

Radar Rainfall Analysis Report

Alexandria, VA
4 Historical Events



Prepared for the City of Alexandria, Virginia

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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.

KLWX – Federal Communications Commission (FCC) call sign for the NEXRAD near Sterling, VA.

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.

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.

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 Season 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) processed radar and rain gauge data over the City of Alexandria, Virginia. Radar and rain gauge data are quality controlled (QC) to produce QC gauge-adjusted radar rainfall (GARR) for 4 historical rainfall events that occurred between July-2019 and August-2021. To produce QC GARR, both radar and rain gauge data are reviewed manually to remove inconsistent data. The Vieux dataset contains continuous data where QC rain gauge and radar data are available for each event.

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.

The radar data source used to process this period was Level II NEXRAD data from KLWX located near Sterling, VA.

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 KLWX to the study area, the polar coordinates defining horizontal resolution range in width from 0.4 – 0.8 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 304 1-km² pixels covering the study area.

Rain gauge data from as many as 28 gauges were used to adjust the radar. Rain gauge locations as well as accumulation data were collected from 13 Fairfax County, 9 City of Alexandria, and 4 DC Water gauges at 5-minute intervals. In addition, rain gauge data were obtained from one United States Geological Survey (USGS) station and one NWS Automated Surface Observing System (ASOS) station. Figure 1 depicts the spatial distribution of the rain gauge network 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.

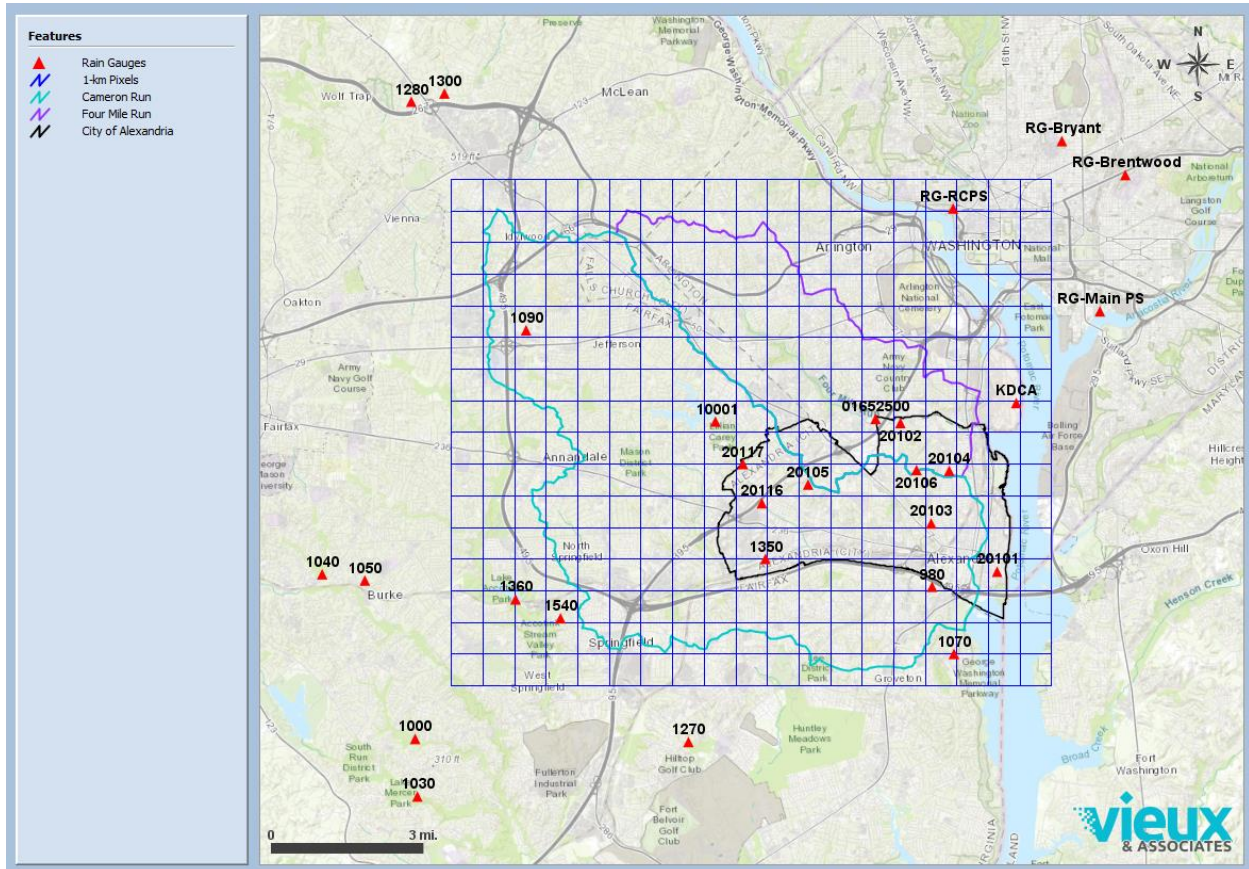


Figure 1. Spatial Distribution of the Rain Gauge Network and 1-km² Pixels

Table 1. Rain Gauge ID, Name and Source

Gauge ID	Gauge Name	Source
10001	Lake Barcroft	Alexandria
20101	Windmill Hill Park	Alexandria
20102	Charles Barrett Elementary	Alexandria
20103	Beach Park	Alexandria
20104	Mount Vernon Elementary	Alexandria
20105	Francis Hammond Middle School	Alexandria
20106	George Mason Elementary	Alexandria
20116	Holmes Run @ Van Dorn	Alexandria
20117	Holmes Run Parkway	Alexandria
980	Huntington Levee - Ponding Area	Fairfax
1000	Huntsman Lake	Fairfax
1030	Lake Mercer	Fairfax
1040	Royal Lake	Fairfax

Gauge ID	Gauge Name	Source
1050	Lake Braddock	Fairfax
1070	Pump Station	Fairfax
1090	Fairview Lake	Fairfax
1270	Kingstowne Regional Pond 4	Fairfax
1280	Carrington	Fairfax
1300	Pulte/McLean	Fairfax
1350	Boothe Park	Fairfax
1360	Lake Accotink (FCPA)	Fairfax
1540	Brookfield Park	Fairfax
RG-Brentwood	RG-Brentwood	DC Water
RG-Bryant	RG-Bryant	DC Water
RG-Main PS	RG-Main PS	DC Water
RG-RCPS	RG-RCPS	DC Water
01652500	FOURMILE RUN AT ALEXANDRIA	USGS
KDCA	Washington Reagan National Airport	NWS-ASOS

The 28 rain gauges and the one NWS NEXRAD radar are used to produce gauge-adjusted radar rainfall (GARR).

Methodology

Statistical control of the data makes radar rainfall measurements more accurate. By statistical comparison between the radar and rain gauge accumulations during a GARR period, certain gauges may be identified as statistical outliers and excluded for all or part of an event. Radar data is enhanced by correcting it for systematic errors called bias, which helps improve the accuracy of the rainfall product. The bias correction factors are multiplicative factors applied to the radar that enhances the accuracy of the radar rainfall for any accumulation period. By adjusting the radar data with rain gauge data, better maps of rainfall are produced than either sensor system could produce alone.

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

The LB uses the ratio between the sum of each gauge divided by the sum of the sampled radar values over each gauge. Gauge and radar accumulations were computed for each event period. A minimum storm total threshold (MSTT) check was used to remove radar/gauge (RG) pairs whose R or G cumulative values for a given event period were below a chosen threshold (i.e. 0.05 inches for this study). The remaining RG pairs were then checked for statistical outliers.

Those RG pairs with individual bias (G/R) or average difference ((G-R)/G) values greater than three standard deviations from the mean were then excluded from being used to adjust the radar.

After RG pairs have been removed on an event basis by either the MSTT, outlier check or gauge performance review, there must be at least three remaining RG pairs to proceed with gauge-adjustment of the radar. The individual biases of the remaining RG pairs are then distributed spatially over the analysis area using the LB weighted distance method. The resulting LB value over each radar bin is the multiplicative factor that adjusts the radar. For example, a bias of 1.5 can be interpreted as a 33% underestimation by the radar. The statistical measures reported are 1) average difference (AD) and 2) calibrated average difference (CAD). Both of these statistical measures are expressed as an absolute percentage about the mean of G/R accumulations for each event period. GARR is then spatially aggregated from the final adjusted radar bins to 1-km² pixels, and subcatchments 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 304 1-km² pixels for the following periods:

2019-07-08 03:00 EDT - 2019-07-08 17:00 EDT
2020-07-23 17:00 EDT - 2020-07-24 17:00 EDT
2020-09-09 09:00 EDT - 2020-09-10 19:00 EDT
2021-08-14 21:00 EDT - 2021-08-15 07:00 EDT

Shapefiles of the 1-km pixels are included in the Shapefiles folder. Animations for each event are included in the Animations folder. The data file documentation follows:

Shapefile metadata:

- NAD 1983, StatePlane Virginia, North (feet).
- Time stamps in dbf are in EDT(mmddhhmm).
- Data values represent 5-min accumulation (inches) at end of interval.
- The sum fields represents rainfall in inches during the entire analysis period.

Gauge-Adjusted Radar Rainfall (GARR)

The GARR statistics for each event are listed in Table 2. All four of the events were split into multiple sub-event periods to improve gauge-adjustment of the radar, resulting in a total of eighteen 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 eighteen event and sub-event periods, the event CAD averaged 4.1%, indicating that the mean GARR agrees with the mean gauge accumulation to within $\pm 2.0\%$.

Table 2. Storm Events and GARR Statistics

Event #	Source	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (28)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E1a	KLWX LII	2019-07-08	2019-07-08 03:05	2019-07-08 11:00	15	3.184	1.865	47.1	2.0
E1b	KLWX LII	2019-07-08	2019-07-08 11:05	2019-07-08 17:00	9	0.058	1.139	15.3	3.6
E2a	KLWX LII	2020-07-23	2020-07-23 17:05	2020-07-23 21:45	15	1.048	1.440	28.6	3.8
E2b	KLWX LII	2020-07-23	2020-07-23 21:50	2020-07-24 02:00	13	0.261	1.009	12.4	7.0
E2c	KLWX LII	2020-07-23	2020-07-24 02:05	2020-07-24 06:00	12	0.082	1.267	21.3	4.6
E2d	KLWX LII	2020-07-23	2020-07-24 06:05	2020-07-24 17:00	10	0.091	1.274	19.7	0.6
E3a	KLWX LII	2020-09-10	2020-09-09 09:05	2020-09-09 16:00	7	0.054	1.214	18.5	0.1
E3b	KLWX LII	2020-09-10	2020-09-09 16:05	2020-09-09 20:00	9	0.082	1.245	20.3	4.3
E3c	KLWX LII	2020-09-10	2020-09-09 20:05	2020-09-10 03:00	17	0.731	1.464	30.6	1.8
E3d	KLWX LII	2020-09-10	2020-09-10 03:05	2020-09-10 12:30	12	0.120	1.344	27.1	1.5

Event #	Source	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (28)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E3e	KLWX LII	2020-09-10	2020-09-10 12:35	2020-09-10 13:45	11	0.460	1.618	40.2	3.1
E3f	KLWX LII	2020-09-10	2020-09-10 13:50	2020-09-10 15:00	13	0.547	2.103	52.2	1.0
E3g	KLWX LII	2020-09-10	2020-09-10 15:05	2020-09-10 19:00	8	0.099	1.289	23.0	4.5
E4a	KLWX LII	2021-08-15	2021-08-14 21:05	2021-08-15 00:15	15	0.358	1.146	36.1	13.6
E4b	KLWX LII	2021-08-15	2021-08-15 00:20	2021-08-15 00:40	21	0.898	1.625	33.8	3.5
E4c	KLWX LII	2021-08-15	2021-08-15 00:45	2021-08-15 01:10	20	0.688	1.244	22.6	7.7
E4d	KLWX LII	2021-08-15	2021-08-15 01:15	2021-08-15 02:00	21	0.259	1.379	30.7	5.6
E4e	KLWX LII	2021-08-15	2021-08-15 02:05	2021-08-15 07:00	24	0.205	1.293	22.7	5.1

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

Rain gauges were analyzed to identify those that were not consistent with the radar or surrounding gauges. Cumulative Distribution Plots (CDPs) at each gauge location showing gauge, unadjusted radar and GARR values were produced for each rainfall event and are presented in Appendices C - F. CDPs are useful for visualizing rain gauge performance. Figure 2 shows the rainfall accumulation at the Holmes Run Parkway (20117) gauge during the 2020-09-10 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.

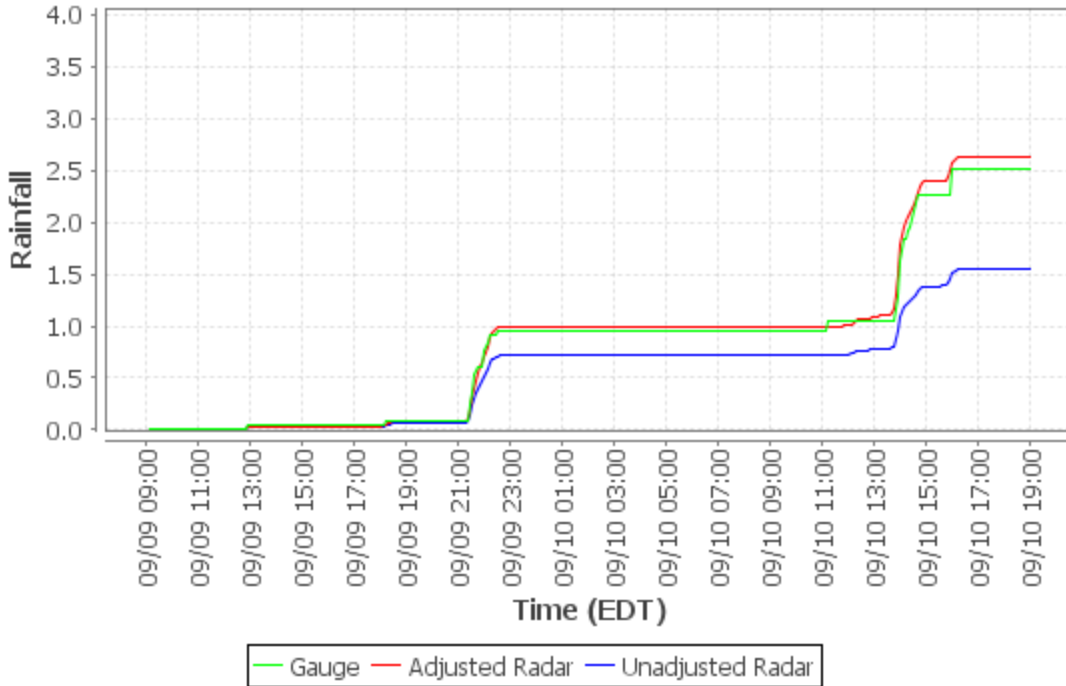


Figure 2. CDP Showing Rain Gauge Versus Unadjusted Radar Versus GARR

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 based on gauge performance are shown in [Appendix A](#). Additional gauges were not used to adjust the radar for a given event or sub-event period if they did not meet the statistical criteria outlined in the Methodology section. A list of reasons for not using a gauge based on statistical criteria is shown in Table 4. The gauges listed in [Appendix B](#) did not meet statistical criteria for gauge-adjustment of the radar and were not used to adjust the radar.

Table 3. Reasons for Gauge Exclusion Based on Performance

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

Table 4. Reasons for Gauge Exclusion Based on Statistical Criteria

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

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

Events

Event 1: 2019-07-08

The analysis period was from 2019-07-08 03:00 EDT to 2019-07-08 17:00 EDT. The event was then split into two sub-event periods at 2019-07-08 11:00 EDT to improve gauge adjustment of the radar.

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

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 5 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 6 - 7 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and $Diff^*$ (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 3 - 4 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 5 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 304 1-km² pixels range from 1.4 - 4.5 inches with a mean of 3.2 inches.

Table 5. GARR Statistics for Event 1

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (28)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E1a	KLWX LII	2019-07-08	2019-07-08 03:05	2019-07-08 11:00	15	3.184	1.865	47.1	2.0
E1b	KLWX LII	2019-07-08	2019-07-08 11:05	2019-07-08 17:00	9	0.058	1.139	15.3	3.6

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

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
20116	Holmes Run @ Van Dorn	2.89	1.72	3.10	-0.21	-7.3	
1050	Lake Braddock	1.64	0.85	1.71	-0.07	-4.3	
1000	Huntsman Lake	1.04	0.52	1.06	-0.02	-1.9	
01652500	FOURMILE RUN AT ALEXANDRIA	2.82	1.60	2.83	-0.01	-0.4	
1280	Carrington	4.32	2.35	4.33	-0.01	-0.2	
1090	Fairview Lake	3.87	2.05	3.87	0.00	0.0	
1270	Kingstowne Regional Pond 4	2.54	1.26	2.54	0.00	0.0	
1350	Boothe Park	3.29	1.87	3.29	0.00	0.0	
1360	Lake Accotink (FCPA)	1.84	1.07	1.84	0.00	0.0	
980	Huntington Levee - Ponding Area	3.20	1.81	3.20	0.00	0.0	
1300	Pulte/McLean	4.51	2.44	4.50	0.01	0.2	
KDCA	Washington Reagan National Airport	3.41	1.75	3.40	0.01	0.3	
1030	Lake Mercer	0.96	0.45	0.94	0.02	2.1	
1040	Royal Lake	1.36	0.63	1.30	0.06	4.4	
20117	Holmes Run Parkway	3.51	1.74	3.25	0.26	7.4	
10001	Lake Barcroft	0.04	---	---	---	---	S
1070	Pump Station	2.68	---	---	---	---	S
1540	Brookfield Park	0.00	---	---	---	---	Z
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
RG-Brentwood	RG-Brentwood	ND	---	---	---	---	ND
RG-Bryant	RG-Bryant	ND	---	---	---	---	ND
RG-Main PS	RG-Main PS	ND	---	---	---	---	ND
RG-RCPS	RG-RCPS	ND	---	---	---	---	ND

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

Gauge ID	Name	G_i (in)	R_i (in)	R_i* (in)	Diff* (in)	Diff* (%)	Flag
1050	Lake Braddock	0.08	0.07	0.09	-0.01	-12.5	
20117	Holmes Run Parkway	0.08	0.09	0.09	-0.01	-12.5	
01652500	FOURMILE RUN AT ALEXANDRIA	0.07	0.06	0.07	0.00	0.0	
1040	Royal Lake	0.08	0.06	0.08	0.00	0.0	
1070	Pump Station	0.08	0.06	0.08	0.00	0.0	
1090	Fairview Lake	0.08	0.07	0.08	0.00	0.0	
1350	Boothe Park	0.12	0.12	0.12	0.00	0.0	
1360	Lake Accotink (FCPA)	0.08	0.06	0.08	0.00	0.0	
20116	Holmes Run @ Van Dorn	0.12	0.11	0.11	0.01	8.3	
1000	Huntsman Lake	0.04	---	---	---	---	MSTT
10001	Lake Barcroft	0.00	---	---	---	---	Z
1030	Lake Mercer	0.00	---	---	---	---	MSTT
1270	Kingstowne Regional Pond 4	0.04	---	---	---	---	MSTT
1280	Carrington	0.00	---	---	---	---	Z
1300	Pulte/McLean	0.04	---	---	---	---	MSTT
1540	Brookfield Park	0.00	---	---	---	---	Z
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
980	Huntington Levee - Ponding Area	0.04	---	---	---	---	U
KDCA	Washington Reagan National Airport	0.03	---	---	---	---	MSTT
RG-Brentwood	RG-Brentwood	ND	---	---	---	---	ND
RG-Bryant	RG-Bryant	ND	---	---	---	---	ND
RG-Main PS	RG-Main PS	ND	---	---	---	---	ND
RG-RCPS	RG-RCPS	ND	---	---	---	---	ND

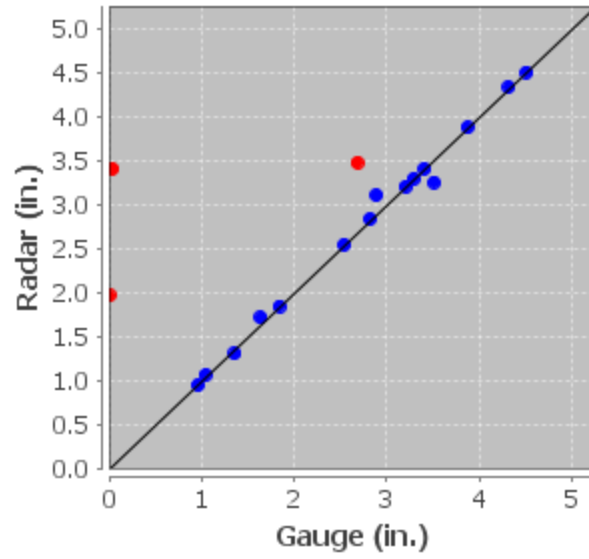


Figure 3. Scatter Plot of RG Pairs for Event 1a

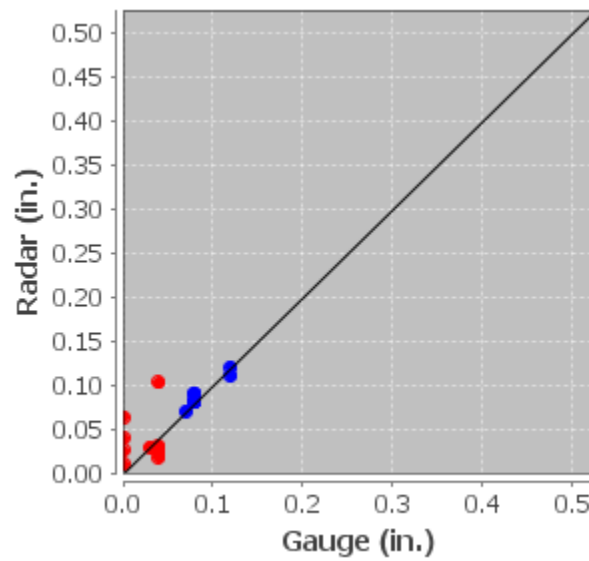


Figure 4. Scatter Plot of RG Pairs for Event 1b

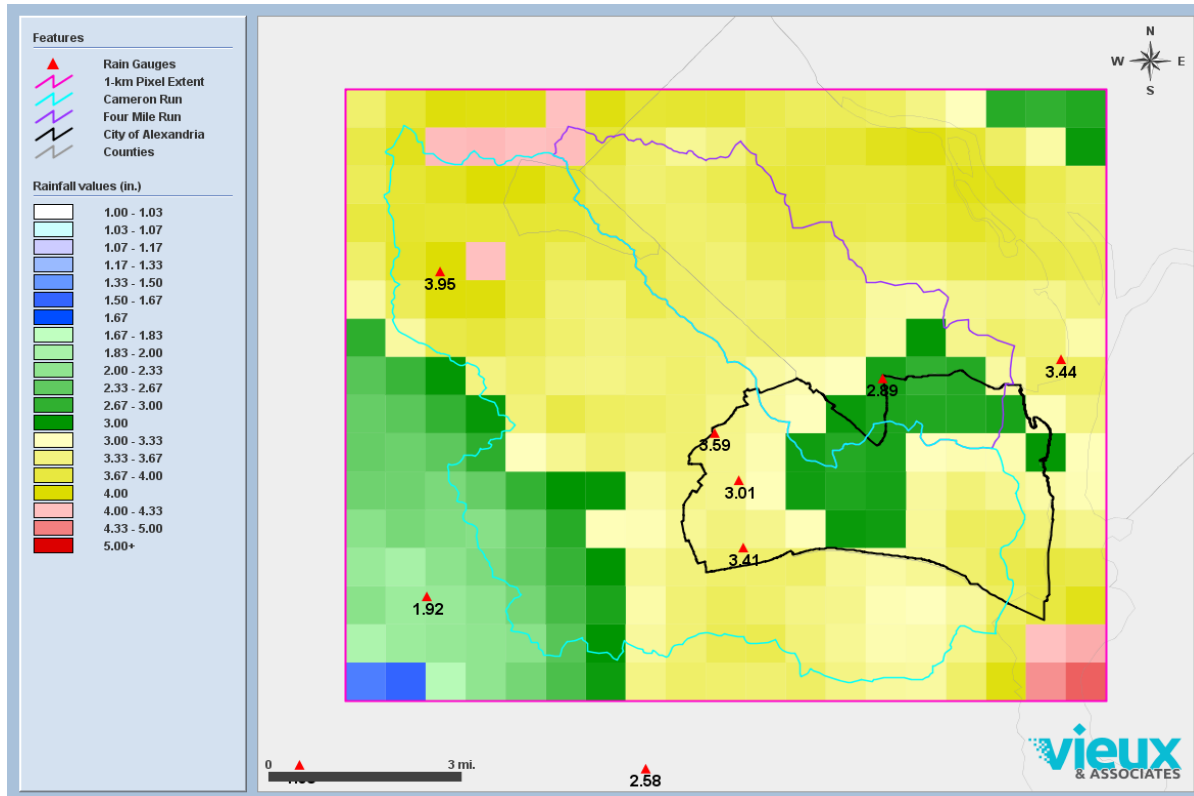


Figure 5. GARR Storm Total for Event 1

Event 2: 2020-07-23

The analysis period was from 2020-07-23 17:00 EDT to 2020-07-24 17:00 EDT. The event was then split into four sub-event periods at 2020-07-23 21:45 EDT, 2020-07-24 02:00 EDT and 2020-07-24 06:00 EDT to improve gauge adjustment of the radar.

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

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 8 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 9 - 12 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and $Diff^*$ (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 6 - 9 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 10 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 304 1-km² pixels range from 0.5 - 2.6 inches with a mean of 1.5 inches.

Table 8. GARR Statistics for Event 2

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (28)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E2a	KLWX LII	2020-07-23	2020-07-23 17:05	2020-07-23 21:45	15	1.048	1.440	28.6	3.8
E2b	KLWX LII	2020-07-23	2020-07-23 21:50	2020-07-24 02:00	13	0.261	1.009	12.4	7.0
E2c	KLWX LII	2020-07-23	2020-07-24 02:05	2020-07-24 06:00	12	0.082	1.267	21.3	4.6
E2d	KLWX LII	2020-07-23	2020-07-24 06:05	2020-07-24 17:00	10	0.091	1.274	19.7	0.6

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* (%)	Flag
1040	Royal Lake	0.40	0.41	0.46	-0.06	-15.0	
1300	Pulte/McLean	0.28	0.22	0.31	-0.03	-10.7	
1030	Lake Mercer	1.24	0.96	1.28	-0.04	-3.2	
1540	Brookfield Park	1.03	0.80	1.06	-0.03	-2.9	
1350	Boothe Park	2.33	1.50	2.35	-0.02	-0.9	
KDCA	Washington Reagan National Airport	1.38	1.03	1.39	-0.01	-0.7	
1070	Pump Station	1.28	0.76	1.28	0.00	0.0	
1090	Fairview Lake	0.24	0.16	0.24	0.00	0.0	
RG-Bryant	RG-Bryant	0.60	0.37	0.60	0.00	0.0	
RG-Main PS	RG-Main PS	1.40	0.96	1.39	0.01	0.7	
20117	Holmes Run Parkway	1.86	1.11	1.84	0.02	1.1	
1360	Lake Accotink (FCPA)	1.23	0.89	1.20	0.03	2.4	
1000	Huntsman Lake	1.30	0.92	1.26	0.04	3.1	
1280	Carrington	0.48	0.30	0.44	0.04	8.3	
1050	Lake Braddock	0.63	0.48	0.57	0.06	9.5	
01652500	FOURMILE RUN AT ALEXANDRIA	0.00	---	---	---	---	ND
10001	Lake Barcroft	0.07	---	---	---	---	S
1270	Kingstowne Regional Pond 4	0.00	---	---	---	---	Z
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
980	Huntington Levee - Ponding Area	1.02	---	---	---	---	S
RG-Brentwood	RG-Brentwood	0.50	---	---	---	---	U
RG-RCPS	RG-RCPS	0.00	---	---	---	---	Z

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* (%)	Flag
1000	Huntsman Lake	0.20	0.24	0.24	-0.04	-20.0	
1360	Lake Accotink (FCPA)	0.40	0.46	0.46	-0.06	-15.0	
1070	Pump Station	0.08	0.09	0.09	-0.01	-12.5	
1050	Lake Braddock	0.24	0.30	0.26	-0.02	-8.3	
1090	Fairview Lake	0.52	0.50	0.52	0.00	0.0	
1350	Boothe Park	0.12	0.15	0.12	0.00	0.0	
20117	Holmes Run Parkway	0.24	0.25	0.24	0.00	0.0	
RG-Brentwood	RG-Brentwood	0.08	0.08	0.08	0.00	0.0	
RG-Main PS	RG-Main PS	0.07	0.07	0.07	0.00	0.0	
1040	Royal Lake	0.40	0.41	0.37	0.03	7.5	
980	Huntington Levee - Ponding Area	0.12	0.10	0.11	0.01	8.3	
1540	Brookfield Park	0.52	0.43	0.47	0.05	9.6	
1030	Lake Mercer	0.48	0.37	0.43	0.05	10.4	
01652500	FOURMILE RUN AT ALEXANDRIA	ND	---	---	---	---	ND
10001	Lake Barcroft	0.02	---	---	---	---	C
1270	Kingstowne Regional Pond 4	0.00	---	---	---	---	Z
1280	Carrington	0.04	---	---	---	---	MSTT
1300	Pulte/McLean	0.04	---	---	---	---	MSTT
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
KDCA	Washington Reagan National Airport	0.51	---	---	---	---	O
RG-Bryant	RG-Bryant	0.37	---	---	---	---	O
RG-RCPS	RG-RCPS	0.00	---	---	---	---	Z

Table 11. Summary of Individual RG Pairs for Event 2c

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1360	Lake Accotink (FCPA)	0.08	0.07	0.09	-0.01	-12.5	
1040	Royal Lake	0.12	0.09	0.13	-0.01	-8.3	
1280	Carrington	0.12	0.09	0.13	-0.01	-8.3	
1070	Pump Station	0.24	0.21	0.24	0.00	0.0	
1090	Fairview Lake	0.16	0.12	0.16	0.00	0.0	
20117	Holmes Run Parkway	0.08	0.08	0.08	0.00	0.0	
KDCA	Washington Reagan National Airport	0.05	0.06	0.05	0.00	0.0	
RG-Brentwood	RG-Brentwood	0.07	0.06	0.07	0.00	0.0	
RG-Main PS	RG-Main PS	0.19	0.16	0.19	0.00	0.0	
1050	Lake Braddock	0.16	0.10	0.15	0.01	6.3	
1300	Pulte/McLean	0.12	0.07	0.11	0.01	8.3	
1540	Brookfield Park	0.08	0.06	0.07	0.01	12.5	
01652500	FOURMILE RUN AT ALEXANDRIA	ND	---	---	---	---	ND
1000	Huntsman Lake	0.00	---	---	---	---	MSTT
10001	Lake Barcroft	0.02	---	---	---	---	C
1030	Lake Mercer	0.00	---	---	---	---	MSTT
1270	Kingstowne Regional Pond 4	0.00	---	---	---	---	MSTT
1350	Boothe Park	0.04	---	---	---	---	MSTT
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
980	Huntington Levee - Ponding Area	0.00	---	---	---	---	MSTT
RG-Bryant	RG-Bryant	0.04	---	---	---	---	MSTT
RG-RCPS	RG-RCPS	0.00	---	---	---	---	Z

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1280	Carrington	0.44	0.33	0.45	-0.01	-2.3	
1030	Lake Mercer	0.20	0.14	0.20	0.00	0.0	
1070	Pump Station	0.12	0.12	0.12	0.00	0.0	
1090	Fairview Lake	0.08	0.05	0.08	0.00	0.0	
980	Huntington Levee - Ponding Area	0.08	0.08	0.08	0.00	0.0	
KDCA	Washington Reagan National Airport	0.38	0.31	0.38	0.00	0.0	
RG-Brentwood	RG-Brentwood	0.14	0.11	0.14	0.00	0.0	
RG-Bryant	RG-Bryant	0.22	0.18	0.22	0.00	0.0	
RG-Main PS	RG-Main PS	0.16	0.13	0.16	0.00	0.0	
1300	Pulte/McLean	0.48	0.36	0.47	0.01	2.1	
01652500	FOURMILE RUN AT ALEXANDRIA	ND	---	---	---	---	ND
1000	Huntsman Lake	0.04	---	---	---	---	MSTT
10001	Lake Barcroft	0.01	---	---	---	---	C
1040	Royal Lake	0.00	---	---	---	---	MSTT
1050	Lake Braddock	0.00	---	---	---	---	MSTT
1270	Kingstowne Regional Pond 4	0.00	---	---	---	---	MSTT
1350	Boothe Park	0.04	---	---	---	---	MSTT
1360	Lake Accotink (FCPA)	0.04	---	---	---	---	MSTT
1540	Brookfield Park	0.00	---	---	---	---	MSTT
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
20117	Holmes Run Parkway	0.08	---	---	---	---	O

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
RG-RCPS	RG-RCPS	0.00	---	---	---	---	Z

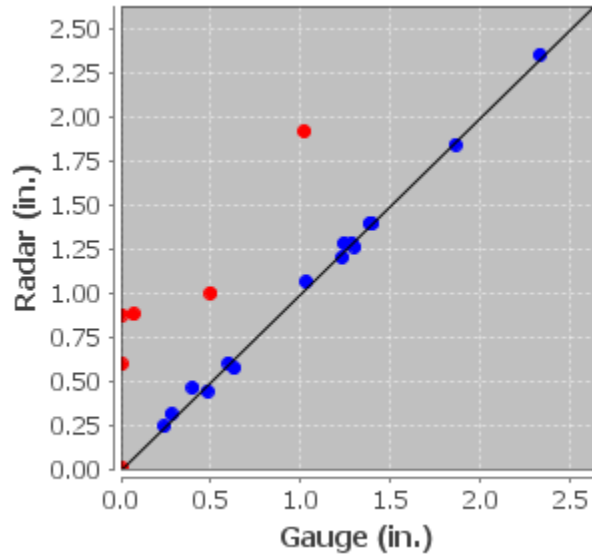


Figure 6. Scatter Plot of RG Pairs for Event 2a

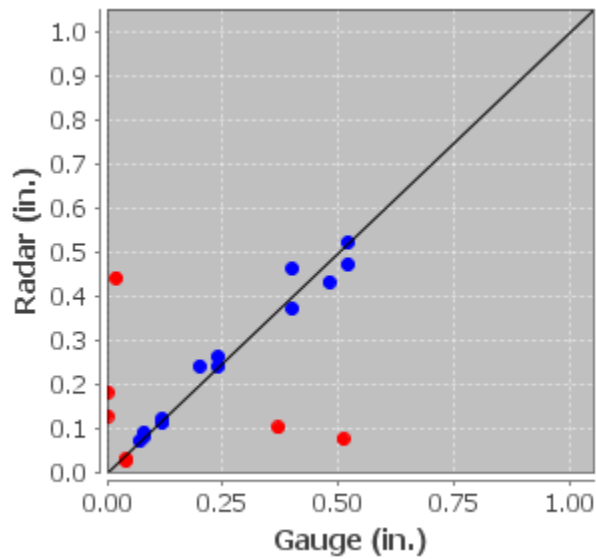


Figure 7. Scatter Plot of RG Pairs for Event 2b

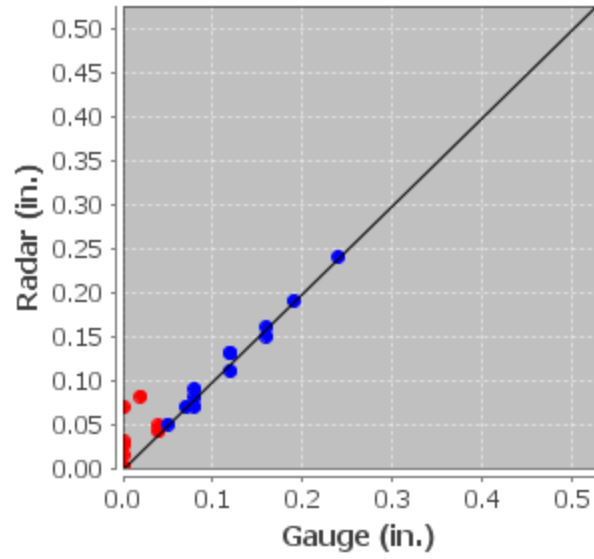


Figure 8. Scatter Plot of RG Pairs for Event 2c

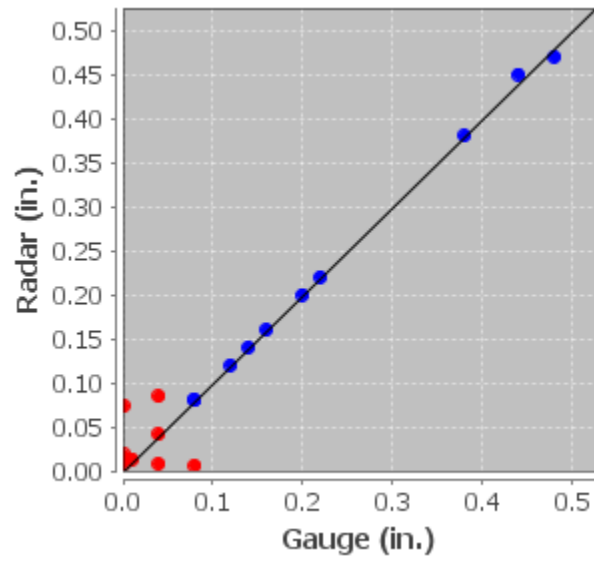


Figure 9. Scatter Plot of RG Pairs for Event 2d

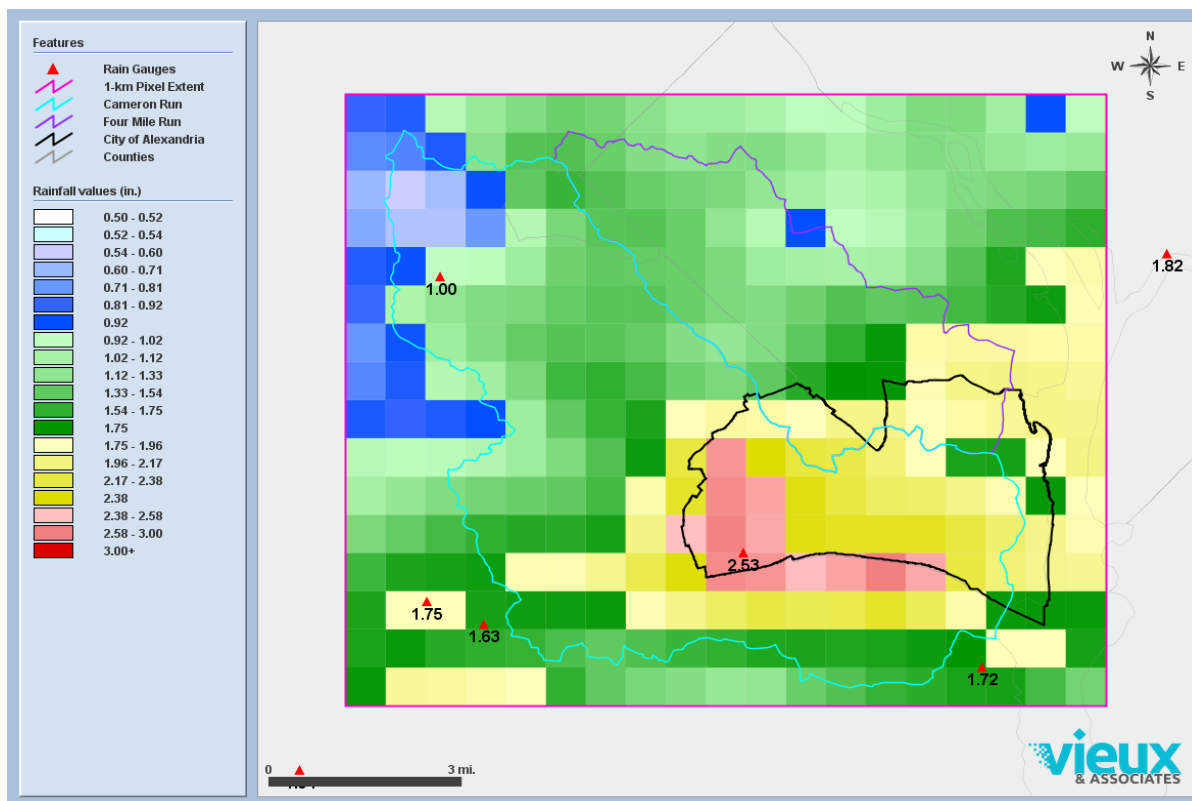


Figure 10. GARR Storm Total for Event 2

Event 3: 2020-09-10

The analysis period was from 2020-09-09 09:00 EDT to 2020-09-10 19:00 EDT. The event was then split into seven sub-event periods at 2020-09-09 16:00 EDT, 2020-09-09 20:00 EDT, 2020-09-10 03:00 EDT, 2020-09-10 12:30 EDT, 2020-09-10 13:45 EDT and 2020-09-10 15:00 EDT to improve gauge adjustment of the radar.

