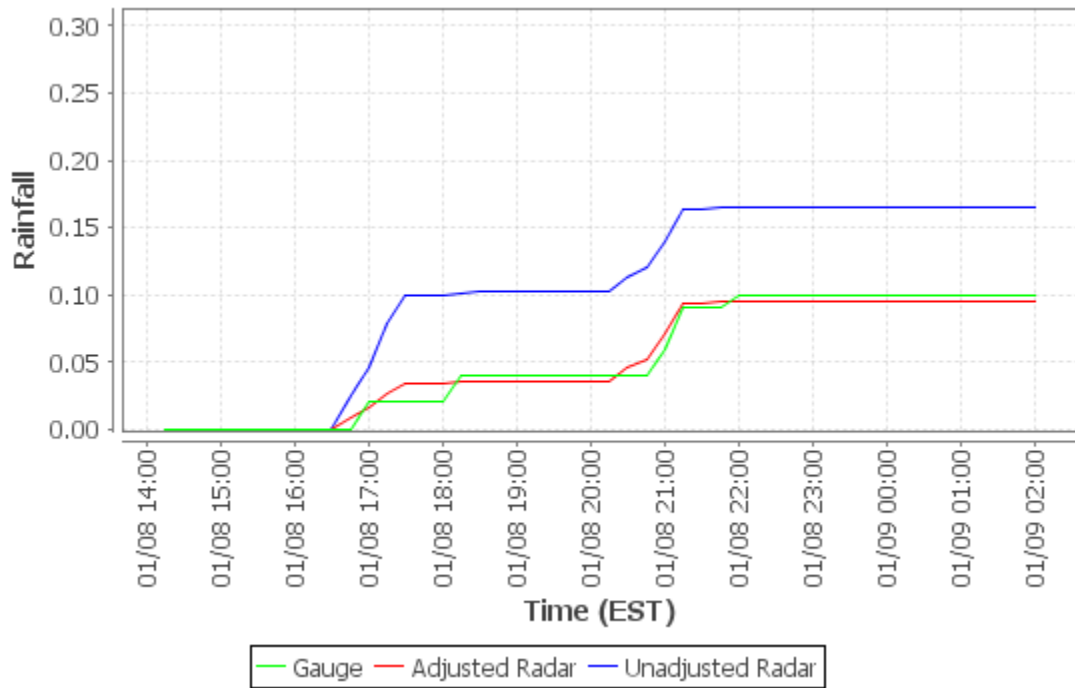
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



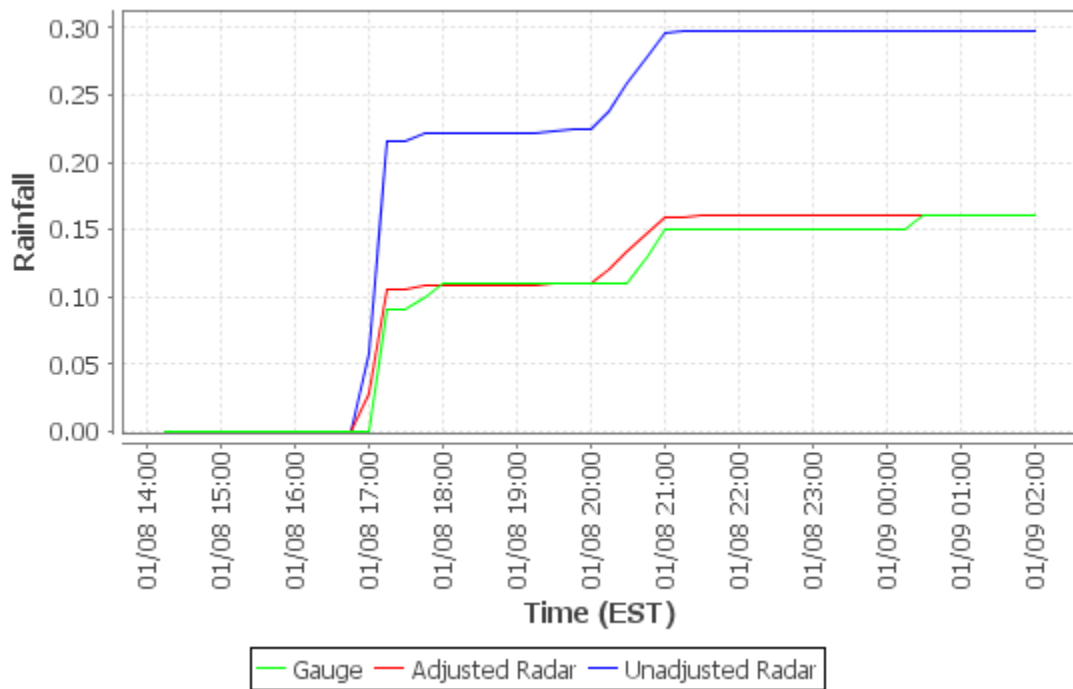
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



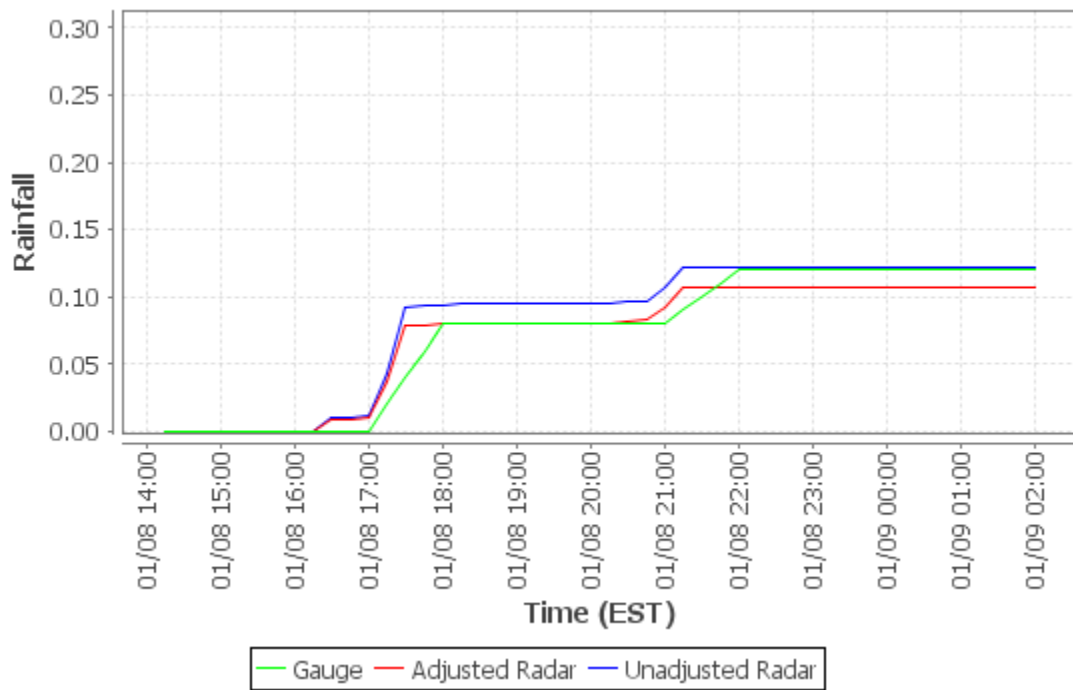
Cumulative Distribution Plot - Arnold (Loc32)



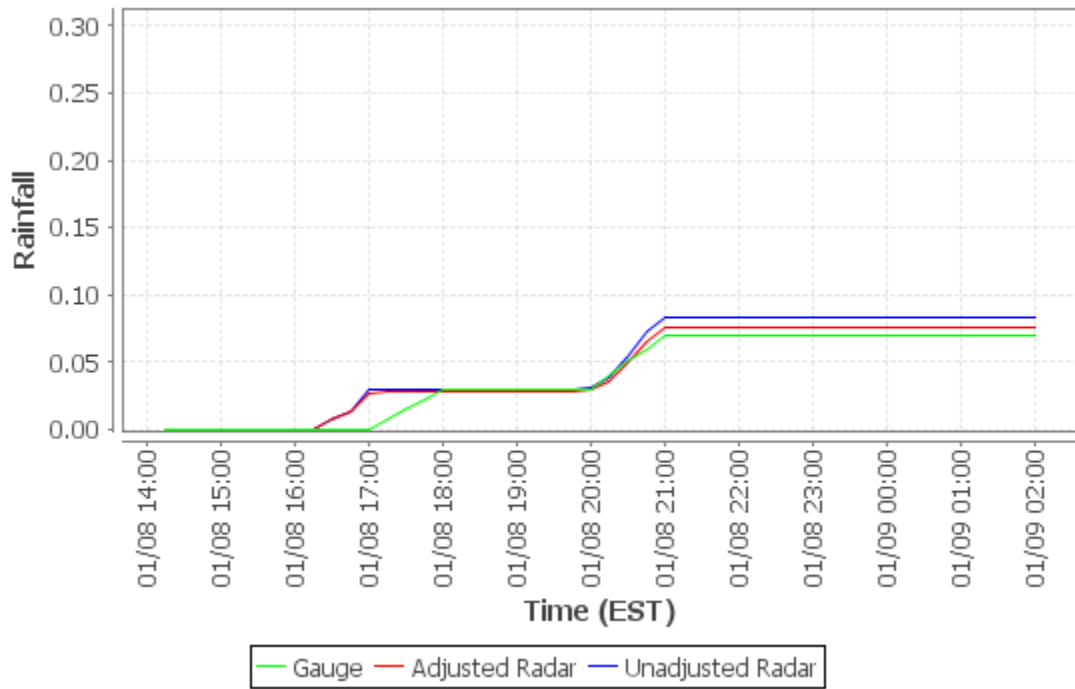
Cumulative Distribution Plot - Richland TWP (Loc33)



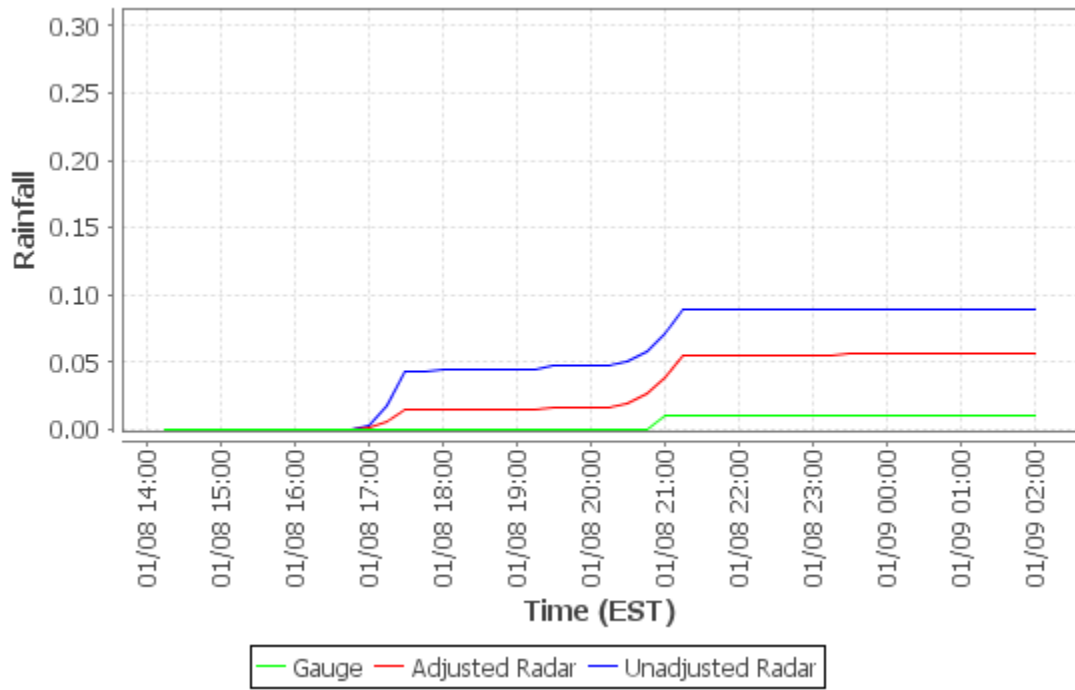
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



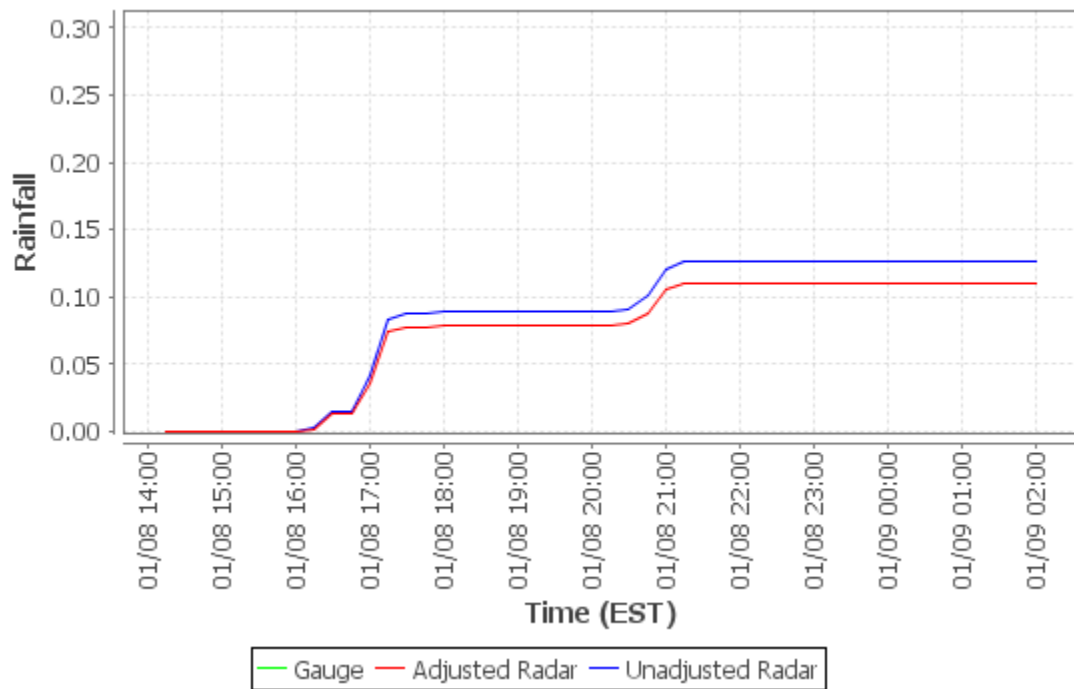
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



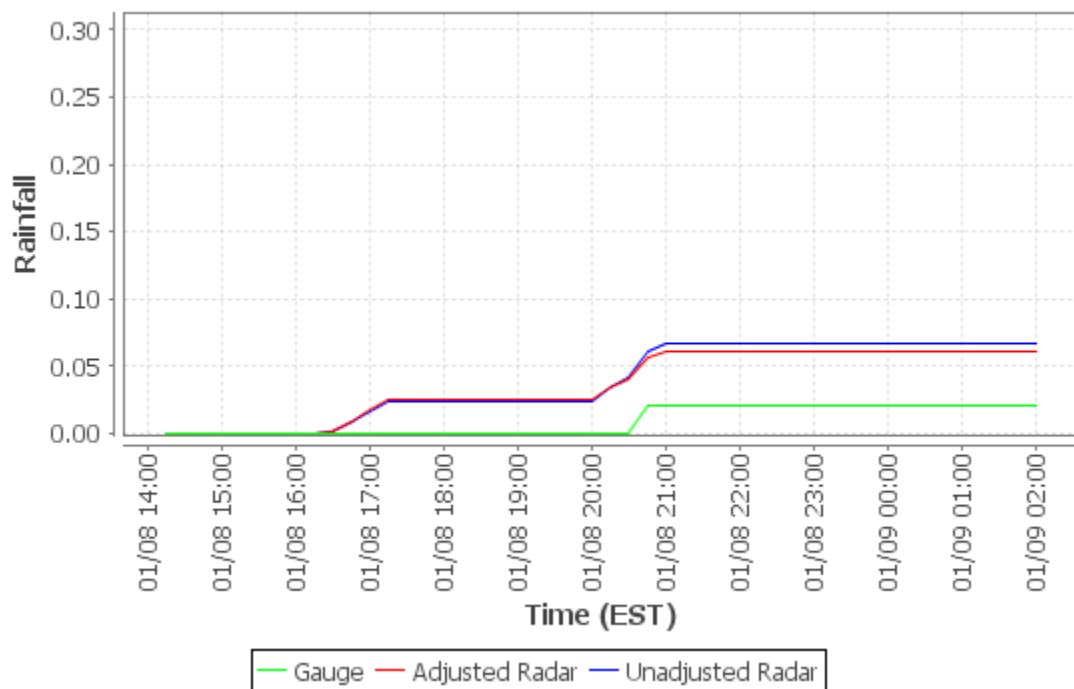
Cumulative Distribution Plot - Allegheny River at Natrona (03049500)



Cumulative Distribution Plot - Chartiers Creek at Carnegie (03085500)

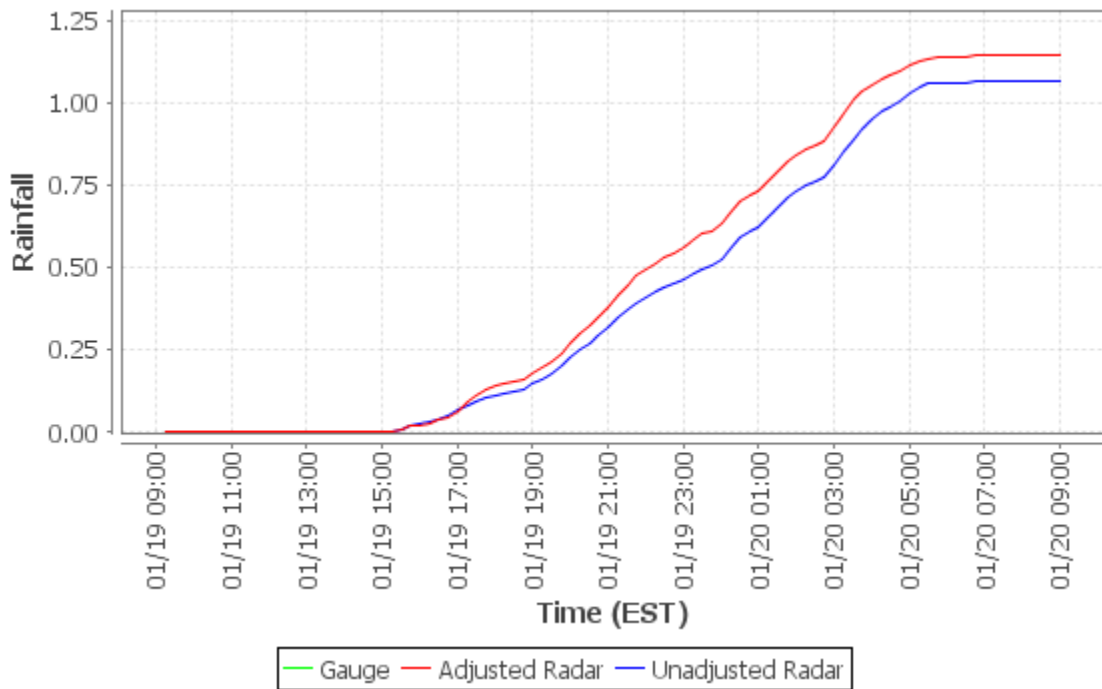


Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth (03085734)

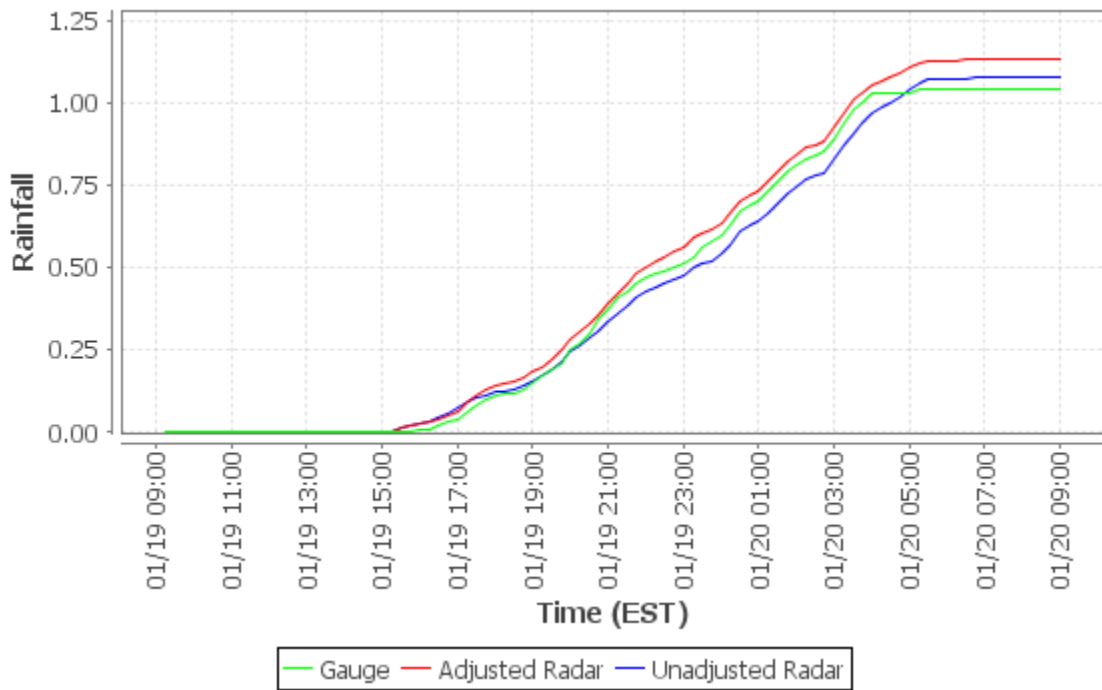


Appendix D - Event 3 (2019-01-19) CDPs

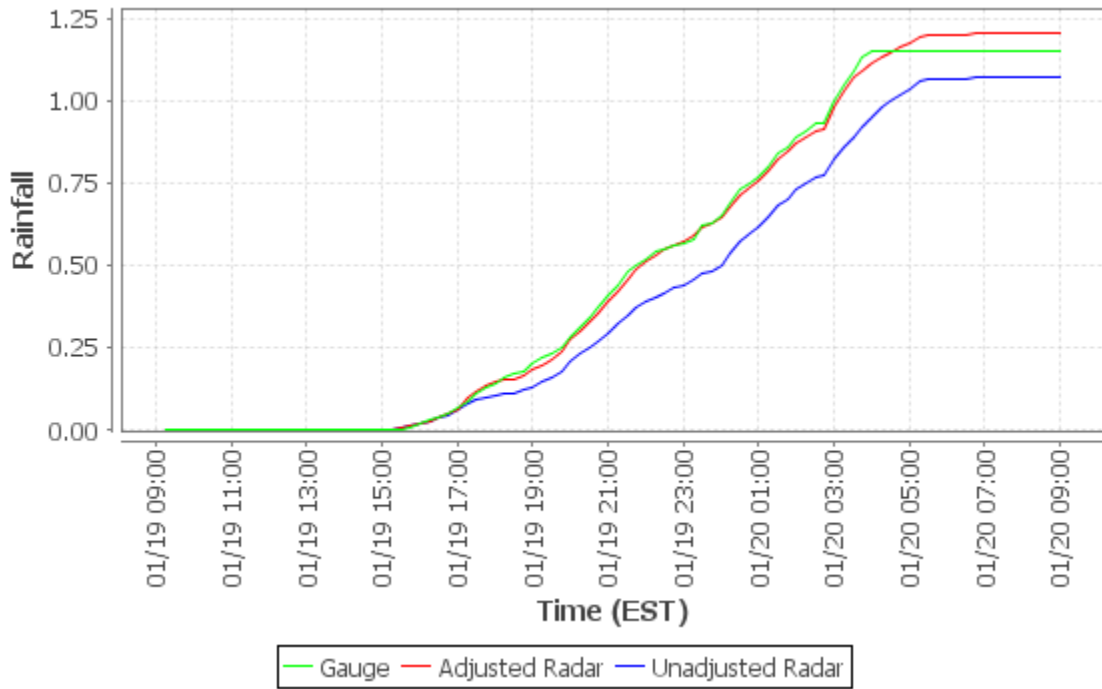
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