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

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 13 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 14 - 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. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 11 - 17 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 18 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 304 1-km² pixels range from 0.5 - 3.7 inches with a mean of 2.1 inches.

Table 13. GARR Statistics for Event 3

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (28)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E3a	KLWX LII	2020-09-10	2020-09-09 09:05	2020-09-09 16:00	7	0.054	1.214	18.5	0.1
E3b	KLWX LII	2020-09-10	2020-09-09 16:05	2020-09-09 20:00	9	0.082	1.245	20.3	4.3
E3c	KLWX LII	2020-09-10	2020-09-09 20:05	2020-09-10 03:00	17	0.731	1.464	30.6	1.8
E3d	KLWX LII	2020-09-10	2020-09-10 03:05	2020-09-10 12:30	12	0.120	1.344	27.1	1.5
E3e	KLWX LII	2020-09-10	2020-09-10 12:35	2020-09-10 13:45	11	0.460	1.618	40.2	3.1
E3f	KLWX LII	2020-09-10	2020-09-10 13:50	2020-09-10 15:00	13	0.547	2.103	52.2	1.0
E3g	KLWX LII	2020-09-10	2020-09-10 15:05	2020-09-10 19:00	8	0.099	1.289	23.0	4.5

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
01652500	FOURMILE RUN AT ALEXANDRIA	0.08	0.06	0.08	0.00	0.0	
1050	Lake Braddock	0.08	0.06	0.08	0.00	0.0	
1070	Pump Station	0.12	0.12	0.12	0.00	0.0	
1270	Kingstowne Regional Pond 4	0.08	0.05	0.08	0.00	0.0	
1360	Lake Accotink (FCPA)	0.08	0.06	0.08	0.00	0.0	
KDCA	Washington Reagan National Airport	0.08	0.07	0.08	0.00	0.0	
RG-RCPS	RG-RCPS	0.06	0.06	0.06	0.00	0.0	
1000	Huntsman Lake	0.12	---	---	---	---	O
10001	Lake Barcroft	0.01	---	---	---	---	MSTT
1030	Lake Mercer	0.04	---	---	---	---	MSTT
1040	Royal Lake	0.04	---	---	---	---	MSTT
1090	Fairview Lake	0.00	---	---	---	---	MSTT
1280	Carrington	0.04	---	---	---	---	MSTT
1300	Pulte/McLean	0.08	---	---	---	---	MSTT
1350	Boothe Park	0.04	---	---	---	---	MSTT
1540	Brookfield Park	0.04	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
20117	Holmes Run Parkway	0.04	---	---	---	---	MSTT
980	Huntington Levee - Ponding Area	0.04	---	---	---	---	MSTT
RG-Brentwood	RG-Brentwood	0.02	---	---	---	---	MSTT
RG-Bryant	RG-Bryant	0.02	---	---	---	---	MSTT
RG-Main PS	RG-Main PS	0.04	---	---	---	---	MSTT

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1540	Brookfield Park	0.12	0.11	0.14	-0.02	-16.7	
980	Huntington Levee - Ponding Area	0.24	0.22	0.25	-0.01	-4.2	
1270	Kingstowne Regional Pond 4	0.16	0.09	0.16	0.00	0.0	
1280	Carrington	0.24	0.19	0.24	0.00	0.0	
1300	Pulte/McLean	0.28	0.22	0.28	0.00	0.0	
1350	Boothe Park	0.12	0.10	0.12	0.00	0.0	
RG-Main PS	RG-Main PS	0.05	0.06	0.05	0.00	0.0	
1070	Pump Station	0.20	0.16	0.19	0.01	5.0	
1360	Lake Accotink (FCPA)	0.16	0.11	0.14	0.02	12.5	
01652500	FOURMILE RUN AT ALEXANDRIA	0.03	---	---	---	---	MSTT
1000	Huntsman Lake	0.08	---	---	---	---	O
10001	Lake Barcroft	0.00	---	---	---	---	C
1030	Lake Mercer	0.04	---	---	---	---	MSTT
1040	Royal Lake	0.04	---	---	---	---	MSTT
1050	Lake Braddock	0.08	---	---	---	---	MSTT
1090	Fairview Lake	0.00	---	---	---	---	MSTT
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
20117	Holmes Run Parkway	0.04	---	---	---	---	MSTT
KDCA	Washington Reagan National Airport	0.04	---	---	---	---	MSTT
RG-Brentwood	RG-Brentwood	0.01	---	---	---	---	U
RG-Bryant	RG-Bryant	0.03	---	---	---	---	U
RG-RCPS	RG-RCPS	0.03	---	---	---	---	MSTT

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1300	Pulte/McLean	1.36	0.94	1.43	-0.07	-5.1	
RG-Bryant	RG-Bryant	0.27	0.23	0.28	-0.01	-3.7	
20117	Holmes Run Parkway	0.88	0.64	0.90	-0.02	-2.3	
1540	Brookfield Park	1.07	0.80	1.09	-0.02	-1.9	
01652500	FOURMILE RUN AT ALEXANDRIA	0.53	0.36	0.53	0.00	0.0	
1040	Royal Lake	0.12	0.08	0.12	0.00	0.0	
1070	Pump Station	0.28	0.19	0.28	0.00	0.0	
1270	Kingstowne Regional Pond 4	0.56	0.37	0.56	0.00	0.0	
KDCA	Washington Reagan National Airport	0.52	0.35	0.52	0.00	0.0	
RG-Brentwood	RG-Brentwood	0.28	0.23	0.28	0.00	0.0	
RG-Main PS	RG-Main PS	0.96	0.65	0.96	0.00	0.0	
1360	Lake Accotink (FCPA)	0.80	0.57	0.79	0.01	1.3	
980	Huntington Levee - Ponding Area	0.76	0.49	0.75	0.01	1.3	
RG-RCPS	RG-RCPS	0.67	0.45	0.66	0.01	1.5	
1350	Boothe Park	0.64	0.41	0.63	0.01	1.6	
1050	Lake Braddock	0.24	0.16	0.23	0.01	4.2	
1280	Carrington	1.52	0.93	1.45	0.07	4.6	
1000	Huntsman Lake	0.08	---	---	---	---	O
10001	Lake Barcroft	0.05	---	---	---	---	C
1030	Lake Mercer	0.08	---	---	---	---	MSTT

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1090	Fairview Lake	0.00	---	---	---	---	Z
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1030	Lake Mercer	0.12	0.11	0.13	-0.01	-8.3	
01652500	FOURMILE RUN AT ALEXANDRIA	0.31	0.21	0.31	0.00	0.0	
1070	Pump Station	0.20	0.13	0.20	0.00	0.0	
1270	Kingstowne Regional Pond 4	0.12	0.07	0.12	0.00	0.0	
1350	Boothe Park	0.12	0.08	0.12	0.00	0.0	
20117	Holmes Run Parkway	0.08	0.06	0.08	0.00	0.0	
980	Huntington Levee - Ponding Area	0.24	0.16	0.24	0.00	0.0	
KDCA	Washington Reagan National Airport	0.29	0.20	0.29	0.00	0.0	
RG- Brentwood	RG-Brentwood	0.28	0.25	0.28	0.00	0.0	
RG-Main PS	RG-Main PS	0.38	0.31	0.38	0.00	0.0	
RG-RCPS	RG-RCPS	0.40	0.32	0.40	0.00	0.0	
1000	Huntsman Lake	0.16	0.12	0.15	0.01	6.3	
10001	Lake Barcroft	0.02	---	---	---	---	C
1040	Royal Lake	0.00	---	---	---	---	MSTT
1050	Lake Braddock	0.04	---	---	---	---	MSTT
1090	Fairview Lake	0.00	---	---	---	---	MSTT
1280	Carrington	0.12	---	---	---	---	MSTT
1300	Pulte/McLean	0.04	---	---	---	---	MSTT
1360	Lake Accotink (FCPA)	0.00	---	---	---	---	MSTT
1540	Brookfield Park	0.04	---	---	---	---	MSTT
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
RG-Bryant	RG-Bryant	0.03	---	---	---	---	S

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1040	Royal Lake	0.08	0.07	0.09	-0.01	-12.5	
980	Huntington Levee - Ponding Area	1.55	1.06	1.61	-0.06	-3.9	
KDCA	Washington Reagan National Airport	1.05	0.68	1.06	-0.01	-1.0	
RG-Main PS	RG-Main PS	1.39	1.00	1.40	-0.01	-0.7	
1270	Kingstowne Regional Pond 4	0.24	0.08	0.24	0.00	0.0	
1350	Boothe Park	0.56	0.23	0.56	0.00	0.0	
RG-Brentwood	RG-Brentwood	1.32	0.98	1.32	0.00	0.0	
RG-RCPS	RG-RCPS	0.78	0.37	0.78	0.00	0.0	
01652500	FOURMILE RUN AT ALEXANDRIA	0.81	0.34	0.80	0.01	1.2	
1070	Pump Station	1.48	0.89	1.43	0.05	3.4	
1050	Lake Braddock	0.40	0.27	0.36	0.04	10.0	
1000	Huntsman Lake	0.04	---	---	---	---	MSTT
10001	Lake Barcroft	0.00	---	---	---	---	C
1030	Lake Mercer	0.00	---	---	---	---	MSTT
1090	Fairview Lake	0.00	---	---	---	---	MSTT
1280	Carrington	0.00	---	---	---	---	MSTT
1300	Pulte/McLean	0.08	---	---	---	---	O
1360	Lake Accotink (FCPA)	0.04	---	---	---	---	MSTT
1540	Brookfield Park	0.04	---	---	---	---	MSTT
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
20117	Holmes Run Parkway	0.00	---	---	---	---	Z
RG-Bryant	RG-Bryant	0.96	---	---	---	---	T

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1360	Lake Accotink (FCPA)	0.24	0.10	0.25	-0.01	-4.2	
01652500	FOURMILE RUN AT ALEXANDRIA	1.07	0.52	1.07	0.00	0.0	
1000	Huntsman Lake	0.24	0.11	0.24	0.00	0.0	
1040	Royal Lake	0.48	0.25	0.48	0.00	0.0	
1070	Pump Station	0.20	0.12	0.20	0.00	0.0	
1270	Kingstowne Regional Pond 4	0.24	0.09	0.24	0.00	0.0	
20117	Holmes Run Parkway	1.23	0.58	1.23	0.00	0.0	
KDCA	Washington Reagan National Airport	1.53	0.74	1.53	0.00	0.0	
RG-Brentwood	RG-Brentwood	1.44	0.68	1.44	0.00	0.0	
RG-Main PS	RG-Main PS	1.03	0.47	1.03	0.00	0.0	
RG-RCPS	RG-RCPS	1.14	0.53	1.14	0.00	0.0	
980	Huntington Levee - Ponding Area	0.56	0.32	0.55	0.01	1.8	
1540	Brookfield Park	0.60	0.23	0.58	0.02	3.3	
10001	Lake Barcroft	0.03	---	---	---	---	C
1030	Lake Mercer	0.08	---	---	---	---	MSTT
1050	Lake Braddock	0.20	---	---	---	---	U
1090	Fairview Lake	0.00	---	---	---	---	MSTT
1280	Carrington	0.00	---	---	---	---	MSTT
1300	Pulte/McLean	0.00	---	---	---	---	MSTT
1350	Boothe Park	0.24	---	---	---	---	U
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
RG-Bryant	RG-Bryant	1.97	---	---	---	---	O

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1360	Lake Accotink (FCPA)	0.16	0.14	0.18	-0.02	-12.5	
1000	Huntsman Lake	0.12	0.10	0.13	-0.01	-8.3	
1040	Royal Lake	0.64	0.52	0.66	-0.02	-3.1	
1030	Lake Mercer	0.08	0.05	0.08	0.00	0.0	
20117	Holmes Run Parkway	0.24	0.17	0.24	0.00	0.0	
RG-Bryant	RG-Bryant	0.06	0.05	0.06	0.00	0.0	
1050	Lake Braddock	0.44	0.34	0.43	0.01	2.3	
1540	Brookfield Park	0.12	0.08	0.11	0.01	8.3	
01652500	FOURMILE RUN AT ALEXANDRIA	0.03	---	---	---	---	MSTT
10001	Lake Barcroft	0.00	---	---	---	---	C
1070	Pump Station	0.04	---	---	---	---	MSTT
1090	Fairview Lake	0.00	---	---	---	---	Z
1270	Kingstowne Regional Pond 4	0.00	---	---	---	---	MSTT
1280	Carrington	0.00	---	---	---	---	MSTT
1300	Pulte/McLean	0.00	---	---	---	---	MSTT
1350	Boothe Park	0.04	---	---	---	---	U
20101	Windmill Hill Park	ND	---	---	---	---	ND
20102	Charles Barrett Elementary	ND	---	---	---	---	ND
20103	Beach Park	ND	---	---	---	---	ND
20104	Mount Vernon Elementary	ND	---	---	---	---	ND
20105	Francis Hammond Middle School	ND	---	---	---	---	ND
20106	George Mason Elementary	ND	---	---	---	---	ND
20116	Holmes Run @ Van Dorn	ND	---	---	---	---	ND
980	Huntington Levee - Ponding Area	0.04	---	---	---	---	MSTT
KDCA	Washington Reagan National Airport	0.01	---	---	---	---	MSTT
RG-Brentwood	RG-Brentwood	0.05	---	---	---	---	MSTT
RG-Main PS	RG-Main PS	0.02	---	---	---	---	MSTT
RG-RCPS	RG-RCPS	0.05	---	---	---	---	MSTT

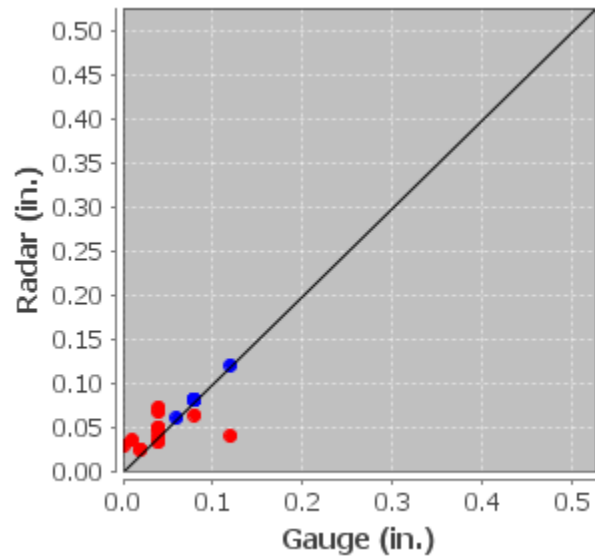


Figure 11. Scatter Plot of RG Pairs for Event 3a

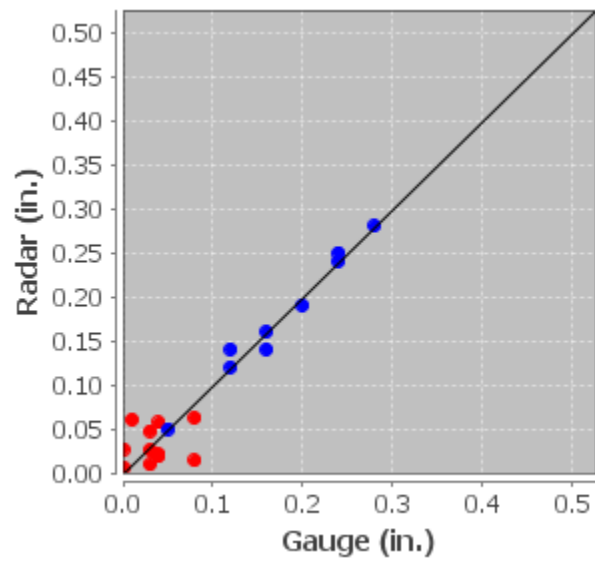


Figure 12. Scatter Plot of RG Pairs for Event 3b

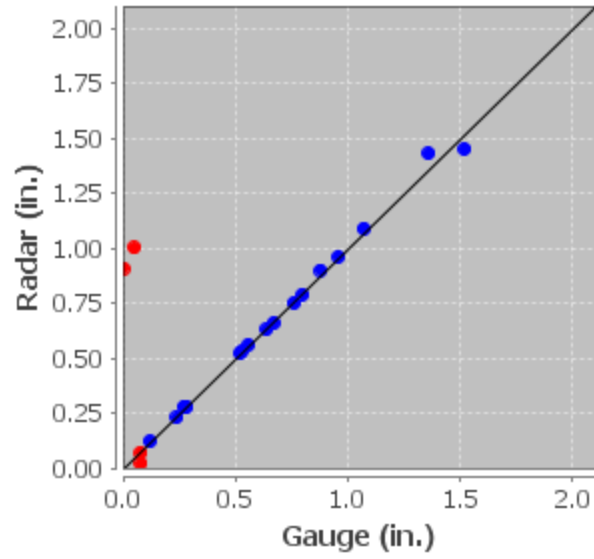


Figure 13. Scatter Plot of RG Pairs for Event 3c

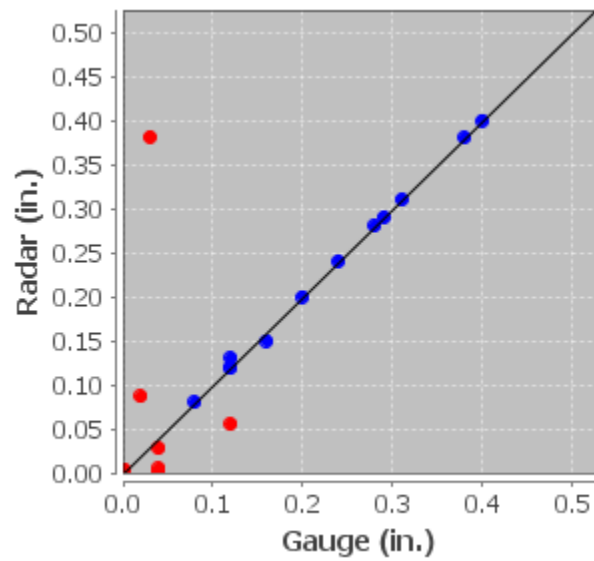


Figure 14. Scatter Plot of RG Pairs for Event 3d

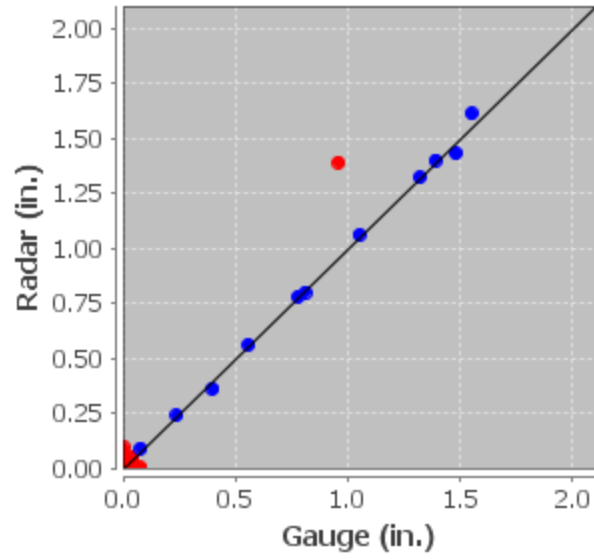


Figure 15. Scatter Plot of RG Pairs for Event 3e

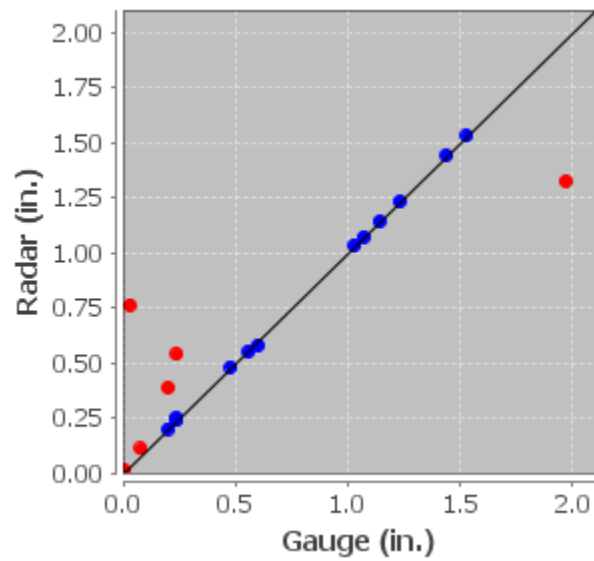


Figure 16. Scatter Plot of RG Pairs for Event 3f

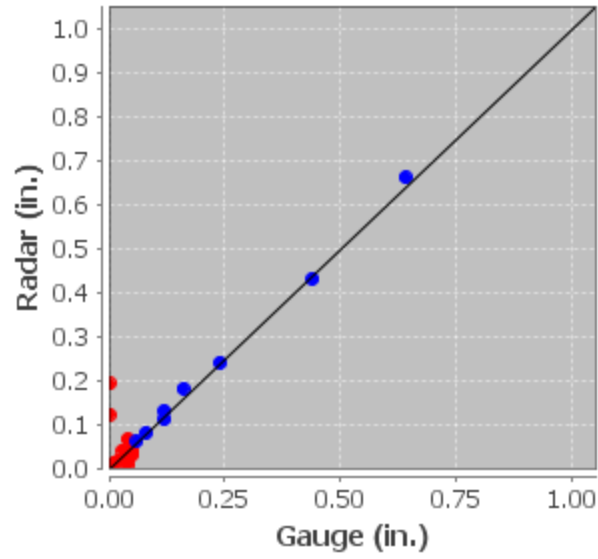


Figure 17. Scatter Plot of RG Pairs for Event 3g

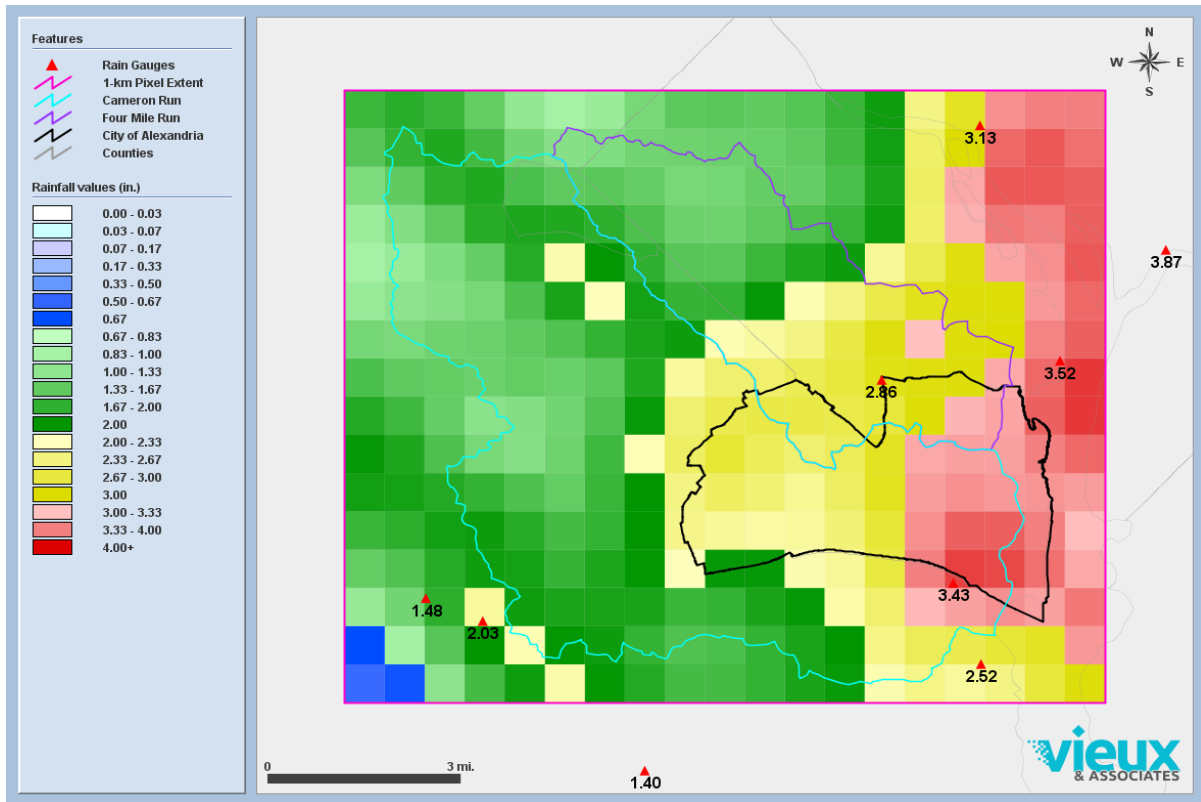


Figure 18. GARR Storm Total for Event 3

Event 4: 2021-08-15

The analysis period was from 2021-08-14 21:00 EDT to 2021-08-15 07:00 EDT. The event was then split into five sub-event periods at 2021-08-15 00:15 EDT, 2021-08-15 00:40 EDT, 2021-08-15 01:10 EDT and 2021-08-15 02:00 EDT to improve gauge adjustment of the radar.

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

A convective Z-R relationship was used to convert radar reflectivity to rainfall rates. Table 21 shows the mean bias and average depth of the event along with the AD and CAD, respectively. Tables 22 - 26 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i^* is the GARR estimate, and $Diff^*$ (%) is the percent difference between the gauge and GARR estimate. Those gauges not used to adjust the radar are shown at the bottom of the table and are highlighted in red. The specific reason for gauge exclusion is displayed in the Flag column. Figures 19 - 23 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 24 depicts the GARR storm total over the 1-km² pixels. The GARR amounts for the 304 1-km² pixels range from 0.6 - 5.4 inches with a mean of 2.4 inches.