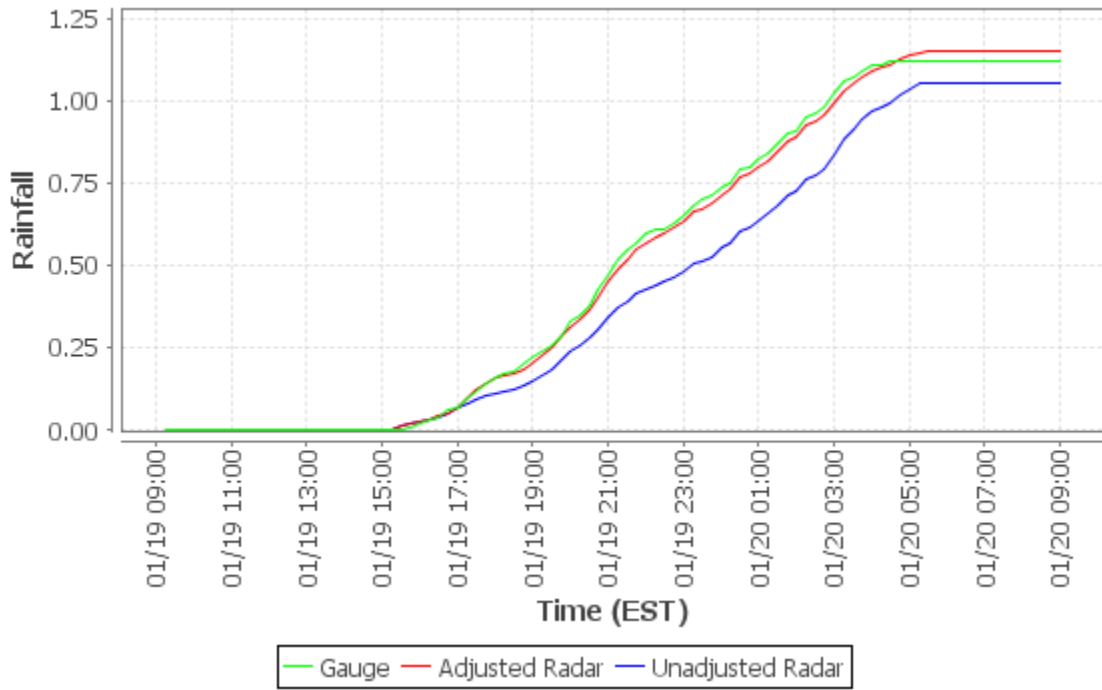
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



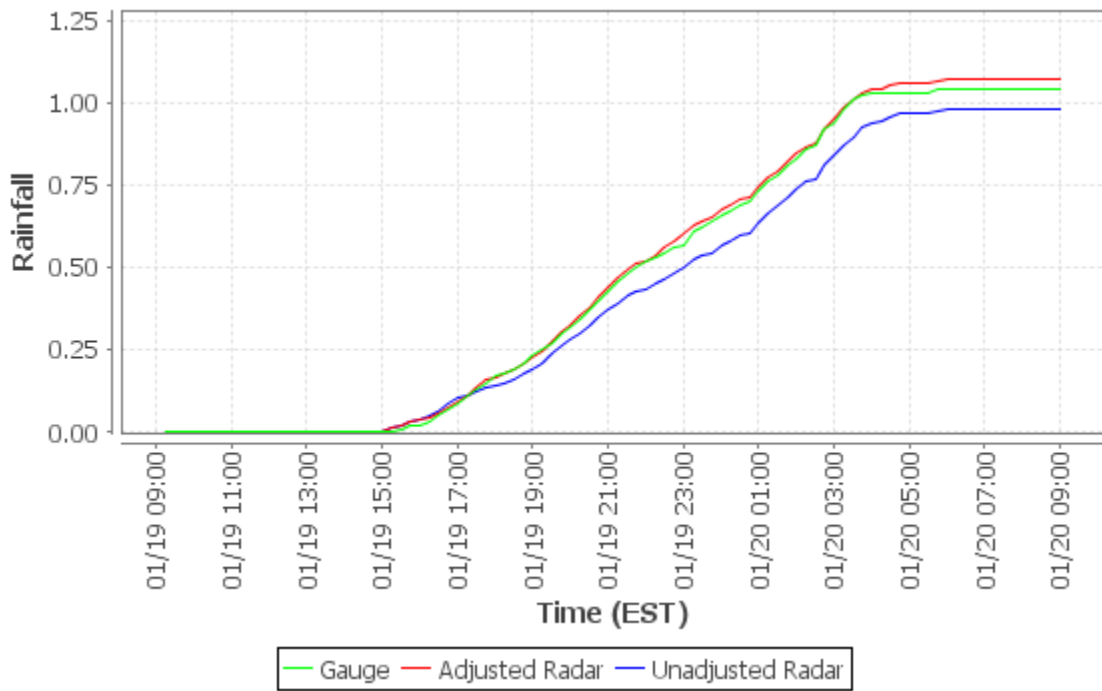
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



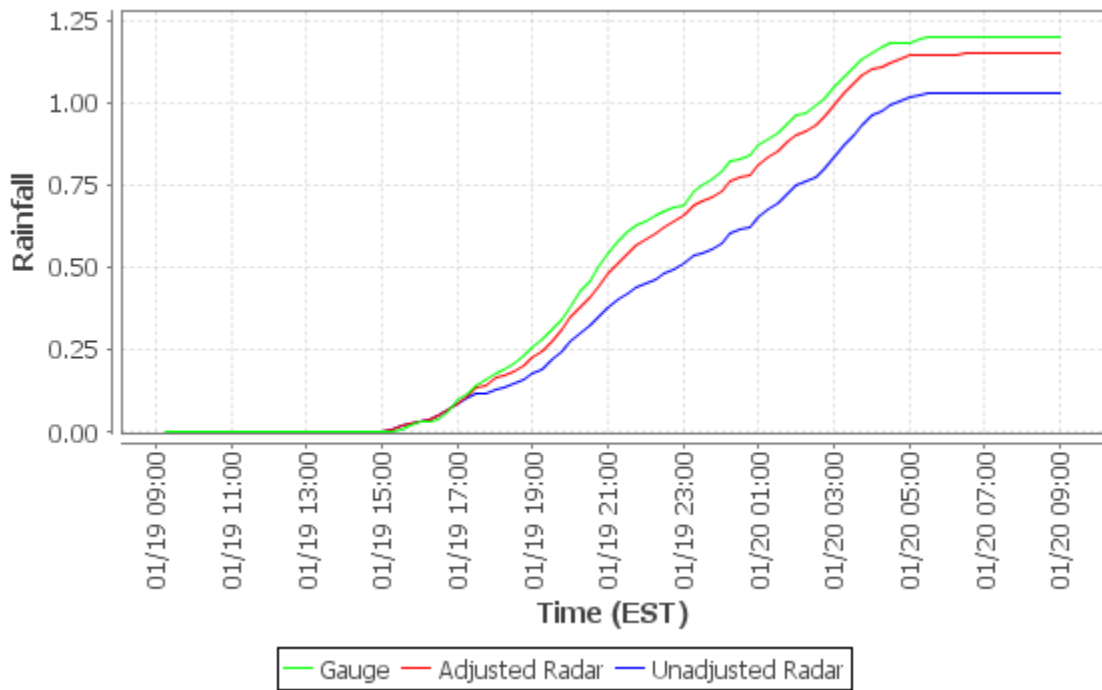
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



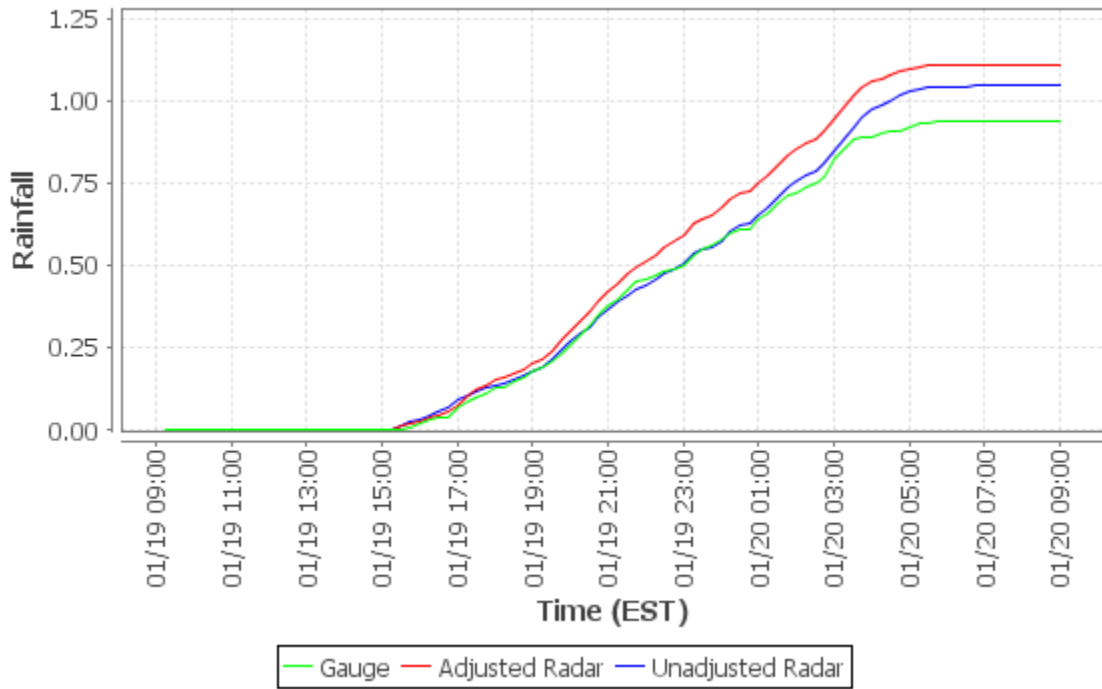
Cumulative Distribution Plot - Upper St. Clair (Loc05)



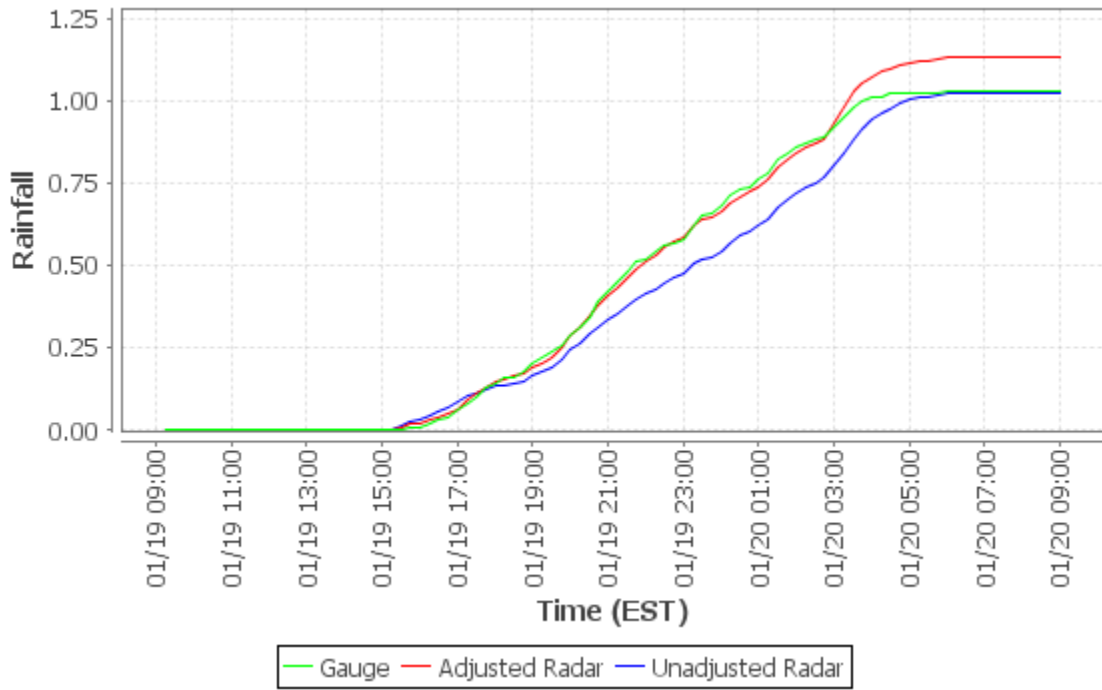
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



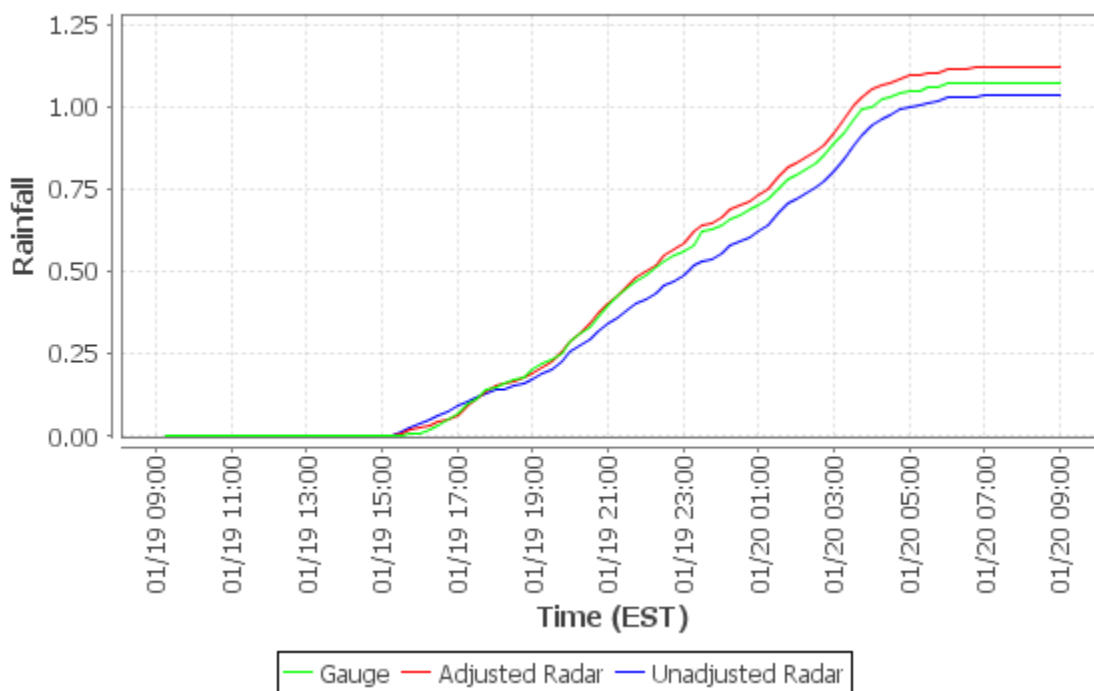
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



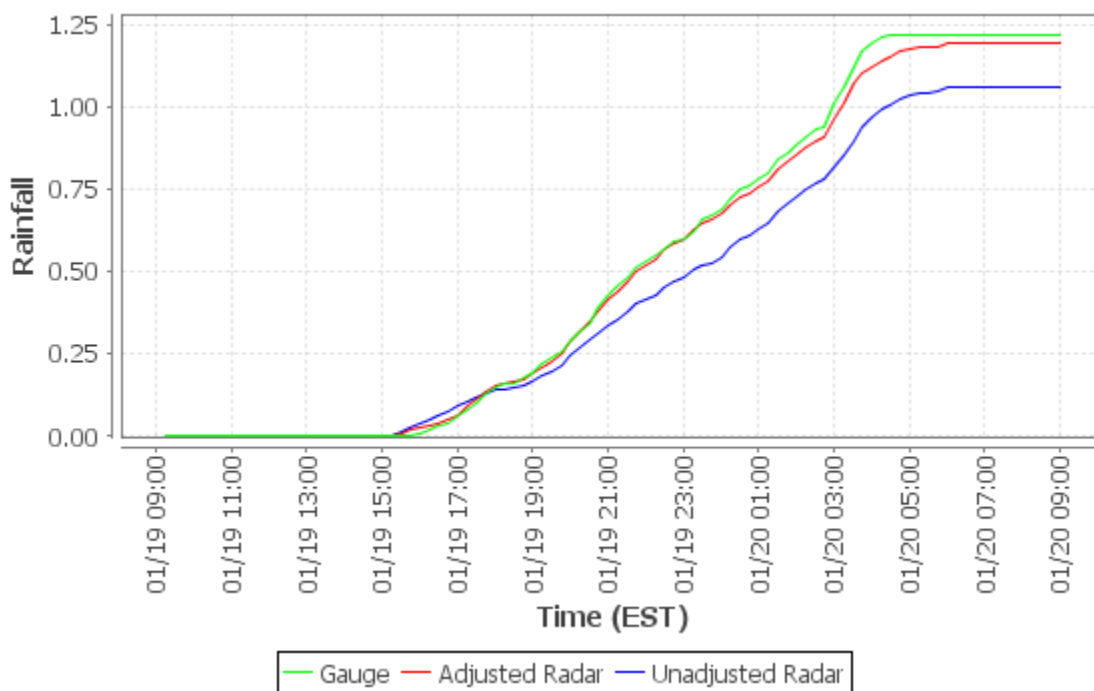
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



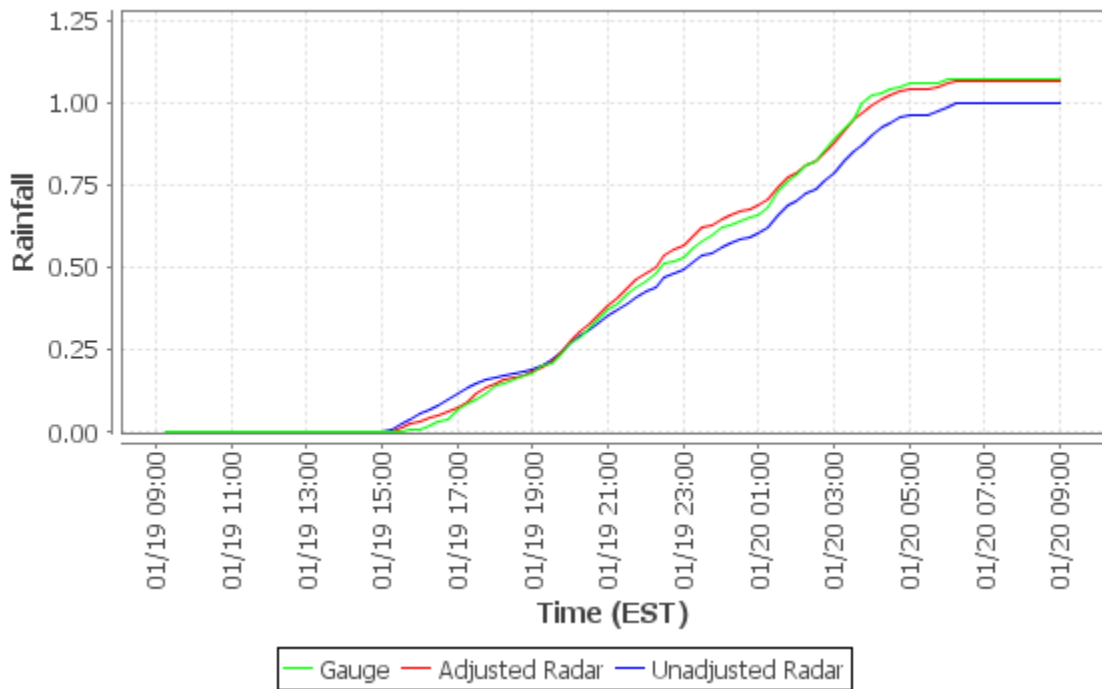
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



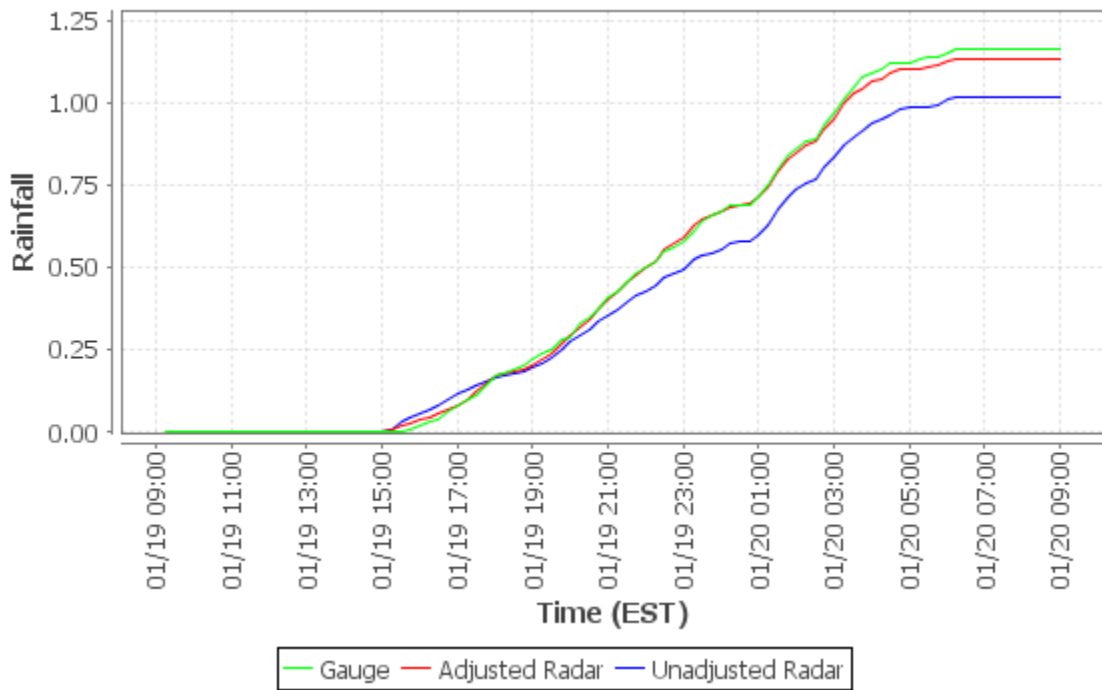
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



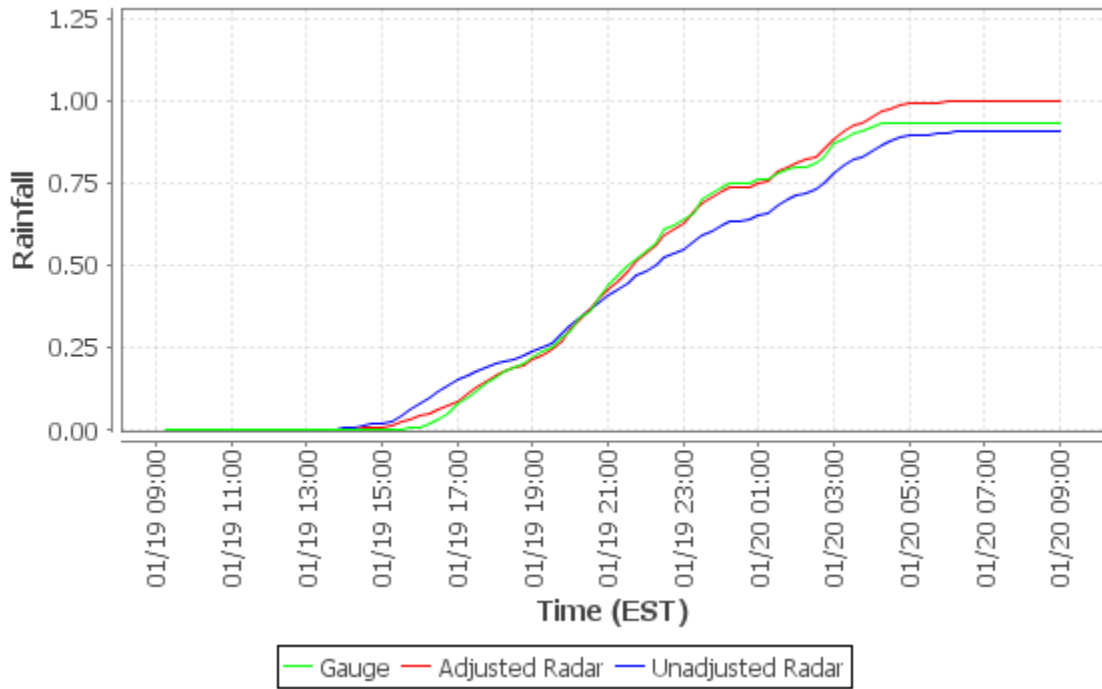
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



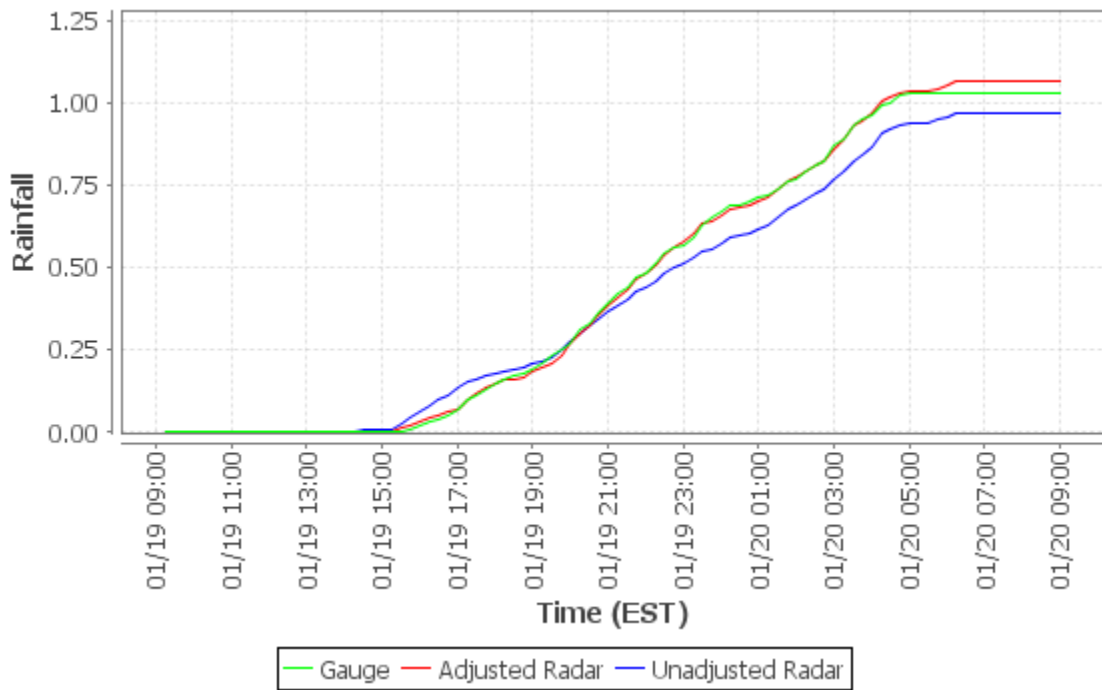
Cumulative Distribution Plot - Baldwin (Loc12)



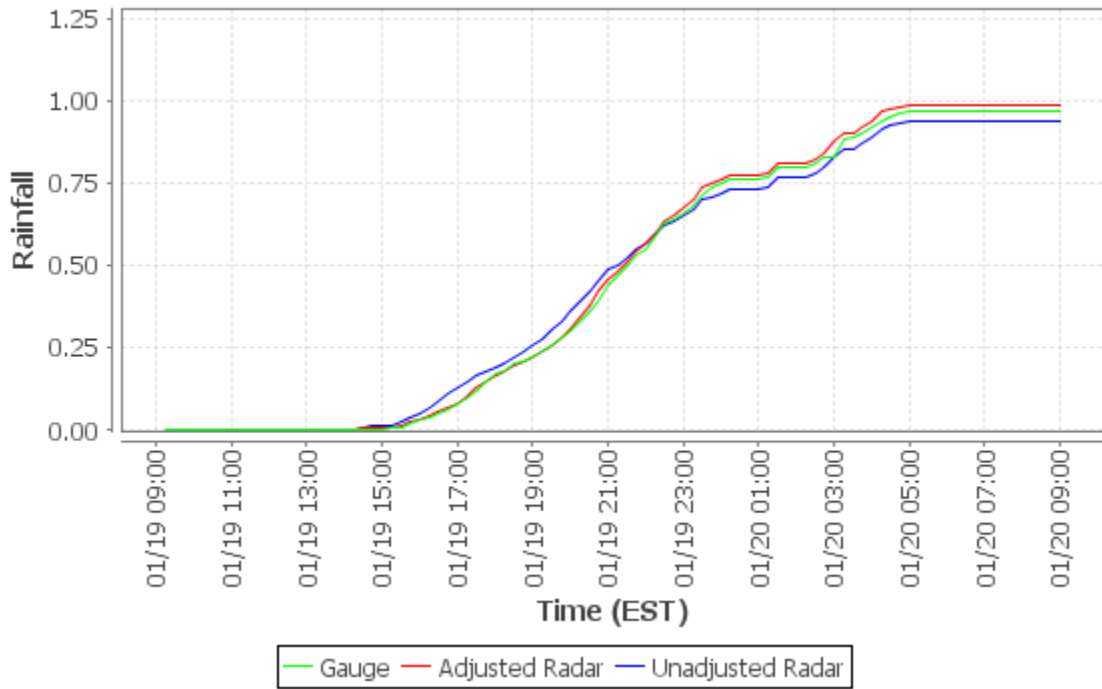
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



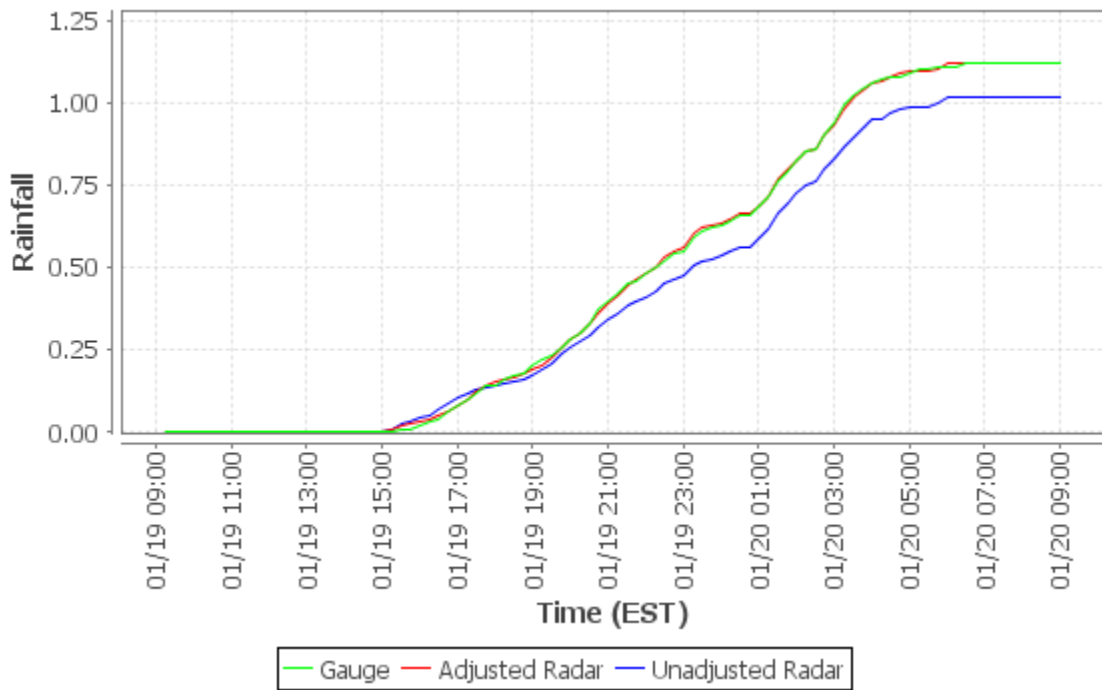
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



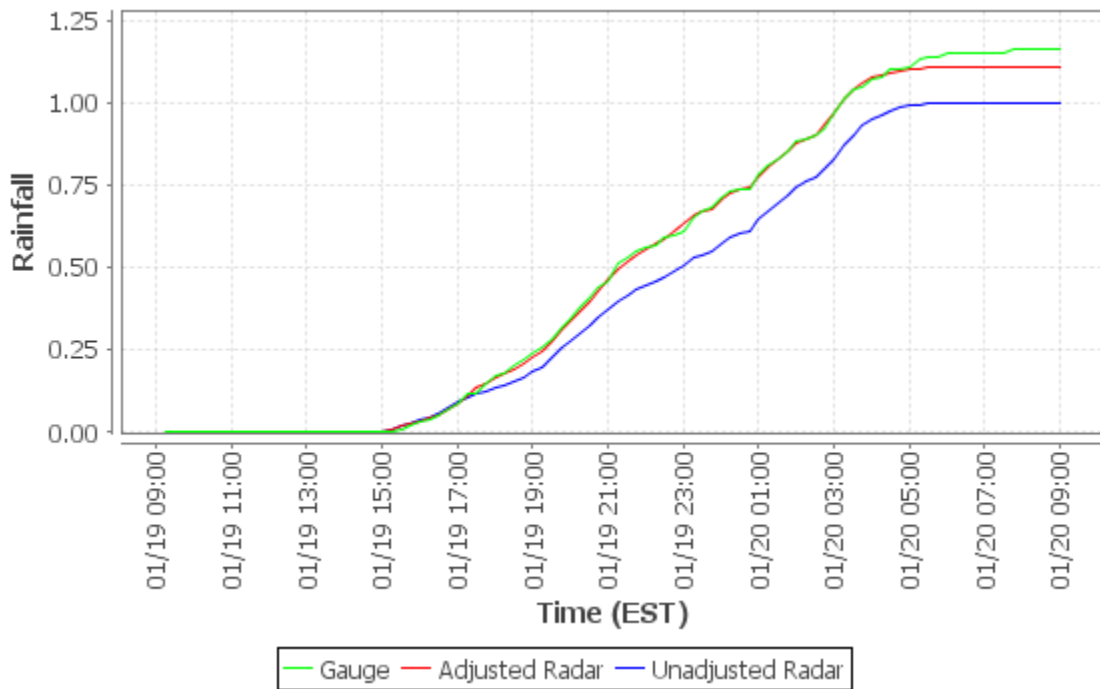
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



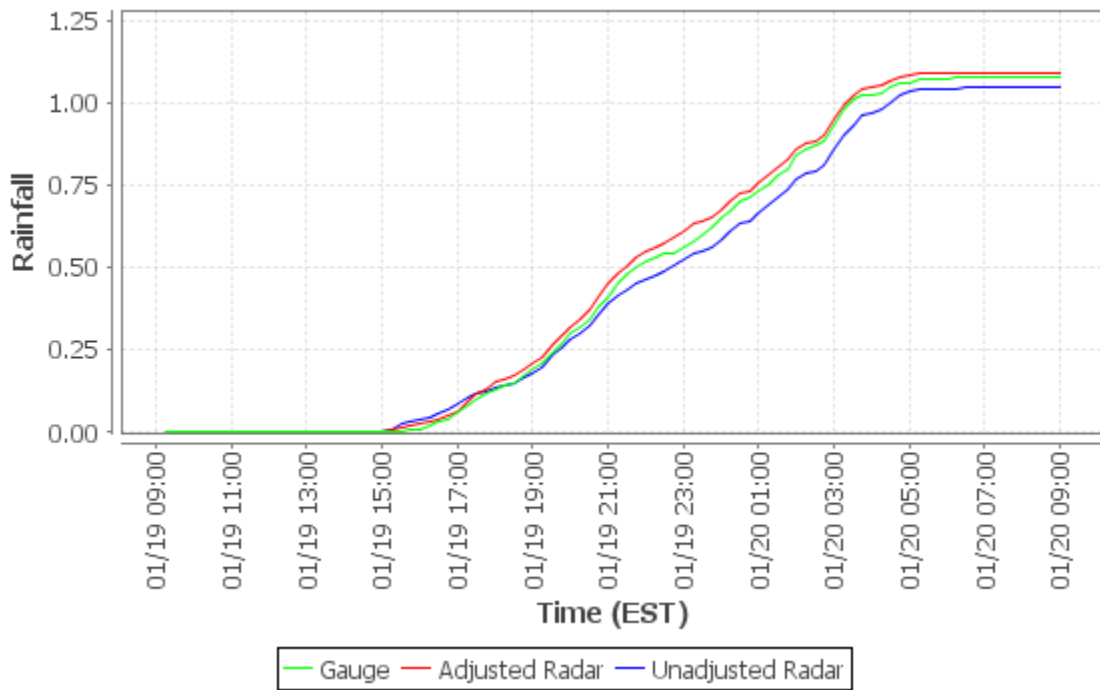
Cumulative Distribution Plot - Castle Shannon (Loc16)



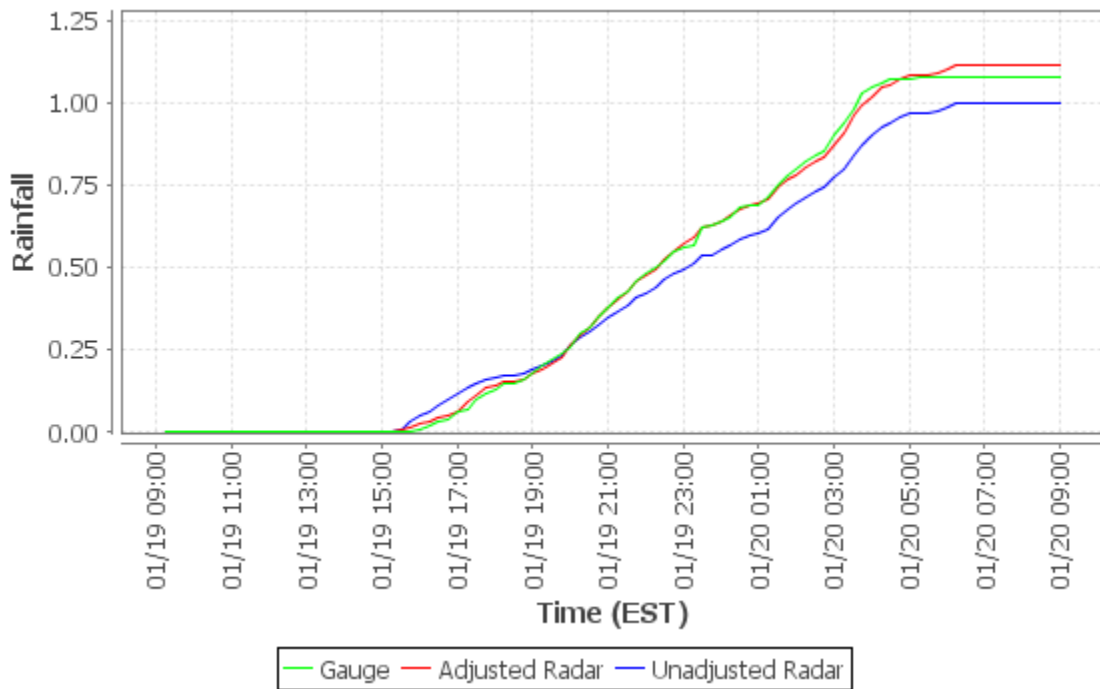
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



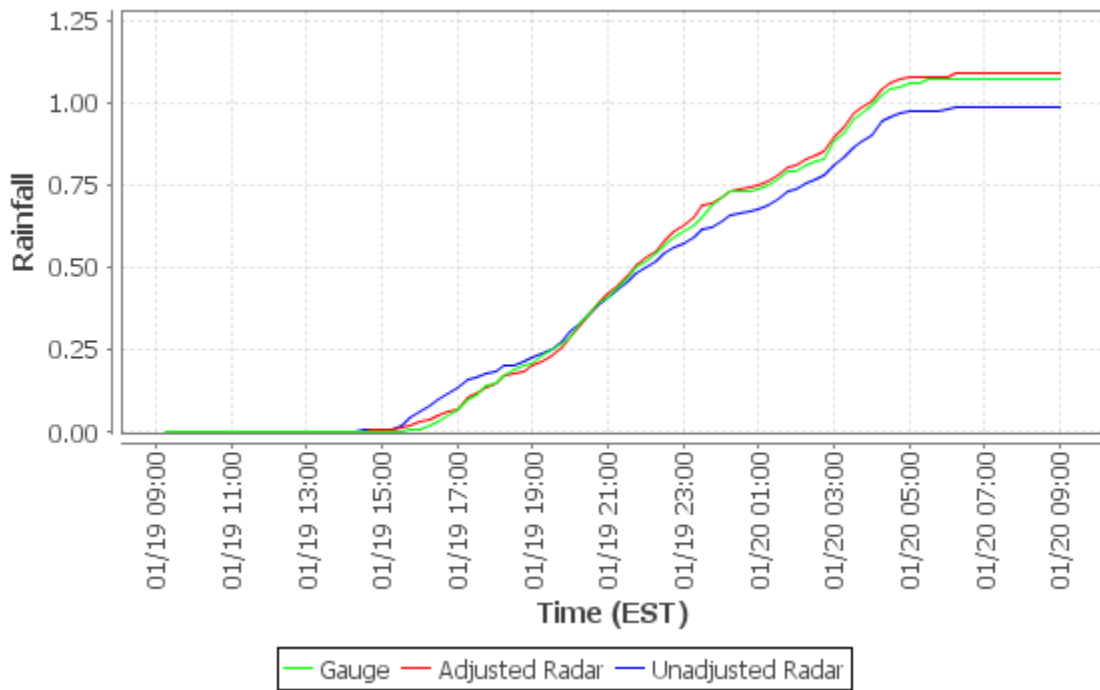
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



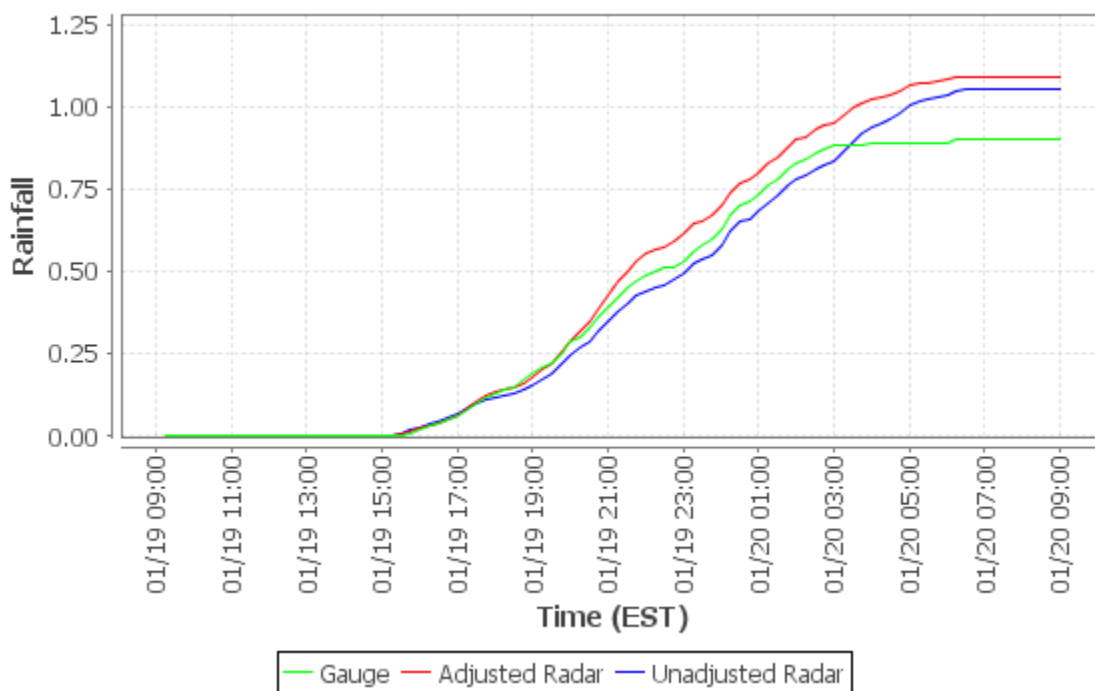
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



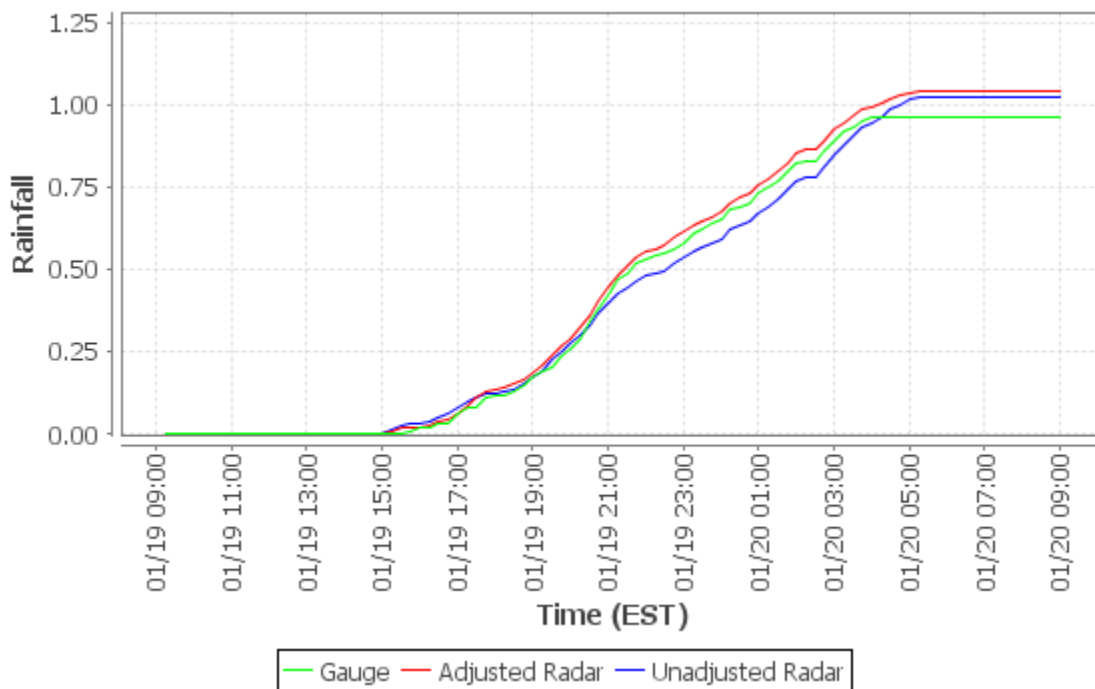
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



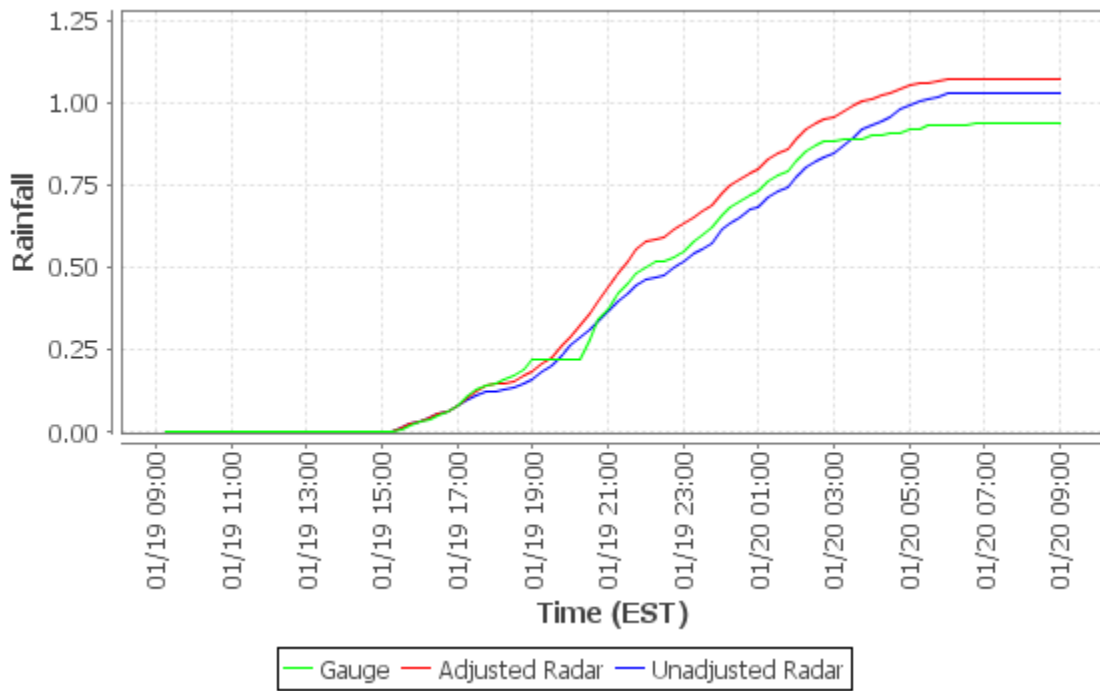
Cumulative Distribution Plot - Moon TWP (Loc21)



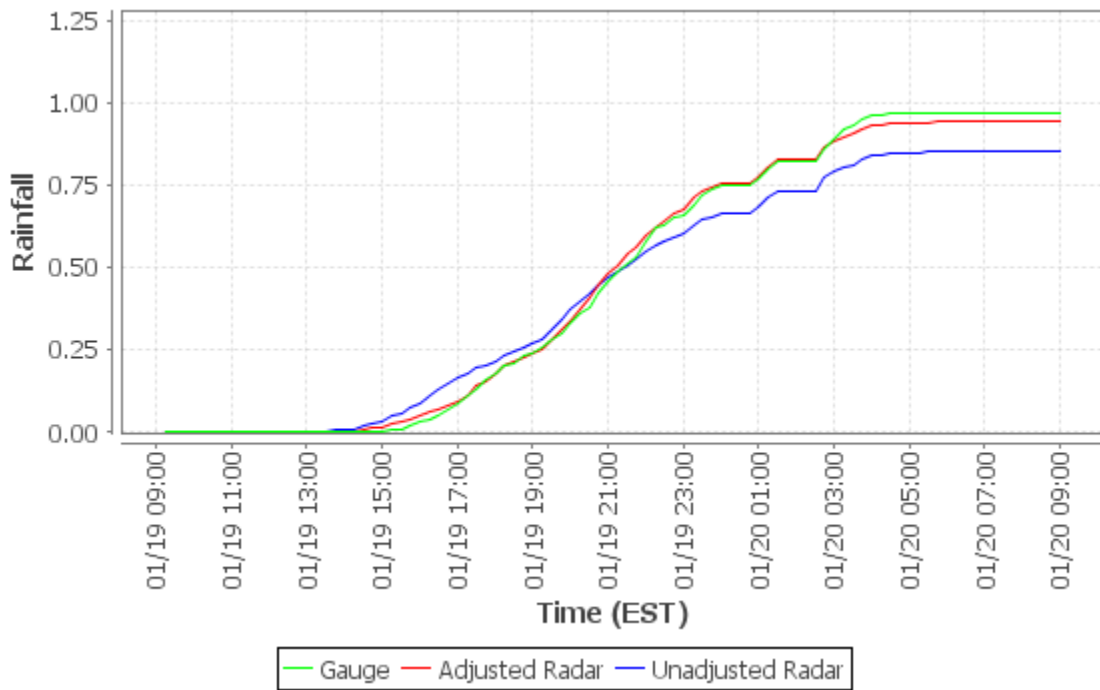
Cumulative Distribution Plot - North Fayette TWP (Loc22)