Table 21. GARR Statistics for Event 4

Event #	Radar	Event Date	Start Time (EDT)	End Time (EDT)	Gauges Used (28)	Avg. Depth (in)	Bias	AD (%)	CAD (%)
E4a	KLWX LII	2021-08-15	2021-08-14 21:05	2021-08-15 00:15	15	0.358	1.146	36.1	13.6
E4b	KLWX LII	2021-08-15	2021-08-15 00:20	2021-08-15 00:40	21	0.898	1.625	33.8	3.5
E4c	KLWX LII	2021-08-15	2021-08-15 00:45	2021-08-15 01:10	20	0.688	1.244	22.6	7.7
E4d	KLWX LII	2021-08-15	2021-08-15 01:15	2021-08-15 02:00	21	0.259	1.379	30.7	5.6
E4e	KLWX LII	2021-08-15	2021-08-15 02:05	2021-08-15 07:00	24	0.205	1.293	22.7	5.1

Table 22. Summary of Individual RG Pairs for Event 4a

Gauge ID	Name	G_i (in)	R_i (in)	R_i^* (in)	$Diff^*$ (in)	$Diff^*$ (%)	Flag
20116	Holmes Run @ Van Dorn	0.32	0.48	0.55	-0.23	-71.9	
20103	Beach Park	1.16	1.27	1.44	-0.28	-24.1	
1070	Pump Station	0.56	0.87	0.68	-0.12	-21.4	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
KDCA	Washington Reagan National Airport	0.65	0.62	0.70	-0.05	-7.7	
20104	Mount Vernon Elementary	1.92	1.62	2.06	-0.14	-7.3	
20101	Windmill Hill Park	0.64	0.72	0.67	-0.03	-4.7	
1000	Huntsman Lake	0.28	0.62	0.28	0.00	0.0	
1050	Lake Braddock	0.24	0.38	0.24	0.00	0.0	
1270	Kingstowne Regional Pond 4	0.16	0.25	0.16	0.00	0.0	
RG-Main PS	RG-Main PS	0.82	0.74	0.82	0.00	0.0	
20105	Francis Hammond Middle School	1.04	0.78	0.95	0.09	8.7	
980	Huntington Levee - Ponding Area	0.94	0.89	0.85	0.09	9.6	
20106	George Mason Elementary	2.95	1.93	2.60	0.35	11.9	
20102	Charles Barrett Elementary	2.12	1.22	1.81	0.31	14.6	
1350	Boothe Park	1.15	0.66	0.90	0.25	21.7	
01652500	FOURMILE RUN AT ALEXANDRIA	0.18	---	---	---	---	U
10001	Lake Barcroft	0.00	---	---	---	---	Z
1030	Lake Mercer	0.04	---	---	---	---	U
1040	Royal Lake	0.00	---	---	---	---	Z
1090	Fairview Lake	0.00	---	---	---	---	MSTT
1280	Carrington	0.00	---	---	---	---	MSTT
1300	Pulte/McLean	0.00	---	---	---	---	MSTT
1360	Lake Accotink (FCPA)	0.00	---	---	---	---	Z
1540	Brookfield Park	0.00	---	---	---	---	Z
20117	Holmes Run Parkway	0.00	---	---	---	---	Z
RG-Brentwood	RG-Brentwood	0.00	---	---	---	---	MSTT
RG-Bryant	RG-Bryant	0.01	---	---	---	---	MSTT
RG-RCPS	RG-RCPS	0.00	---	---	---	---	MSTT

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1350	Boothe Park	0.60	0.48	0.66	-0.06	-10.0	
01652500	FOURMILE RUN AT ALEXANDRIA	0.92	0.53	0.99	-0.07	-7.6	
20105	Francis Hammond Middle School	1.20	0.85	1.28	-0.08	-6.7	
20103	Beach Park	1.52	0.90	1.61	-0.09	-5.9	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1070	Pump Station	0.96	0.66	1.00	-0.04	-4.2	
980	Huntington Levee - Ponding Area	1.14	0.73	1.18	-0.04	-3.5	
1000	Huntsman Lake	0.40	0.41	0.41	-0.01	-2.5	
RG-Main PS	RG-Main PS	1.54	0.95	1.55	-0.01	-0.6	
1050	Lake Braddock	0.68	0.42	0.68	0.00	0.0	
1090	Fairview Lake	1.38	0.68	1.38	0.00	0.0	
1270	Kingstowne Regional Pond 4	1.07	0.64	1.07	0.00	0.0	
1540	Brookfield Park	1.04	0.78	1.04	0.00	0.0	
KDCA	Washington Reagan National Airport	0.94	0.49	0.94	0.00	0.0	
RG-RCPS	RG-RCPS	0.11	0.11	0.11	0.00	0.0	
RG-Bryant	RG-Bryant	0.77	0.51	0.76	0.01	1.3	
20106	George Mason Elementary	1.52	0.78	1.48	0.04	2.6	
20101	Windmill Hill Park	1.12	0.65	1.09	0.03	2.7	
1030	Lake Mercer	0.24	0.23	0.23	0.01	4.2	
20104	Mount Vernon Elementary	1.32	0.66	1.26	0.06	4.5	
20116	Holmes Run @ Van Dorn	1.23	0.81	1.16	0.07	5.7	
20102	Charles Barrett Elementary	1.04	0.49	0.94	0.10	9.6	
10001	Lake Barcroft	0.00	---	---	---	---	Z
1040	Royal Lake	0.00	---	---	---	---	Z
1280	Carrington	0.00	---	---	---	---	MSTT
1300	Pulte/McLean	0.00	---	---	---	---	MSTT
1360	Lake Accotink (FCPA)	0.28	---	---	---	---	U
20117	Holmes Run Parkway	0.24	---	---	---	---	C
RG-Brentwood	RG-Brentwood	0.04	---	---	---	---	S

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1070	Pump Station	0.48	0.54	0.62	-0.14	-29.2	
20102	Charles Barrett Elementary	0.32	0.33	0.39	-0.07	-21.9	
20104	Mount Vernon Elementary	0.24	0.23	0.29	-0.05	-20.8	
1000	Huntsman Lake	0.20	0.19	0.22	-0.02	-10.0	
1360	Lake Accotink (FCPA)	0.64	0.54	0.68	-0.04	-6.3	
RG-Brentwood	RG-Brentwood	0.58	0.51	0.60	-0.02	-3.4	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20116	Holmes Run @ Van Dorn	1.12	0.84	1.13	-0.01	-0.9	
1050	Lake Braddock	0.24	0.30	0.24	0.00	0.0	
1090	Fairview Lake	1.58	1.29	1.58	0.00	0.0	
1270	Kingstowne Regional Pond 4	0.83	0.99	0.83	0.00	0.0	
20105	Francis Hammond Middle School	1.08	0.81	1.08	0.00	0.0	
RG-Main PS	RG-Main PS	0.22	0.14	0.22	0.00	0.0	
1350	Boothe Park	1.15	0.84	1.14	0.01	0.9	
RG-Bryant	RG-Bryant	1.33	1.03	1.29	0.04	3.0	
20103	Beach Park	0.64	0.44	0.62	0.02	3.1	
1540	Brookfield Park	0.96	0.69	0.90	0.06	6.2	
20101	Windmill Hill Park	0.52	0.33	0.48	0.04	7.7	
1030	Lake Mercer	0.36	0.25	0.33	0.03	8.3	
980	Huntington Levee - Ponding Area	0.88	0.55	0.79	0.09	10.2	
20106	George Mason Elementary	0.56	0.37	0.47	0.09	16.1	
01652500	FOURMILE RUN AT ALEXANDRIA	1.43	---	---	---	---	O
10001	Lake Barcroft	0.00	---	---	---	---	Z
1040	Royal Lake	0.00	---	---	---	---	Z
1280	Carrington	0.04	---	---	---	---	MSTT
1300	Pulte/McLean	0.04	---	---	---	---	MSTT
20117	Holmes Run Parkway	0.04	---	---	---	---	C
KDCA	Washington Reagan National Airport	0.77	---	---	---	---	O
RG-RCPS	RG-RCPS	0.18	---	---	---	---	U

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20105	Francis Hammond Middle School	0.24	0.22	0.27	-0.03	-12.5	
20106	George Mason Elementary	0.16	0.11	0.18	-0.02	-12.5	
980	Huntington Levee - Ponding Area	0.16	0.12	0.18	-0.02	-12.5	
1360	Lake Accotink (FCPA)	0.28	0.24	0.31	-0.03	-10.7	
1000	Huntsman Lake	0.12	0.09	0.13	-0.01	-8.3	
1070	Pump Station	0.16	0.12	0.17	-0.01	-6.3	
1350	Boothe Park	0.79	0.67	0.81	-0.02	-2.5	
1050	Lake Braddock	0.16	0.14	0.16	0.00	0.0	
1090	Fairview Lake	0.32	0.25	0.32	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20104	Mount Vernon Elementary	0.16	0.10	0.16	0.00	0.0	
KDCA	Washington Reagan National Airport	0.10	0.05	0.10	0.00	0.0	
RG-Brentwood	RG-Brentwood	0.14	0.09	0.14	0.00	0.0	
RG-Bryant	RG-Bryant	0.14	0.09	0.14	0.00	0.0	
RG-Main PS	RG-Main PS	0.16	0.10	0.16	0.00	0.0	
RG-RCPS	RG-RCPS	0.12	0.07	0.12	0.00	0.0	
20103	Beach Park	0.16	0.09	0.15	0.01	6.3	
20116	Holmes Run @ Van Dorn	0.64	0.49	0.60	0.04	6.3	
1030	Lake Mercer	0.28	0.18	0.26	0.02	7.1	
1540	Brookfield Park	0.64	0.43	0.59	0.05	7.8	
20102	Charles Barrett Elementary	0.24	0.14	0.22	0.02	8.3	
20101	Windmill Hill Park	0.16	0.08	0.14	0.02	12.5	
01652500	FOURMILE RUN AT ALEXANDRIA	1.20	---	---	---	---	O
10001	Lake Barcroft	0.00	---	---	---	---	Z
1040	Royal Lake	0.00	---	---	---	---	Z
1270	Kingstowne Regional Pond 4	0.40	---	---	---	---	U
1280	Carrington	0.00	---	---	---	---	MSTT
1300	Pulte/McLean	0.00	---	---	---	---	MSTT
20117	Holmes Run Parkway	0.00	---	---	---	---	C

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

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
20116	Holmes Run @ Van Dorn	0.20	0.18	0.24	-0.04	-20.0	
20104	Mount Vernon Elementary	0.20	0.19	0.23	-0.03	-15.0	
1280	Carrington	0.28	0.24	0.31	-0.03	-10.7	
KDCA	Washington Reagan National Airport	0.15	0.15	0.16	-0.01	-6.7	
1360	Lake Accotink (FCPA)	0.16	0.14	0.17	-0.01	-6.3	
20102	Charles Barrett Elementary	0.20	0.17	0.21	-0.01	-5.0	
1070	Pump Station	0.32	0.25	0.33	-0.01	-3.1	
1000	Huntsman Lake	0.12	0.07	0.12	0.00	0.0	
1050	Lake Braddock	0.16	0.11	0.16	0.00	0.0	
1090	Fairview Lake	0.20	0.20	0.20	0.00	0.0	

Gauge ID	Name	G _i (in)	R _i (in)	R _i * (in)	Diff* (in)	Diff* (%)	Flag
1270	Kingstowne Regional Pond 4	0.24	0.18	0.24	0.00	0.0	
20101	Windmill Hill Park	0.28	0.21	0.28	0.00	0.0	
20103	Beach Park	0.28	0.22	0.28	0.00	0.0	
RG-Brentwood	RG-Brentwood	0.11	0.08	0.11	0.00	0.0	
RG-Bryant	RG-Bryant	0.10	0.07	0.10	0.00	0.0	
RG-Main PS	RG-Main PS	0.15	0.11	0.15	0.00	0.0	
RG-RCPS	RG-RCPS	0.12	0.08	0.12	0.00	0.0	
980	Huntington Levee - Ponding Area	0.28	0.21	0.27	0.01	3.6	
01652500	FOURMILE RUN AT ALEXANDRIA	0.22	0.16	0.21	0.01	4.5	
1540	Brookfield Park	0.16	0.12	0.15	0.01	6.3	
1350	Boothe Park	0.28	0.19	0.26	0.02	7.1	
1300	Pulte/McLean	0.32	0.22	0.29	0.03	9.4	
20105	Francis Hammond Middle School	0.28	0.18	0.25	0.03	10.7	
20106	George Mason Elementary	0.28	0.19	0.25	0.03	10.7	
10001	Lake Barcroft	0.00	---	---	---	---	Z
1030	Lake Mercer	0.04	---	---	---	---	MSTT
1040	Royal Lake	0.00	---	---	---	---	Z
20117	Holmes Run Parkway	1.83	---	---	---	---	C

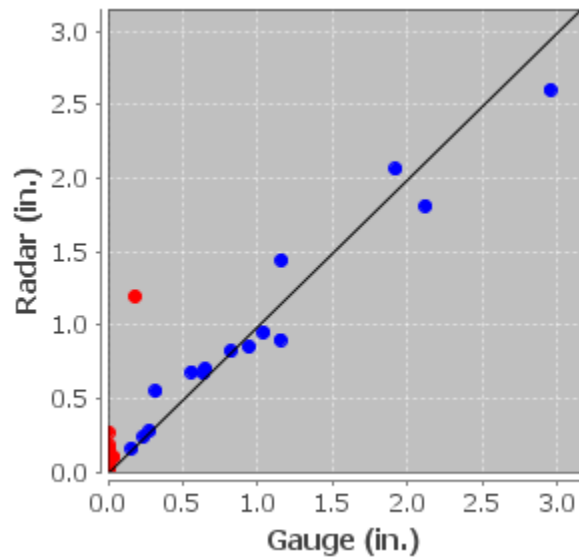


Figure 19. Scatter Plot of RG Pairs for Event 4a

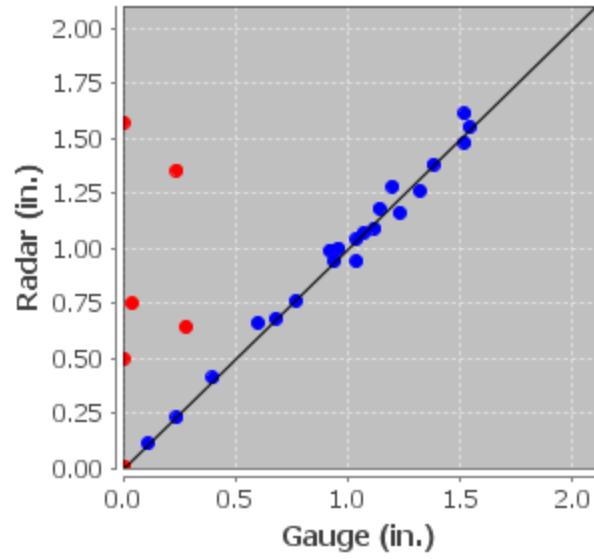


Figure 20. Scatter Plot of RG Pairs for Event 4b

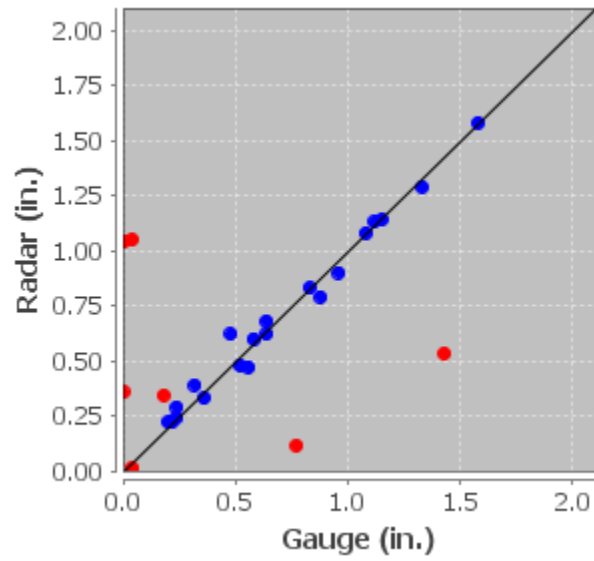


Figure 21. Scatter Plot of RG Pairs for Event 4c

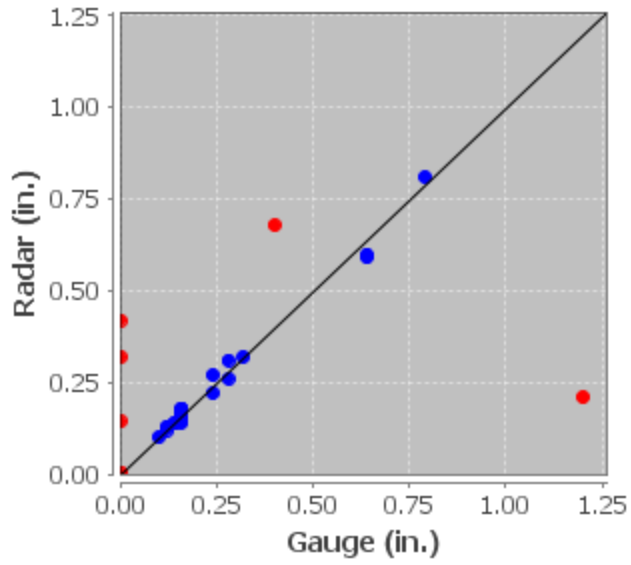


Figure 22. Scatter Plot of RG Pairs for Event 4d

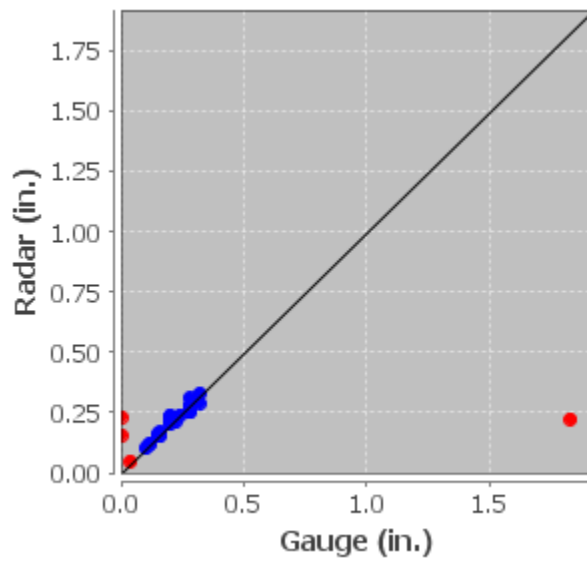


Figure 23. Scatter Plot of RG Pairs for Event 4e

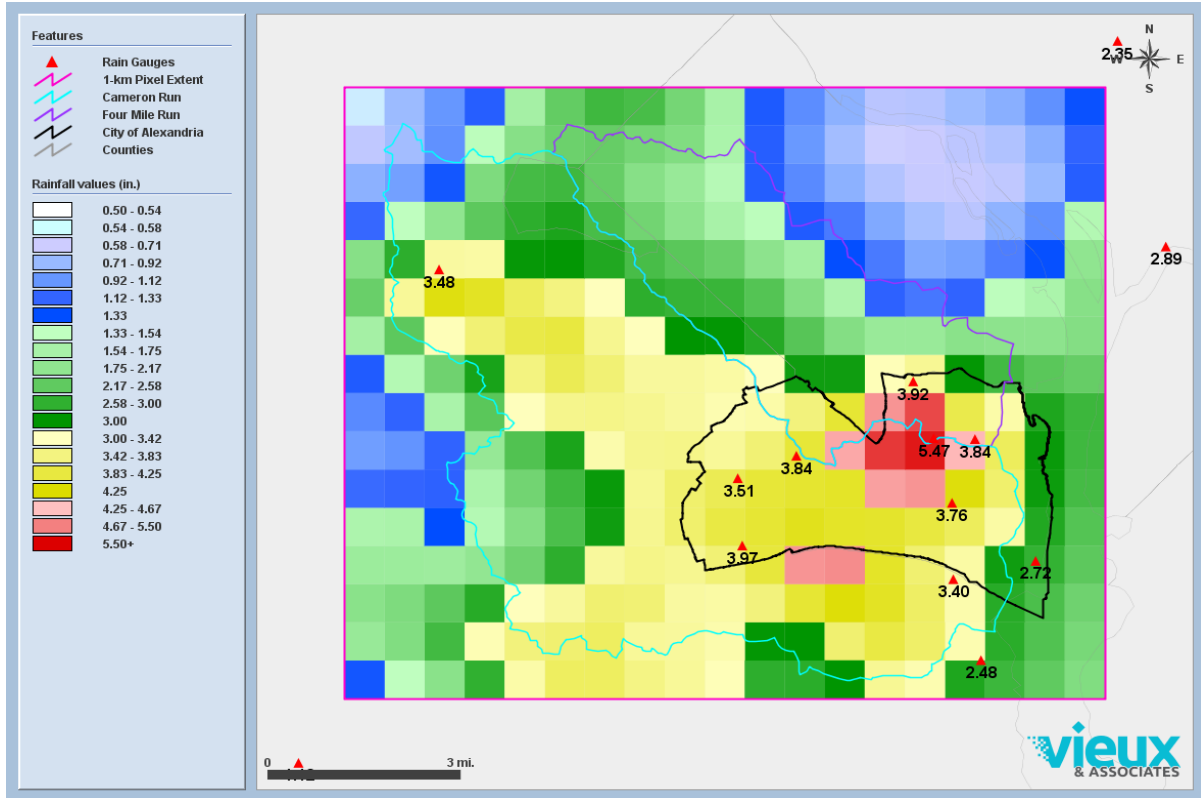


Figure 24. GARR Storm Total for Event 4

Appendices

- [Appendix A](#) - Gauge Performance Exclusion Table
- [Appendix B](#) - Gauge Statistical Criteria Exclusion Table
- [Appendix C](#) - Event 1 (2019-07-08) CDPs
- [Appendix D](#) - Event 2 (2020-07-23) CDPs
- [Appendix E](#) - Event 3 (2020-09-10) CDPs
- [Appendix F](#) - Event 4 (2021-08-15) CDPs

Appendix A - Gauge Performance Exclusion Table

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

Event #	<u>E1a</u>	<u>E1b</u>	<u>E2a</u>	<u>E2b</u>	<u>E2c</u>
Event Date	2019-07-08	2019-07-08	2020-07-23	2020-07-23	2020-07-23
Start Time (EDT)	2019-07-08 03:05	2019-07-08 11:05	2020-07-23 17:05	2020-07-23 21:50	2020-07-24 02:05
End Time (EDT)	2019-07-08 11:00	2019-07-08 17:00	2020-07-23 21:45	2020-07-24 02:00	2020-07-24 06:00
10001	S	Z	S	C	C
20101	ND	ND	ND	ND	ND
20102	ND	ND	ND	ND	ND
20103	ND	ND	ND	ND	ND
20104	ND	ND	ND	ND	ND
20105	ND	ND	ND	ND	ND
20106	ND	ND	ND	ND	ND
20116			ND	ND	ND
20117					
980		U	S		
1000					
1030					
1040					
1050					
1070	S				
1090					
1270			Z	Z	
1280		Z			
1300					
1350					
1360					
1540	Z	Z			
RG-Brentwood	ND	ND	U		
RG-Bryant	ND	ND		O	
RG-Main PS	ND	ND			

Event #	<u>E1a</u>	<u>E1b</u>	<u>E2a</u>	<u>E2b</u>	<u>E2c</u>
Event Date	2019-07-08	2019-07-08	2020-07-23	2020-07-23	2020-07-23
Start Time (EDT)	2019-07-08 03:05	2019-07-08 11:05	2020-07-23 17:05	2020-07-23 21:50	2020-07-24 02:05
End Time (EDT)	2019-07-08 11:00	2019-07-08 17:00	2020-07-23 21:45	2020-07-24 02:00	2020-07-24 06:00
RG-RCPS	ND	ND	Z	Z	Z
01652500			ND	ND	ND
KDCA				O	

Event #	<u>E2d</u>	<u>E3a</u>	<u>E3b</u>	<u>E3c</u>	<u>E3d</u>
Event Date	2020-07-23	2020-09-10	2020-09-10	2020-09-10	2020-09-10
Start Time (EDT)	2020-07-24 06:05	2020-09-09 09:05	2020-09-09 16:05	2020-09-09 20:05	2020-09-10 03:05
End Time (EDT)	2020-07-24 17:00	2020-09-09 16:00	2020-09-09 20:00	2020-09-10 03:00	2020-09-10 12:30
10001	C		C	C	C
20101	ND	ND	ND	ND	ND
20102	ND	ND	ND	ND	ND
20103	ND	ND	ND	ND	ND
20104	ND	ND	ND	ND	ND
20105	ND	ND	ND	ND	ND
20106	ND	ND	ND	ND	ND
20116	ND	ND	ND	ND	ND
20117	O				
980					
1000		O	O	O	
1030					
1040					
1050					
1070					
1090				Z	
1270					
1280					
1300					
1350					
1360					
1540					
RG-Brentwood			U		
RG-Bryant			U		S
RG-Main PS					

Event #	<u>E2d</u>	<u>E3a</u>	<u>E3b</u>	<u>E3c</u>	<u>E3d</u>
Event Date	2020-07-23	2020-09-10	2020-09-10	2020-09-10	2020-09-10
Start Time (EDT)	2020-07-24 06:05	2020-09-09 09:05	2020-09-09 16:05	2020-09-09 20:05	2020-09-10 03:05
End Time (EDT)	2020-07-24 17:00	2020-09-09 16:00	2020-09-09 20:00	2020-09-10 03:00	2020-09-10 12:30
RG-RCPS	Z				
01652500	ND				
KDCA					

Event #	<u>E3e</u>	<u>E3f</u>	<u>E3g</u>	<u>E4a</u>	<u>E4b</u>
Event Date	2020-09-10	2020-09-10	2020-09-10	2021-08-15	2021-08-15
Start Time (EDT)	2020-09-10 12:35	2020-09-10 13:50	2020-09-10 15:05	2021-08-14 21:05	2021-08-15 00:20
End Time (EDT)	2020-09-10 13:45	2020-09-10 15:00	2020-09-10 19:00	2021-08-15 00:15	2021-08-15 00:40
10001	C	C	C	Z	Z
20101	ND	ND	ND		
20102	ND	ND	ND		
20103	ND	ND	ND		
20104	ND	ND	ND		
20105	ND	ND	ND		
20106	ND	ND	ND		
20116	ND	ND	ND		
20117	Z			Z	C
980					
1000					
1030				U	
1040				Z	Z
1050		U			
1070					
1090			Z		
1270					
1280					
1300	O				
1350		U	U		
1360				Z	U
1540				Z	
RG-Brentwood					S
RG-Bryant	T	O			
RG-Main PS					

Event #	<u>E3e</u>	<u>E3f</u>	<u>E3g</u>	<u>E4a</u>	<u>E4b</u>
Event Date	2020-09-10	2020-09-10	2020-09-10	2021-08-15	2021-08-15
Start Time (EDT)	2020-09-10 12:35	2020-09-10 13:50	2020-09-10 15:05	2021-08-14 21:05	2021-08-15 00:20
End Time (EDT)	2020-09-10 13:45	2020-09-10 15:00	2020-09-10 19:00	2021-08-15 00:15	2021-08-15 00:40
RG-RCPS					
01652500				U	
KDCA					

Event #	<u>E4c</u>	<u>E4d</u>	<u>E4e</u>
Event Date	2021-08-15	2021-08-15	2021-08-15
Start Time (EDT)	2021-08-15 00:45	2021-08-15 01:15	2021-08-15 02:05
End Time (EDT)	2021-08-15 01:10	2021-08-15 02:00	2021-08-15 07:00
10001	Z	Z	Z
20101			
20102			
20103			
20104			
20105			
20106			
20116			
20117	C	C	C
980			
1000			
1030			
1040	Z	Z	Z
1050			
1070			
1090			
1270		U	
1280			
1300			
1350			
1360			
1540			
RG-Brentwood			
RG-Bryant			
RG-Main PS			
RG-RCPS	U		

Event #	<u>E4c</u>	<u>E4d</u>	<u>E4e</u>
Event Date	2021-08-15	2021-08-15	2021-08-15
Start Time (EDT)	2021-08-15 00:45	2021-08-15 01:15	2021-08-15 02:05
End Time (EDT)	2021-08-15 01:10	2021-08-15 02:00	2021-08-15 07:00
01652500	O	O	
KDCA	O		

Appendix B - Gauge Statistical Criteria Exclusion Table

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

Event #	<u>E1a</u>	<u>E1b</u>	<u>E2a</u>	<u>E2b</u>	<u>E2c</u>
Event Date	2019-07-08	2019-07-08	2020-07-23	2020-07-23	2020-07-23
Start Time (EDT)	2019-07-08 03:05	2019-07-08 11:05	2020-07-23 17:05	2020-07-23 21:50	2020-07-24 02:05
End Time (EDT)	2019-07-08 11:00	2019-07-08 17:00	2020-07-23 21:45	2020-07-24 02:00	2020-07-24 06:00
Source	KLWX LII	KLWX LII	KLWX LII	KLWX LII	KLWX LII
10001					
20101					
20102					
20103					
20104					
20105					
20106					
20116					
20117					
980					MSTT
1000		MSTT			MSTT
1030		MSTT			MSTT
1040					
1050					
1070					
1090					
1270		MSTT			MSTT
1280				MSTT	
1300		MSTT		MSTT	
1350					MSTT
1360					
1540					
RG-Brentwood					
RG-Bryant					MSTT

Event #	<u>E1a</u>	<u>E1b</u>	<u>E2a</u>	<u>E2b</u>	<u>E2c</u>
Event Date	2019-07-08	2019-07-08	2020-07-23	2020-07-23	2020-07-23
Start Time (EDT)	2019-07-08 03:05	2019-07-08 11:05	2020-07-23 17:05	2020-07-23 21:50	2020-07-24 02:05
End Time (EDT)	2019-07-08 11:00	2019-07-08 17:00	2020-07-23 21:45	2020-07-24 02:00	2020-07-24 06:00
Source	KLWX LII	KLWX LII	KLWX LII	KLWX LII	KLWX LII
RG-Main PS					
01652500					
KDCA		MSTT			

Event #	<u>E2d</u>	<u>E3a</u>	<u>E3b</u>	<u>E3c</u>	<u>E3d</u>
Event Date	2020-07-23	2020-09-10	2020-09-10	2020-09-10	2020-09-10
Start Time (EDT)	2020-07-24 06:05	2020-09-09 09:05	2020-09-09 16:05	2020-09-09 20:05	2020-09-10 03:05
End Time (EDT)	2020-07-24 17:00	2020-09-09 16:00	2020-09-09 20:00	2020-09-10 03:00	2020-09-10 12:30
Source	KLWX LII	KLWX LII	KLWX LII	KLWX LII	KLWX LII
10001		MSTT			
20101					
20102					
20103					
20104					
20105					
20106					
20116					
20117		MSTT	MSTT		
980		MSTT			
1000	MSTT				
1030		MSTT	MSTT	MSTT	
1040	MSTT	MSTT	MSTT		MSTT
1050	MSTT		MSTT		MSTT
1070					
1090		MSTT	MSTT		MSTT
1270	MSTT				
1280		MSTT			MSTT
1300		MSTT			MSTT
1350	MSTT	MSTT			
1360	MSTT				MSTT
1540	MSTT	MSTT			MSTT
RG-Brentwood		MSTT			
RG-Bryant		MSTT			

Event #	<u>E2d</u>	<u>E3a</u>	<u>E3b</u>	<u>E3c</u>	<u>E3d</u>
Event Date	2020-07-23	2020-09-10	2020-09-10	2020-09-10	2020-09-10
Start Time (EDT)	2020-07-24 06:05	2020-09-09 09:05	2020-09-09 16:05	2020-09-09 20:05	2020-09-10 03:05
End Time (EDT)	2020-07-24 17:00	2020-09-09 16:00	2020-09-09 20:00	2020-09-10 03:00	2020-09-10 12:30
Source	KLWX LII	KLWX LII	KLWX LII	KLWX LII	KLWX LII
RG-Main PS		MSTT			
01652500			MSTT		
KDCA			MSTT		

Event #	<u>E3e</u>	<u>E3f</u>	<u>E3g</u>	<u>E4a</u>	<u>E4b</u>
Event Date	2020-09-10	2020-09-10	2020-09-10	2021-08-15	2021-08-15
Start Time (EDT)	2020-09-10 12:35	2020-09-10 13:50	2020-09-10 15:05	2021-08-14 21:05	2021-08-15 00:20
End Time (EDT)	2020-09-10 13:45	2020-09-10 15:00	2020-09-10 19:00	2021-08-15 00:15	2021-08-15 00:40
Source	KLWX LII	KLWX LII	KLWX LII	KLWX LII	KLWX LII
10001					
20101					
20102					
20103					
20104					
20105					
20106					
20116					
20117					
980			MSTT		
1000	MSTT				
1030	MSTT	MSTT			
1040					
1050					
1070			MSTT		
1090	MSTT	MSTT		MSTT	
1270			MSTT		
1280	MSTT	MSTT	MSTT	MSTT	MSTT
1300		MSTT	MSTT	MSTT	MSTT
1350					
1360	MSTT				
1540	MSTT				
RG-Brentwood			MSTT	MSTT	
RG-Bryant				MSTT	

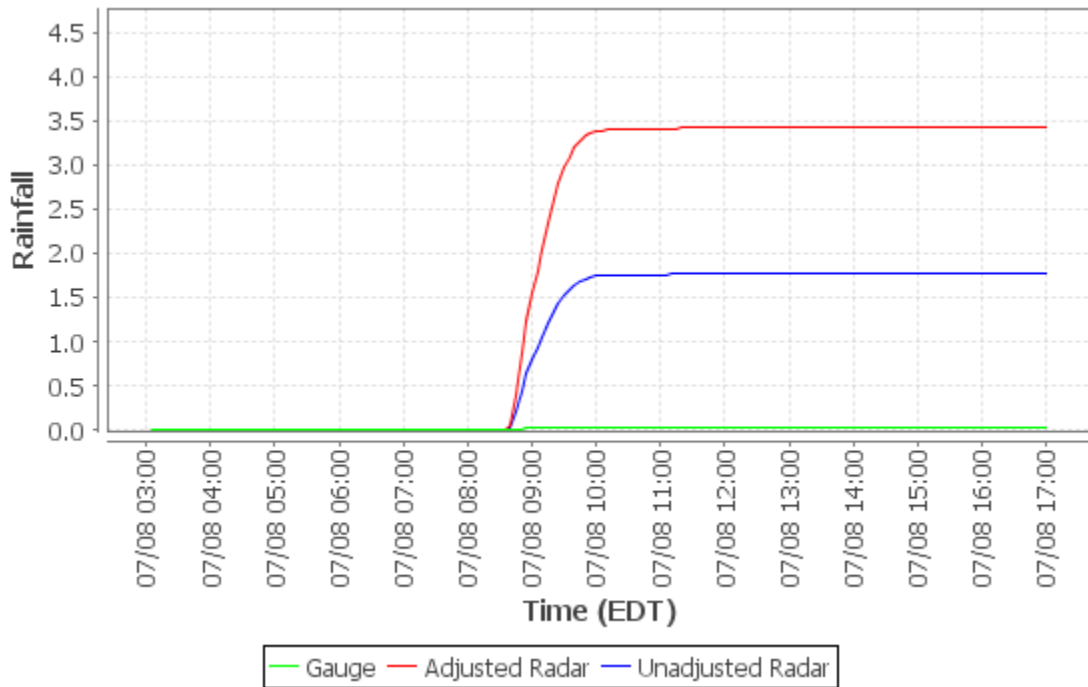
Event #	E3e	E3f	E3g	E4a	E4b
Event Date	2020-09-10	2020-09-10	2020-09-10	2021-08-15	2021-08-15
Start Time (EDT)	2020-09-10 12:35	2020-09-10 13:50	2020-09-10 15:05	2021-08-14 21:05	2021-08-15 00:20
End Time (EDT)	2020-09-10 13:45	2020-09-10 15:00	2020-09-10 19:00	2021-08-15 00:15	2021-08-15 00:40
Source	KLWX LII	KLWX LII	KLWX LII	KLWX LII	KLWX LII
RG-Main PS			MSTT		
01652500			MSTT	MSTT	
KDCA			MSTT		

Event #	<u>E4c</u>	<u>E4d</u>	<u>E4e</u>
Event Date	2021-08-15	2021-08-15	2021-08-15
Start Time (EDT)	2021-08-15 00:45	2021-08-15 01:15	2021-08-15 02:05
End Time (EDT)	2021-08-15 01:10	2021-08-15 02:00	2021-08-15 07:00
Source	KLWX LII	KLWX LII	KLWX LII
10001			
20101			
20102			
20103			
20104			
20105			
20106			
20116			
20117			
980			
1000			
1030			MSTT
1040			
1050			
1070			
1090			
1270			
1280	MSTT	MSTT	
1300	MSTT	MSTT	
1350			
1360			
1540			
RG-Brentwood			
RG-Bryant			
RG-Main PS			

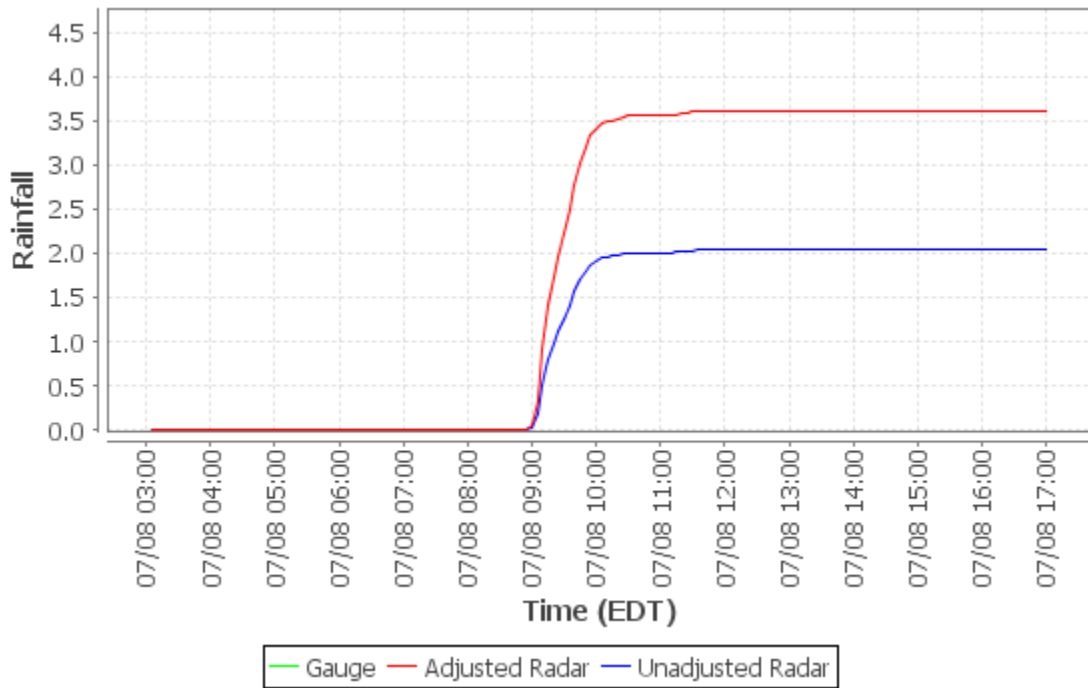
Event #	<u>E4c</u>	<u>E4d</u>	<u>E4e</u>
Event Date	2021-08-15	2021-08-15	2021-08-15
Start Time (EDT)	2021-08-15 00:45	2021-08-15 01:15	2021-08-15 02:05
End Time (EDT)	2021-08-15 01:10	2021-08-15 02:00	2021-08-15 07:00
Source	KLWX LII	KLWX LII	KLWX LII
01652500			
KDCA			

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

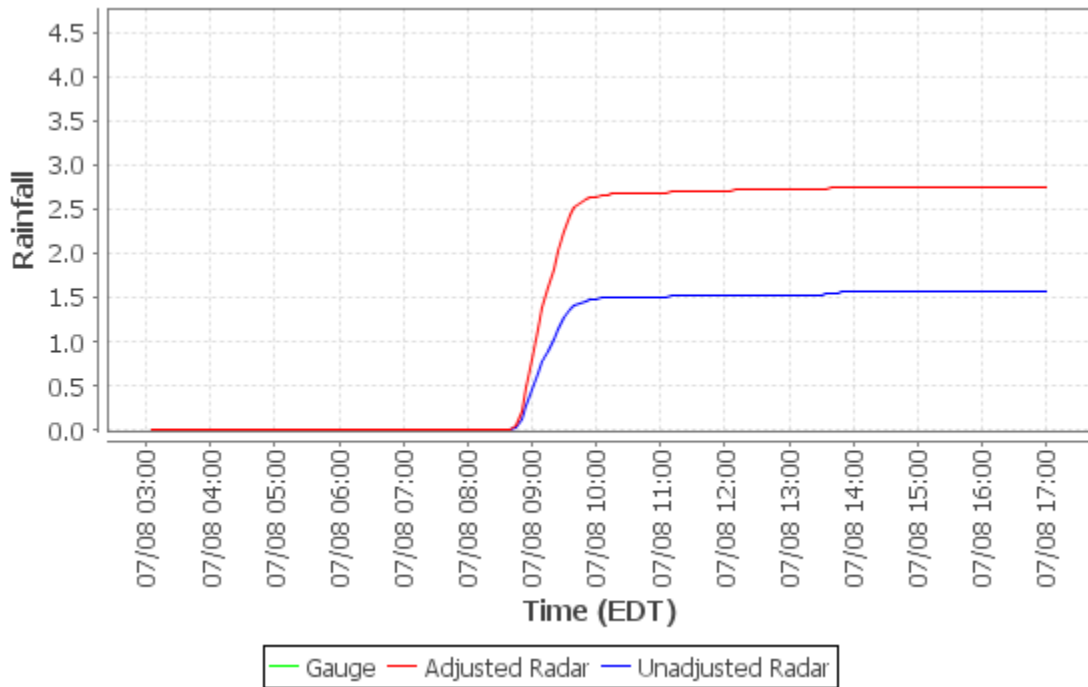
Cumulative Distribution Plot - Lake Barcroft (10001)



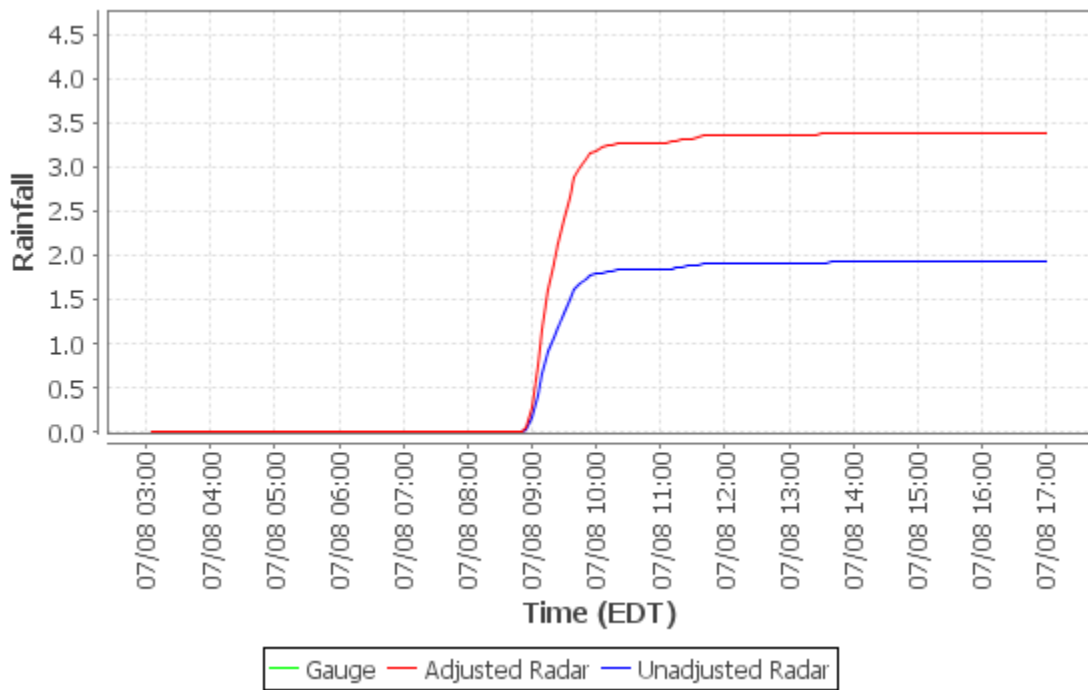
Cumulative Distribution Plot - Windmill Hill Park (20101)



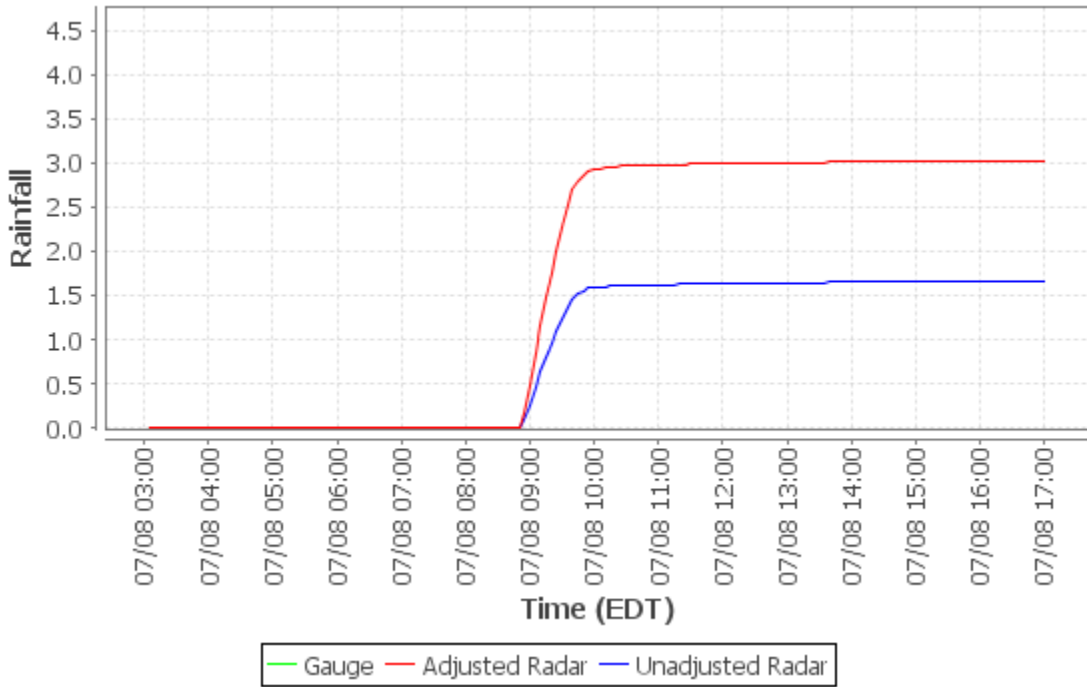
Cumulative Distribution Plot - Charles Barrett Elementary (20102)



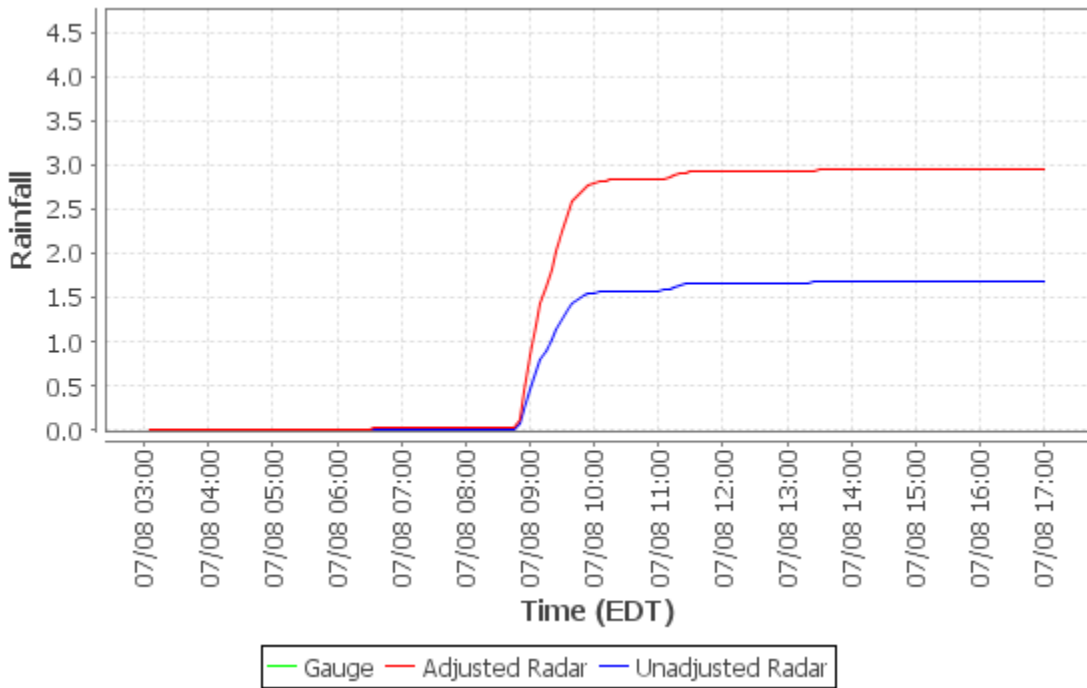
Cumulative Distribution Plot - Beach Park (20103)



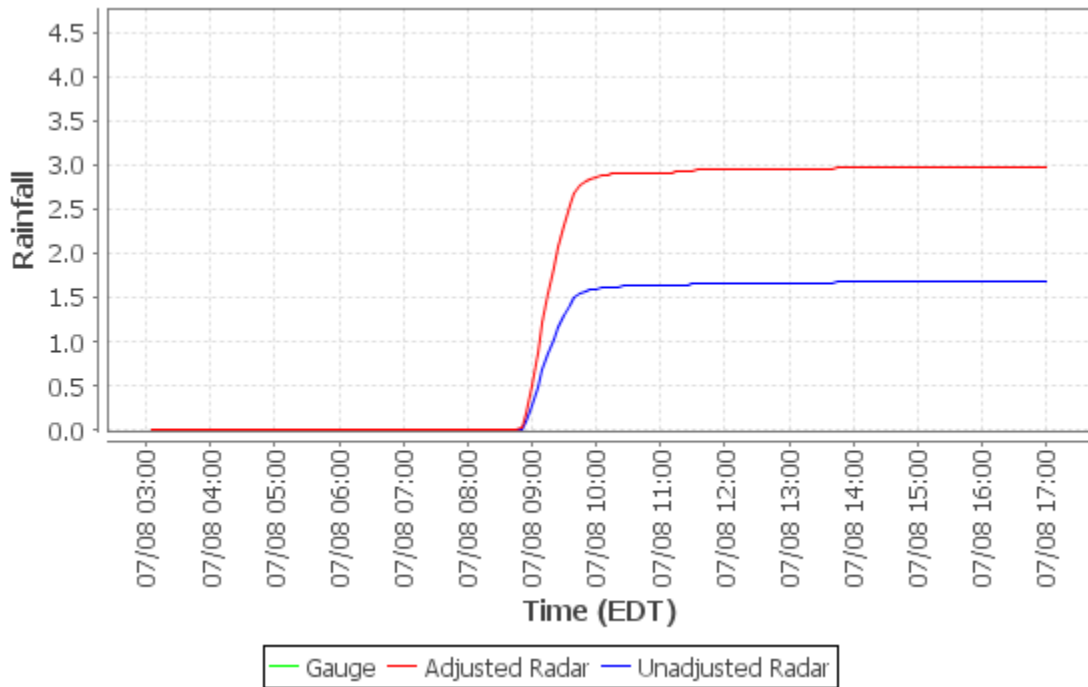
Cumulative Distribution Plot - Mount Vernon Elementary (20104)



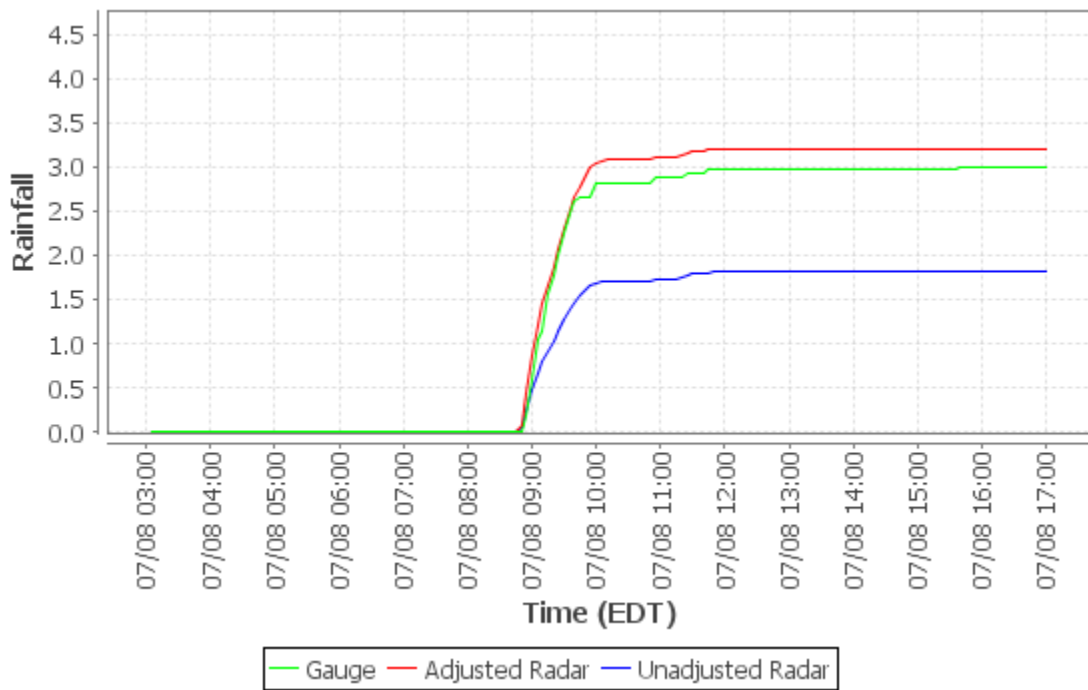
Cumulative Distribution Plot - Francis Hammond Middle School (20105)



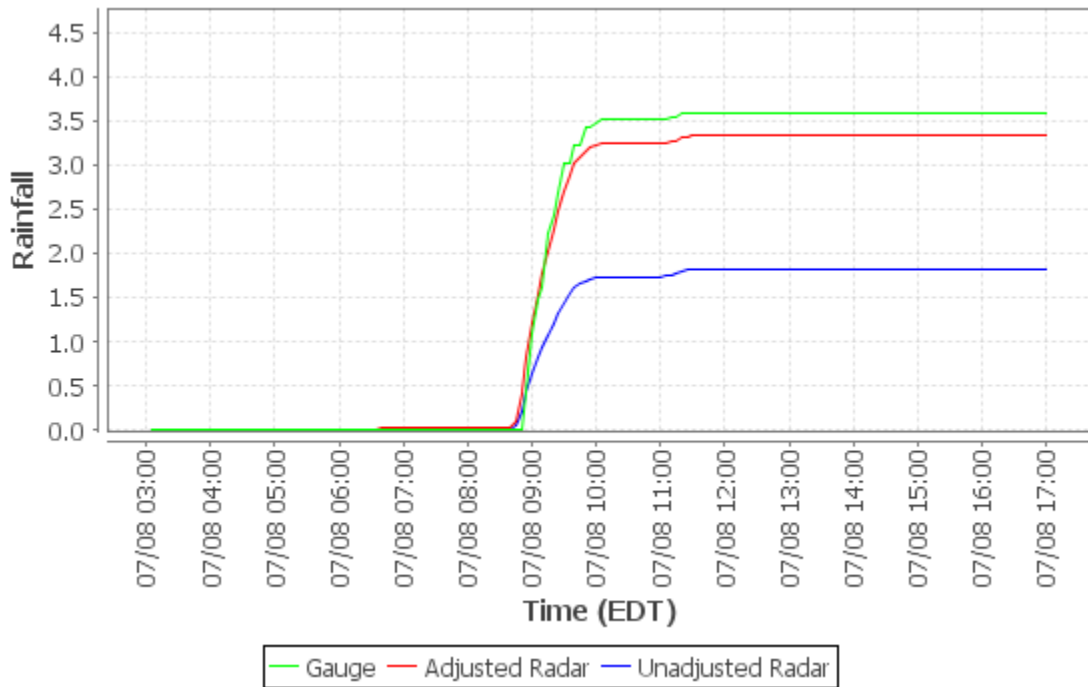
Cumulative Distribution Plot - George Mason Elementary (20106)



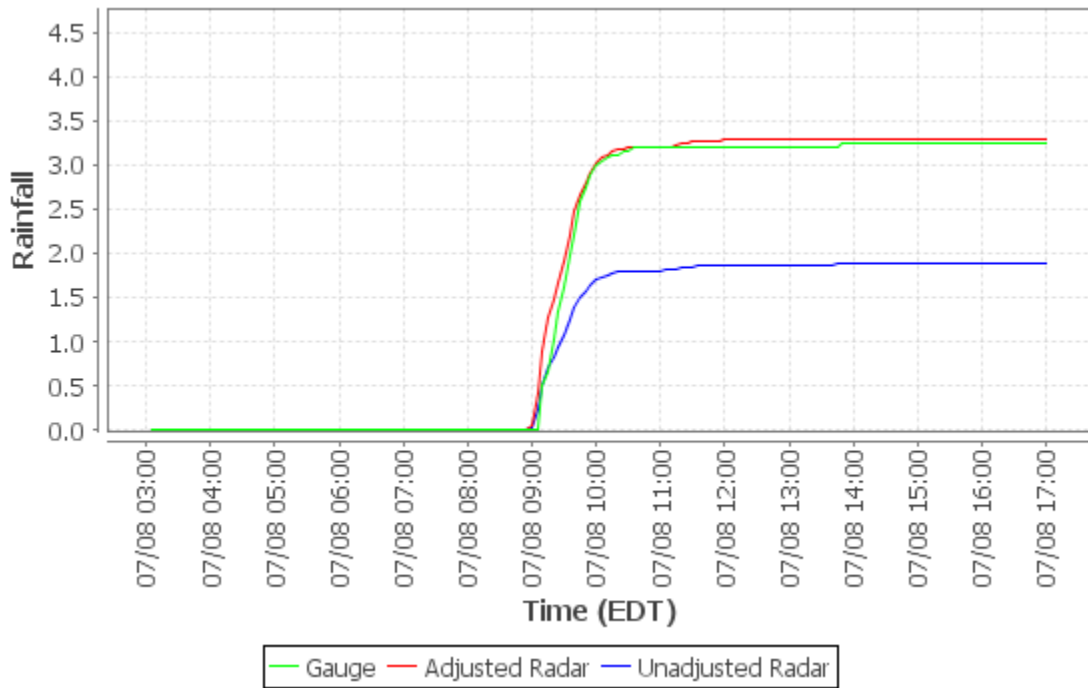
Cumulative Distribution Plot - Holmes Run @ Van Dorn (20116)



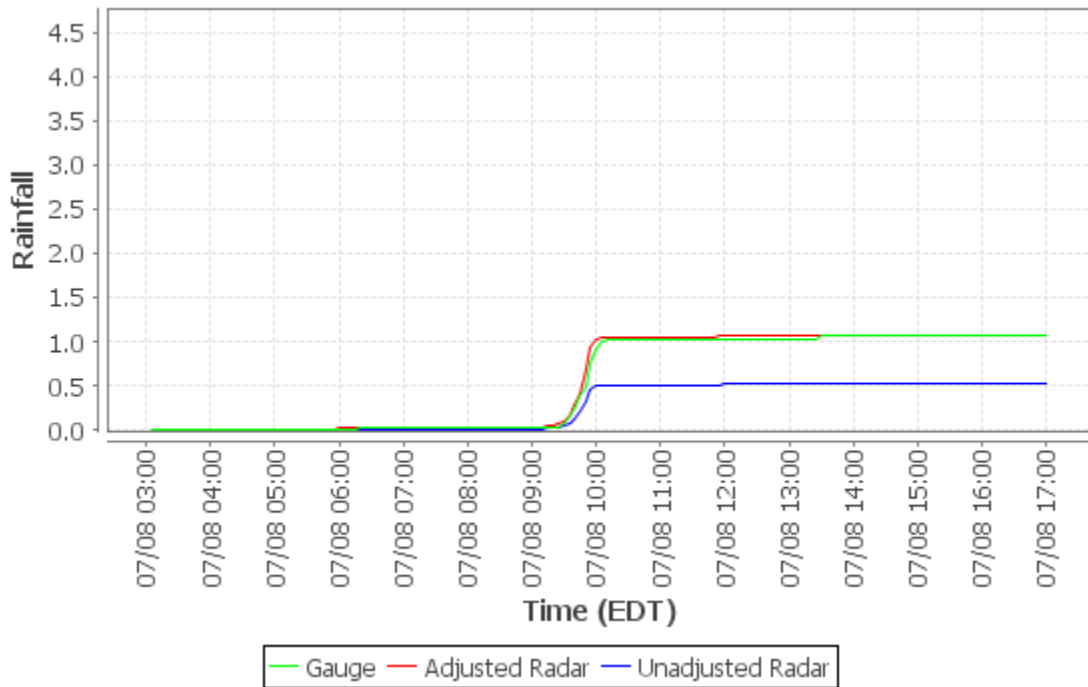
Cumulative Distribution Plot - Holmes Run Parkway (20117)



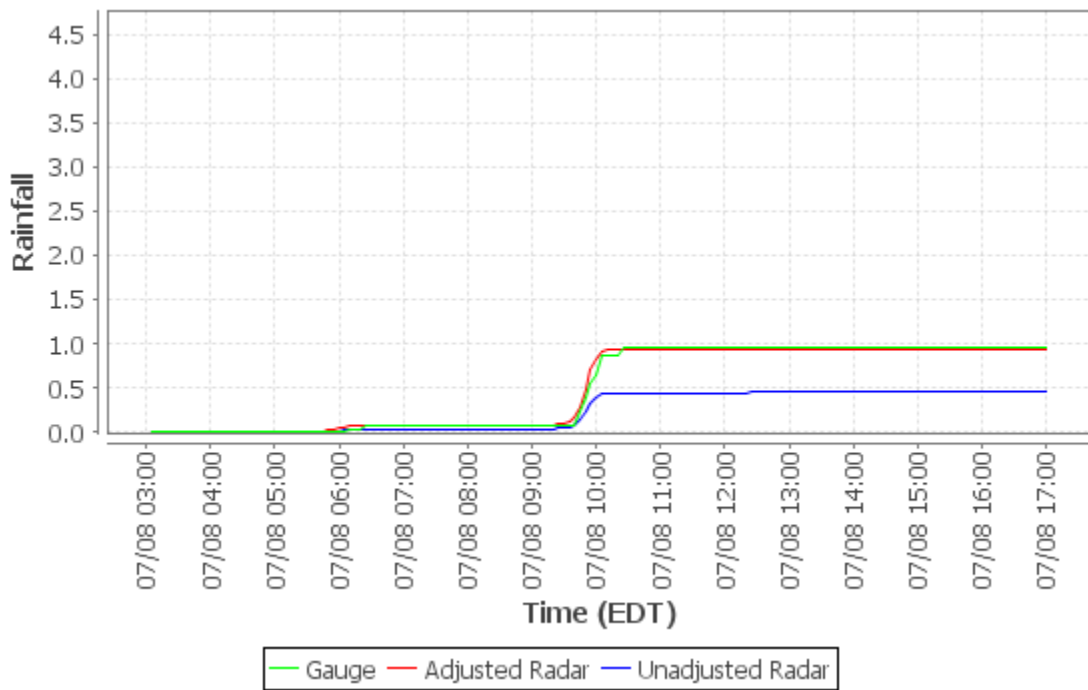
Cumulative Distribution Plot - Huntington Levee - Ponding Area (980)



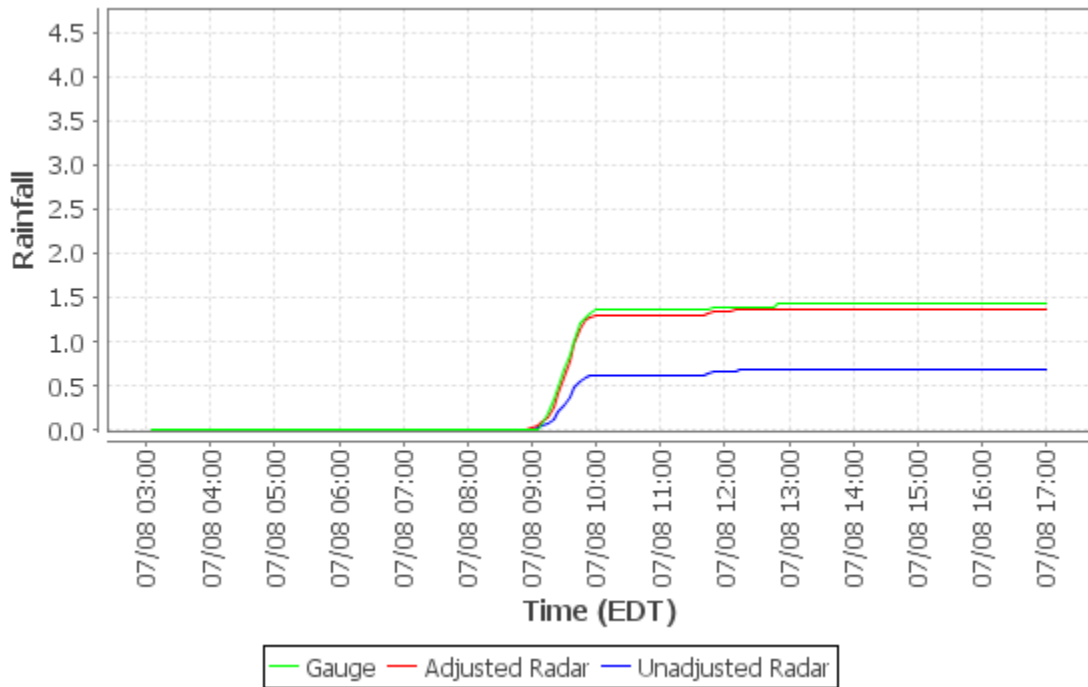
Cumulative Distribution Plot - Huntsman Lake (1000)



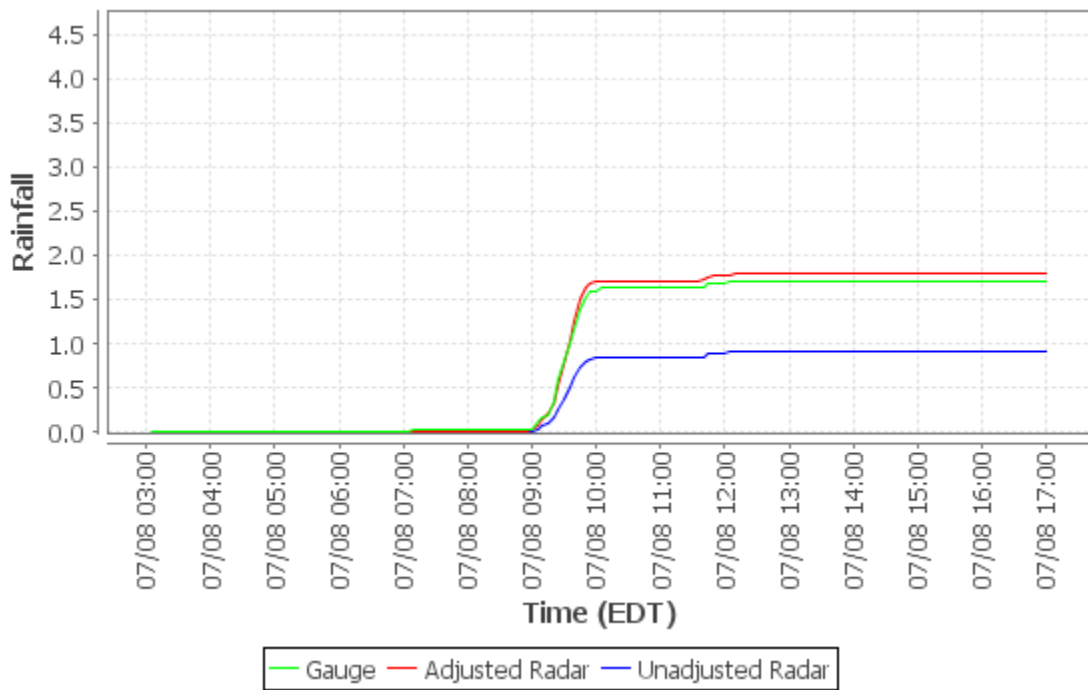
Cumulative Distribution Plot - Lake Mercer (1030)



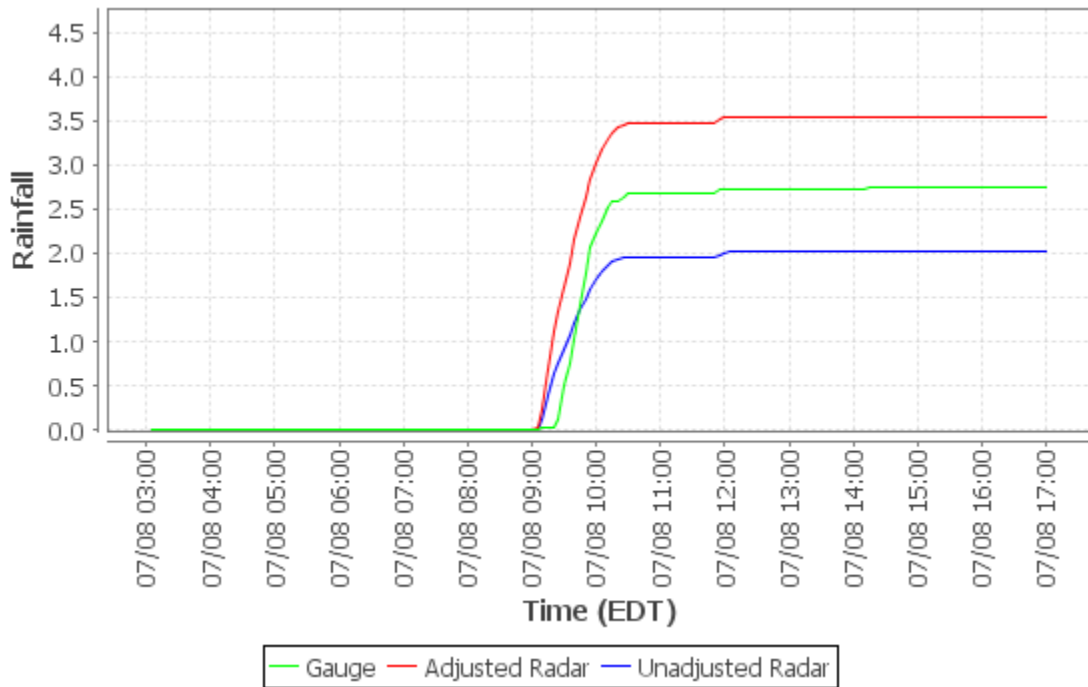
Cumulative Distribution Plot - Royal Lake (1040)



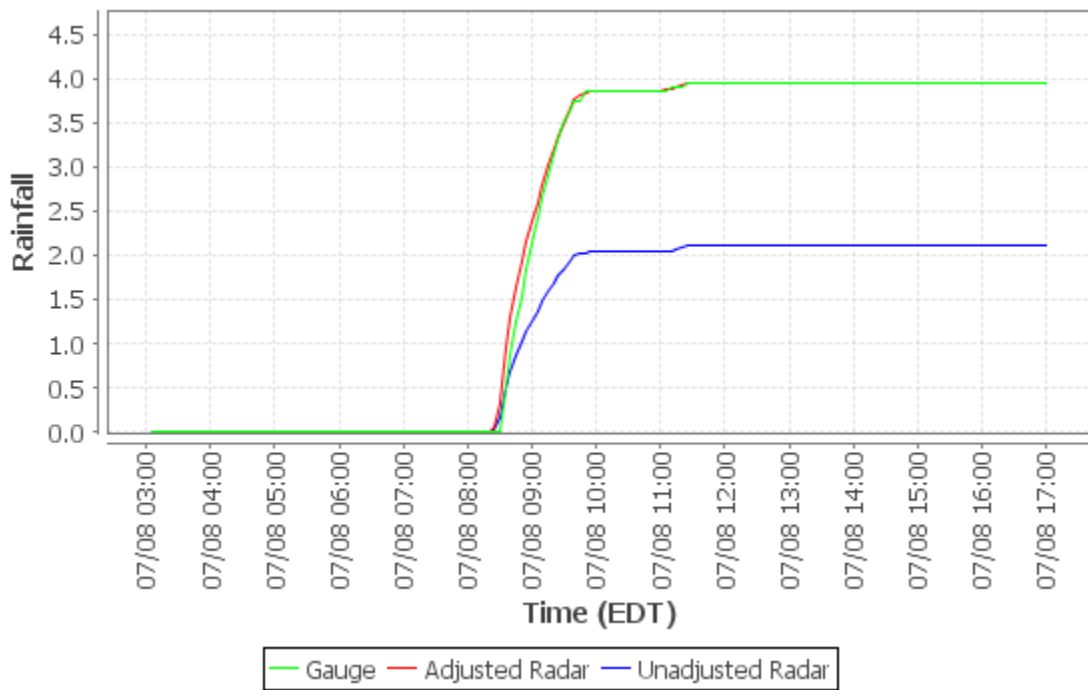
Cumulative Distribution Plot - Lake Braddock (1050)



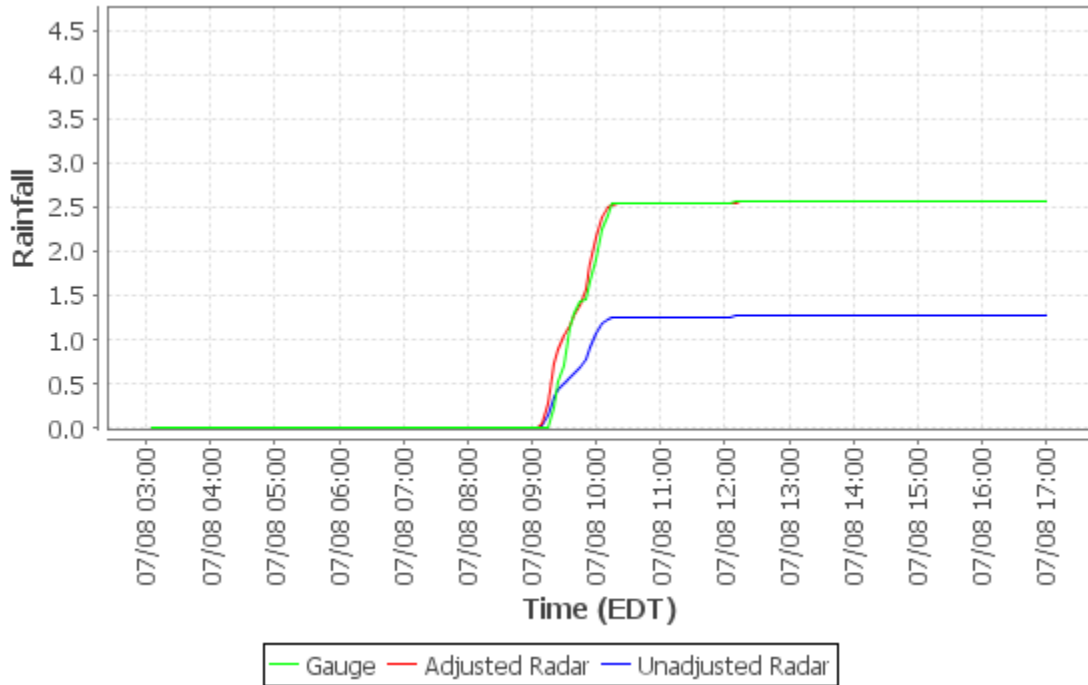
Cumulative Distribution Plot - Pump Station (1070)