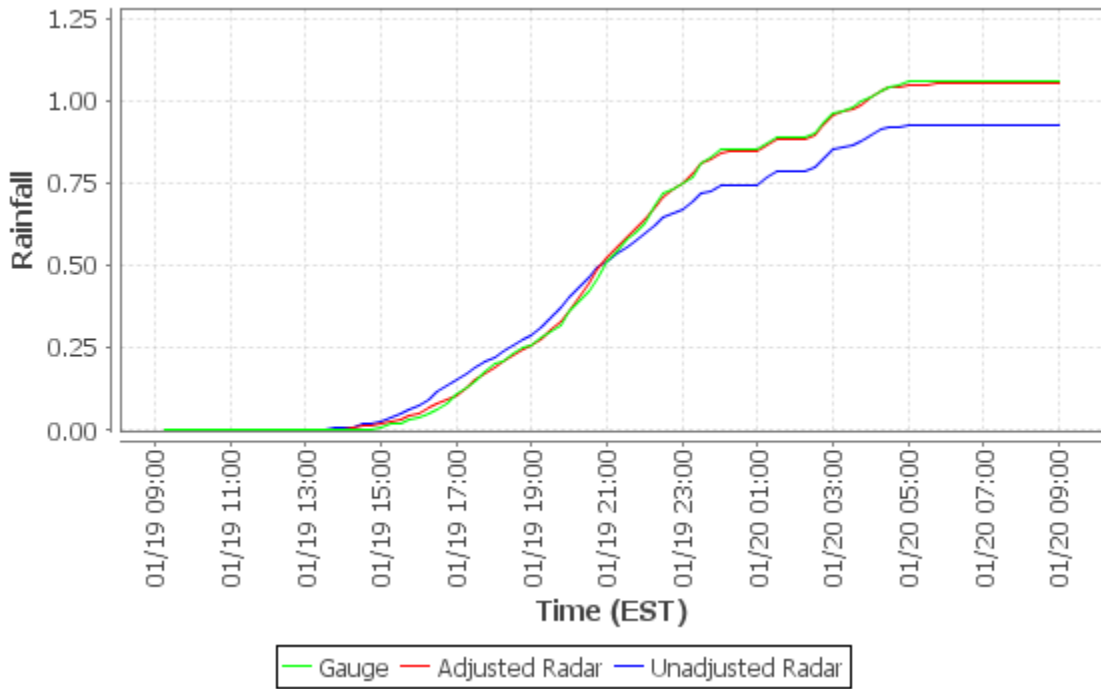
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



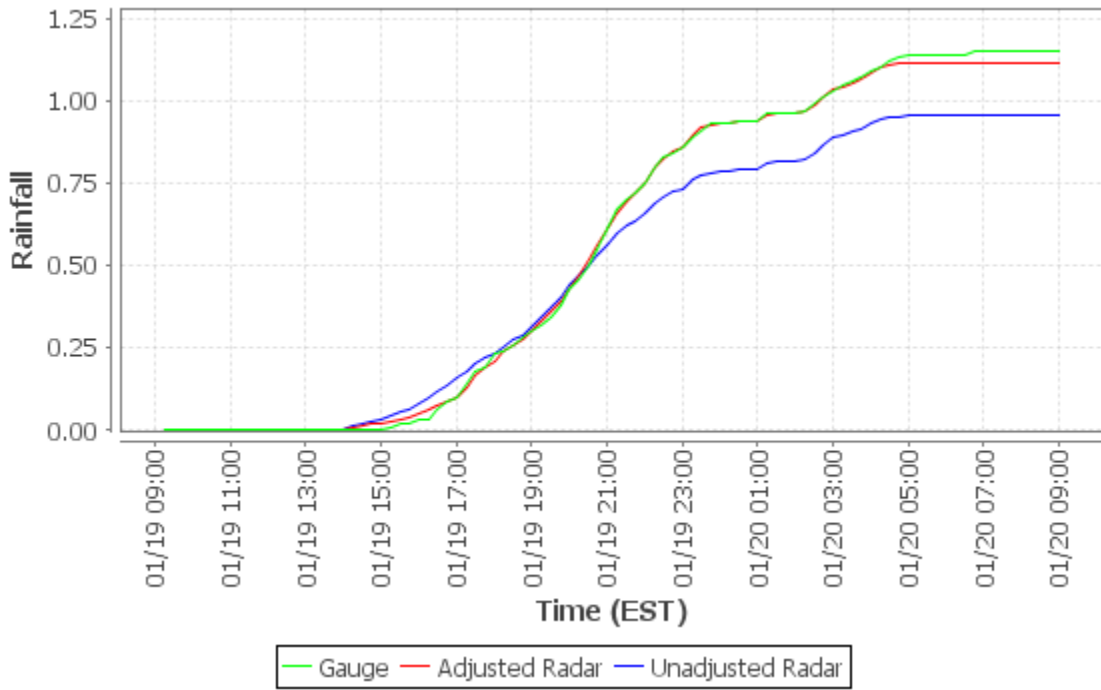
Cumulative Distribution Plot - Jefferson Hills (Loc24)



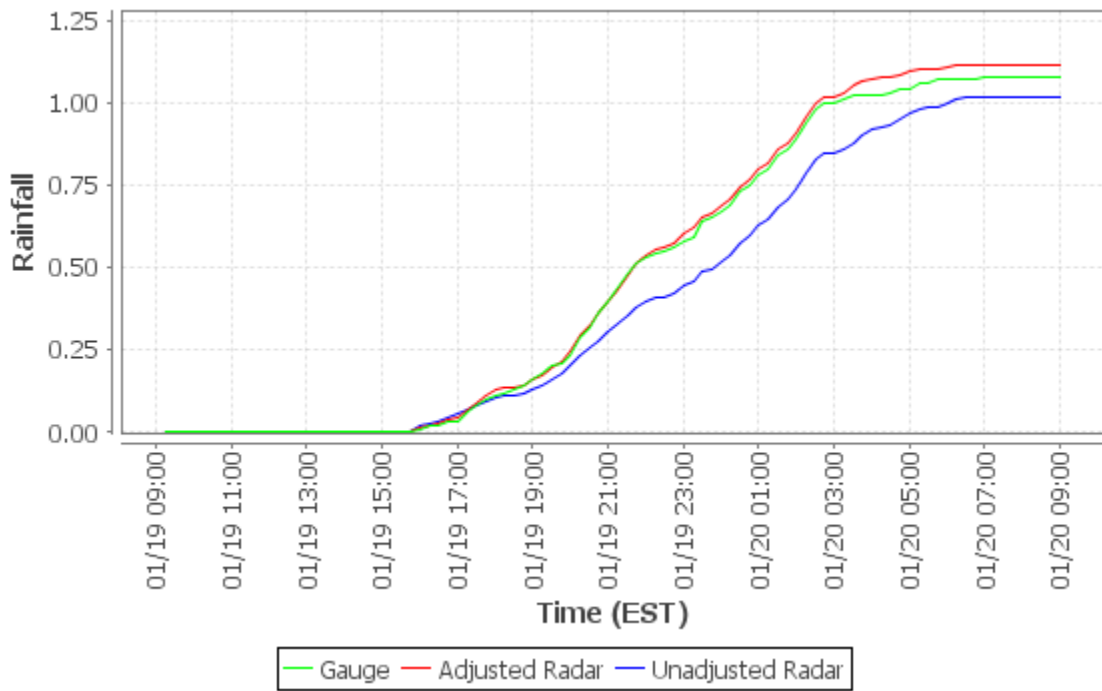
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



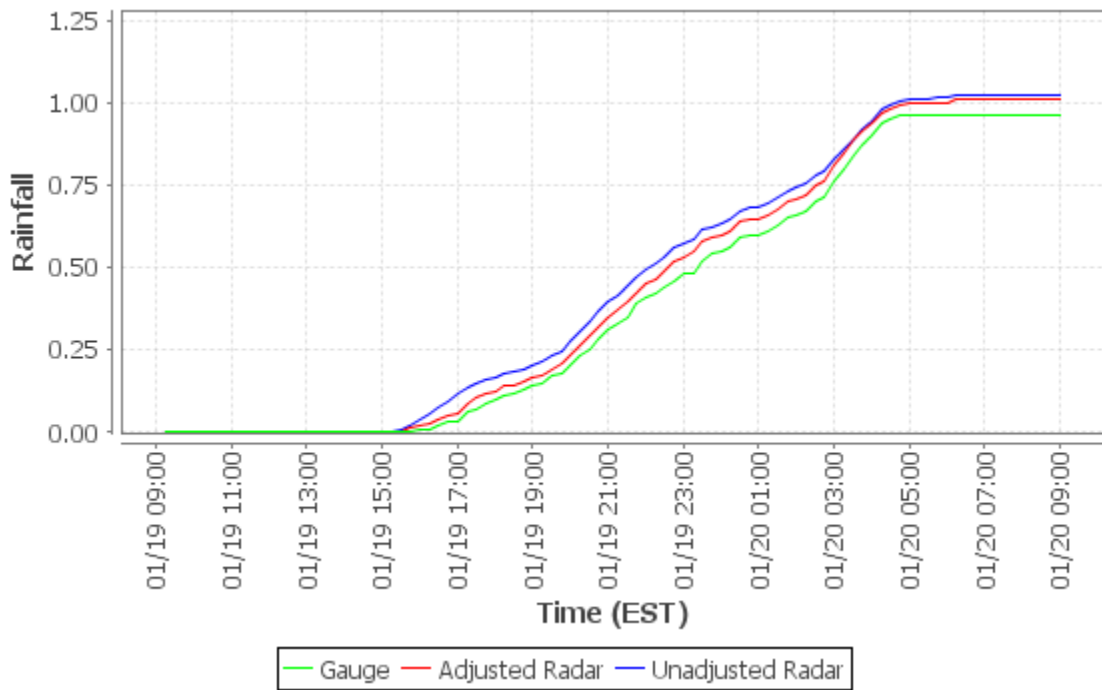
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



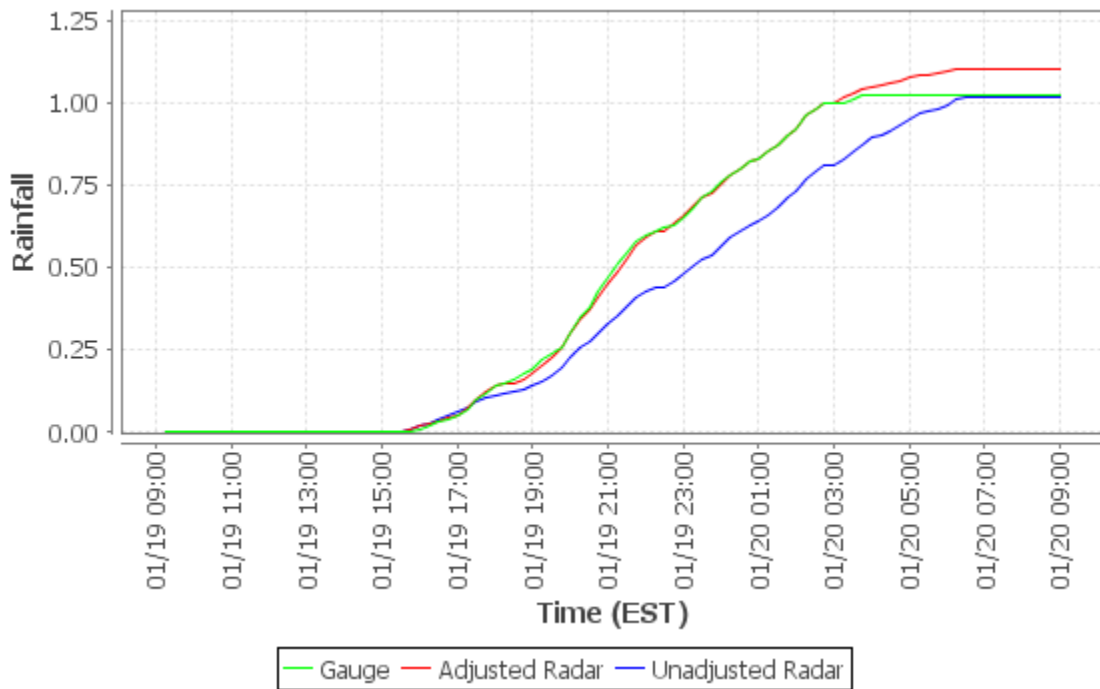
Cumulative Distribution Plot - Marshall TWP (Loc27)



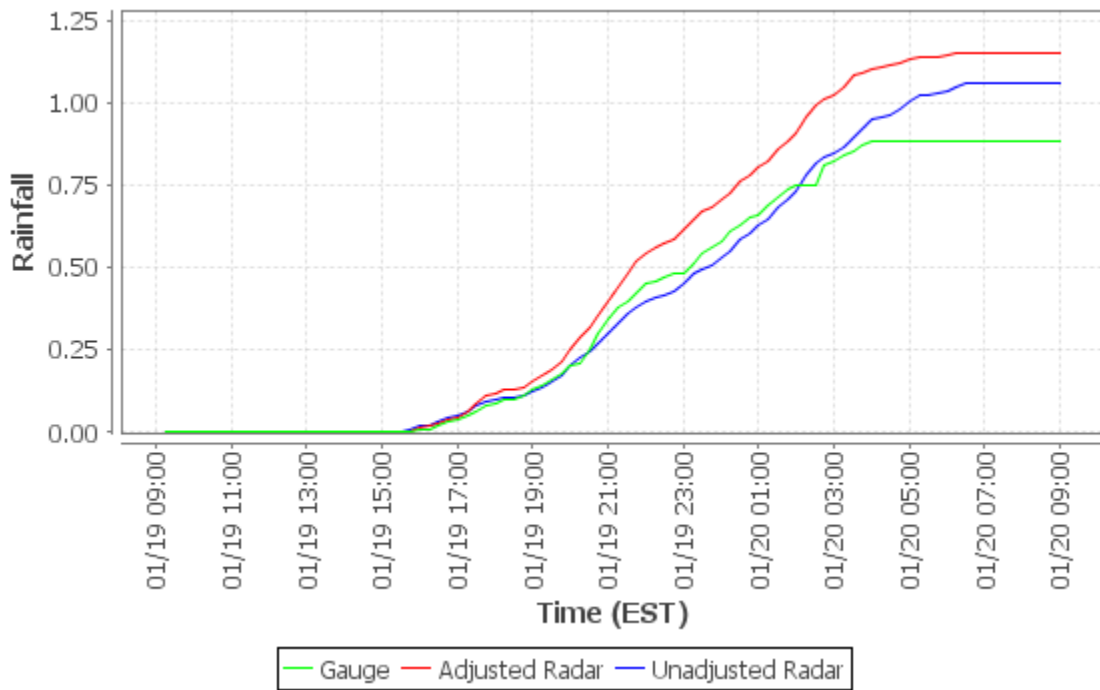
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



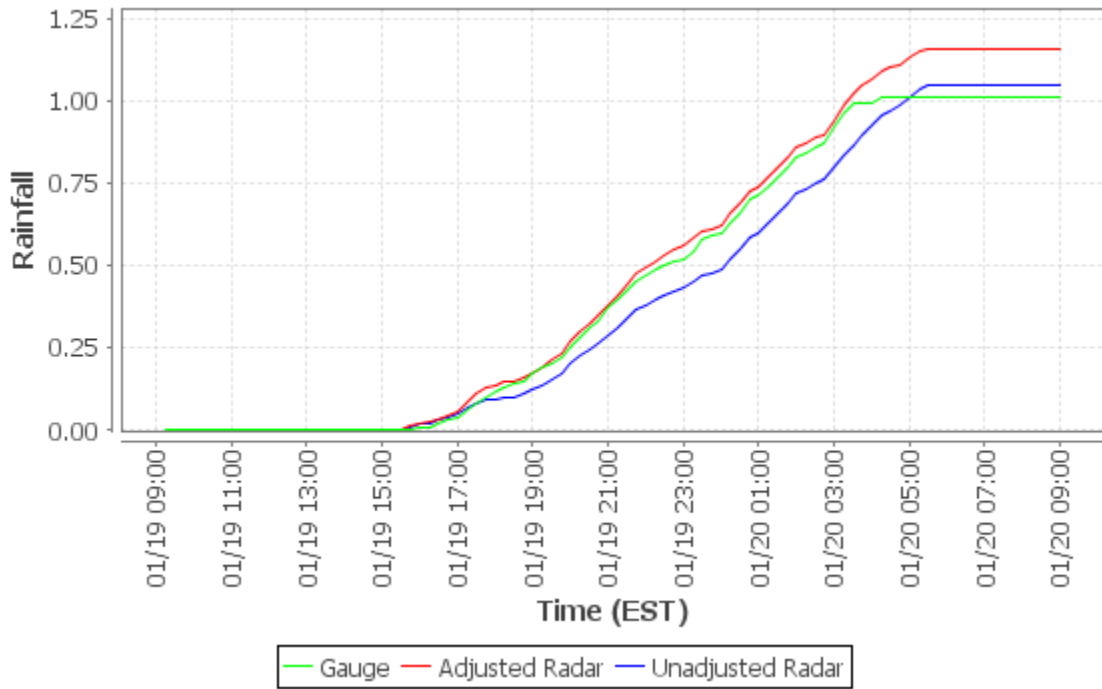
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



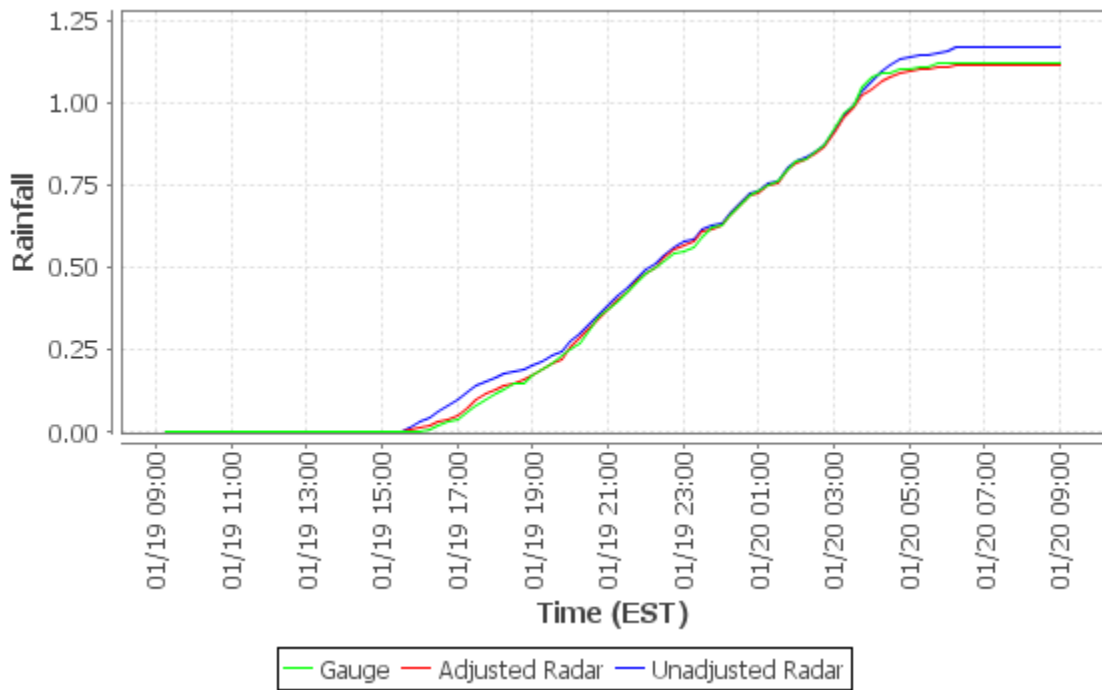
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



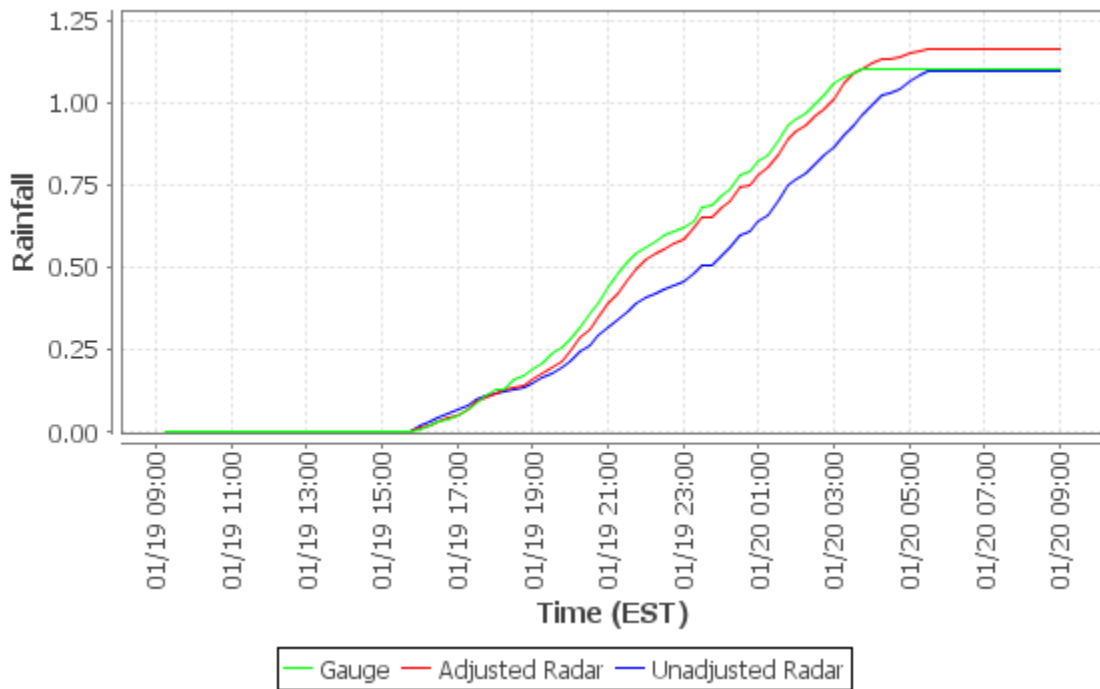
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



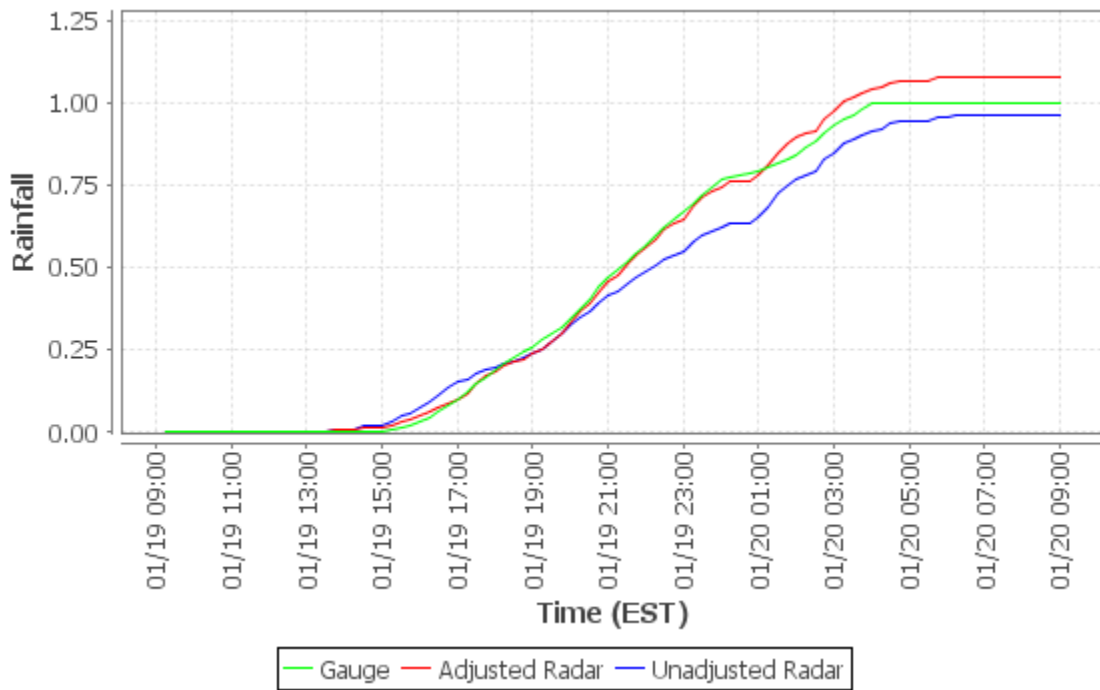
Cumulative Distribution Plot - Arnold (Loc32)



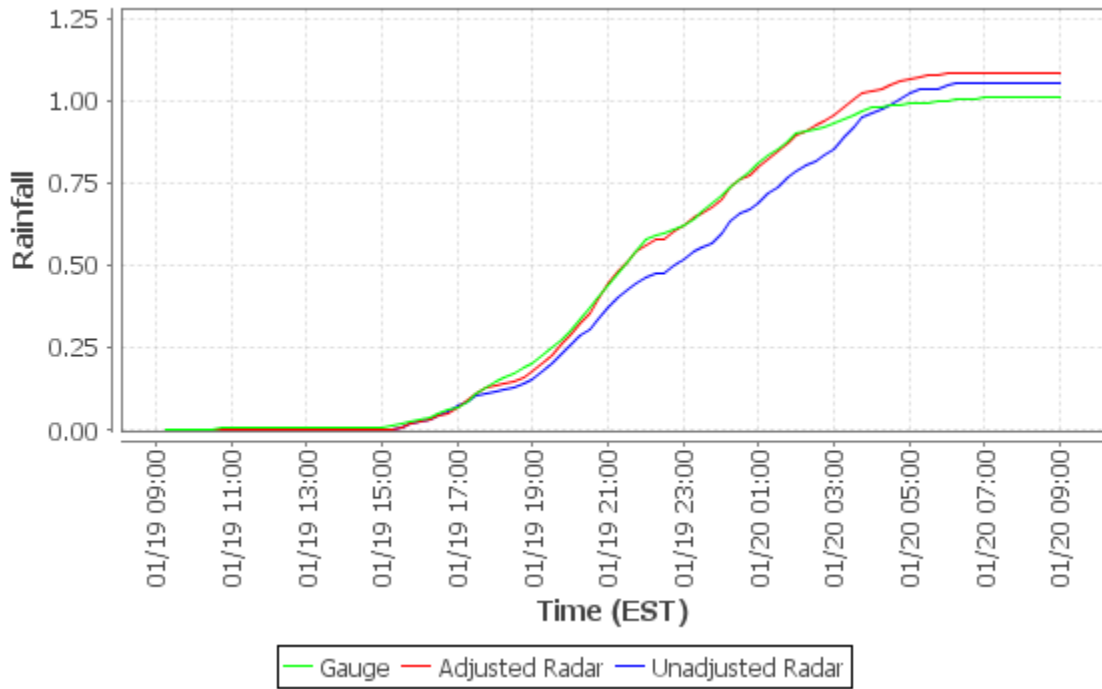
Cumulative Distribution Plot - Richland TWP (Loc33)



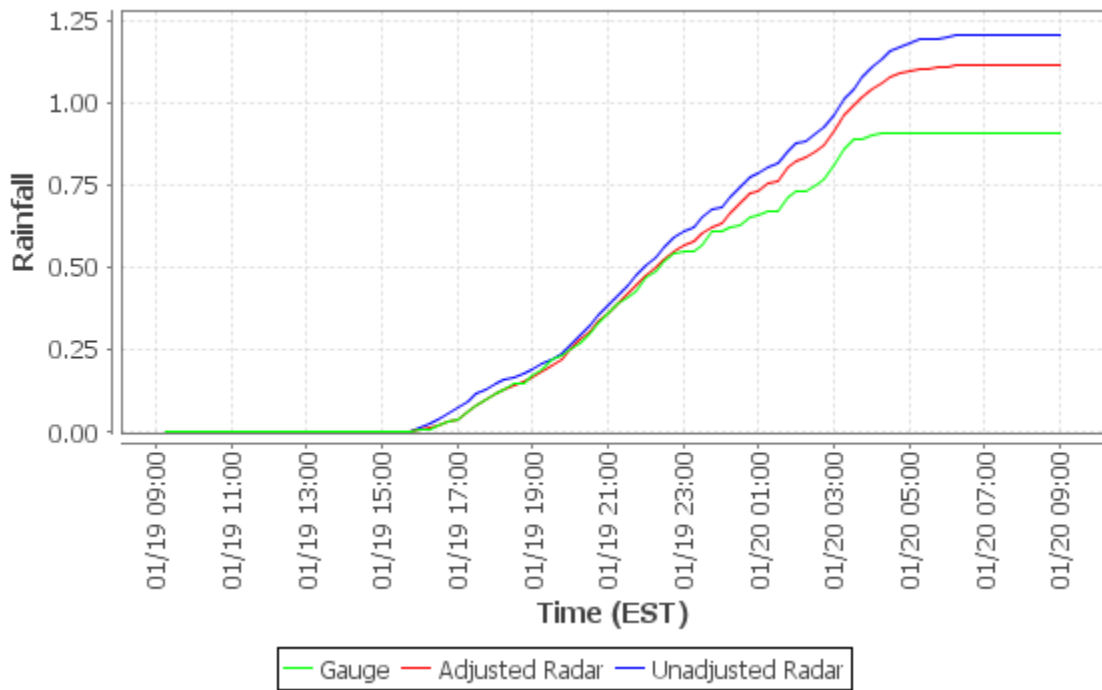
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



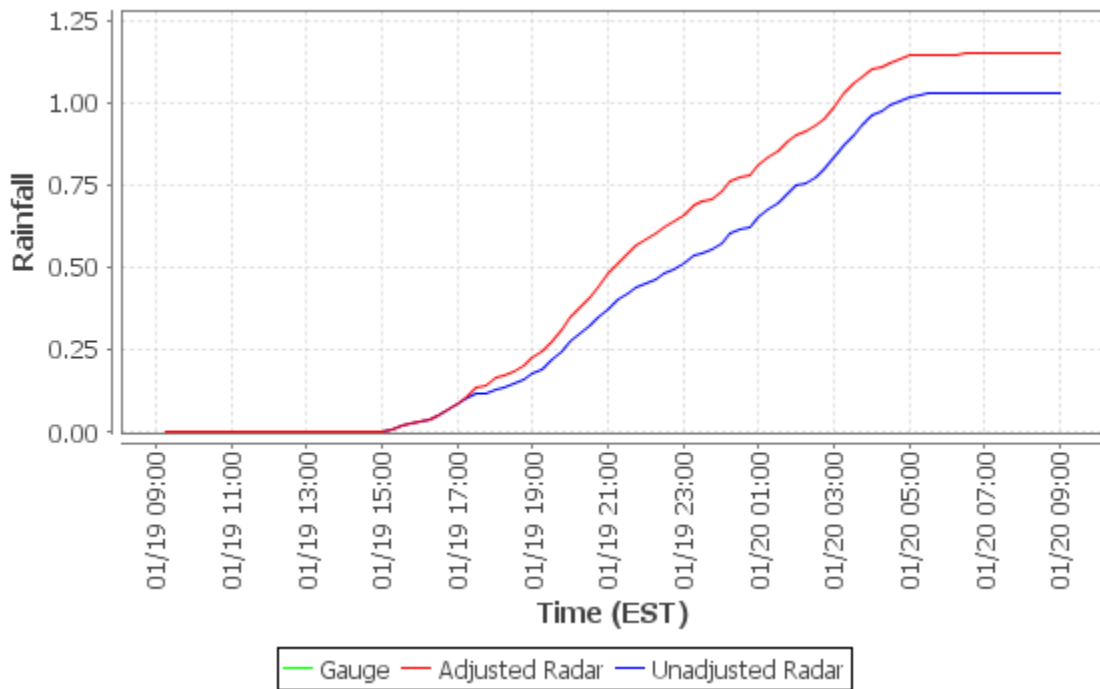
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



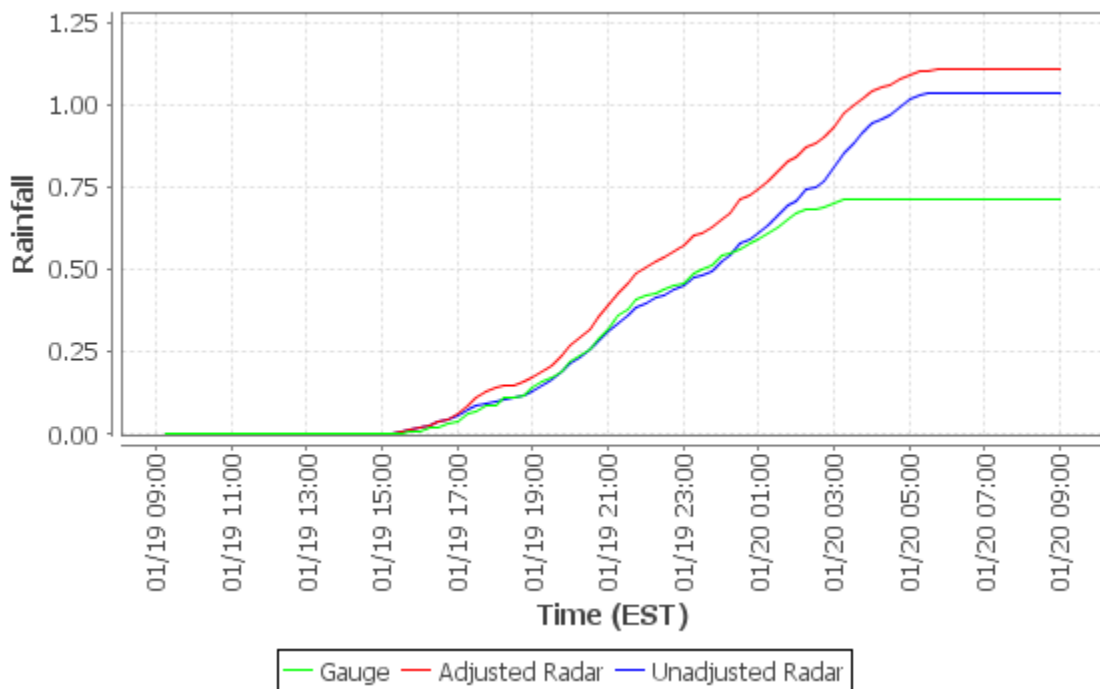
Cumulative Distribution Plot - Allegheny River at Natrona (03049500)



Cumulative Distribution Plot - Chartiers Creek at Carnegie (03085500)

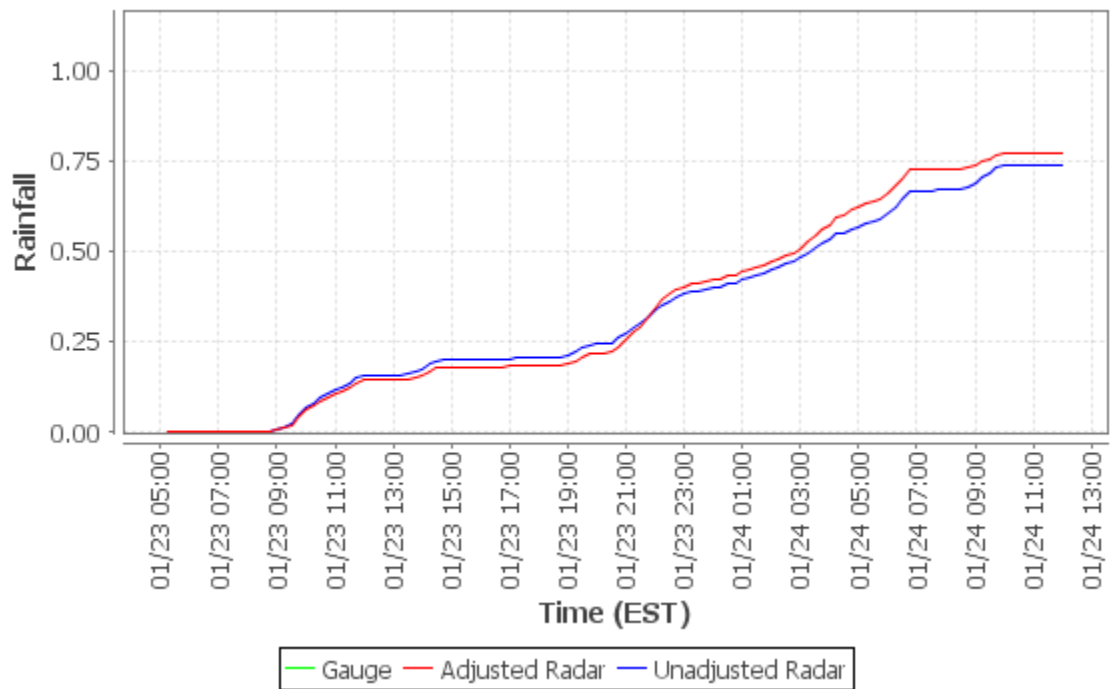


Cumulative Distribution Plot - Ohio River at Emsworth Dam Lower Pool at Emsworth (03085734)

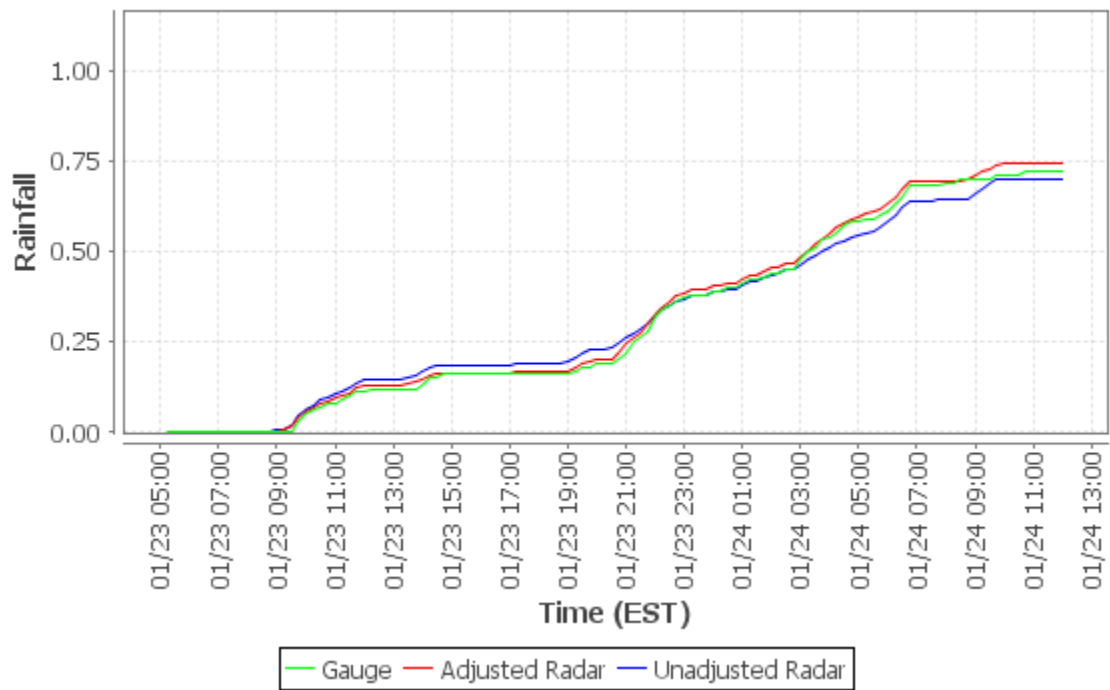


Appendix E - Event 4 (2019-01-23) CDPs

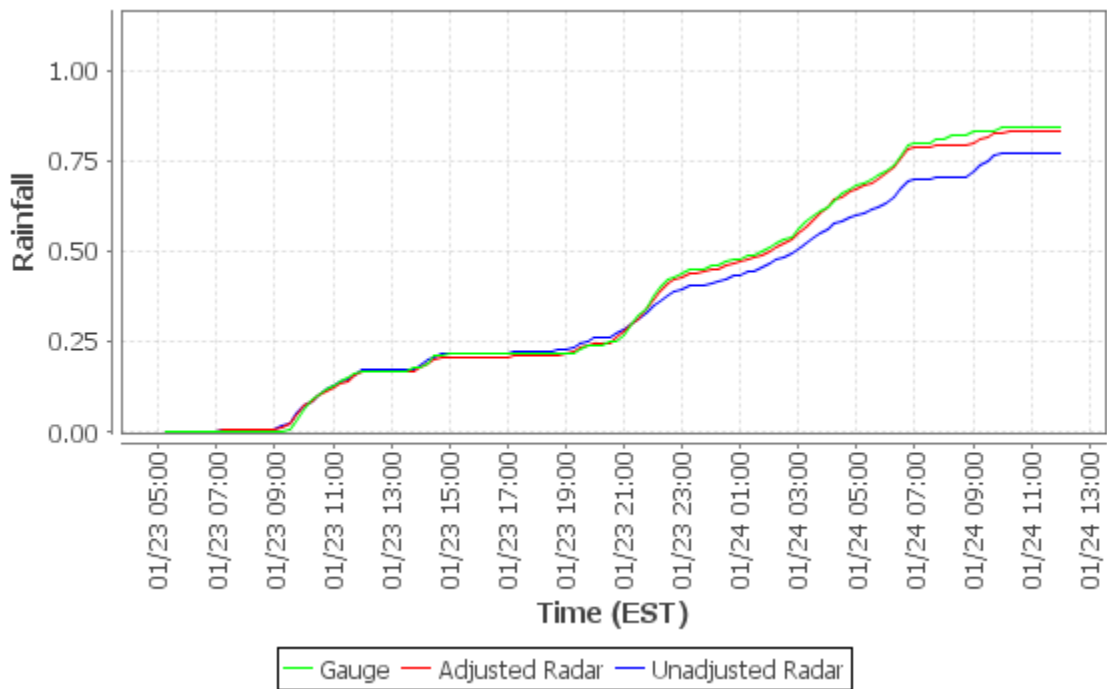
Cumulative Distribution Plot - PWSA-Montana St. (Loc01)



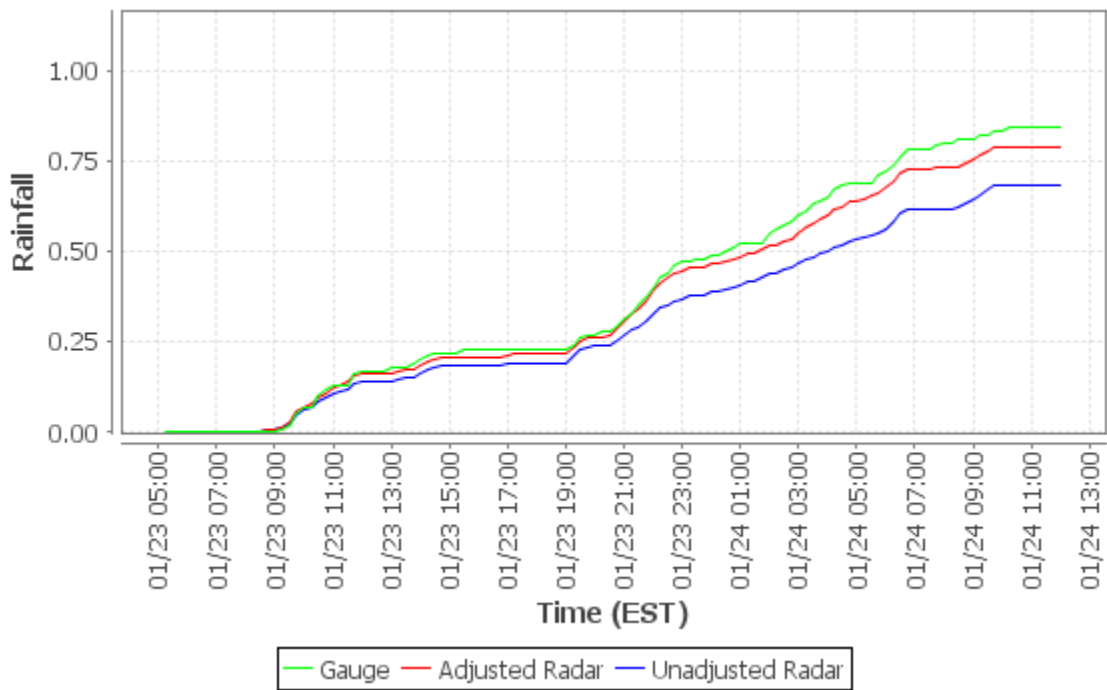
Cumulative Distribution Plot - ALCOSAN WWTP Lab (Loc02)



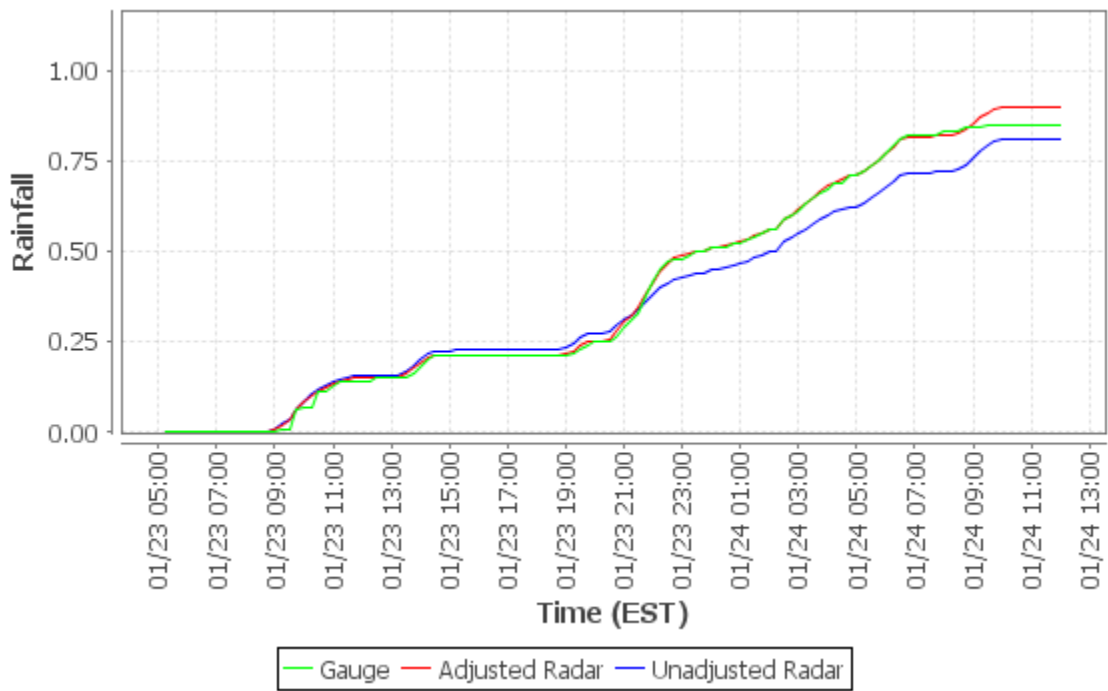
Cumulative Distribution Plot - Shaler Munic Bldg (Loc03)



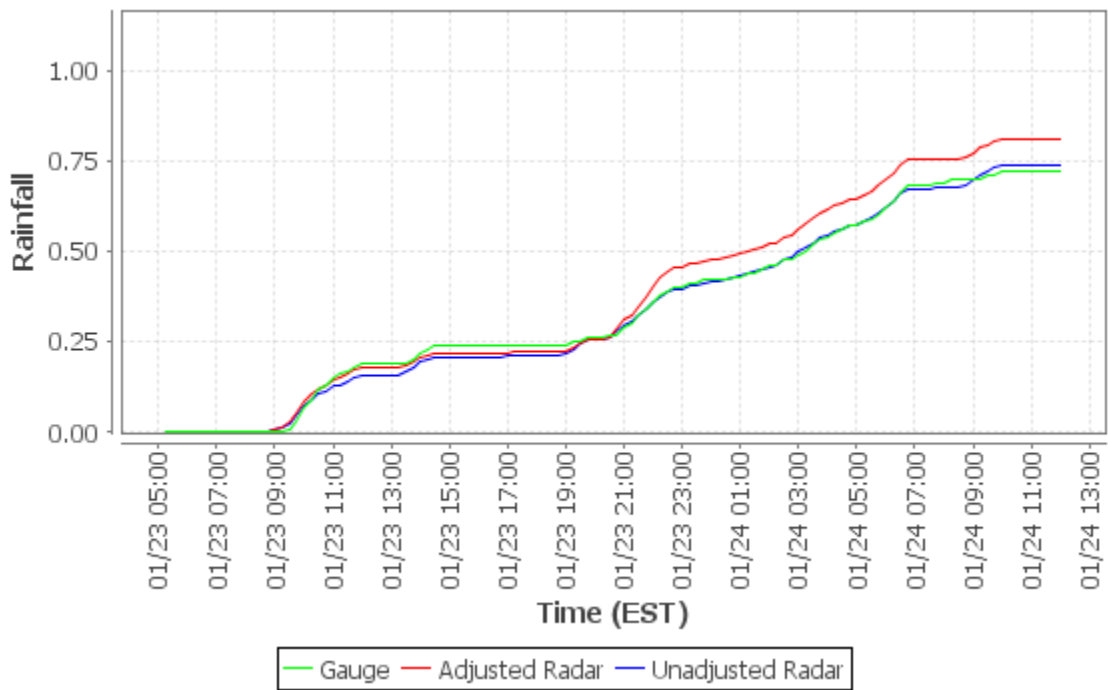
Cumulative Distribution Plot - Kennedy Twp PS (Loc04)



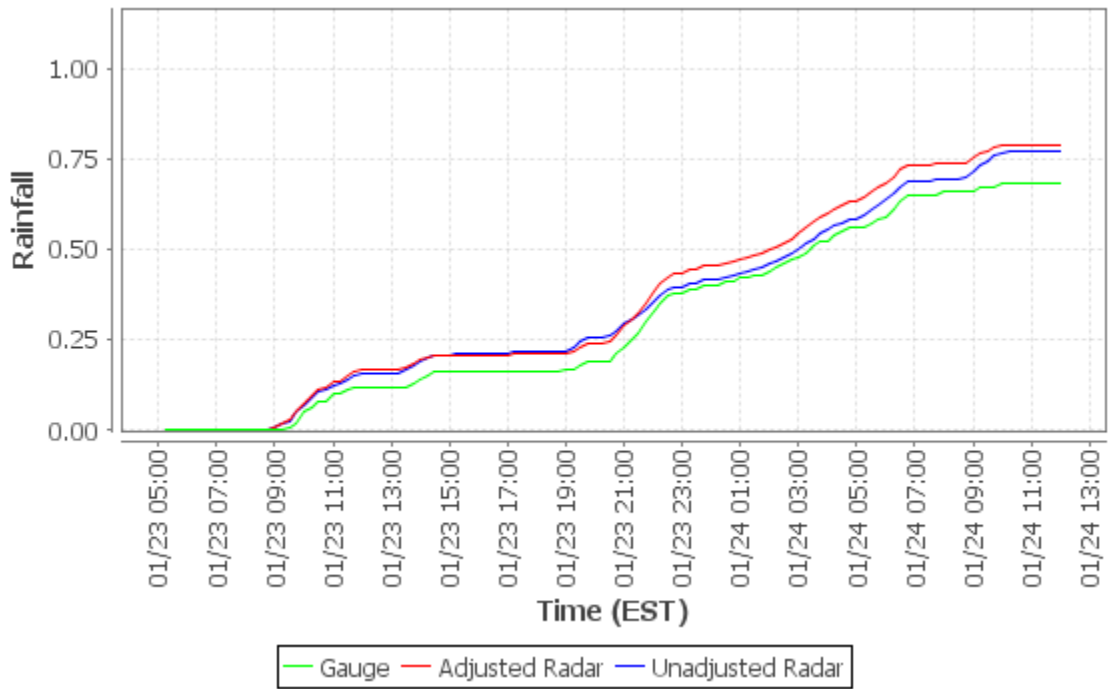
Cumulative Distribution Plot - Upper St. Clair (Loc05)