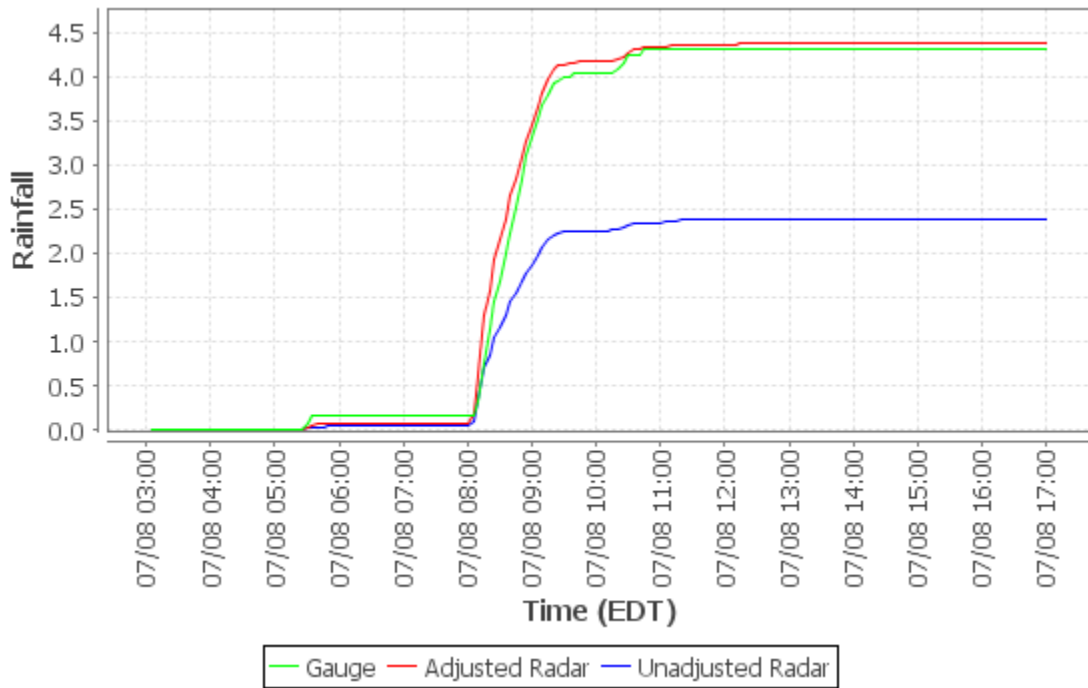
Cumulative Distribution Plot - Fairview Lake (1090)



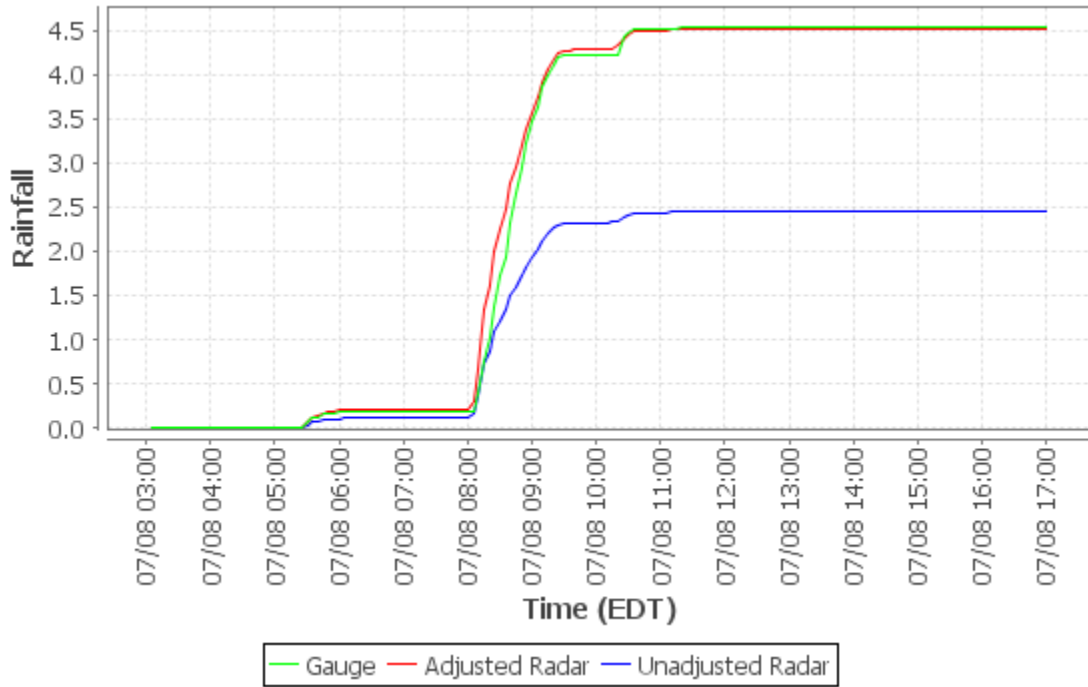
Cumulative Distribution Plot - Kingstowne Regional Pond 4 (1270)



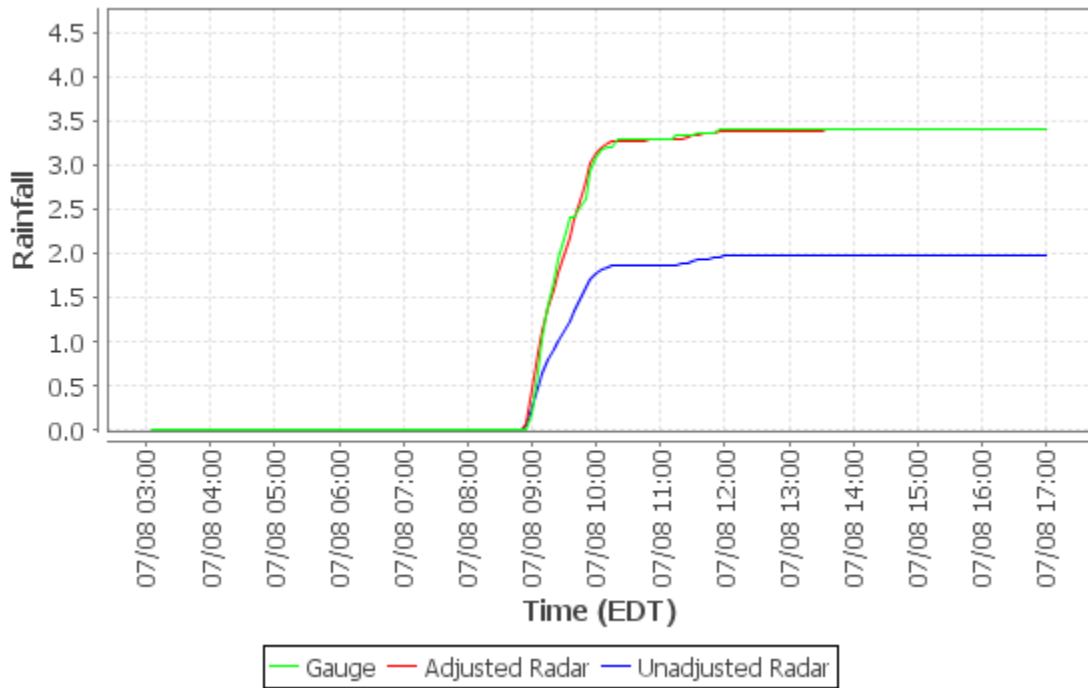
Cumulative Distribution Plot - Carrington (1280)



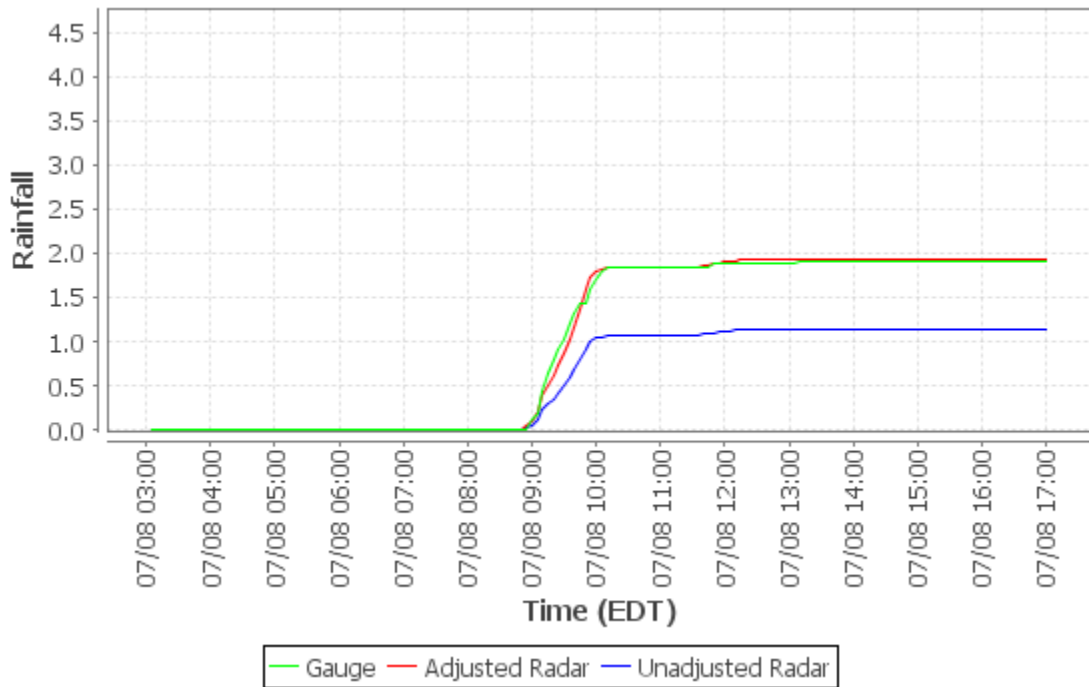
Cumulative Distribution Plot - Pulte/McLean (1300)



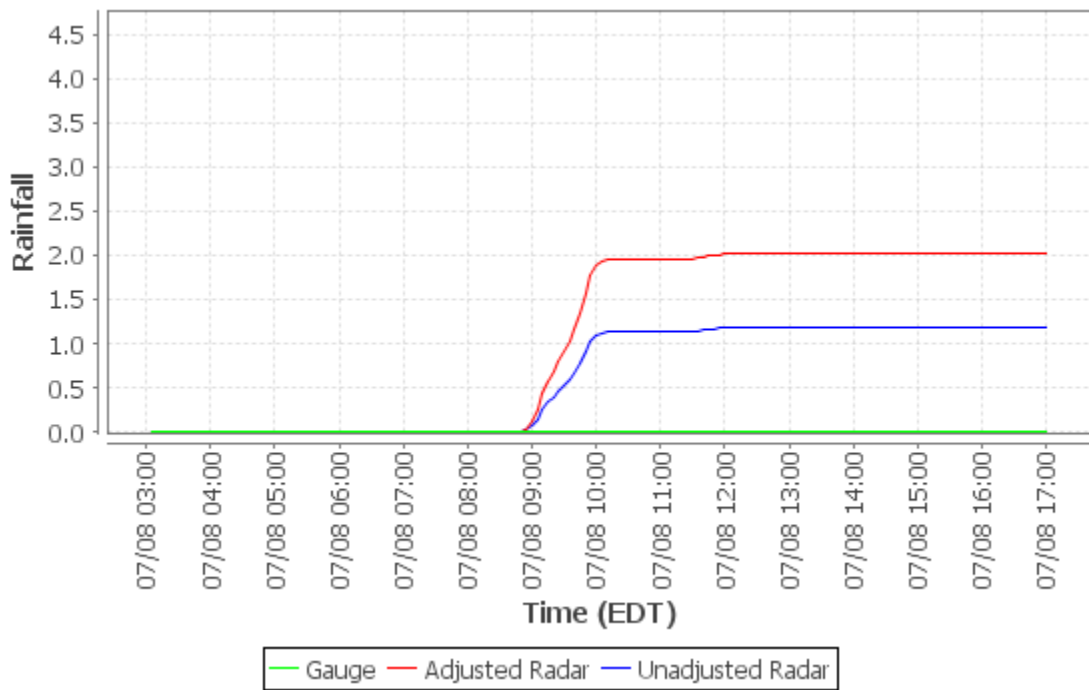
Cumulative Distribution Plot - Boothe Park (1350)



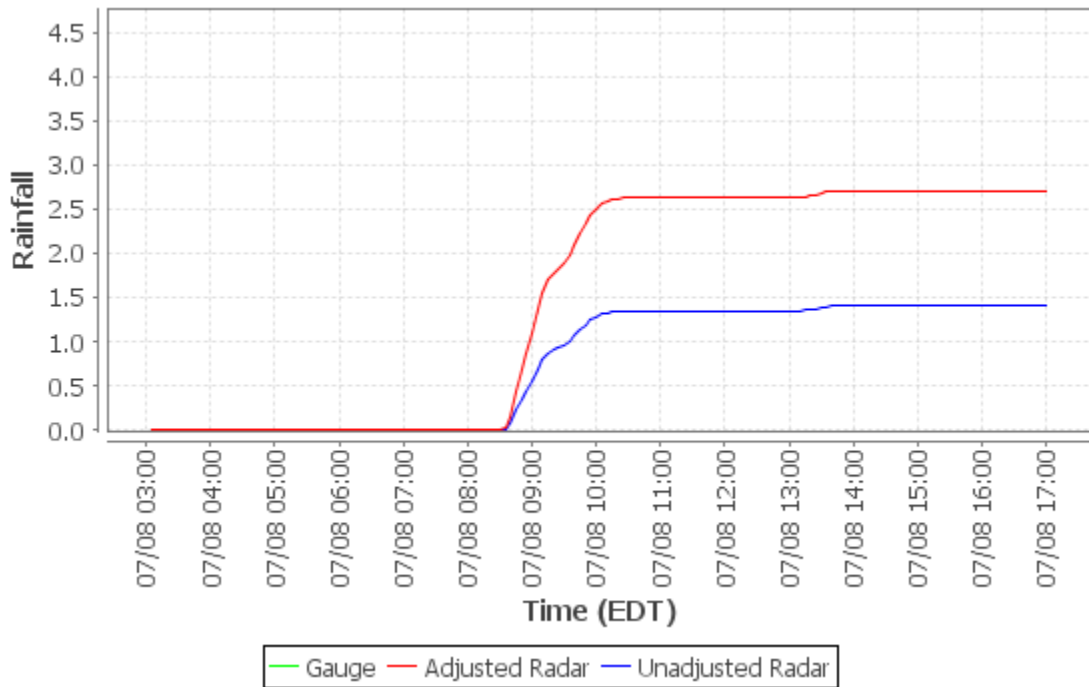
Cumulative Distribution Plot - Lake Accotink (FCPA) (1360)



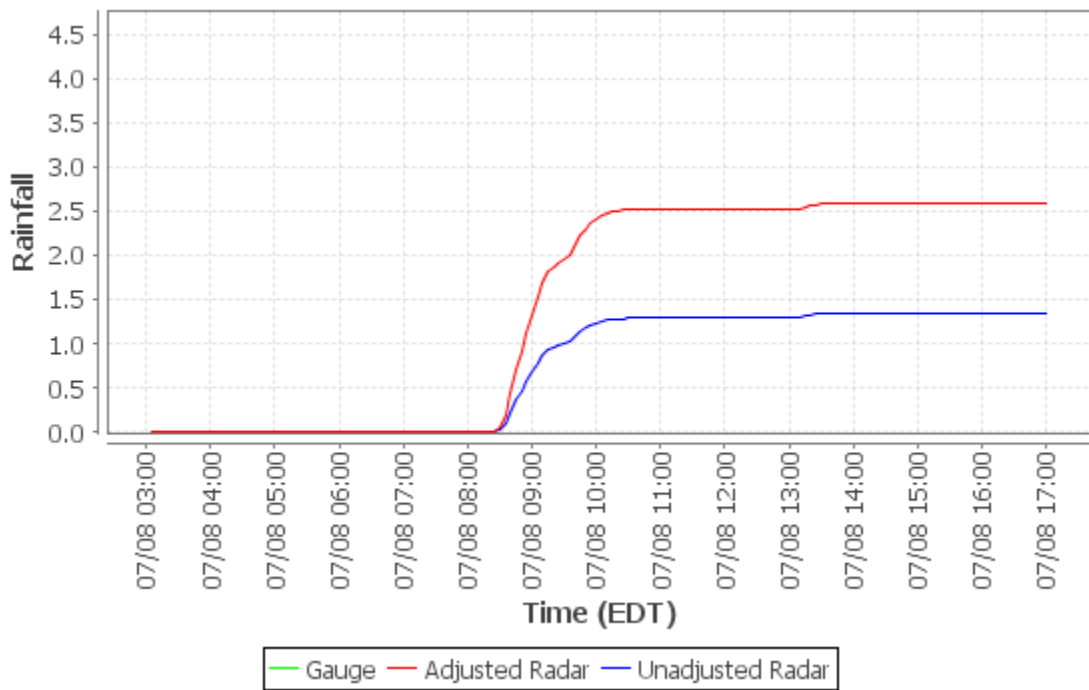
Cumulative Distribution Plot - Brookfield Park (1540)



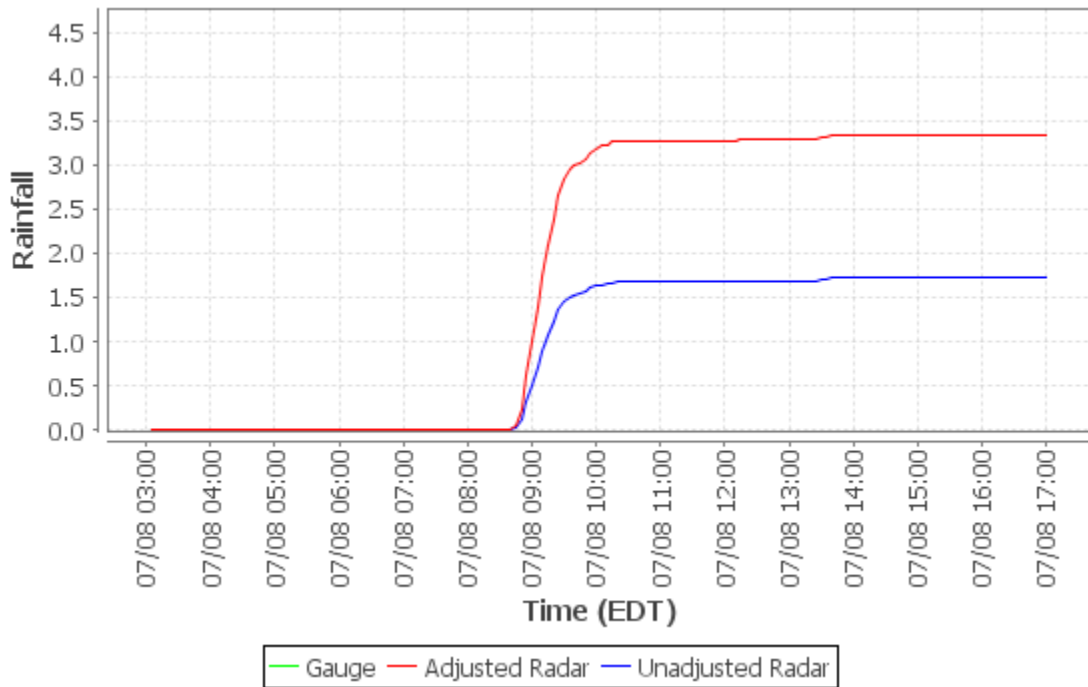
Cumulative Distribution Plot - RG-Brentwood (RG-Brentwood)



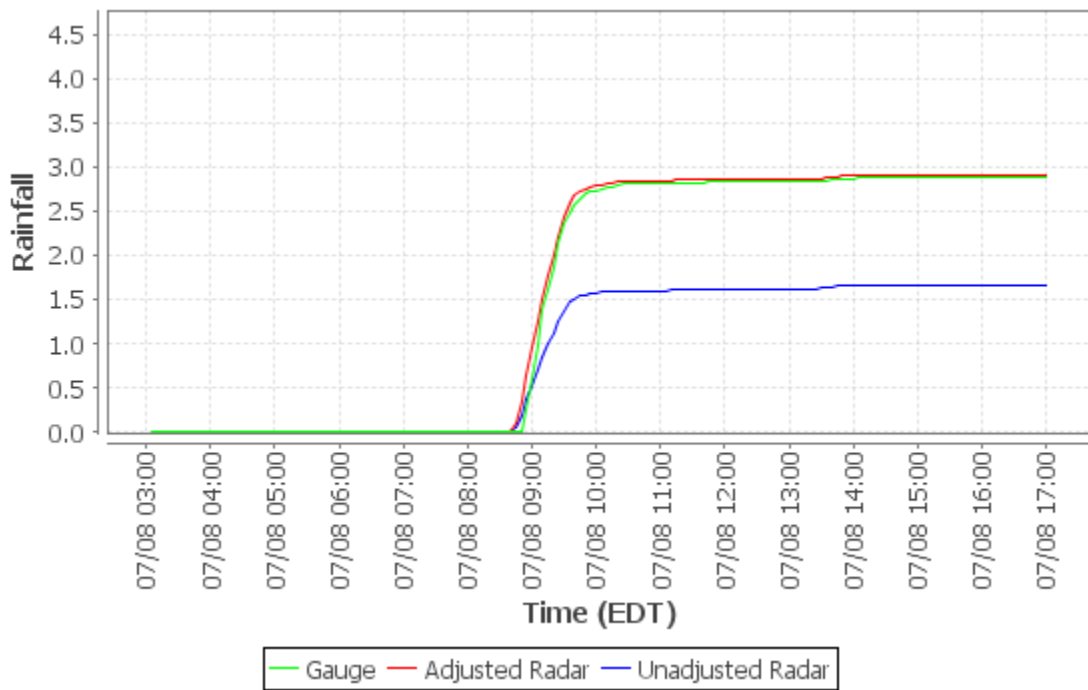
Cumulative Distribution Plot - RG-Bryant (RG-Bryant)



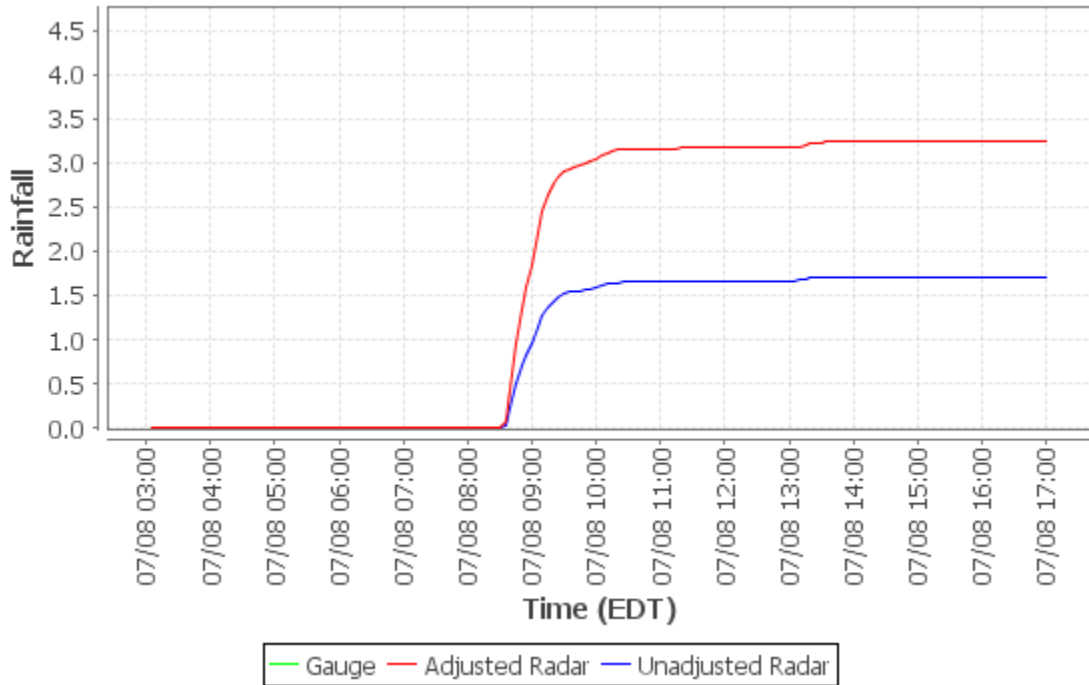
Cumulative Distribution Plot - RG-Main PS (RG-Main PS)



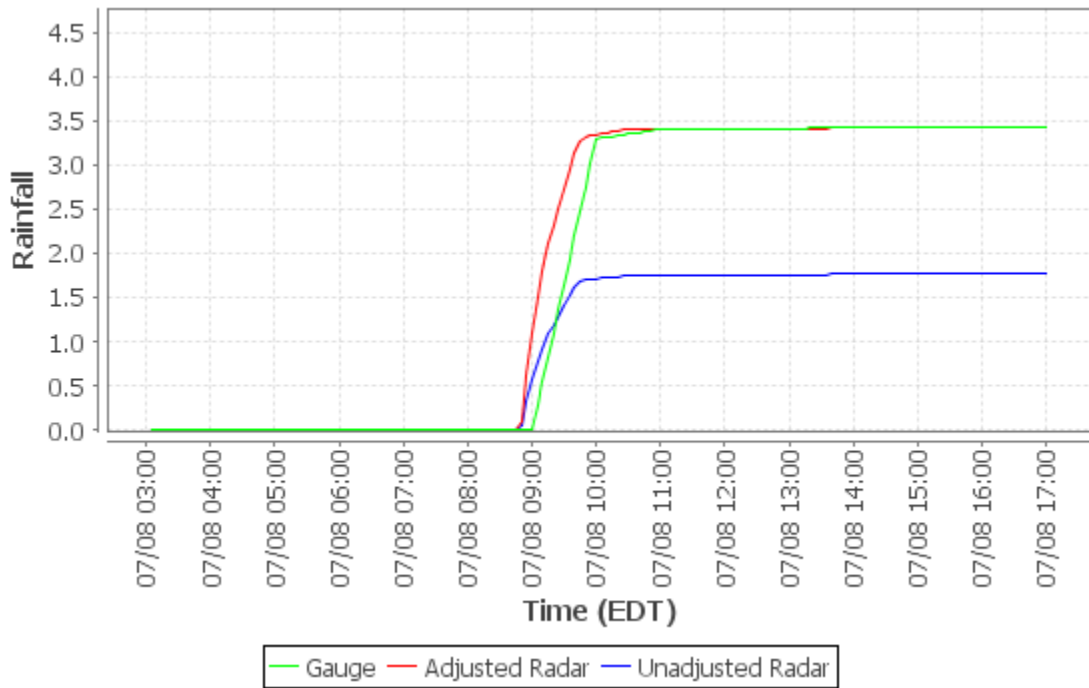
Cumulative Distribution Plot - FOURMILE RUN AT ALEXANDRIA (01652500)



Cumulative Distribution Plot - RG-RCPS (RG-RCPS)

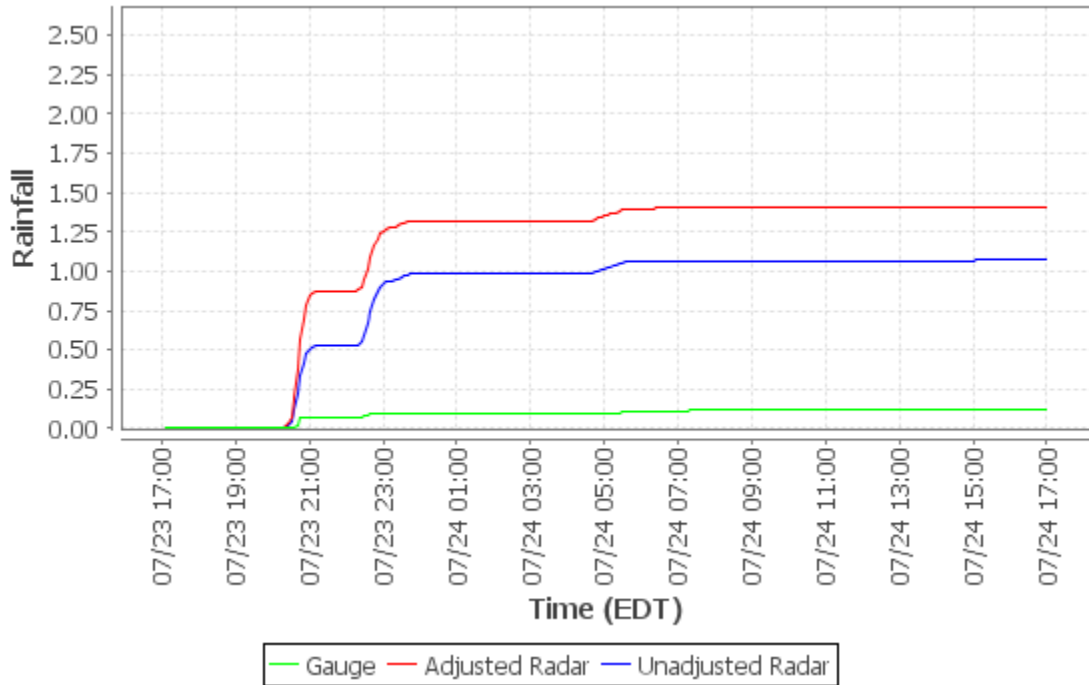


Cumulative Distribution Plot - Washington Reagan National Airport (KDCA)

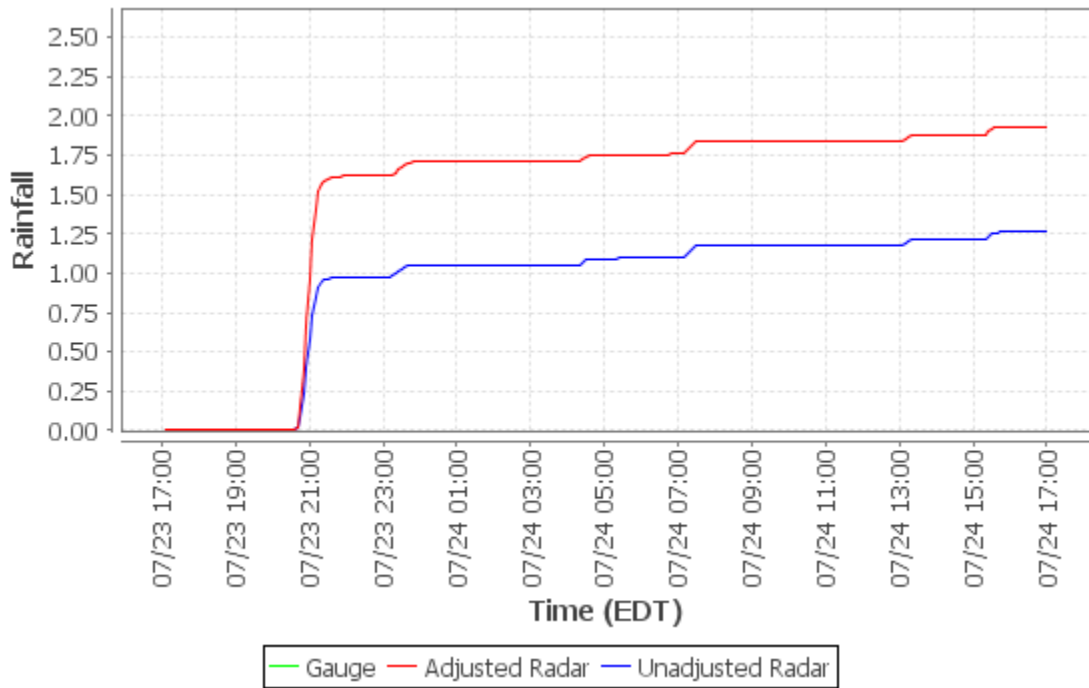


Appendix D - Event 2 (2020-07-23) CDPs

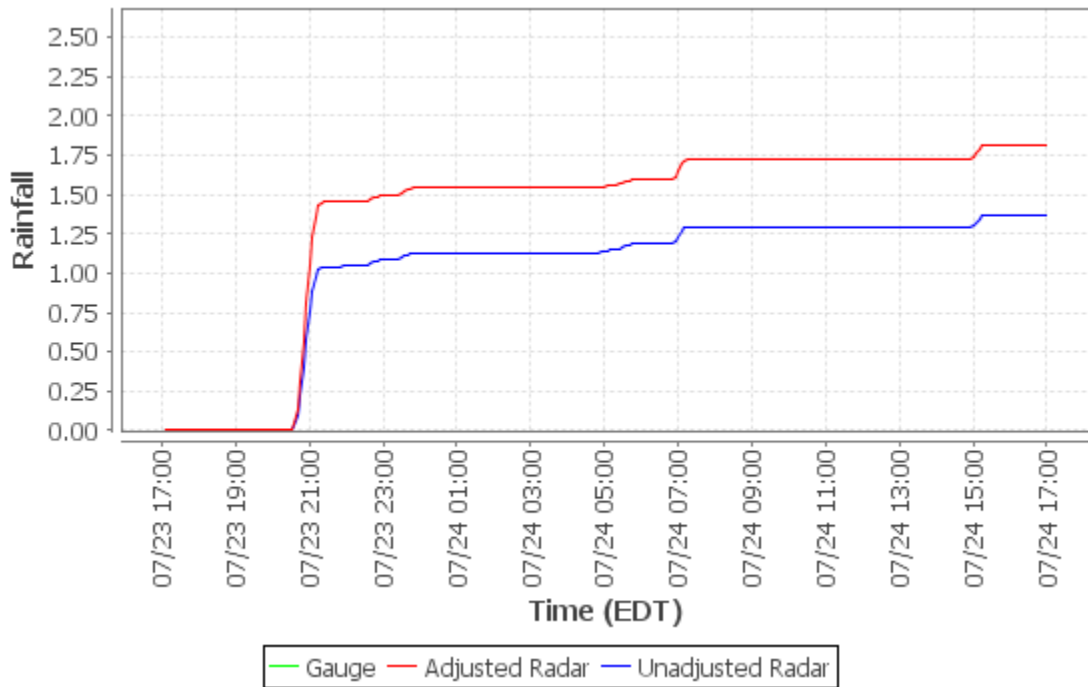
Cumulative Distribution Plot - Lake Barcroft (10001)



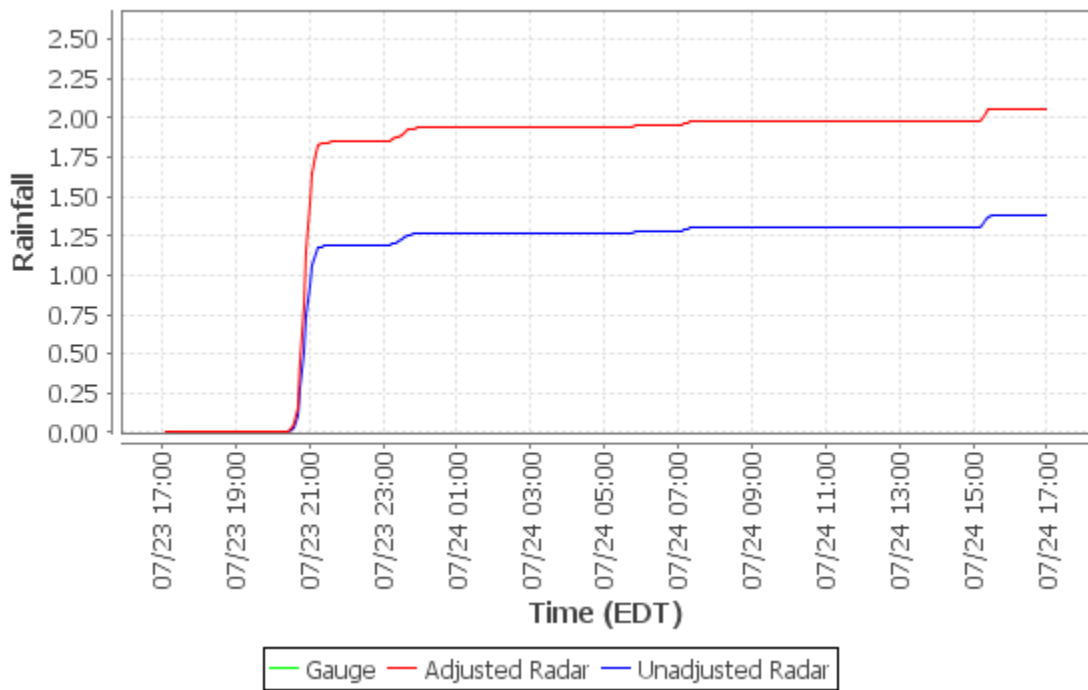
Cumulative Distribution Plot - Windmill Hill Park (20101)



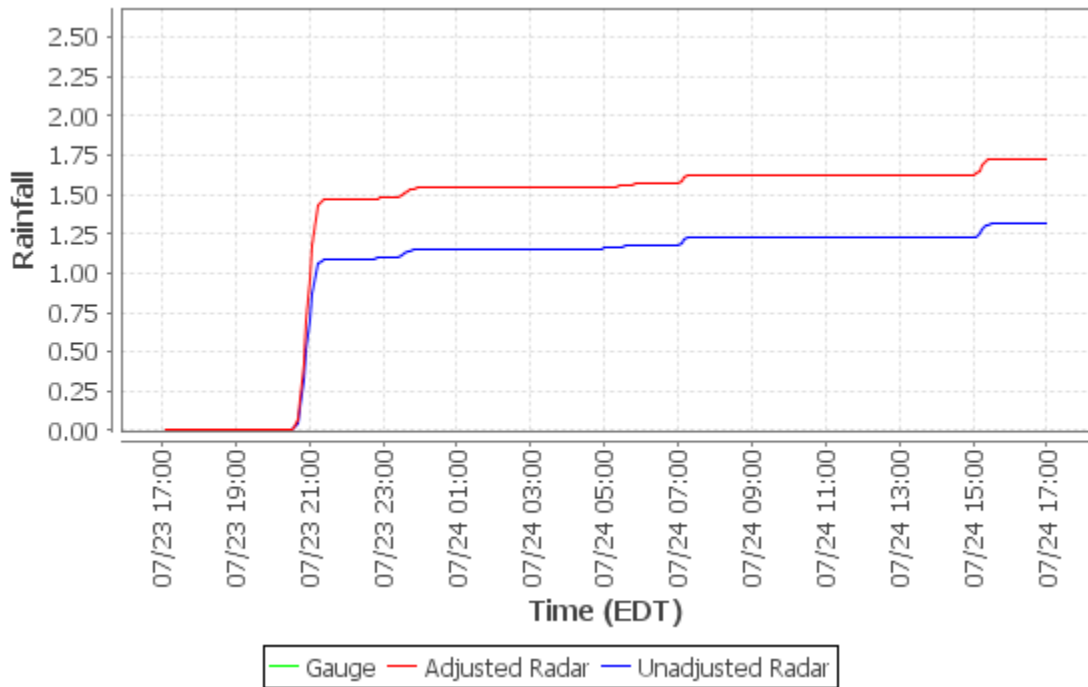
Cumulative Distribution Plot - Charles Barrett Elementary (20102)



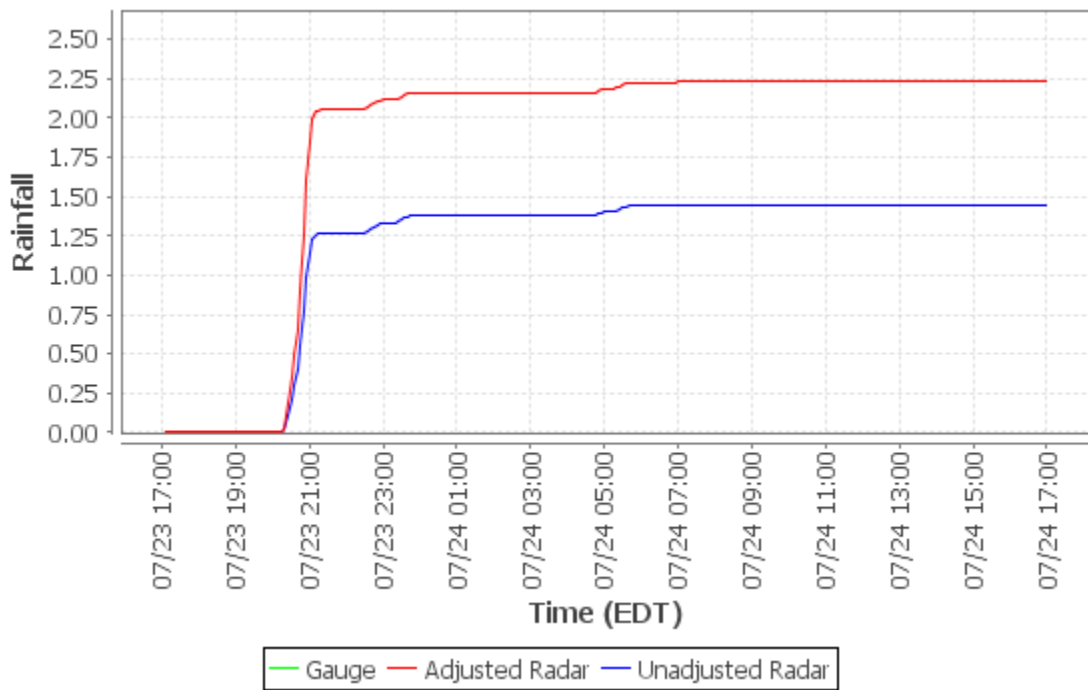
Cumulative Distribution Plot - Beach Park (20103)



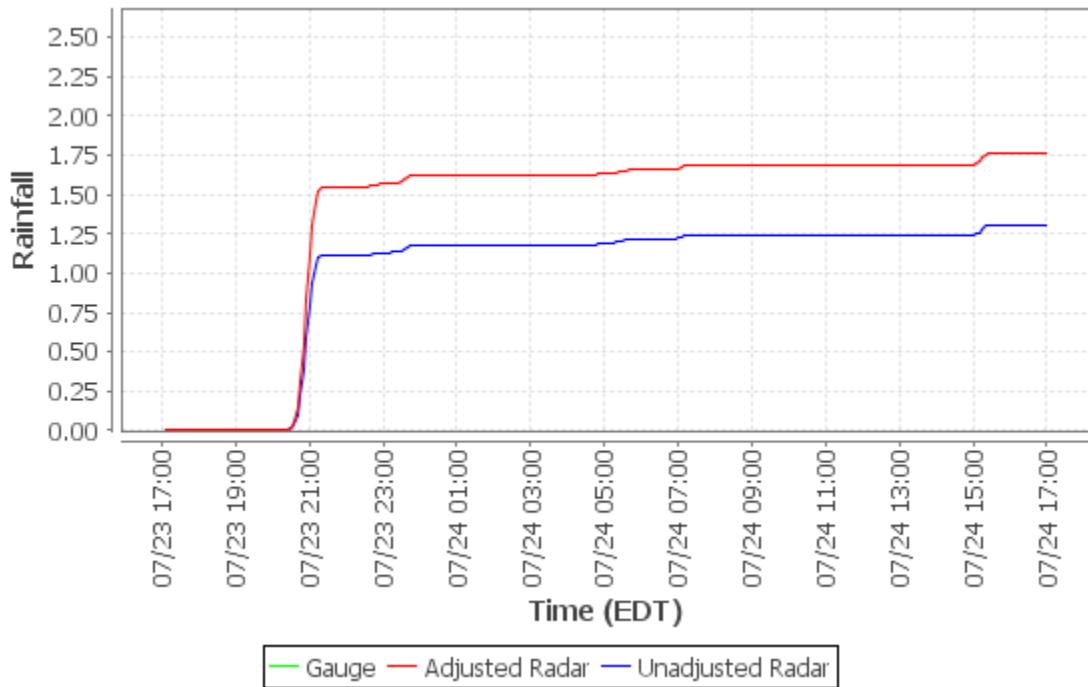
Cumulative Distribution Plot - Mount Vernon Elementary (20104)



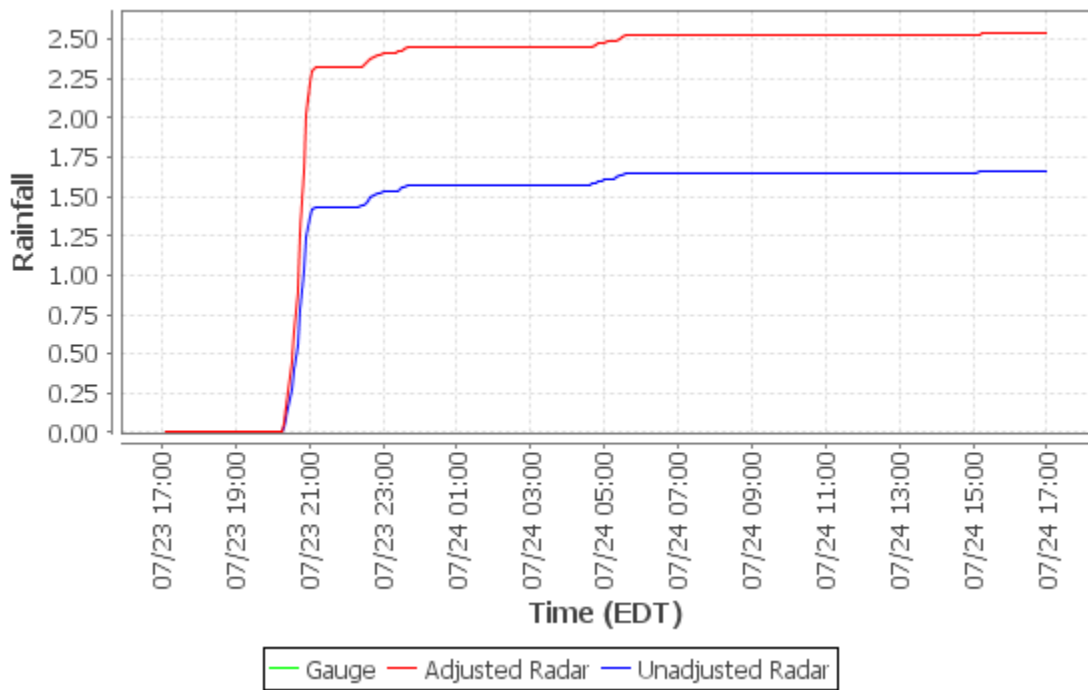
Cumulative Distribution Plot - Francis Hammond Middle School (20105)



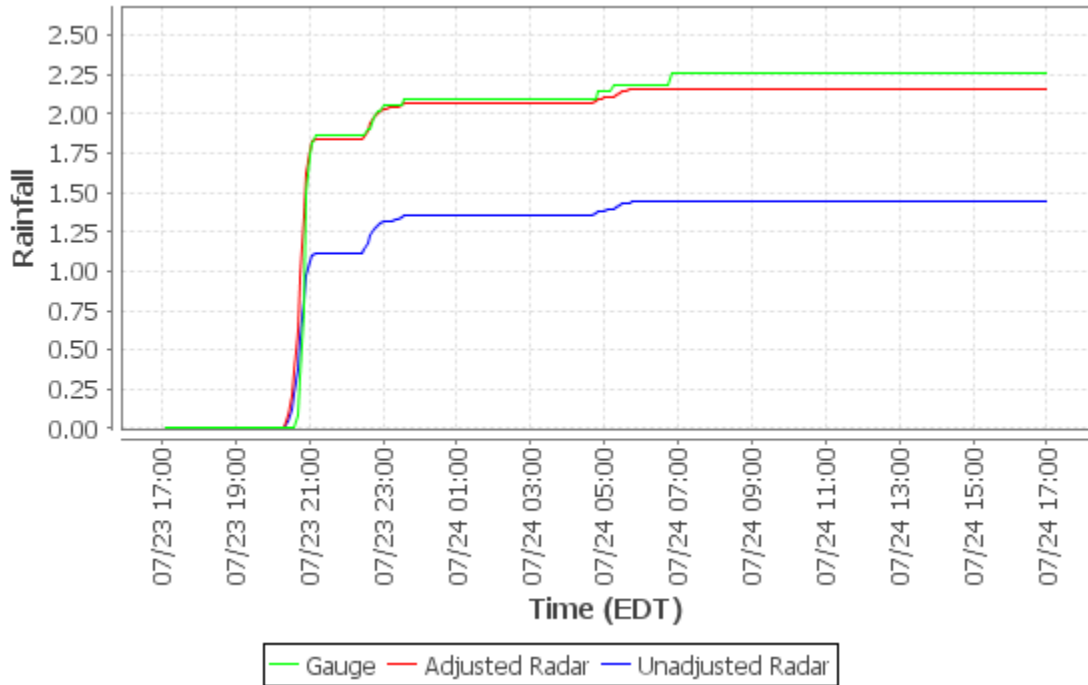
Cumulative Distribution Plot - George Mason Elementary (20106)



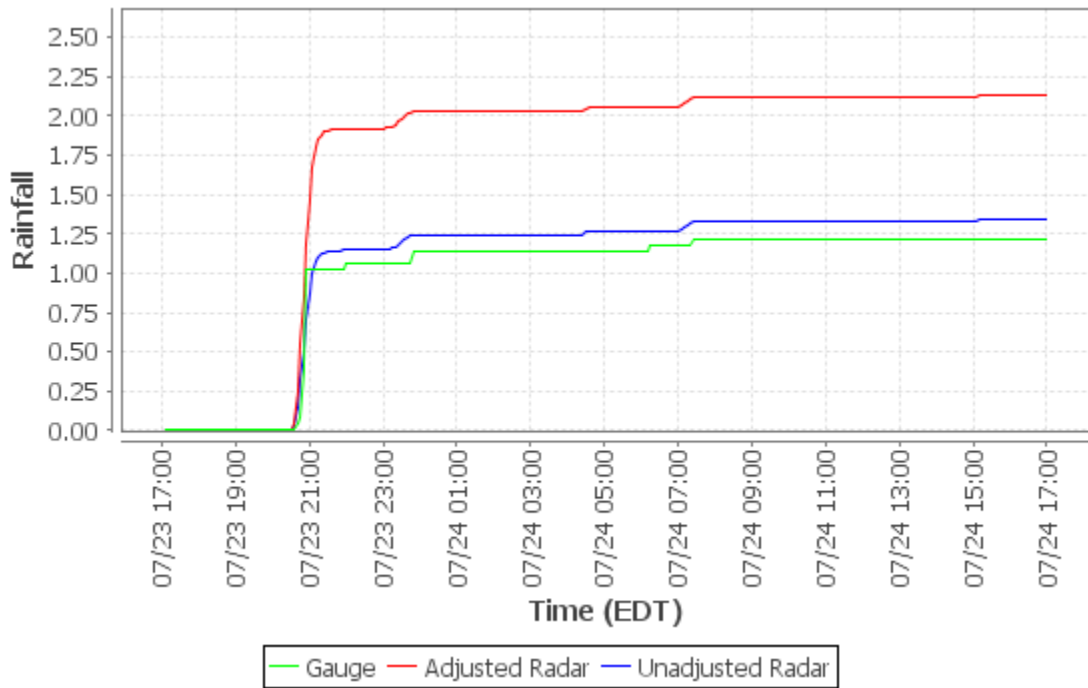
Cumulative Distribution Plot - Holmes Run @ Van Dorn (20116)



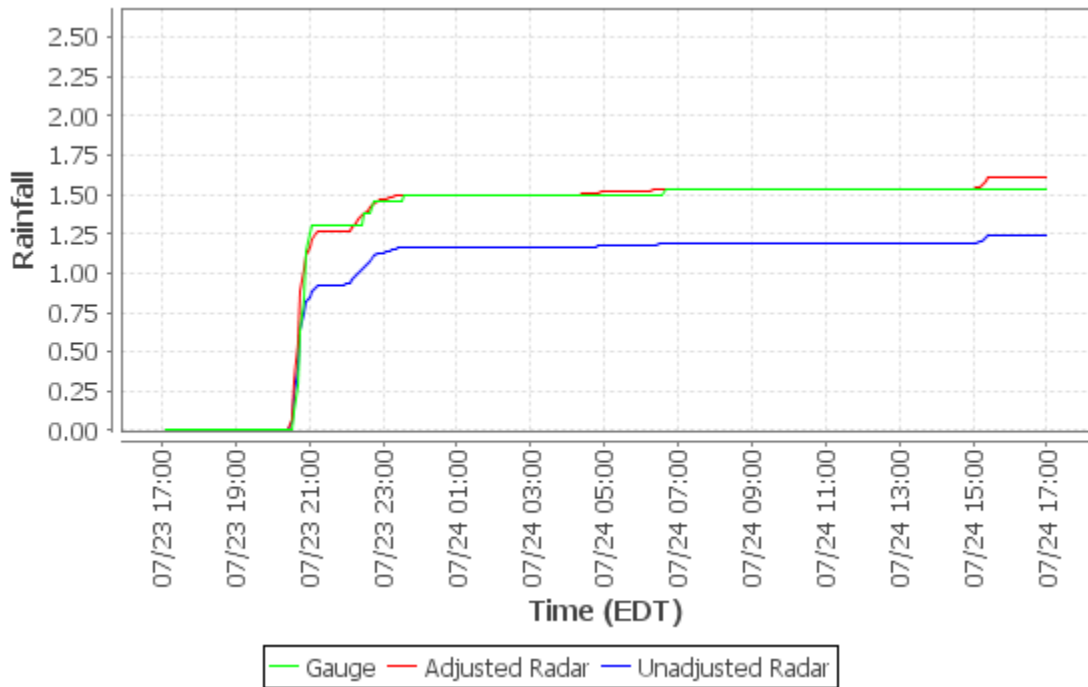
Cumulative Distribution Plot - Holmes Run Parkway (20117)



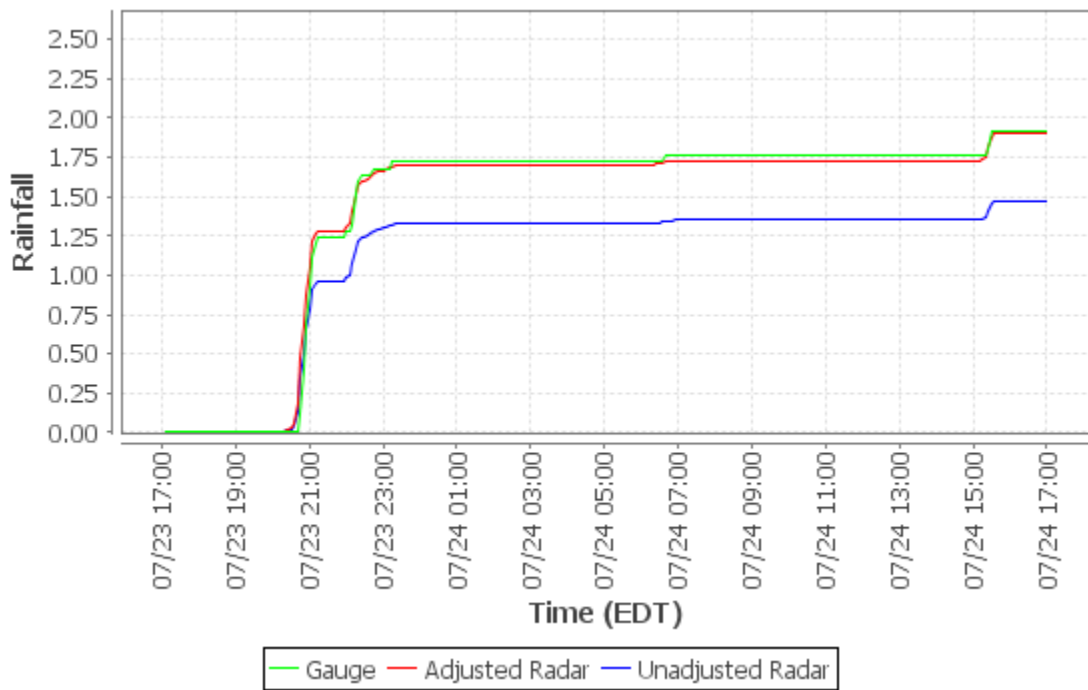
Cumulative Distribution Plot - Huntington Levee - Ponding Area (980)



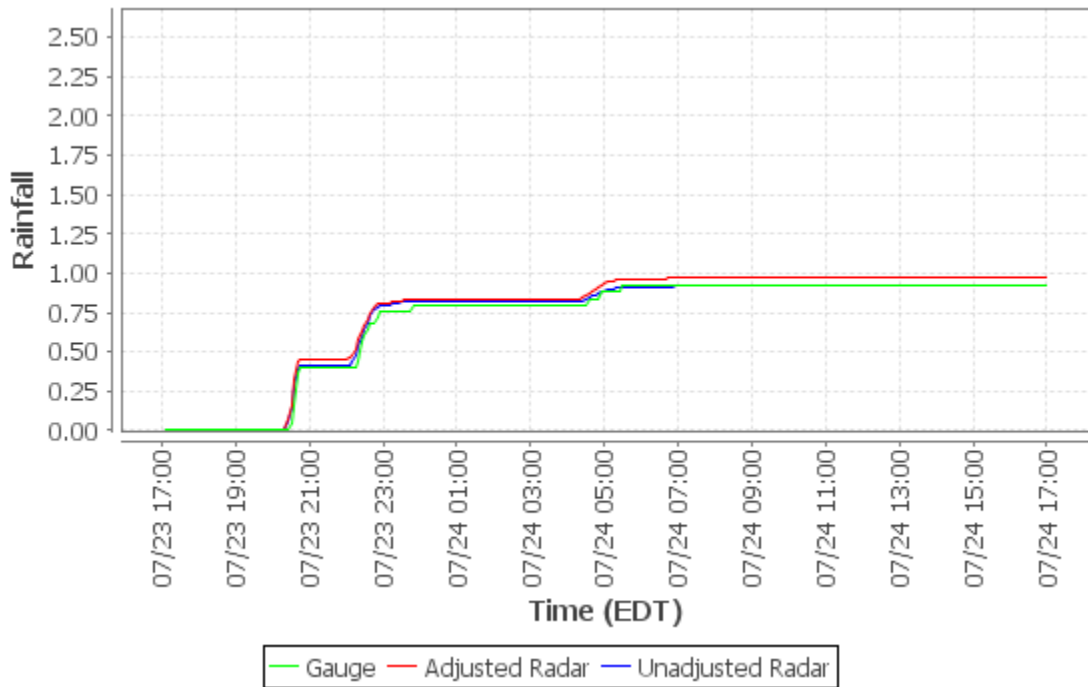
Cumulative Distribution Plot - Huntsman Lake (1000)



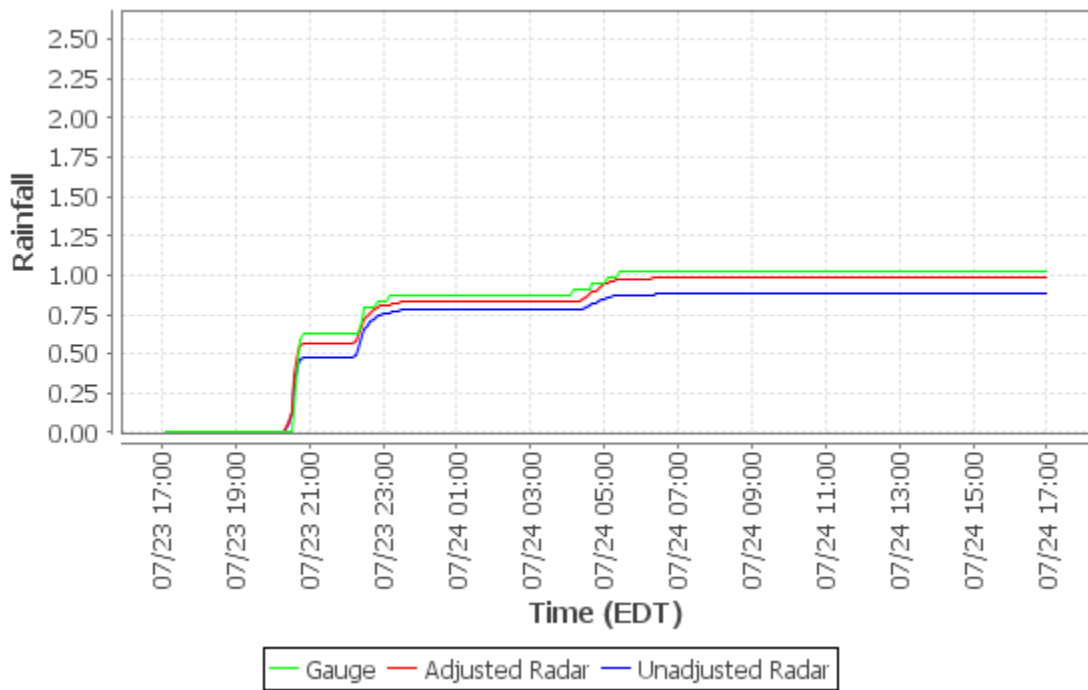
Cumulative Distribution Plot - Lake Mercer (1030)



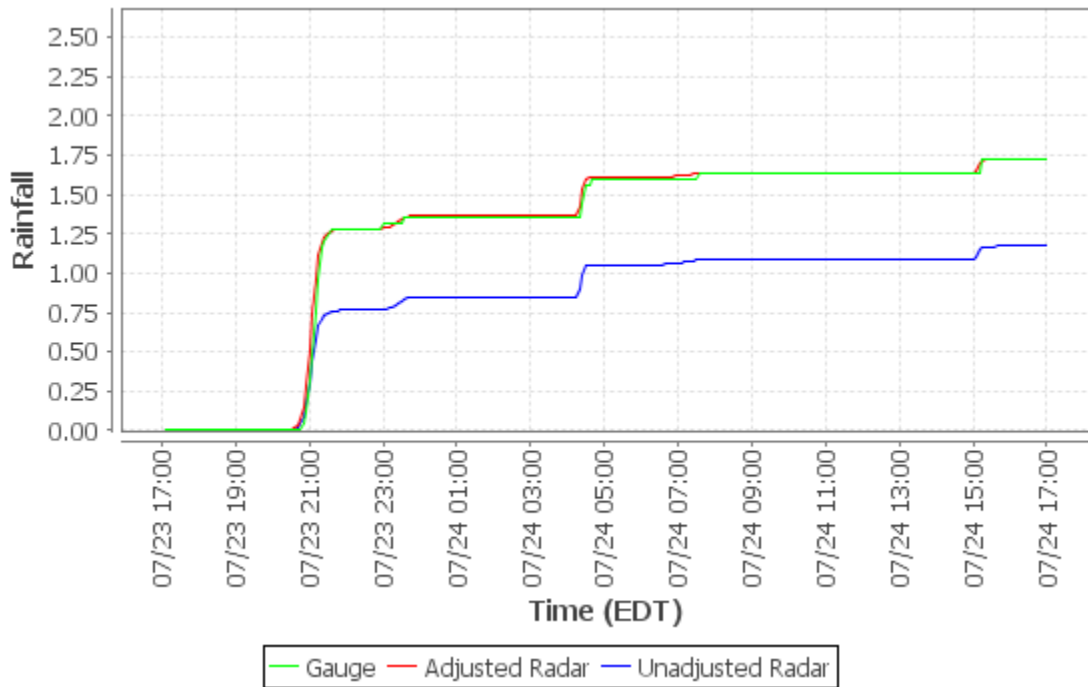
Cumulative Distribution Plot - Royal Lake (1040)



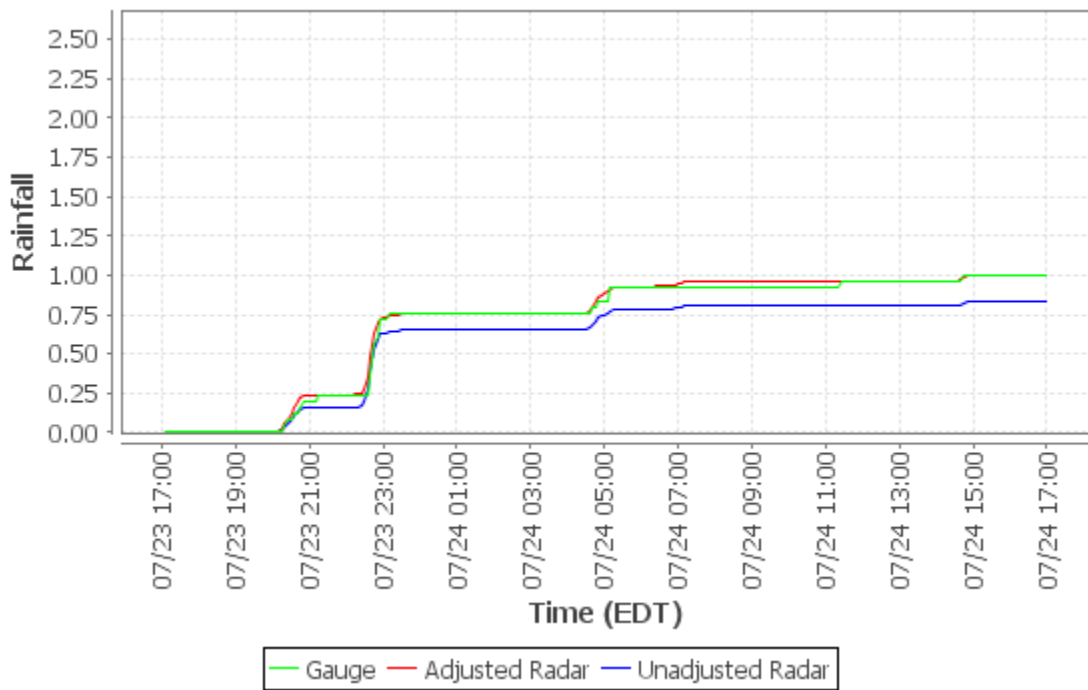
Cumulative Distribution Plot - Lake Braddock (1050)



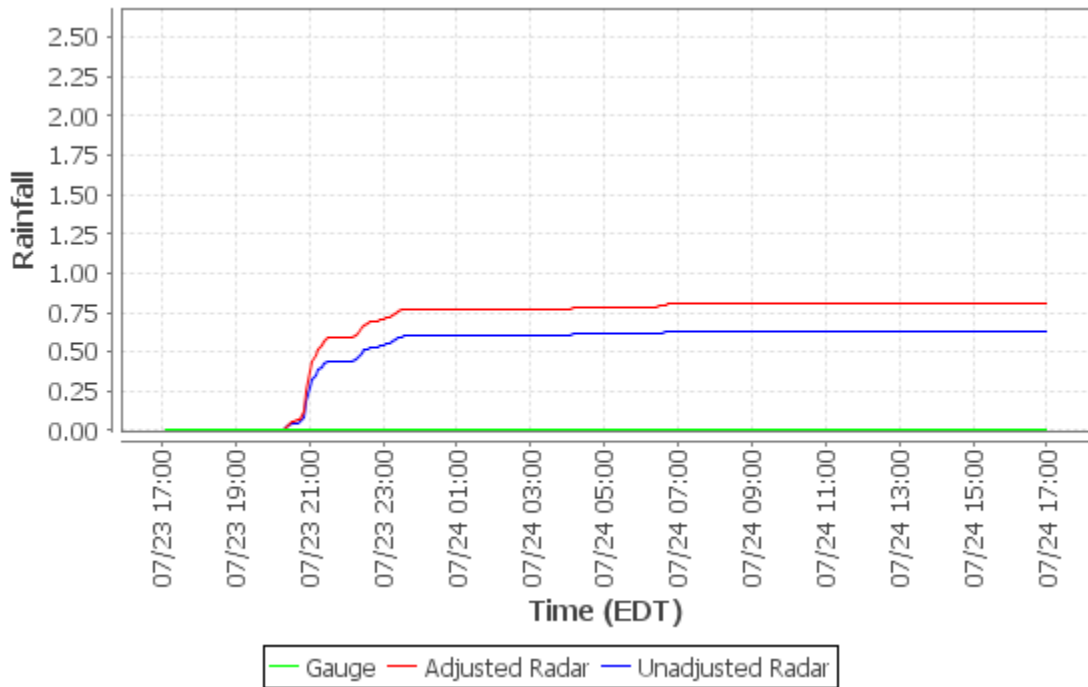
Cumulative Distribution Plot - Pump Station (1070)



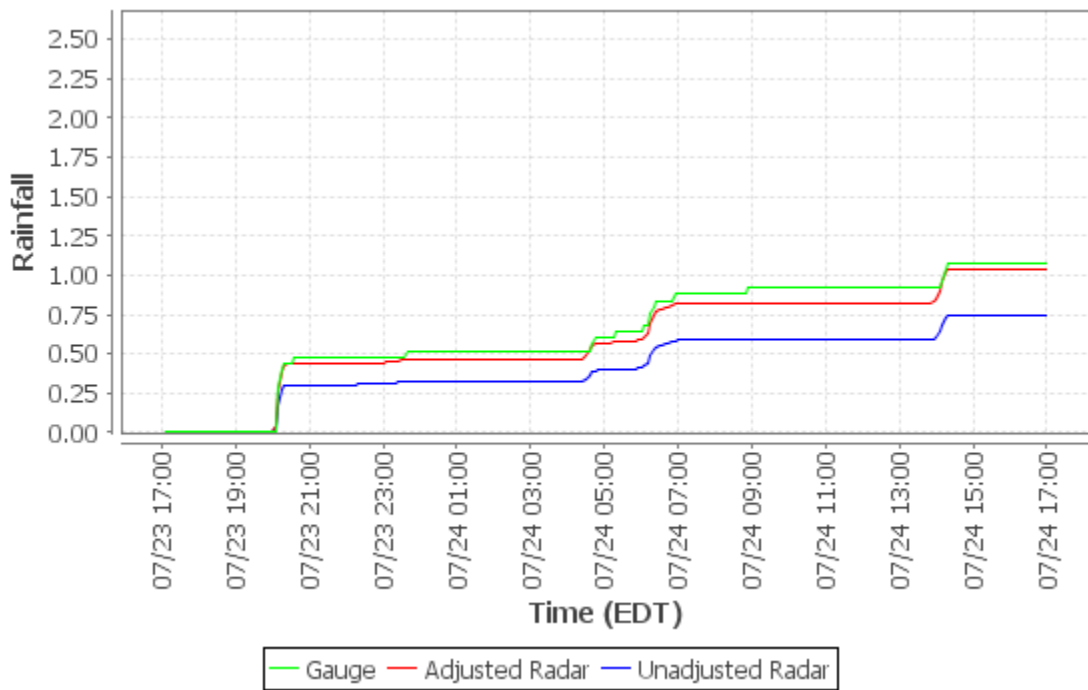
Cumulative Distribution Plot - Fairview Lake (1090)



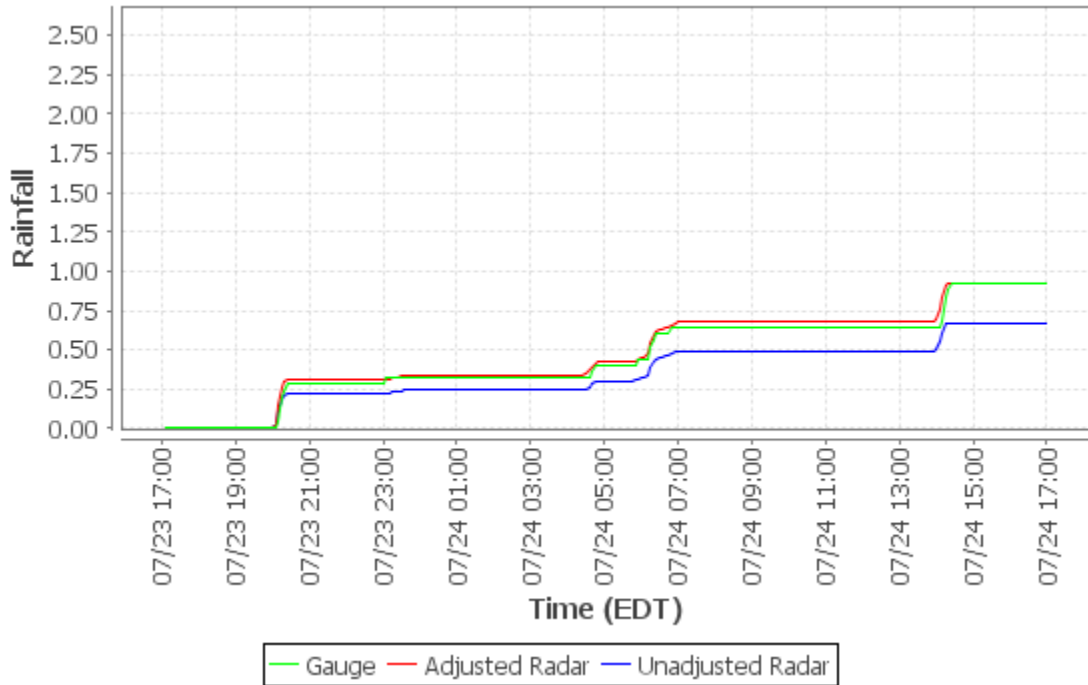
Cumulative Distribution Plot - Kingstowne Regional Pond 4 (1270)