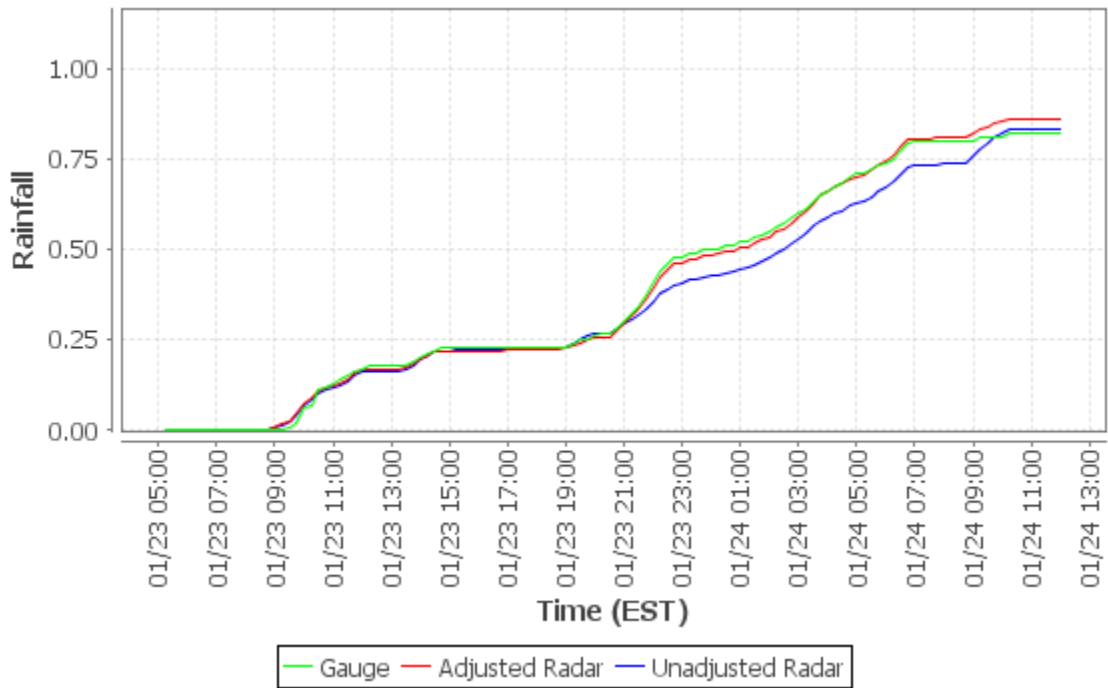
Cumulative Distribution Plot - Carnegie Transit Time (Loc06)



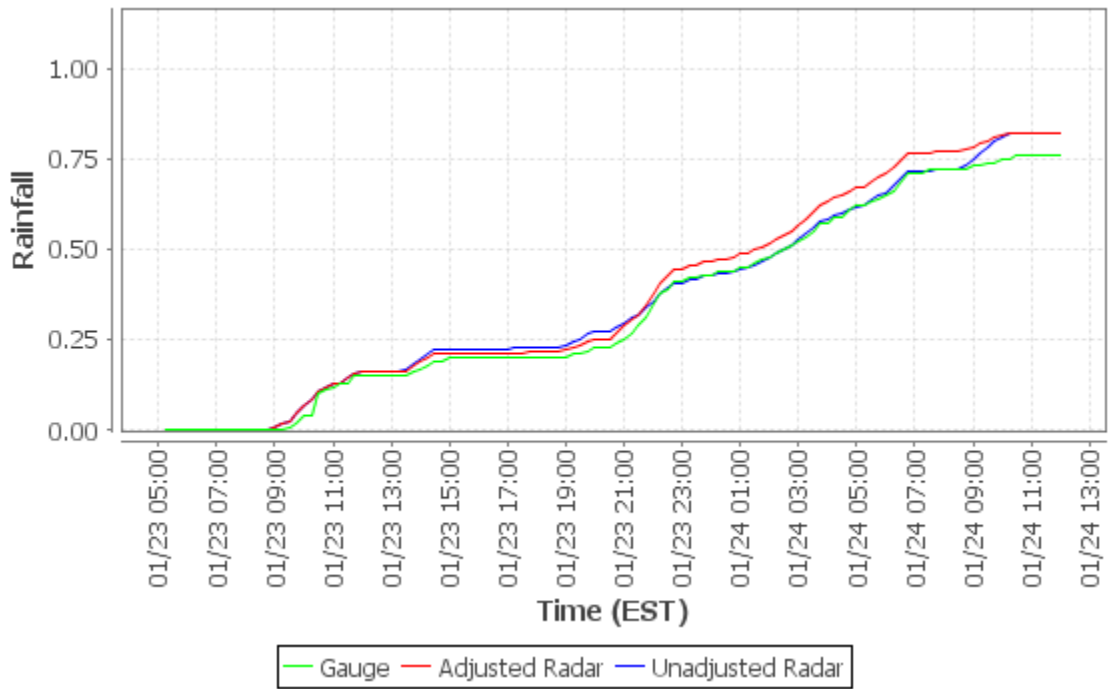
Cumulative Distribution Plot - Greentree Munic Bldg (Loc07)



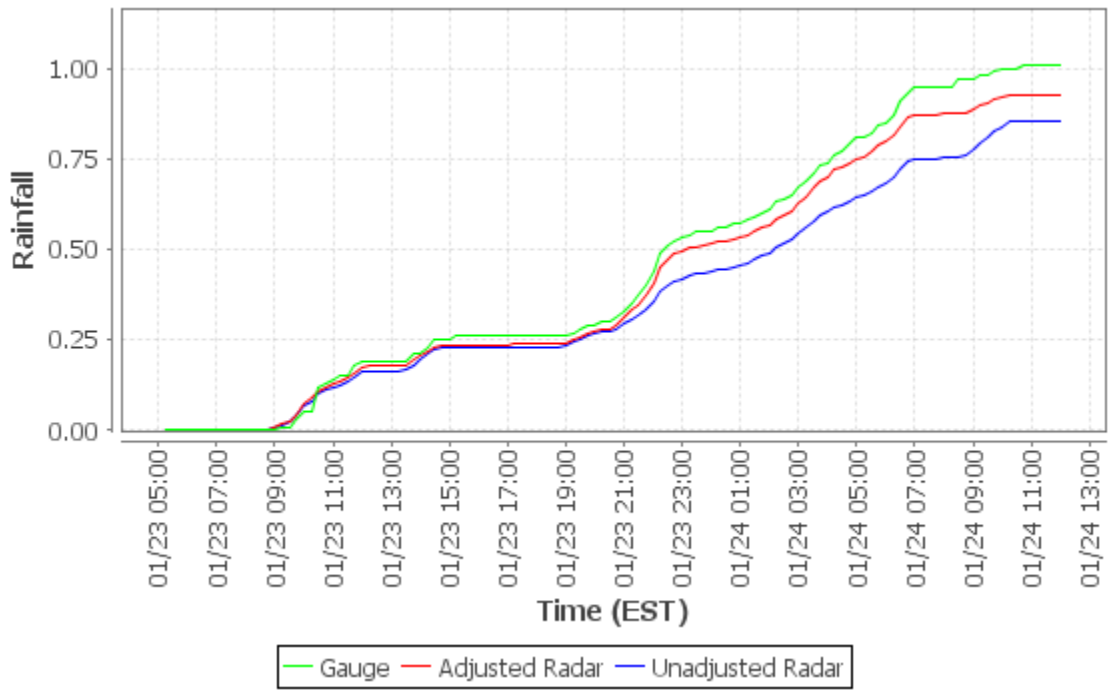
Cumulative Distribution Plot - AC Health Dept Bldg (Loc08)



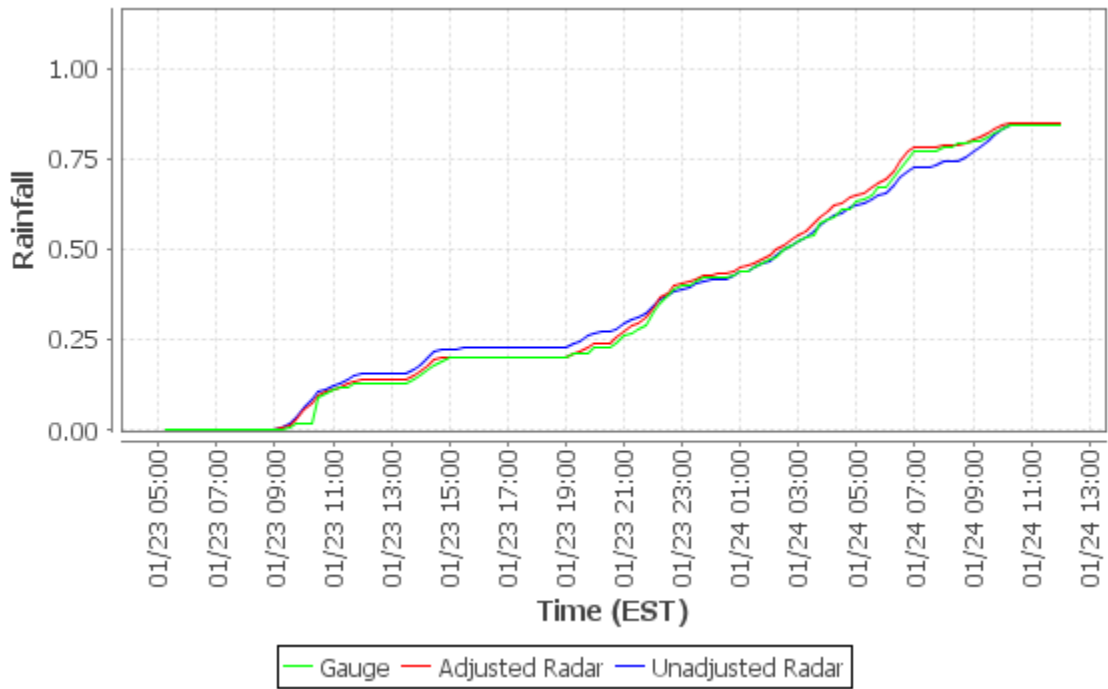
Cumulative Distribution Plot - Univ of Pittsburgh (Loc09)



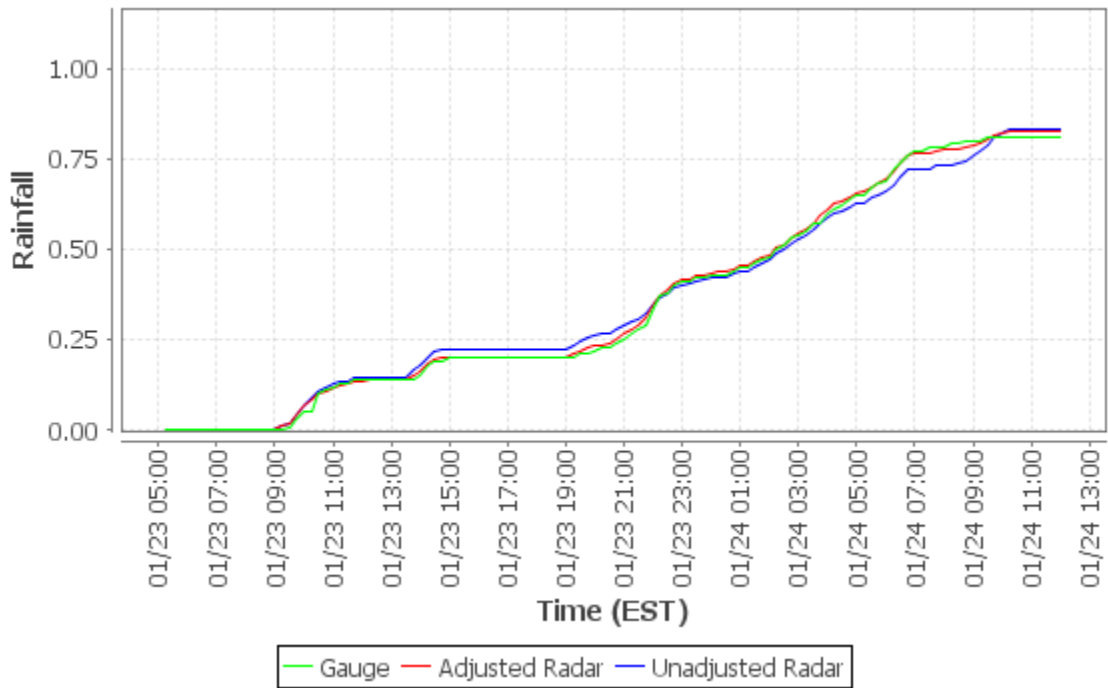
Cumulative Distribution Plot - PWSA-Highland Park (Loc10)



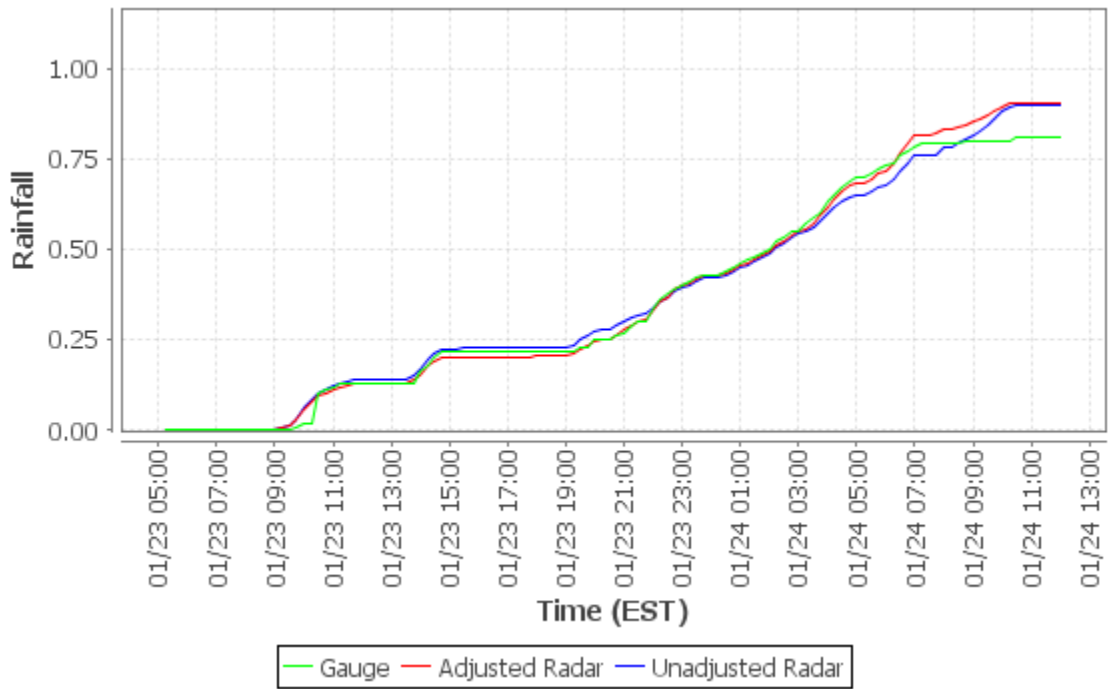
Cumulative Distribution Plot - M-46 Access Shaft (Loc11)



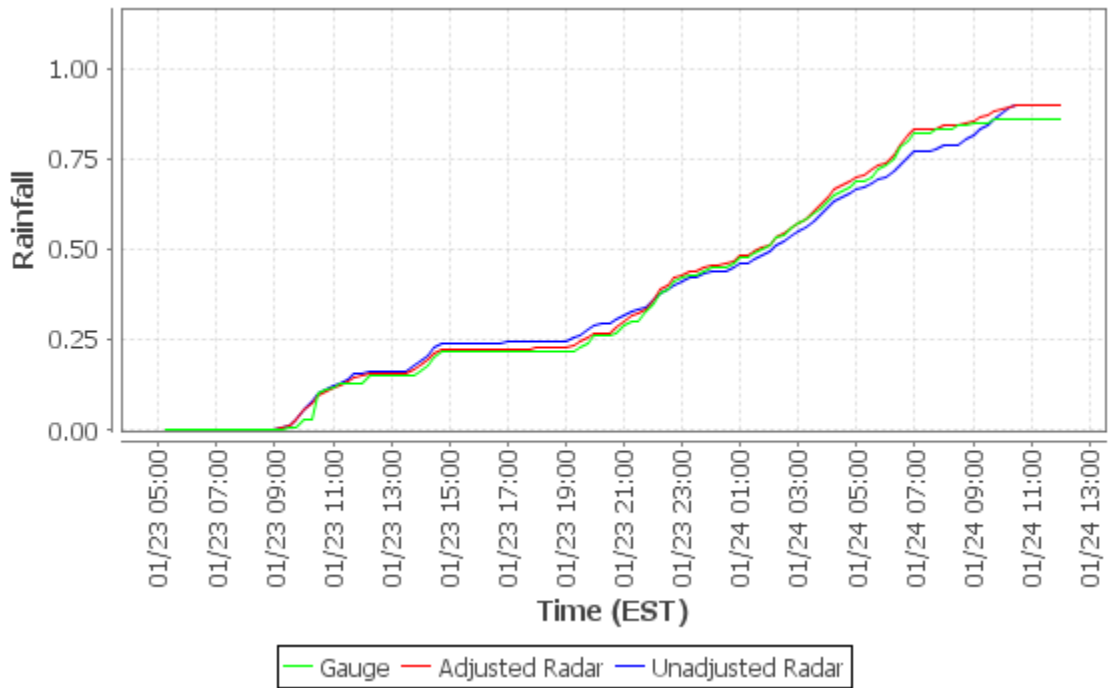
Cumulative Distribution Plot - Baldwin (Loc12)



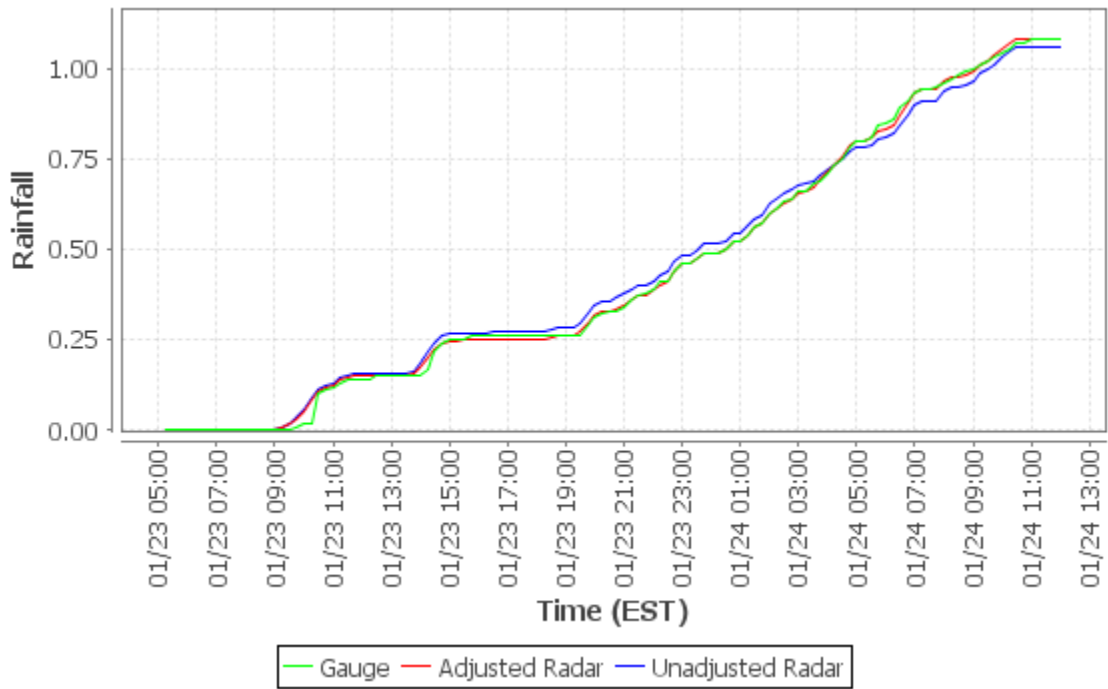
Cumulative Distribution Plot - M-59 Access Shaft (Loc13)



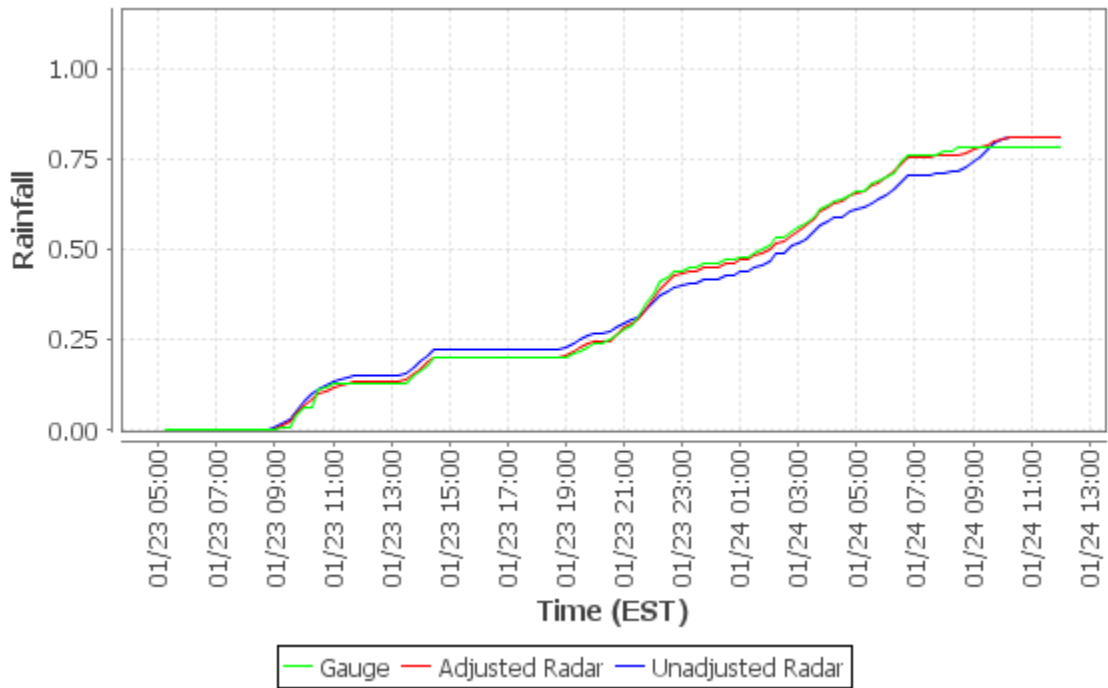
Cumulative Distribution Plot - Churchill Munic Bldg (Loc14)



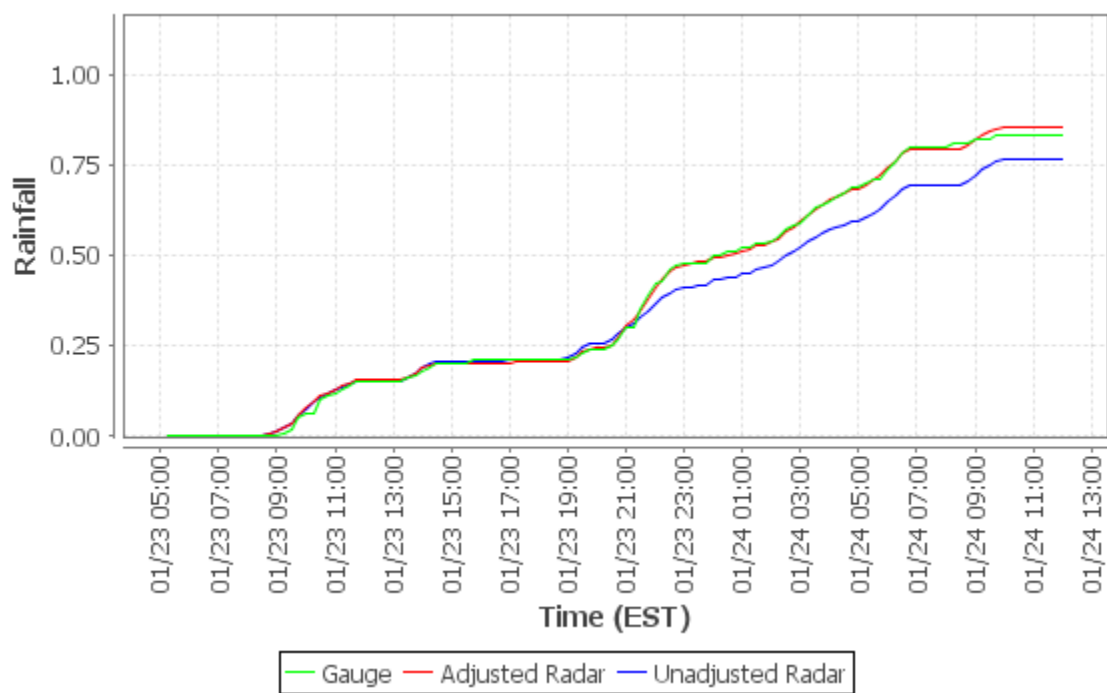
Cumulative Distribution Plot - Trafford Maint Bldg (Loc15)