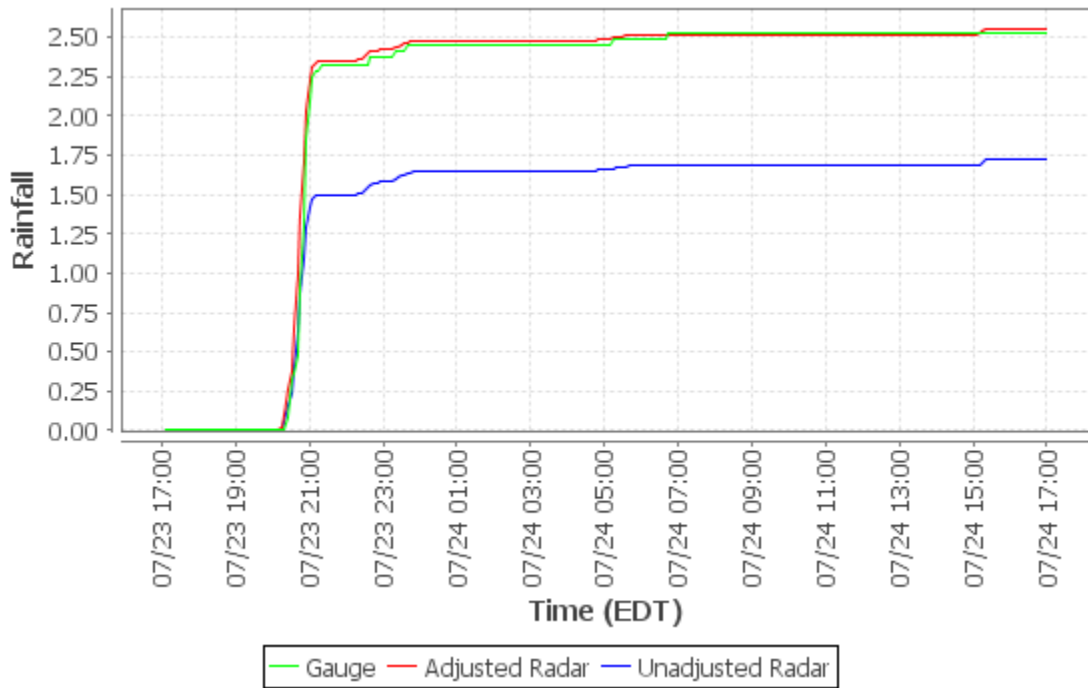
Cumulative Distribution Plot - Carrington (1280)



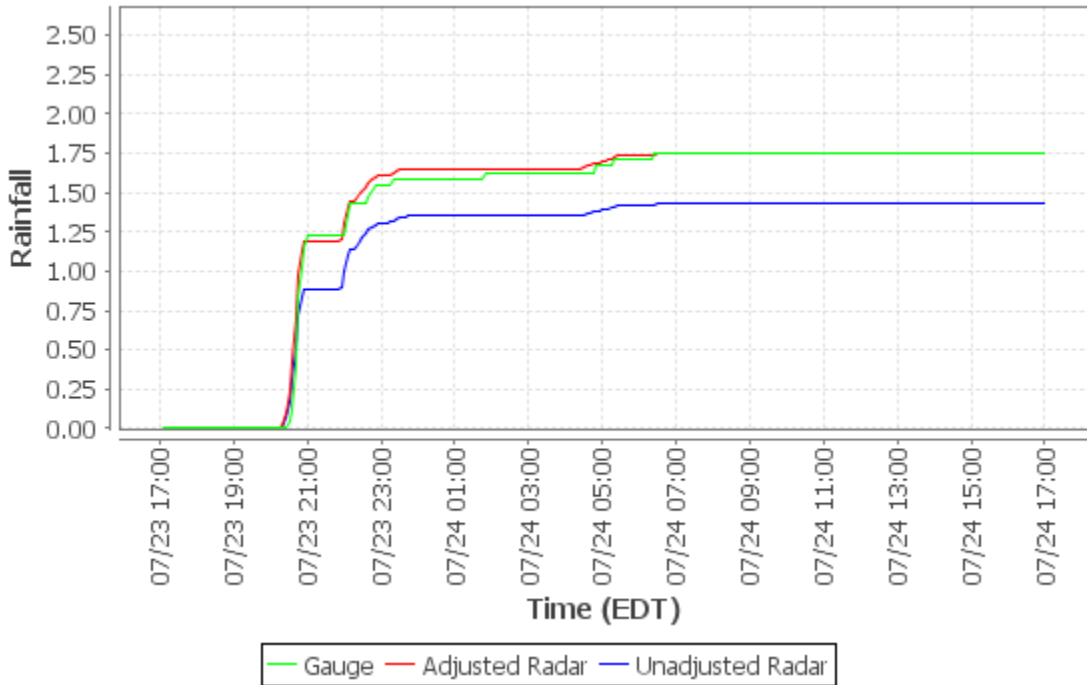
Cumulative Distribution Plot - Pulte/McLean (1300)



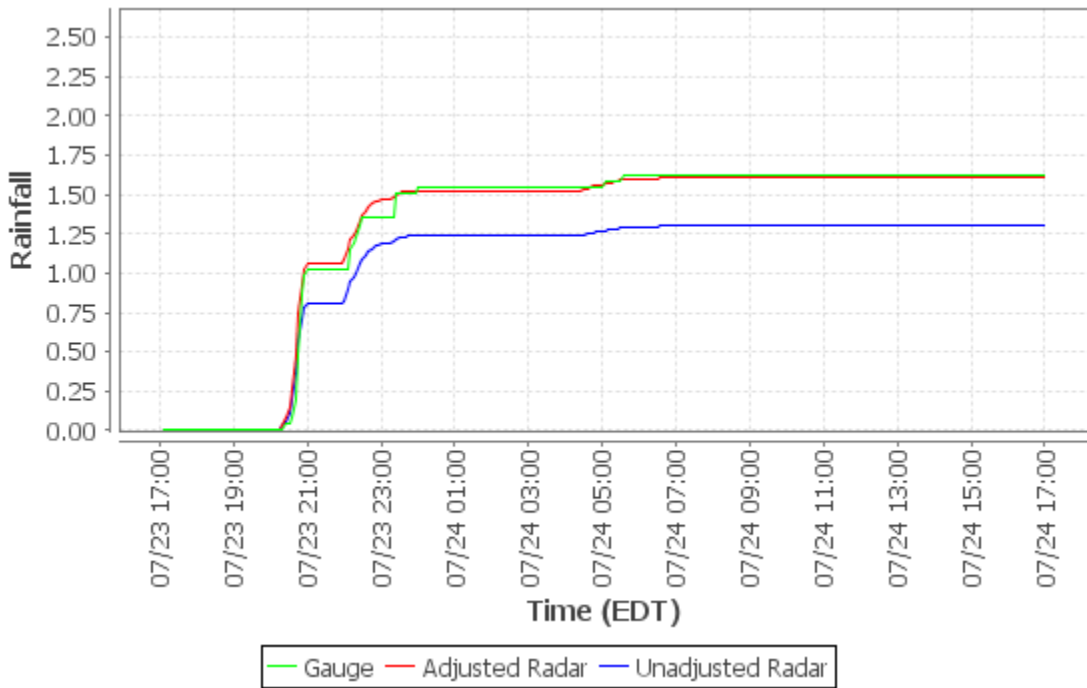
Cumulative Distribution Plot - Boothe Park (1350)



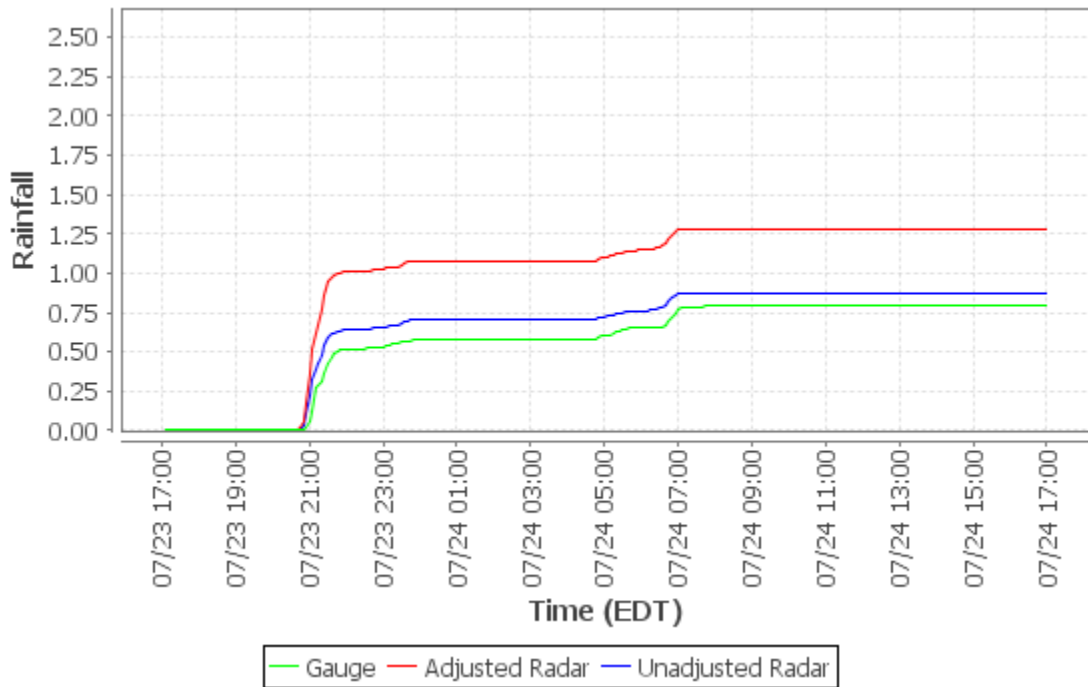
Cumulative Distribution Plot - Lake Accotink (FCPA) (1360)



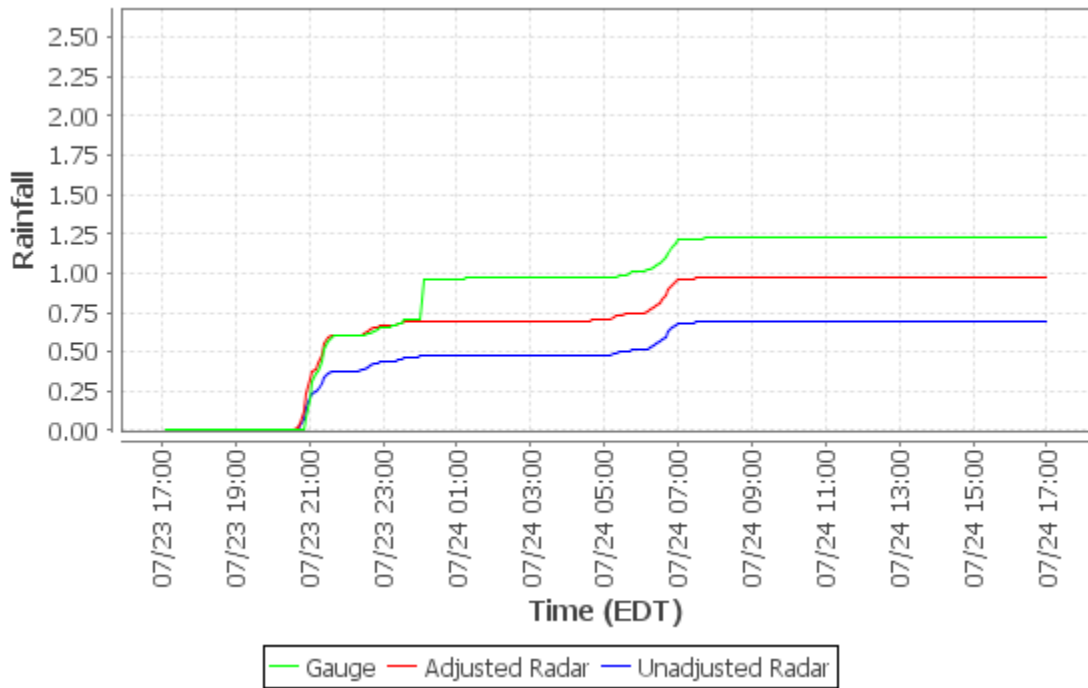
Cumulative Distribution Plot - Brookfield Park (1540)



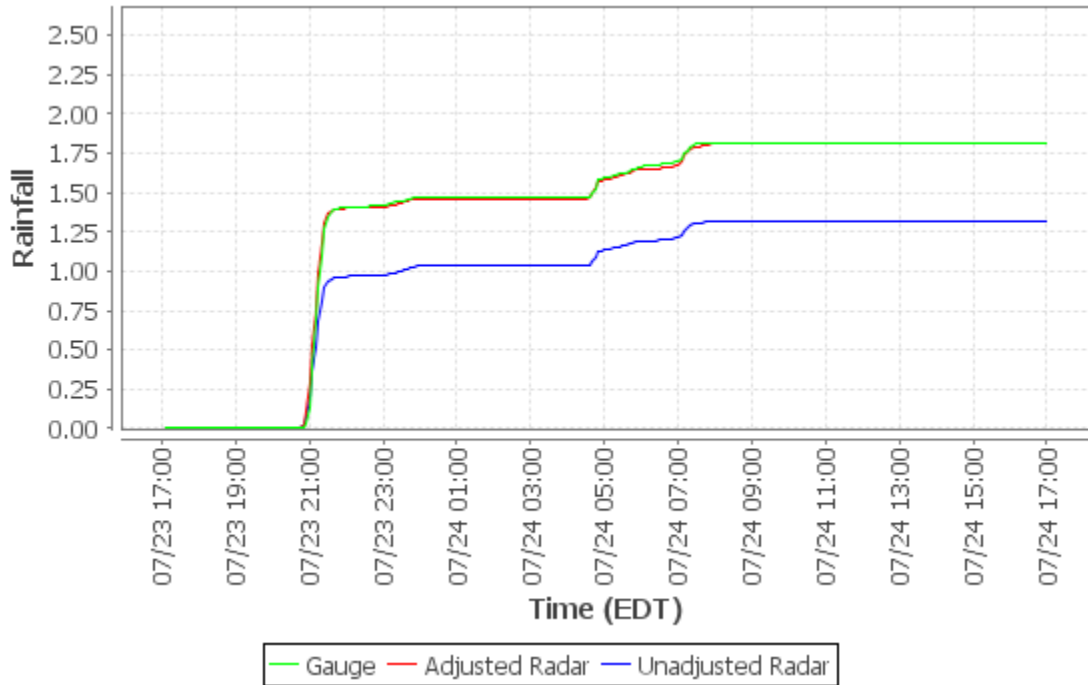
Cumulative Distribution Plot - RG-Brentwood (RG-Brentwood)



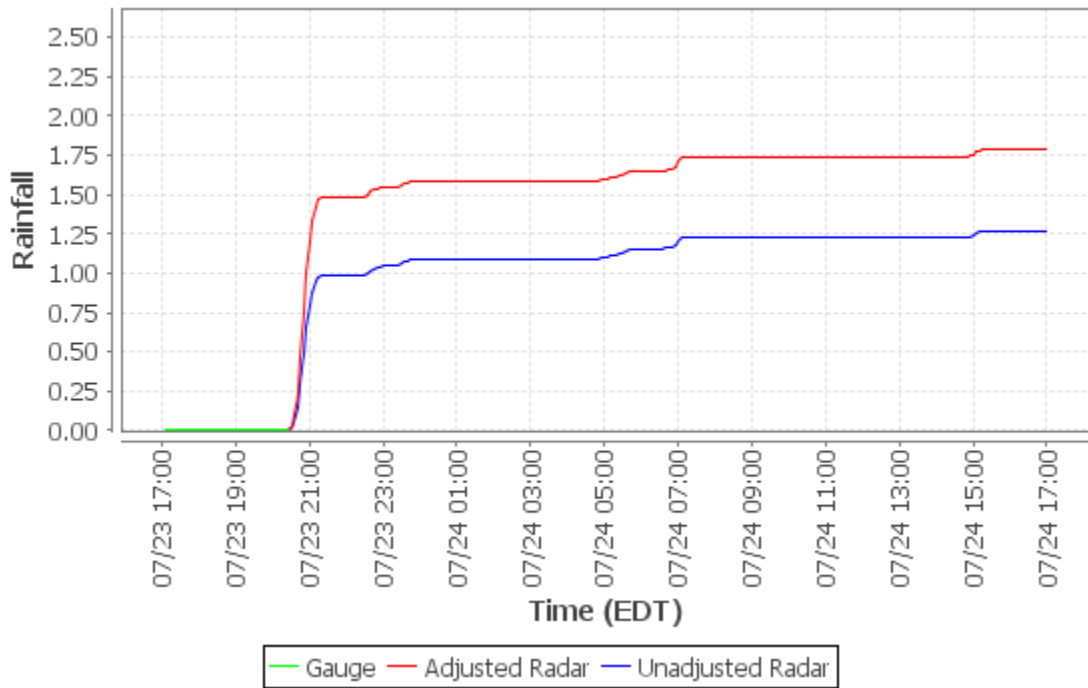
Cumulative Distribution Plot - RG-Bryant (RG-Bryant)



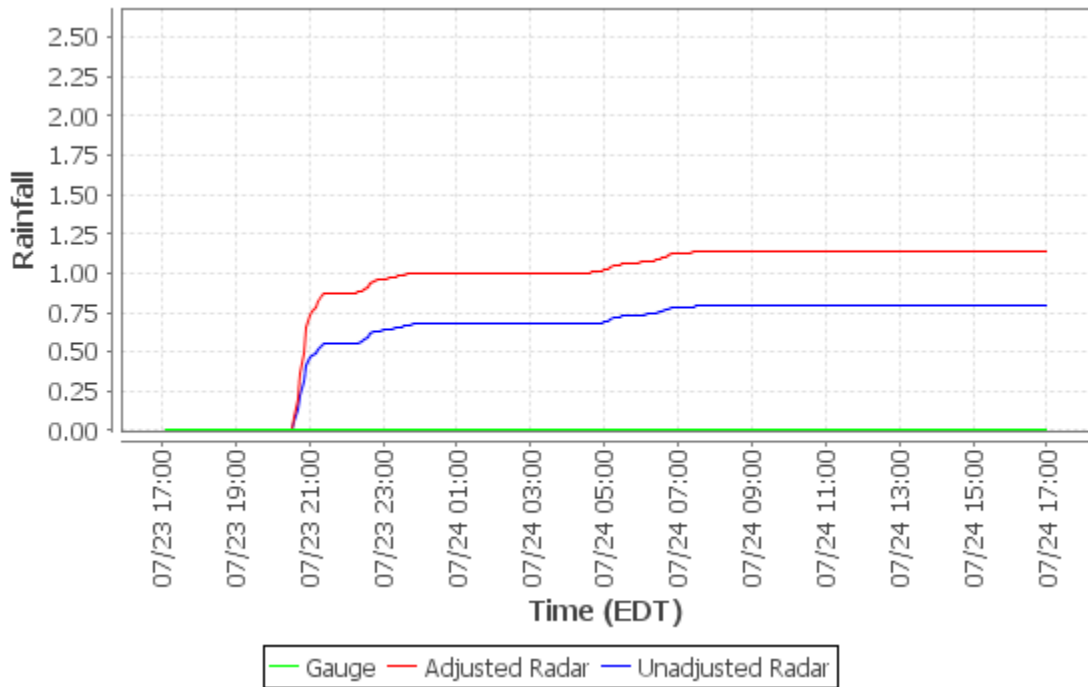
Cumulative Distribution Plot - RG-Main PS (RG-Main PS)



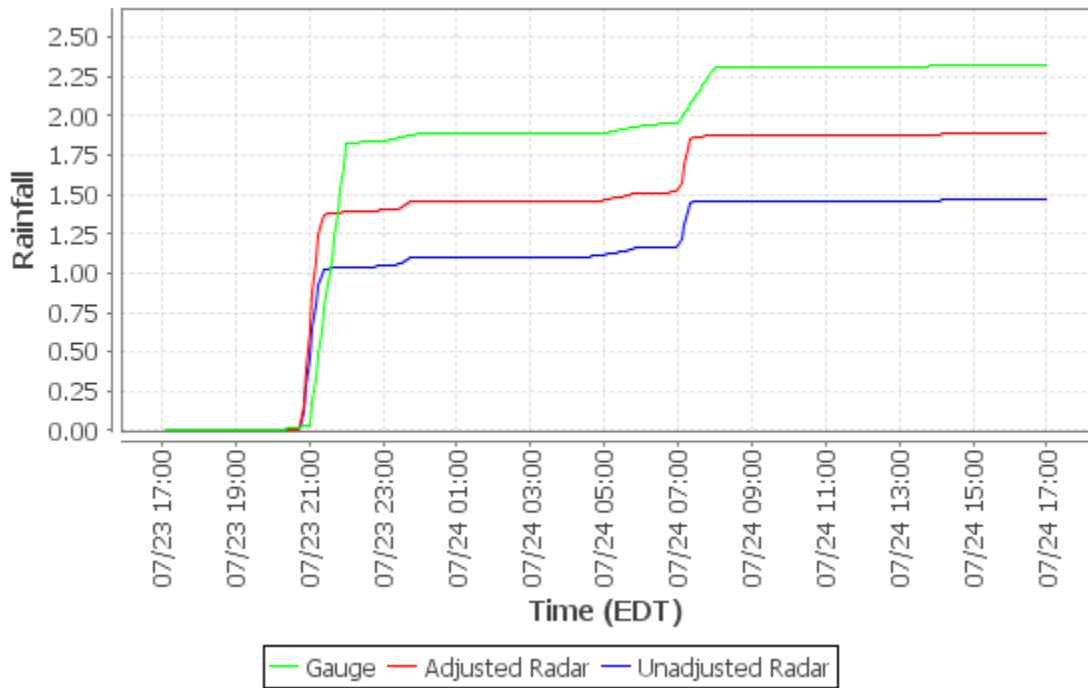
Cumulative Distribution Plot - FOURMILE RUN AT ALEXANDRIA (01652500)



Cumulative Distribution Plot - RG-RCPS (RG-RCPS)

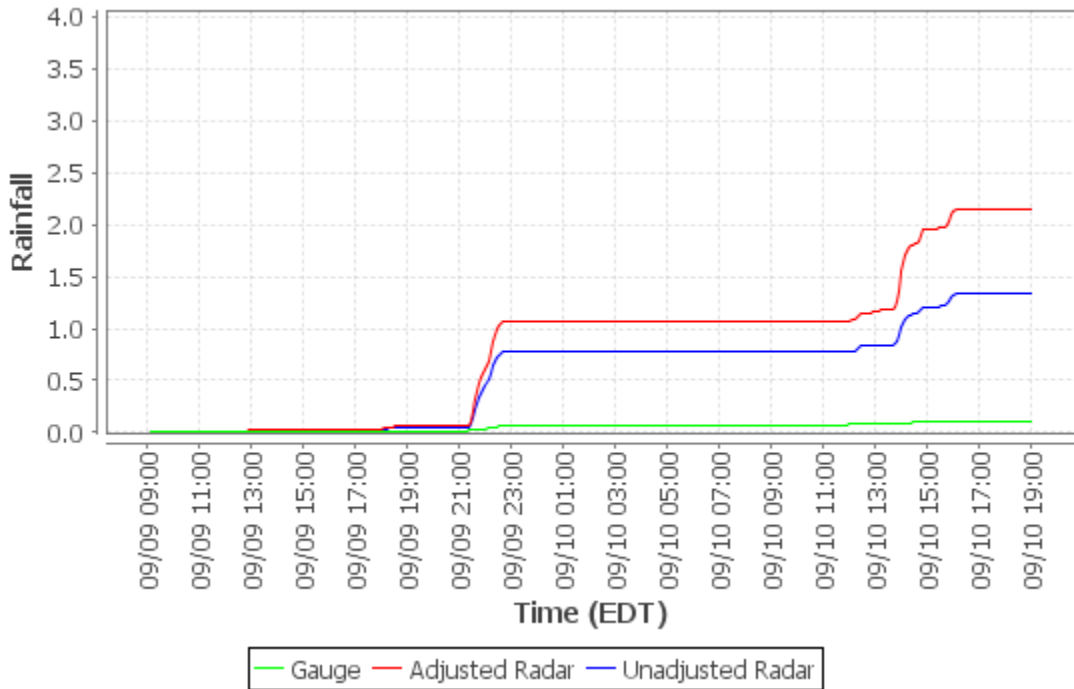


Cumulative Distribution Plot - Washington Reagan National Airport (KDCA)

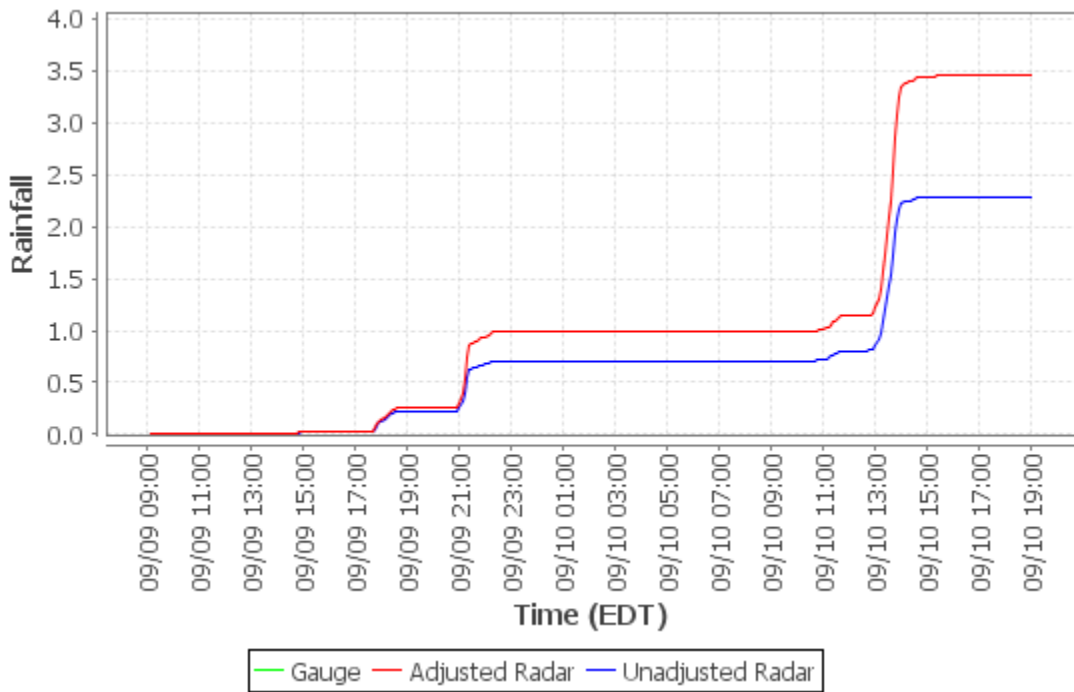


Appendix E - Event 3 (2020-09-10) CDPs

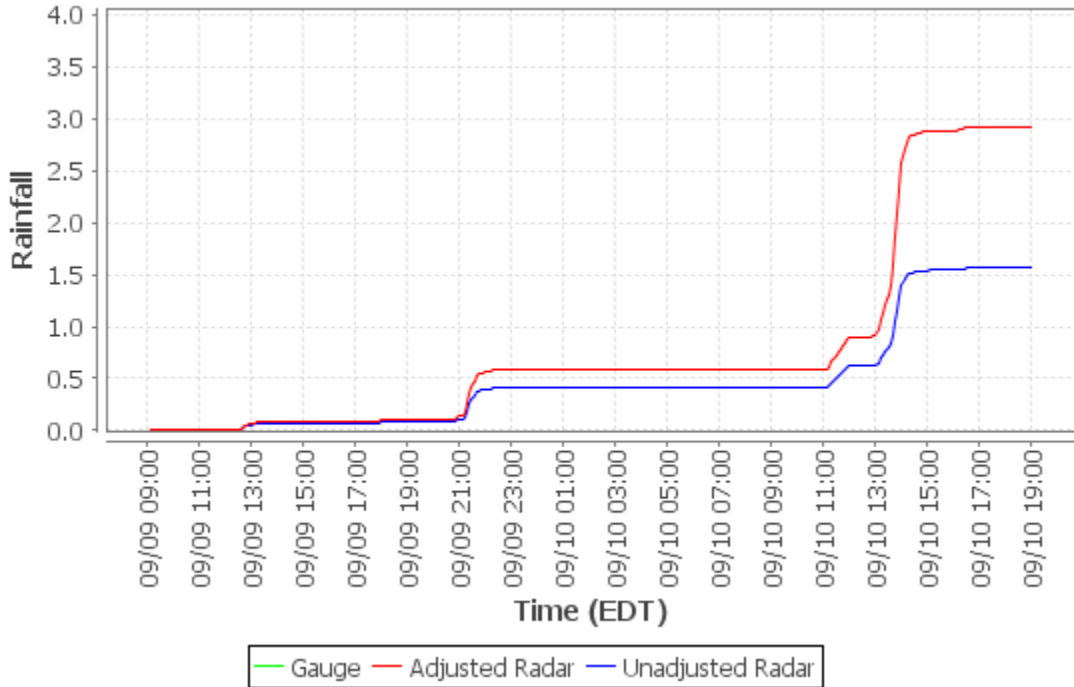
Cumulative Distribution Plot - Lake Barcroft (10001)



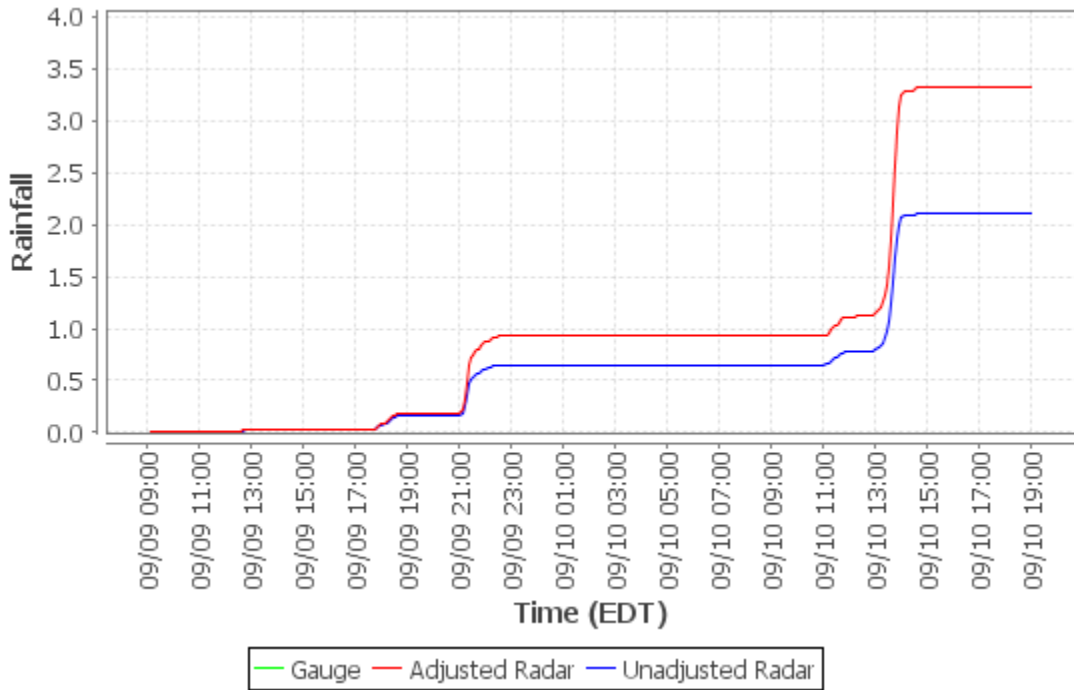
Cumulative Distribution Plot - Windmill Hill Park (20101)



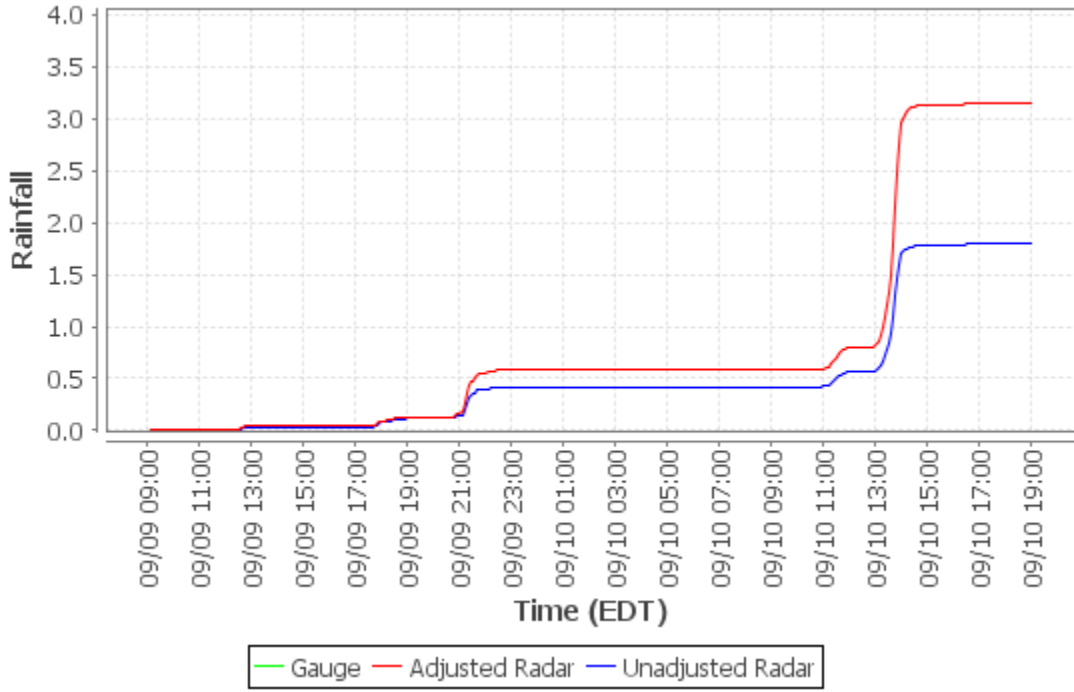
Cumulative Distribution Plot - Charles Barrett Elementary (20102)