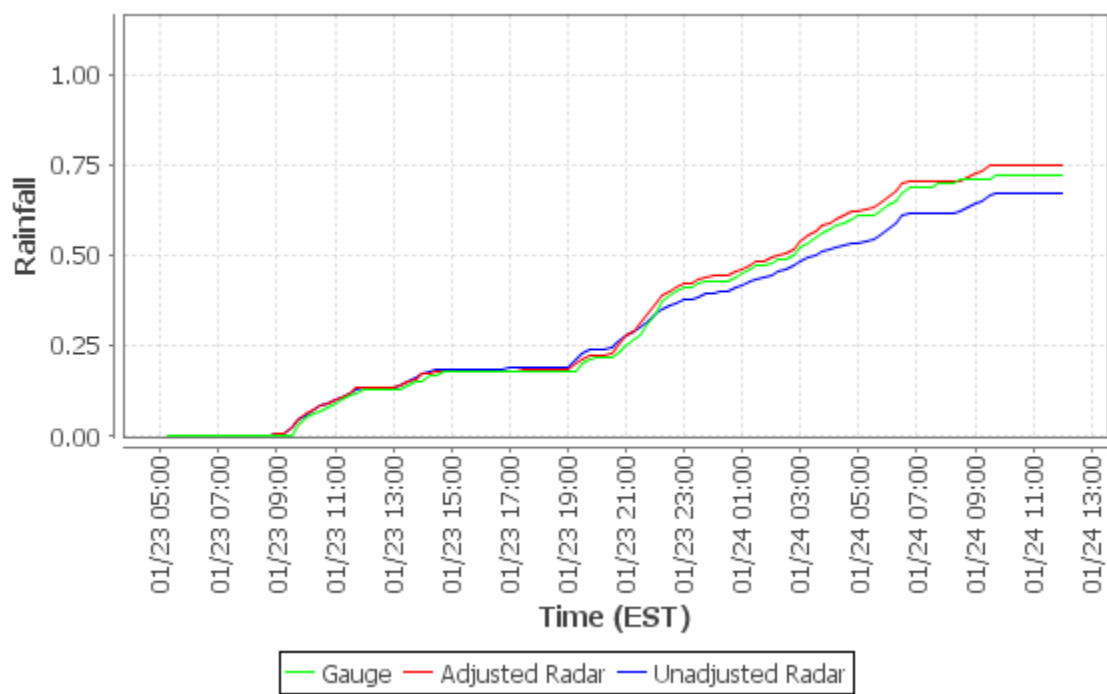
Cumulative Distribution Plot - Castle Shannon (Loc16)



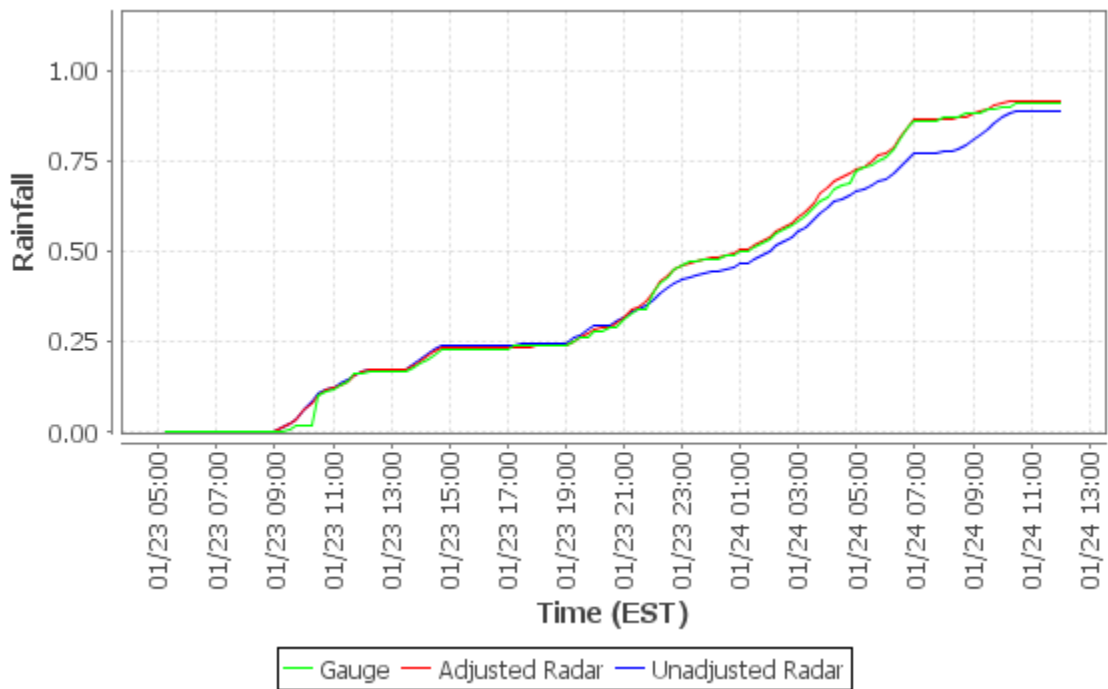
Cumulative Distribution Plot - Chartiers Pump Station (Loc17)



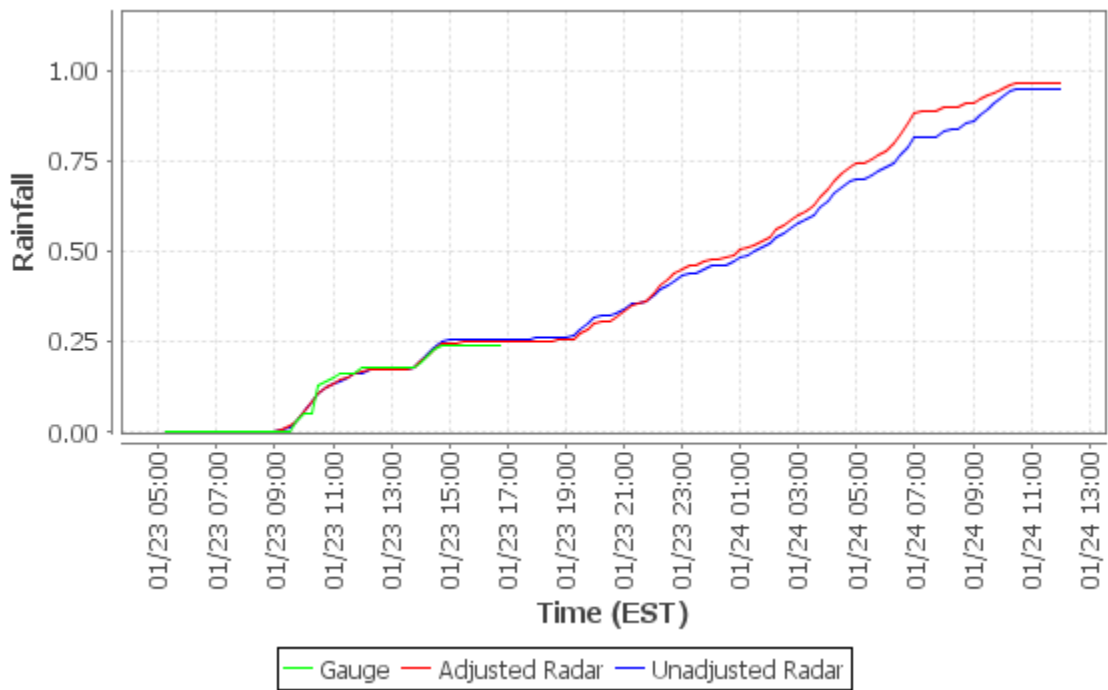
Cumulative Distribution Plot - Oakdale Pump Station (Loc18)



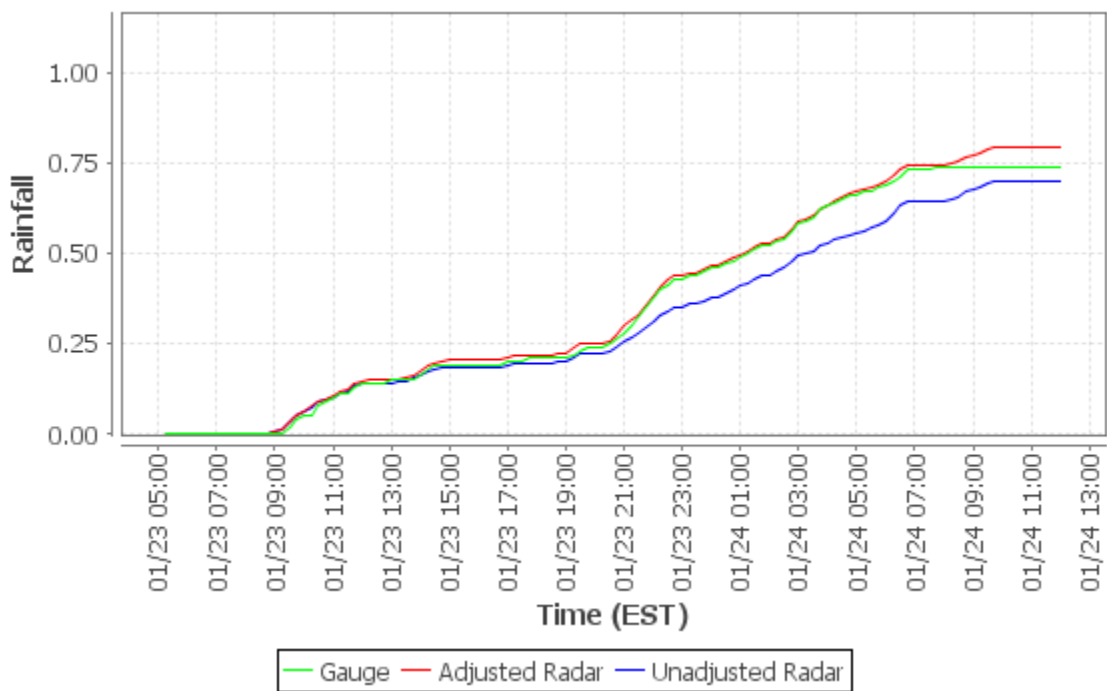
Cumulative Distribution Plot - Sandy Creek Eq Facility (Loc19)



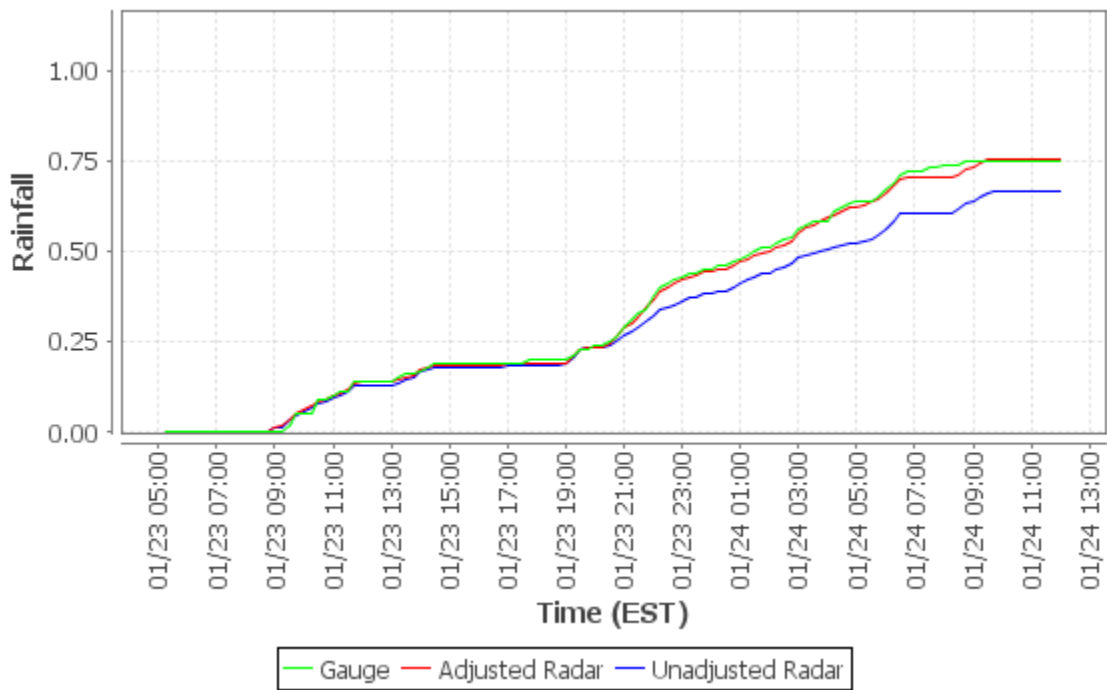
Cumulative Distribution Plot - Gascola Eq Facility (Loc20)



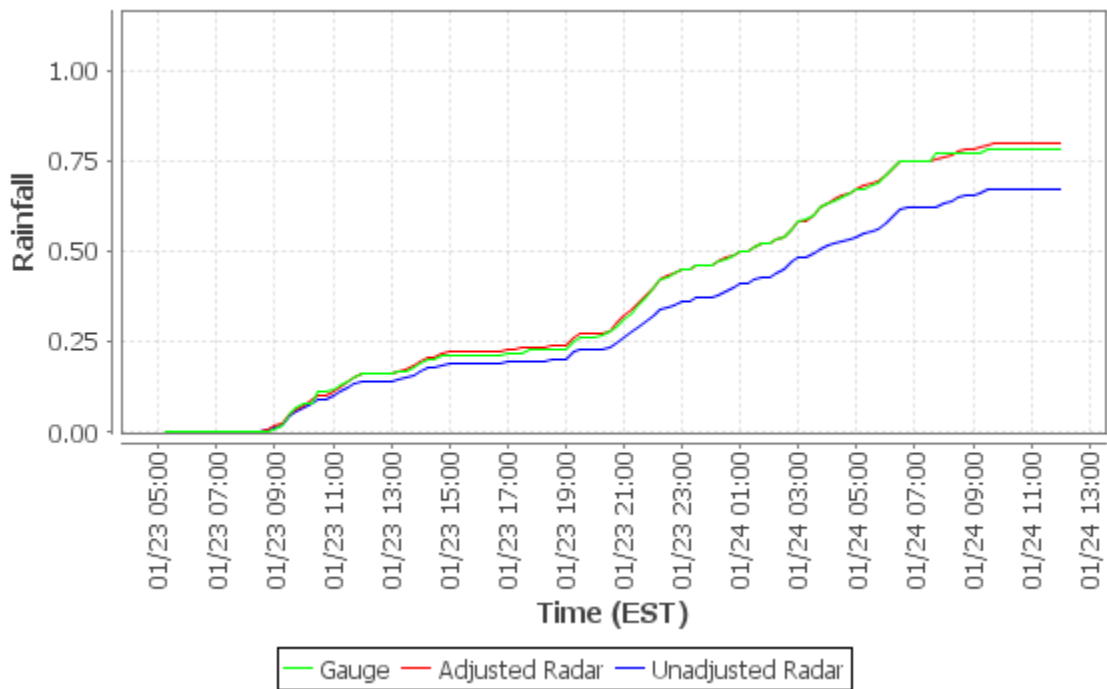
Cumulative Distribution Plot - Moon TWP (Loc21)



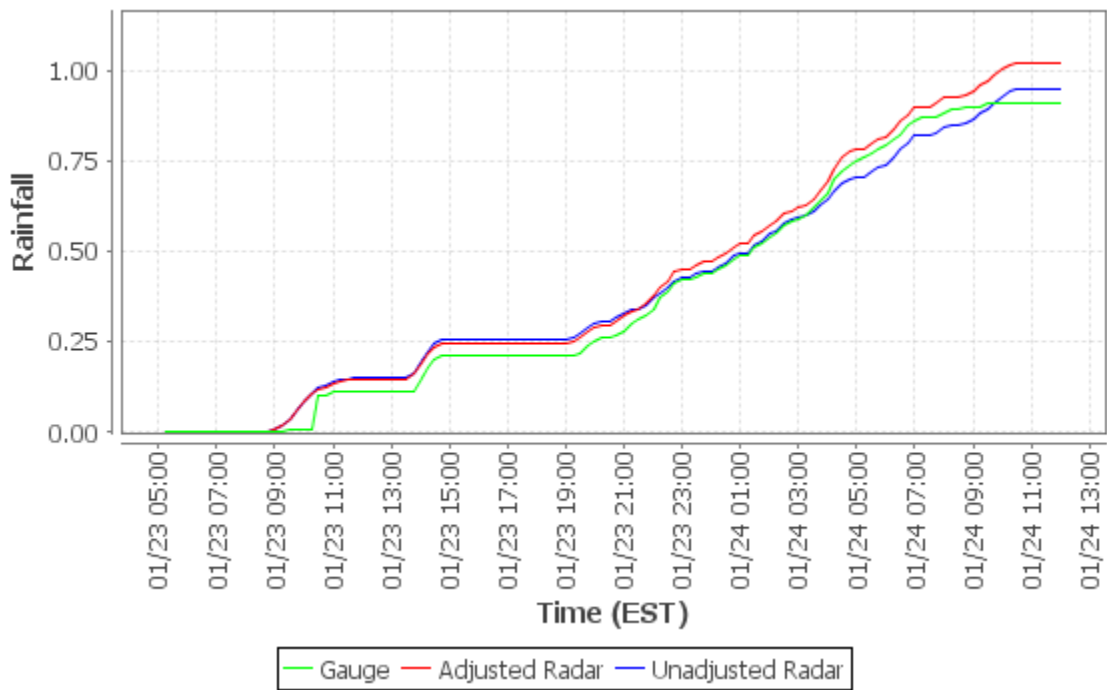
Cumulative Distribution Plot - North Fayette TWP (Loc22)



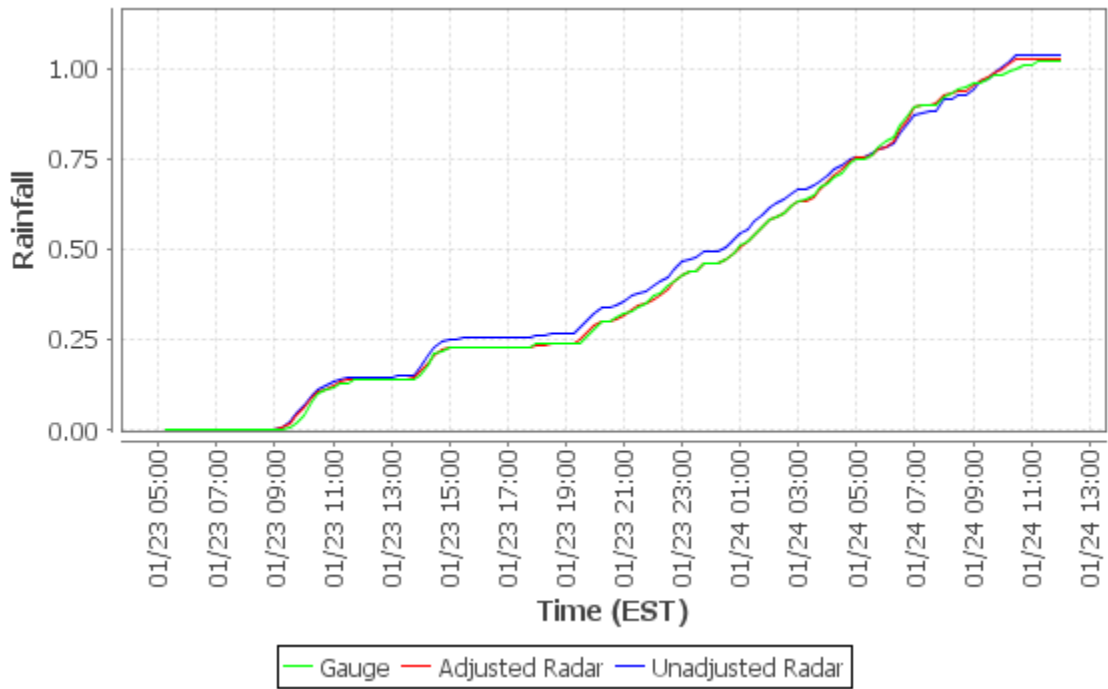
Cumulative Distribution Plot - Clinton Munic Bldg (Loc23)



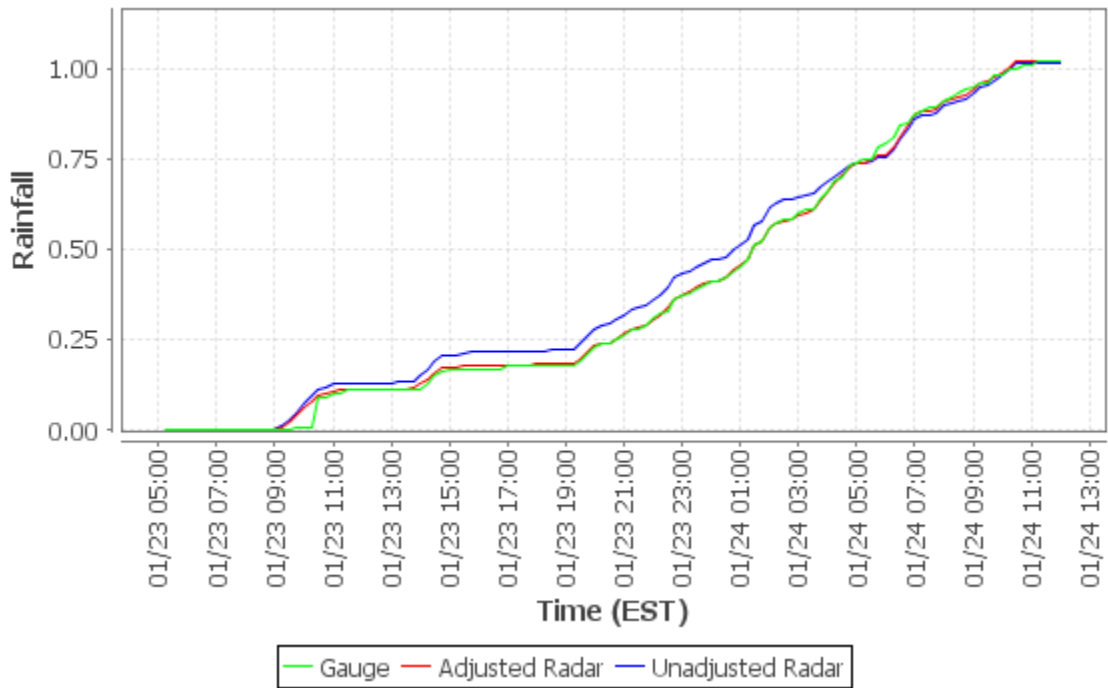
Cumulative Distribution Plot - Jefferson Hills (Loc24)



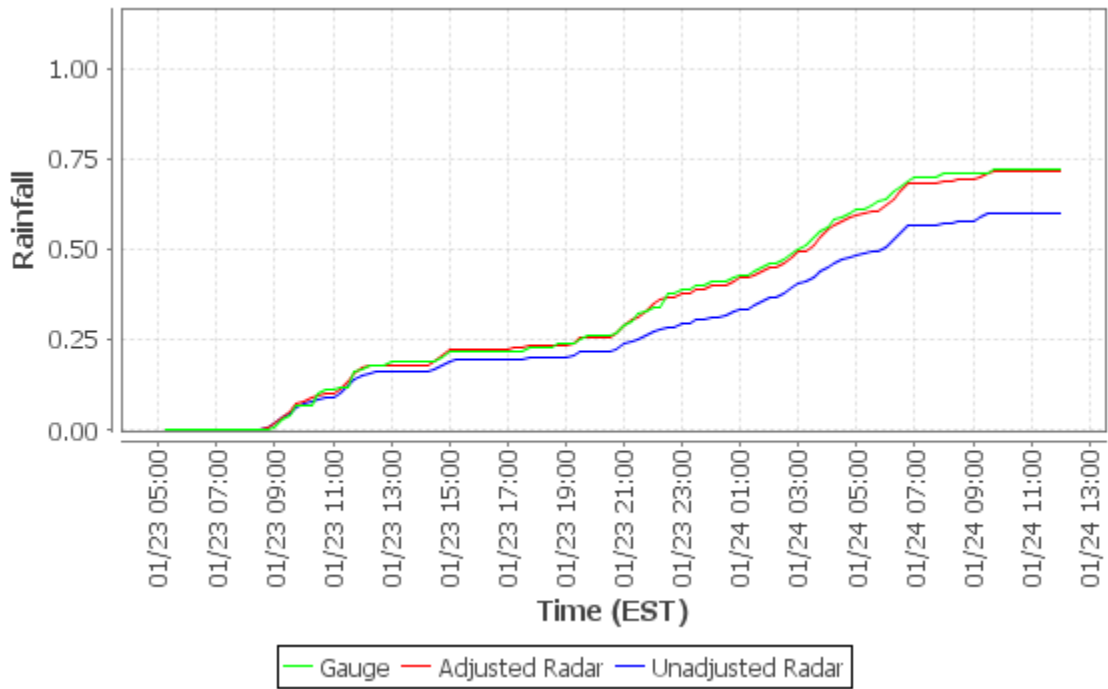
Cumulative Distribution Plot - White Oak Public Works Bldg (Loc25)



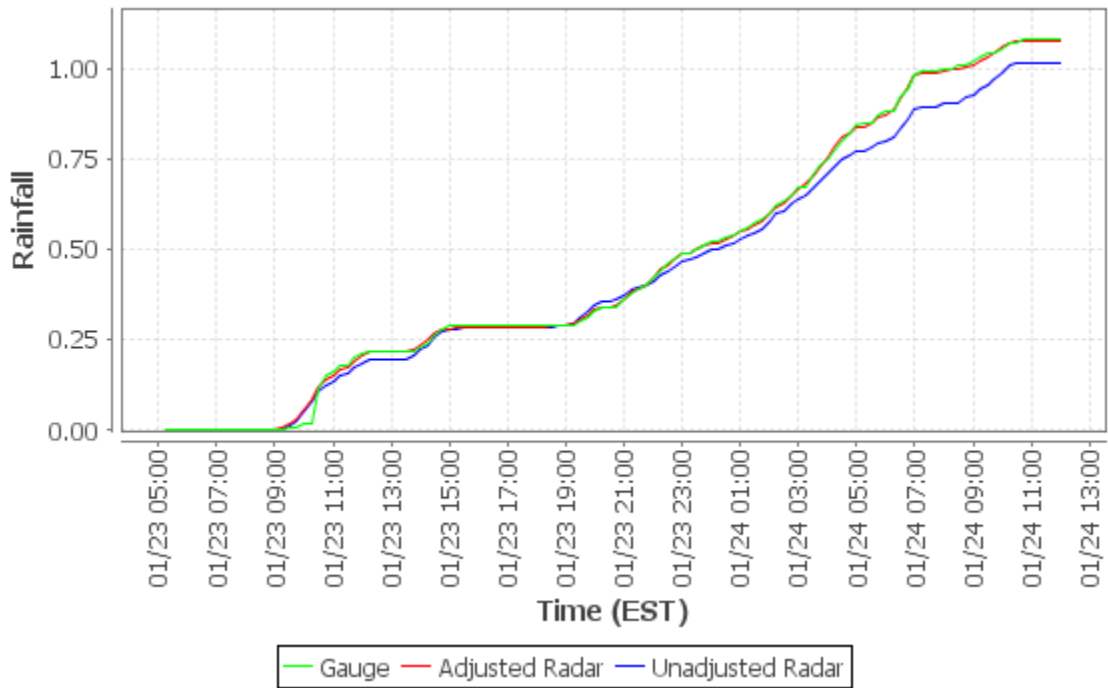
Cumulative Distribution Plot - Elizabeth TWP Municipal Bldg (Loc26)



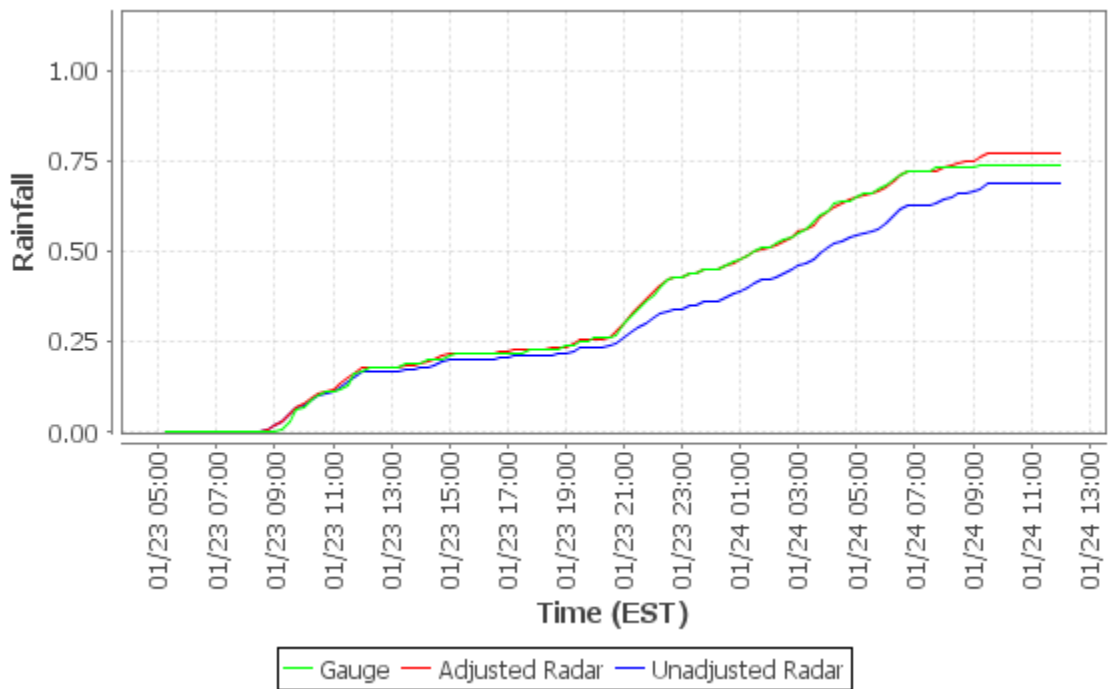
Cumulative Distribution Plot - Marshall TWP (Loc27)



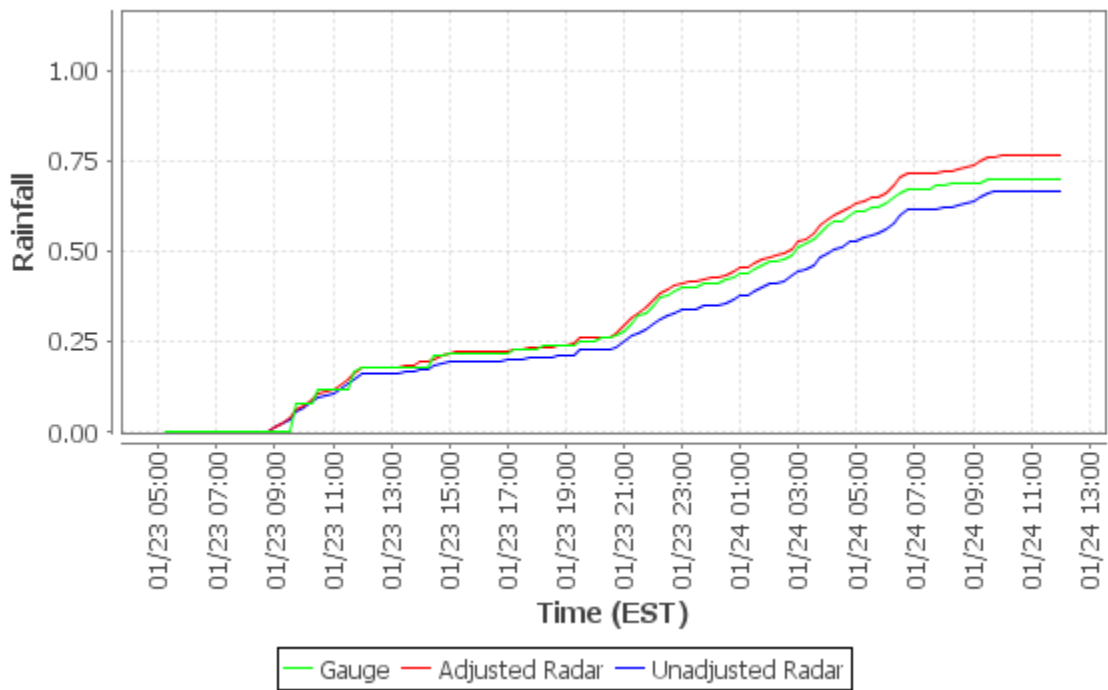
Cumulative Distribution Plot - Plum Municipal Bldg (Loc28)



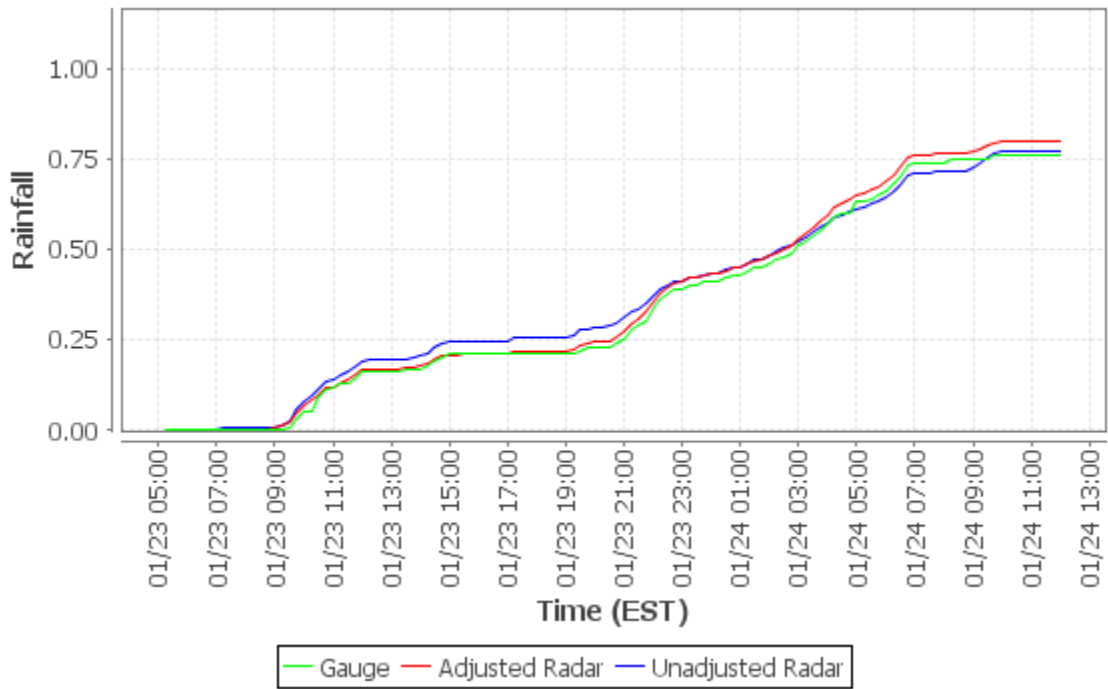
Cumulative Distribution Plot - Bell Acres Munic Bldg (Loc29)



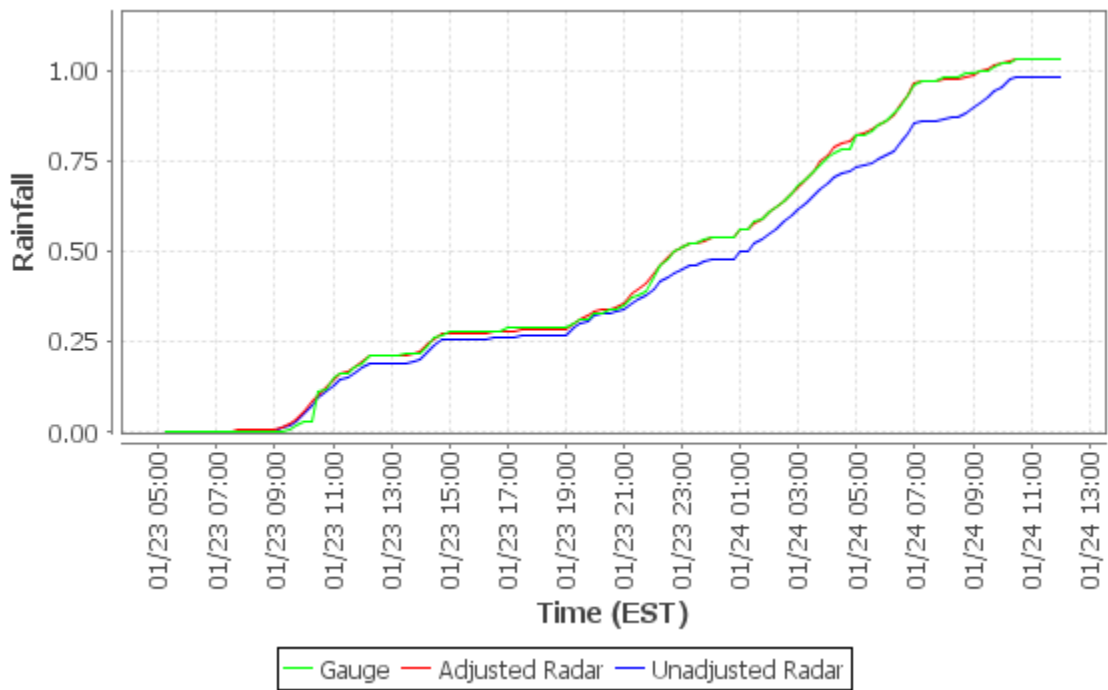
Cumulative Distribution Plot - McCandless Twn Hall (Loc30)



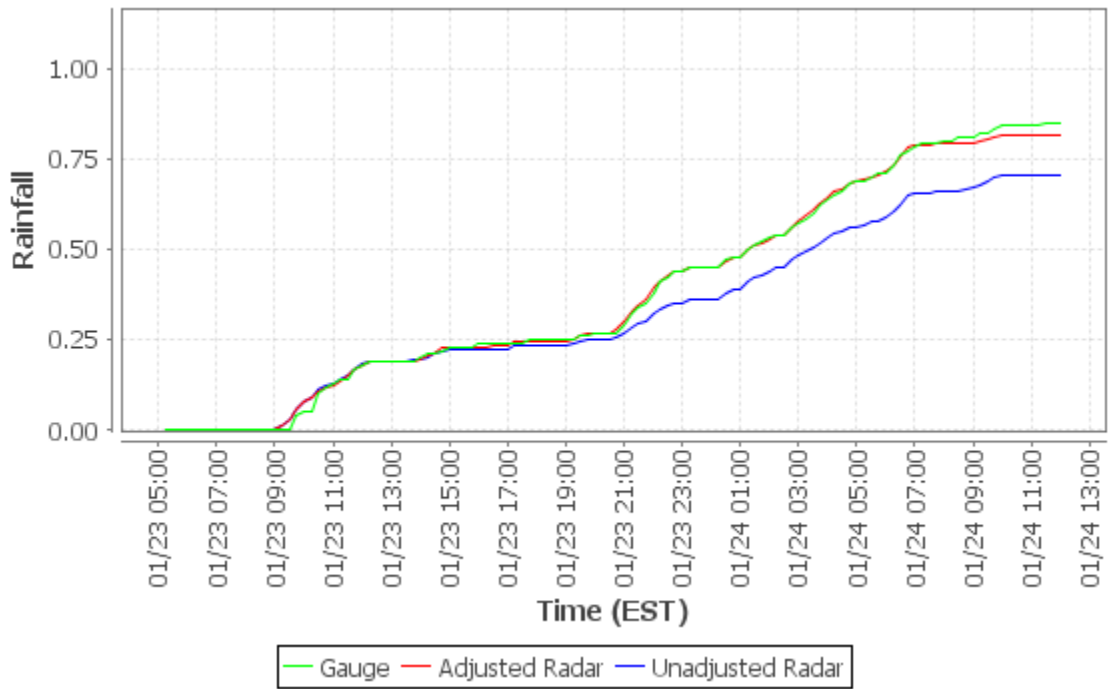
Cumulative Distribution Plot - Hampton Municipal Bldg (Loc31)



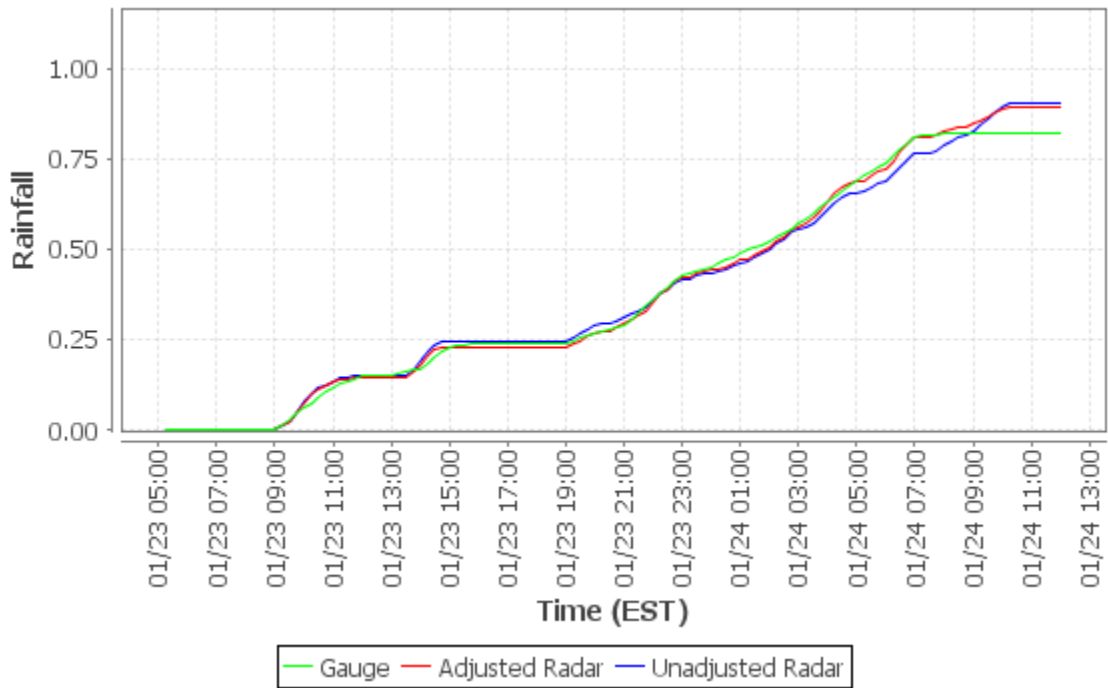
Cumulative Distribution Plot - Arnold (Loc32)



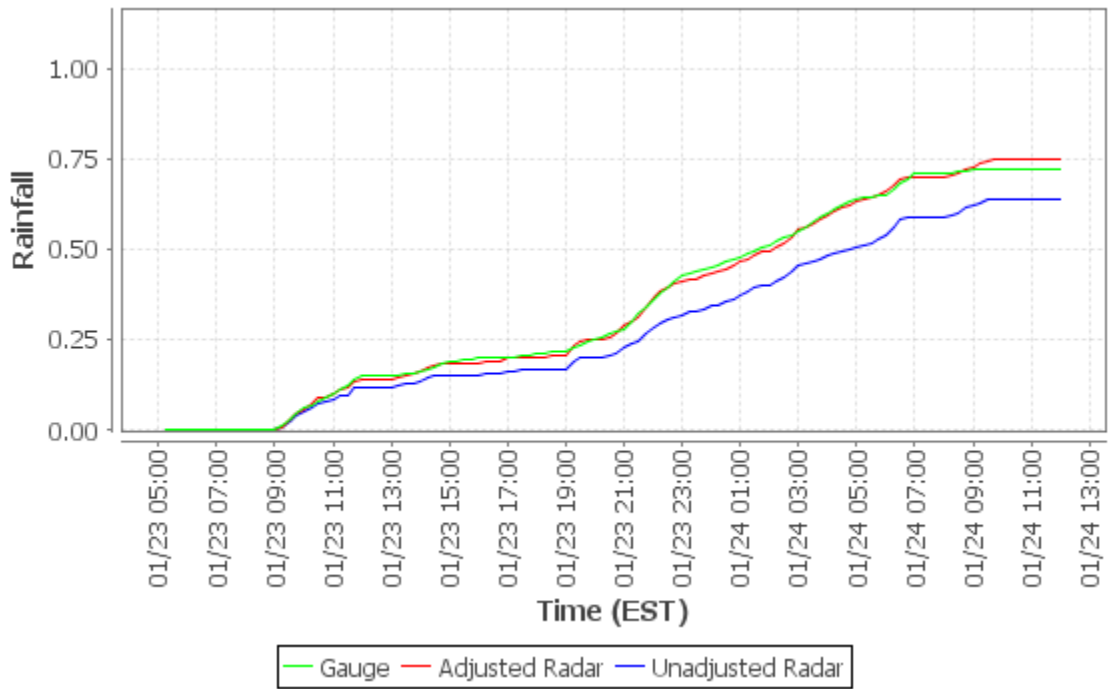
Cumulative Distribution Plot - Richland TWP (Loc33)



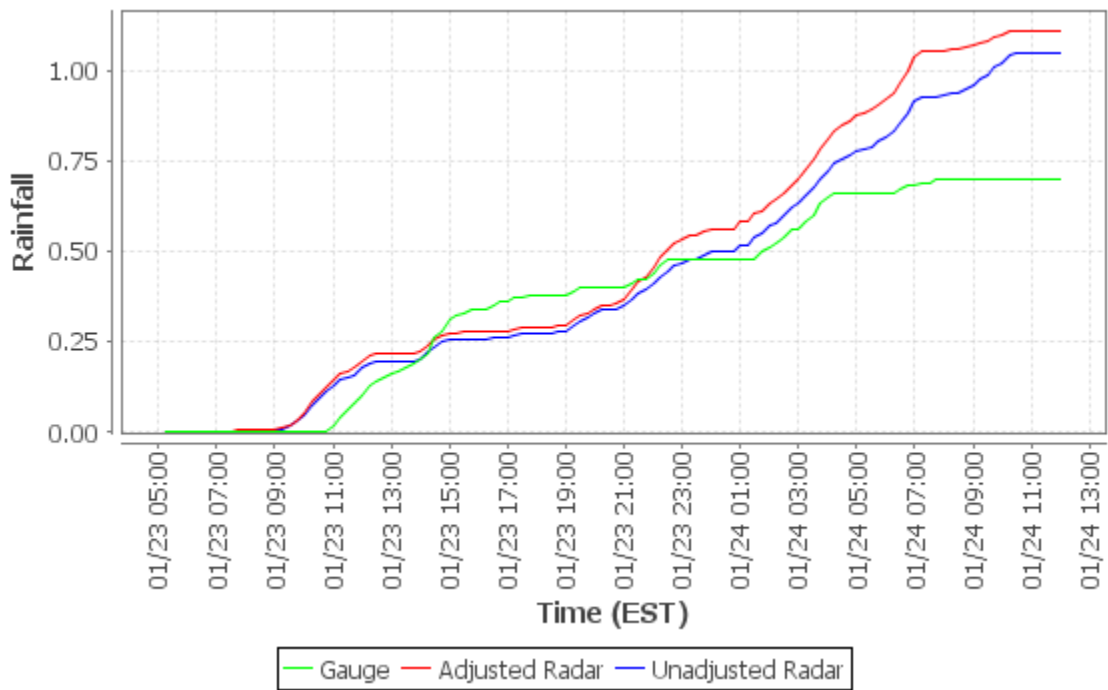
Cumulative Distribution Plot - Pittsburgh Allegheny Cty (KAGC)



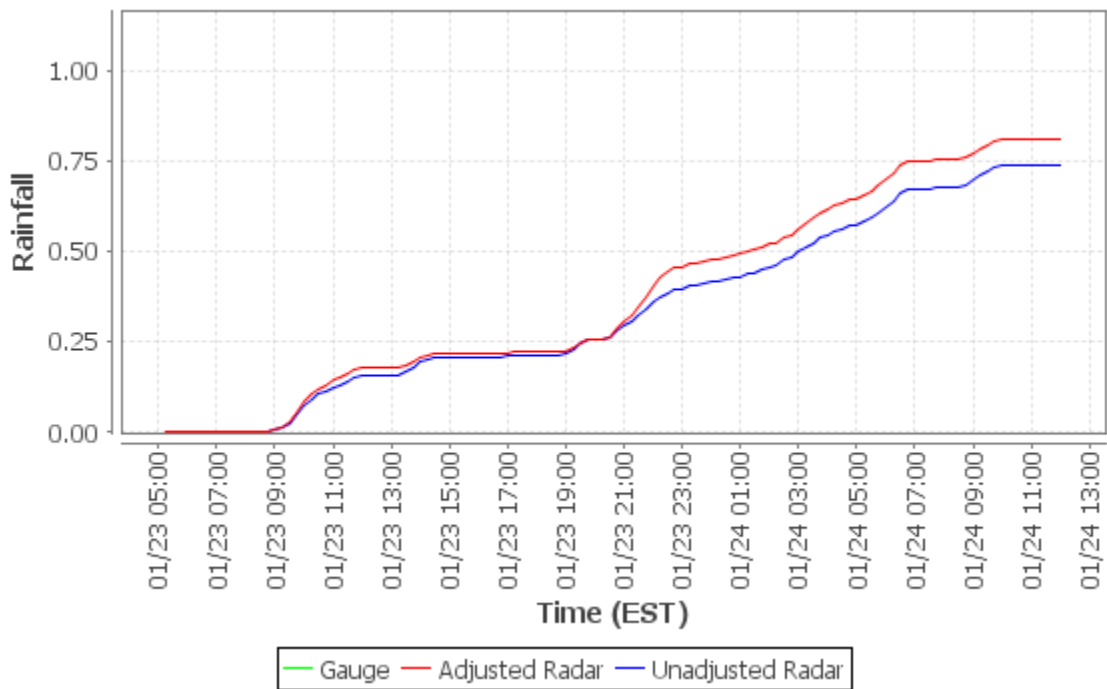
Cumulative Distribution Plot - Greater Pittsburgh Int'l (KPIT)



Cumulative Distribution Plot - Allegheny River at Natrona (03049500)



Cumulative Distribution Plot - Chartiers Creek at Carnegie (03085500)



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