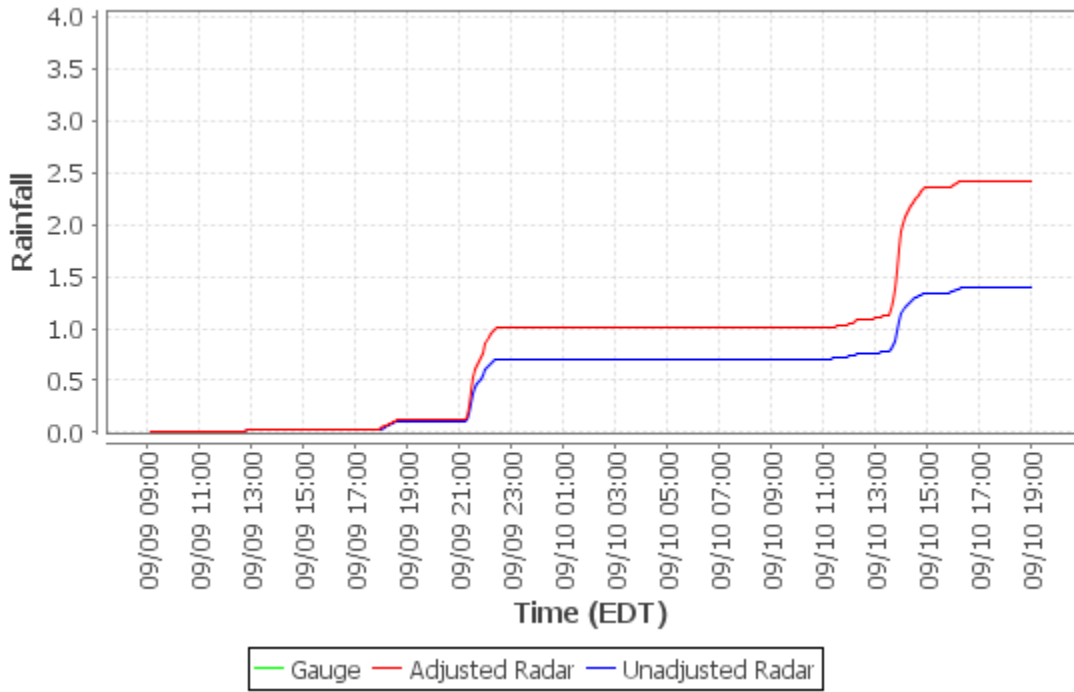
Cumulative Distribution Plot - Beach Park (20103)



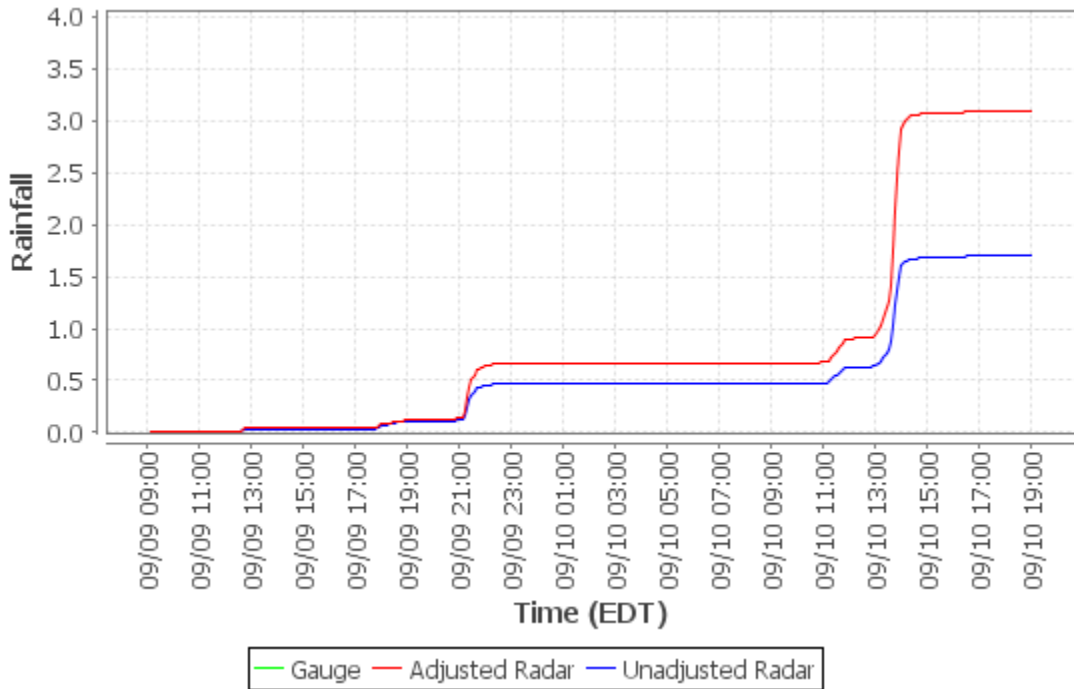
Cumulative Distribution Plot - Mount Vernon Elementary (20104)



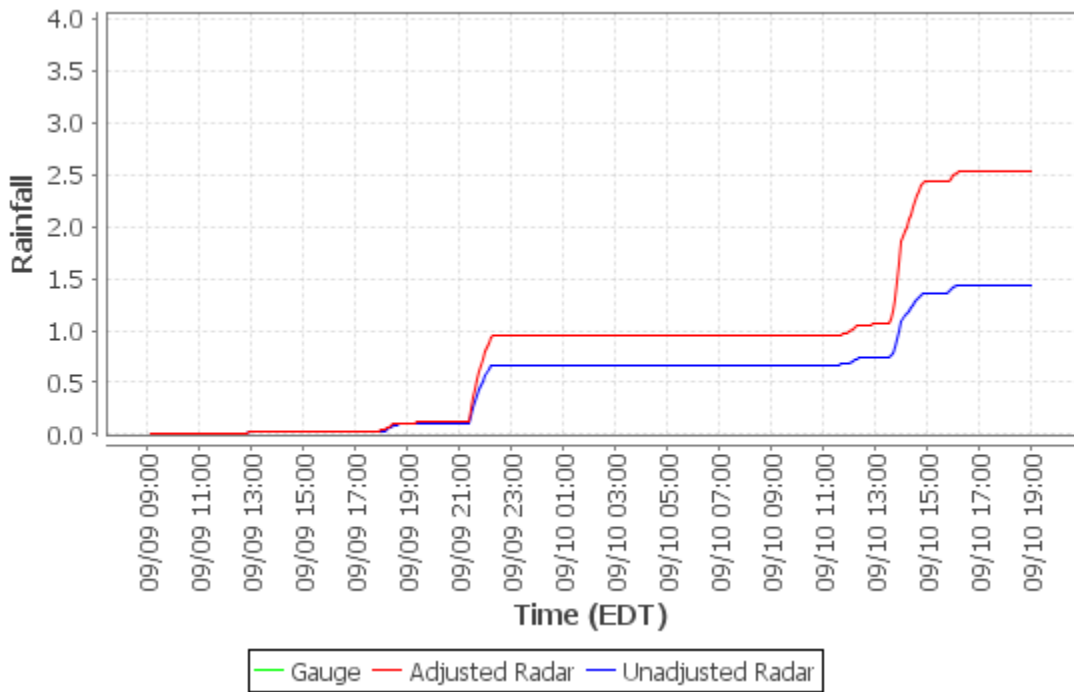
Cumulative Distribution Plot - Francis Hammond Middle School (20105)



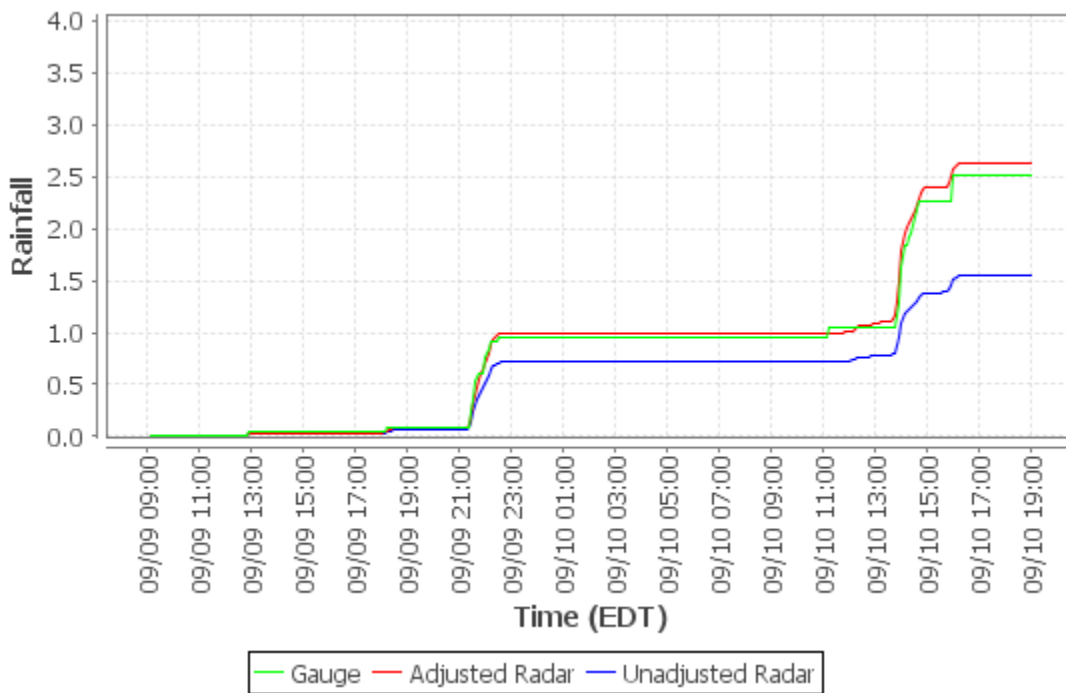
Cumulative Distribution Plot - George Mason Elementary (20106)



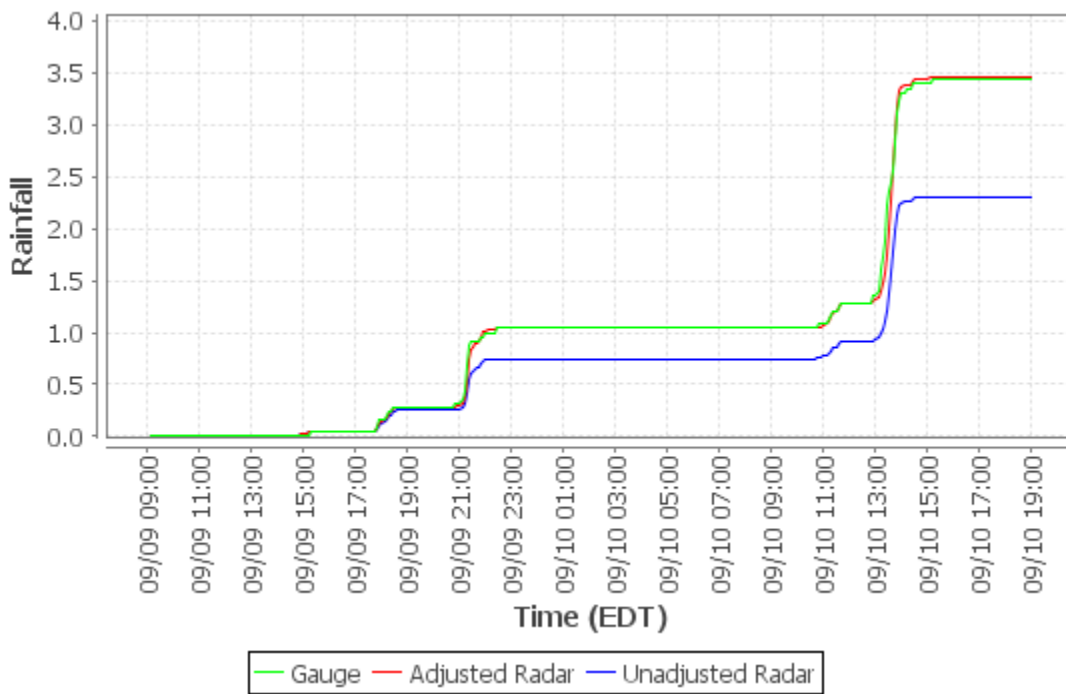
Cumulative Distribution Plot - Holmes Run @ Van Dorn (20116)



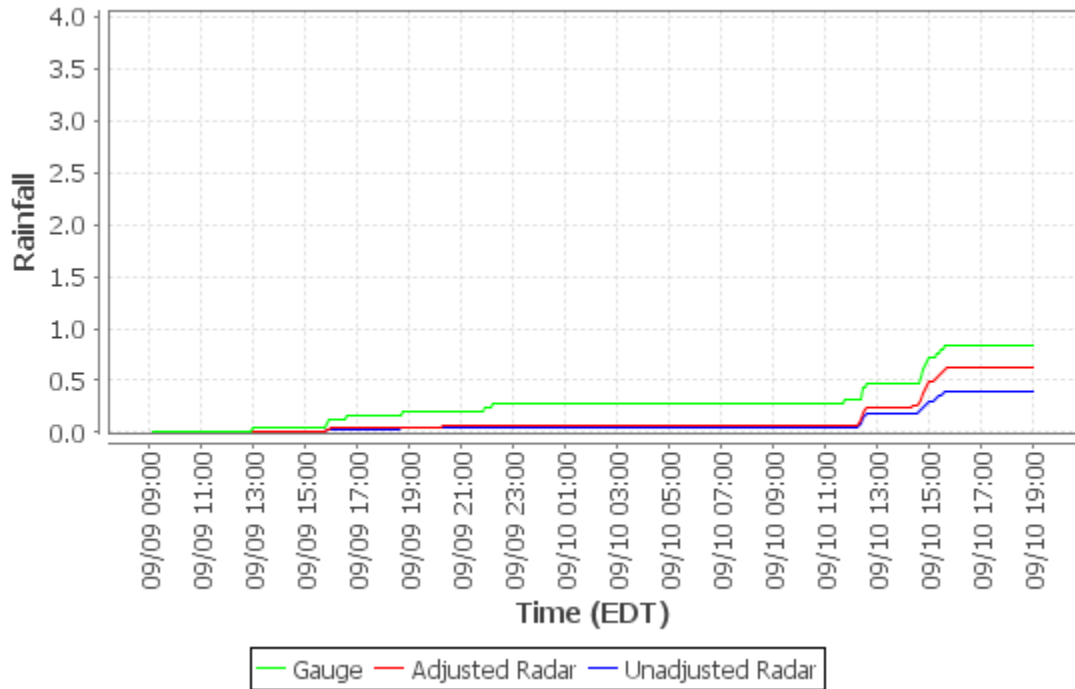
Cumulative Distribution Plot - Holmes Run Parkway (20117)



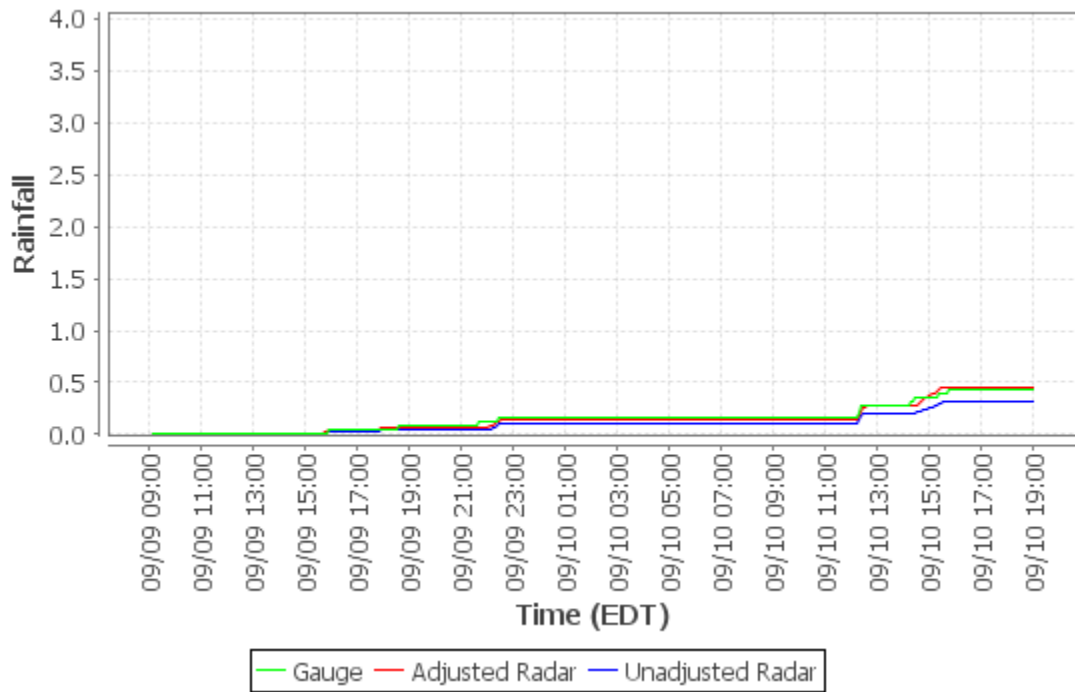
Cumulative Distribution Plot - Huntington Levee - Ponding Area (980)



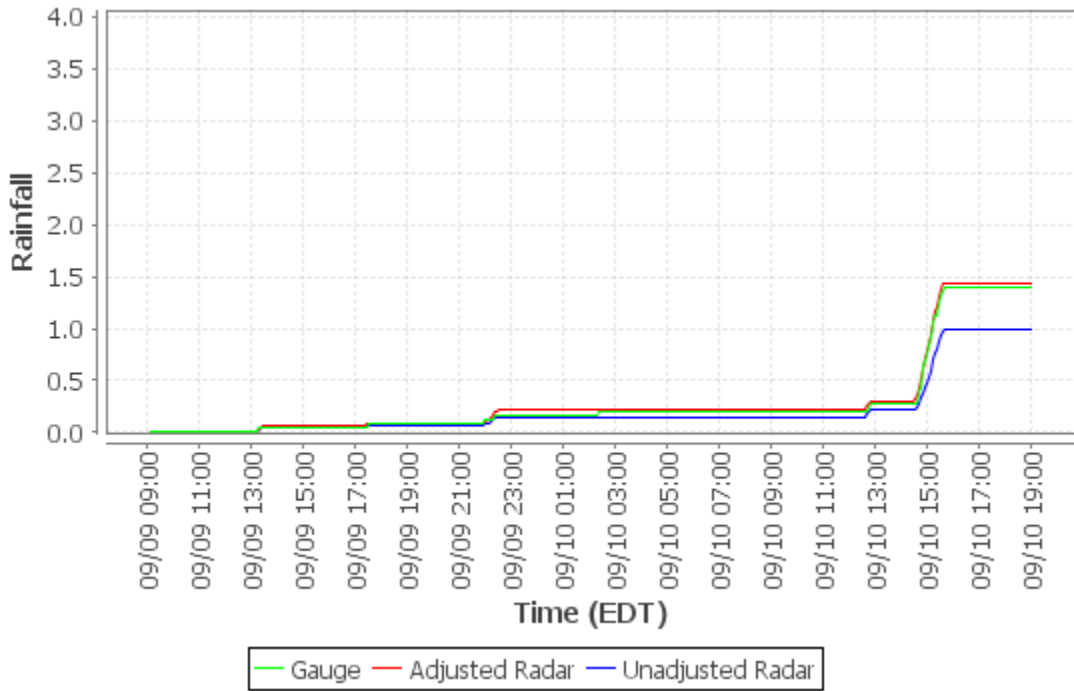
Cumulative Distribution Plot - Huntsman Lake (1000)



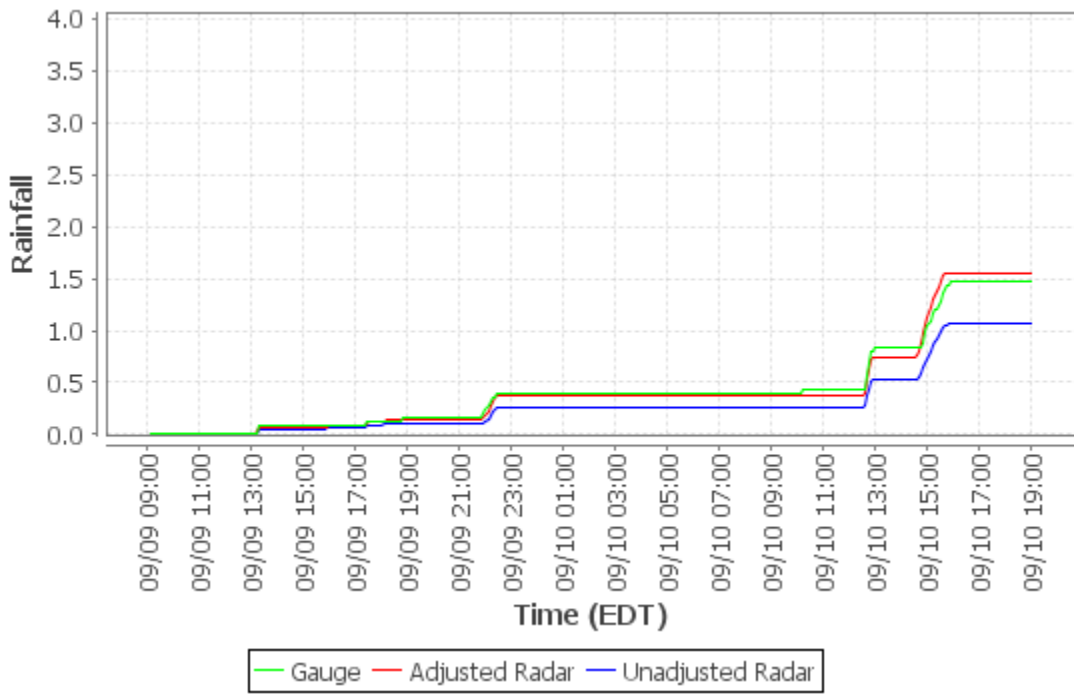
Cumulative Distribution Plot - Lake Mercer (1030)



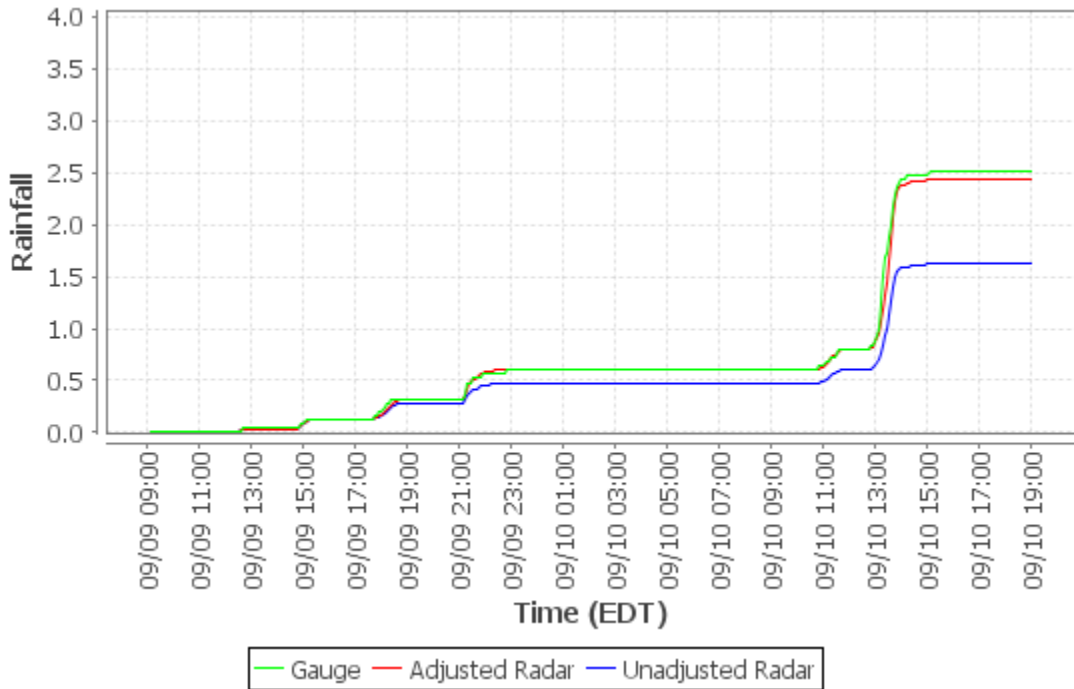
Cumulative Distribution Plot - Royal Lake (1040)



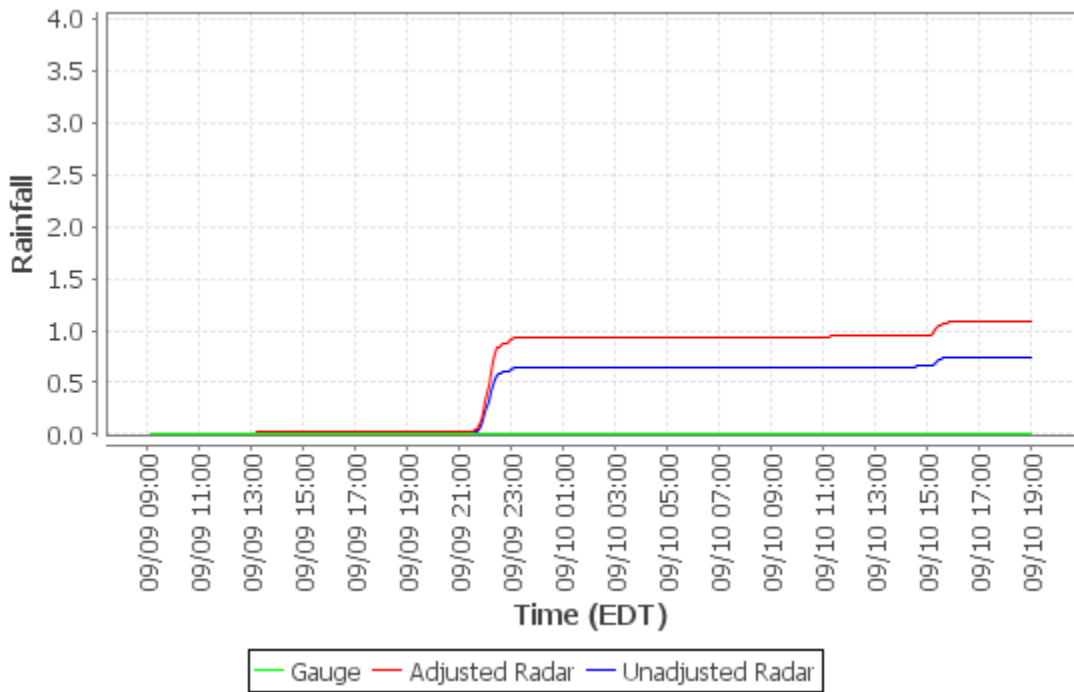
Cumulative Distribution Plot - Lake Braddock (1050)



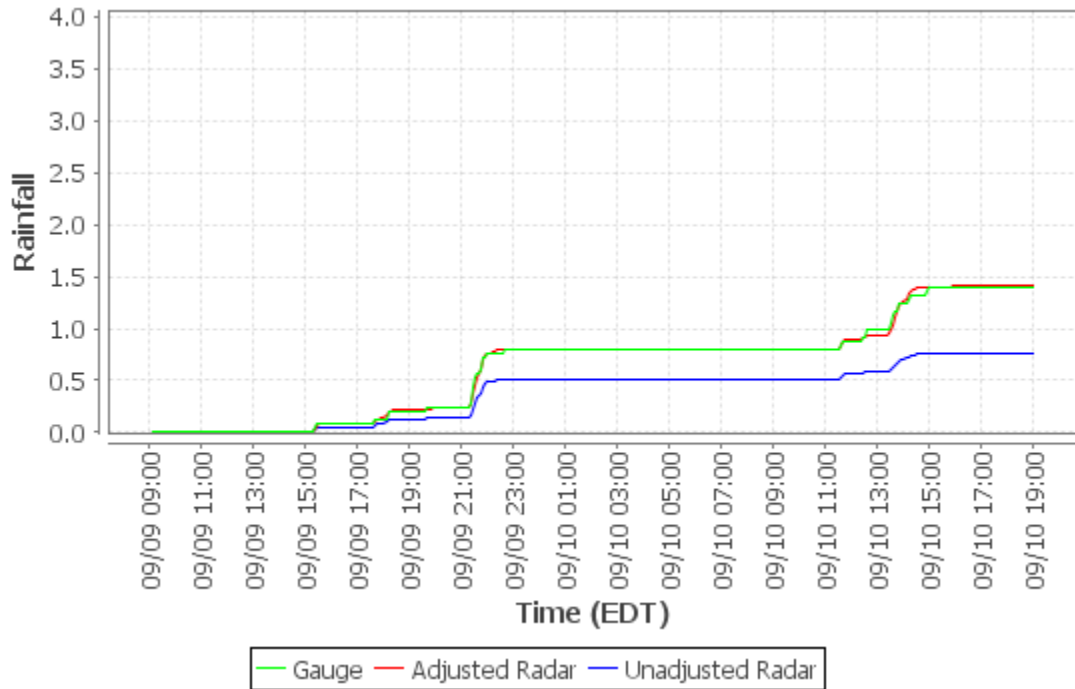
Cumulative Distribution Plot - Pump Station (1070)



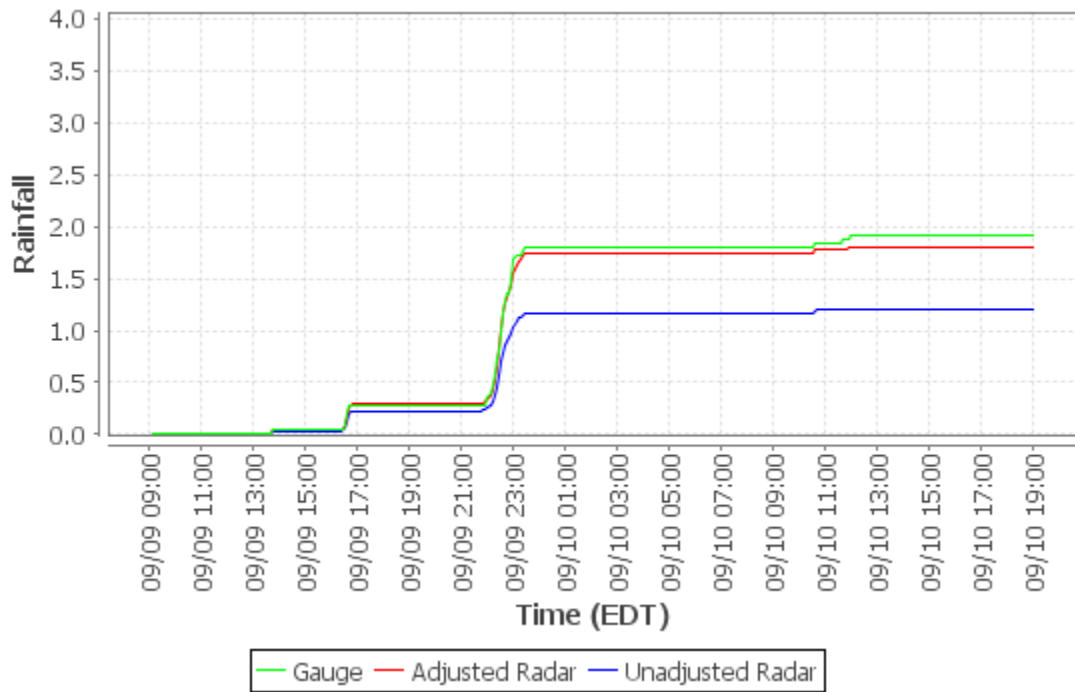
Cumulative Distribution Plot - Fairview Lake (1090)



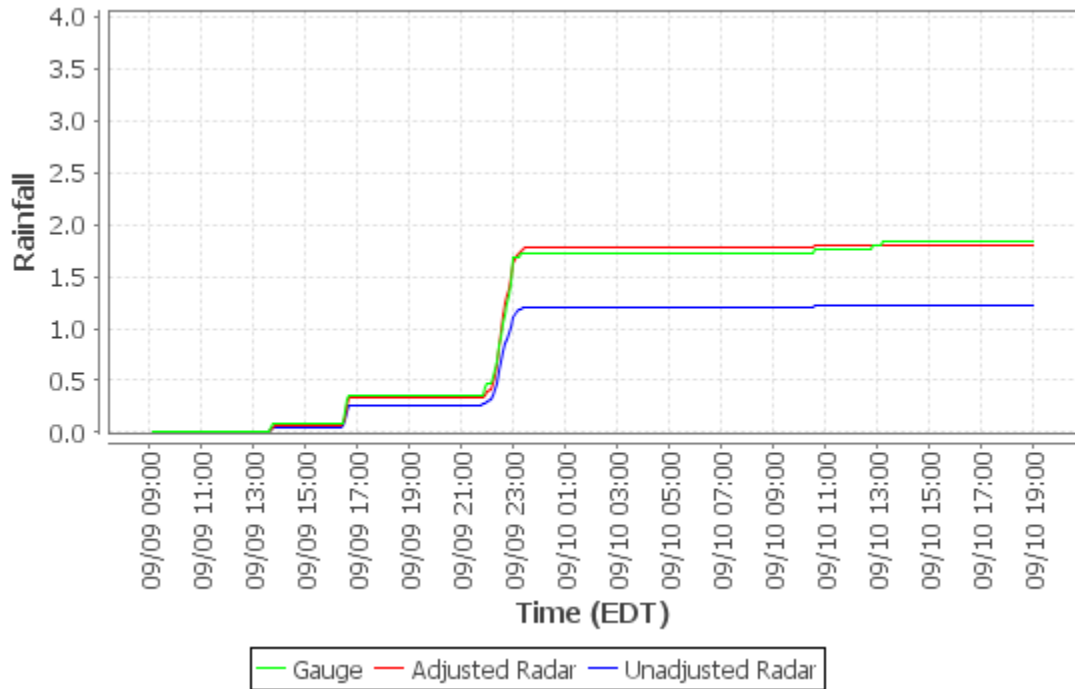
Cumulative Distribution Plot - Kingstowne Regional Pond 4 (1270)



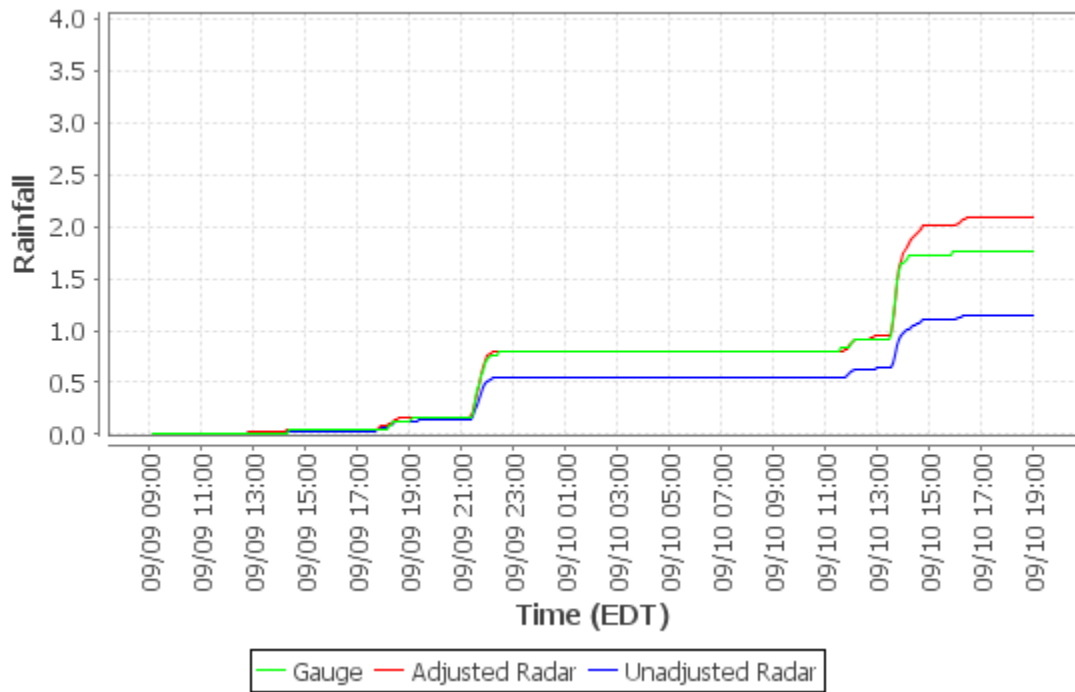
Cumulative Distribution Plot - Carrington (1280)



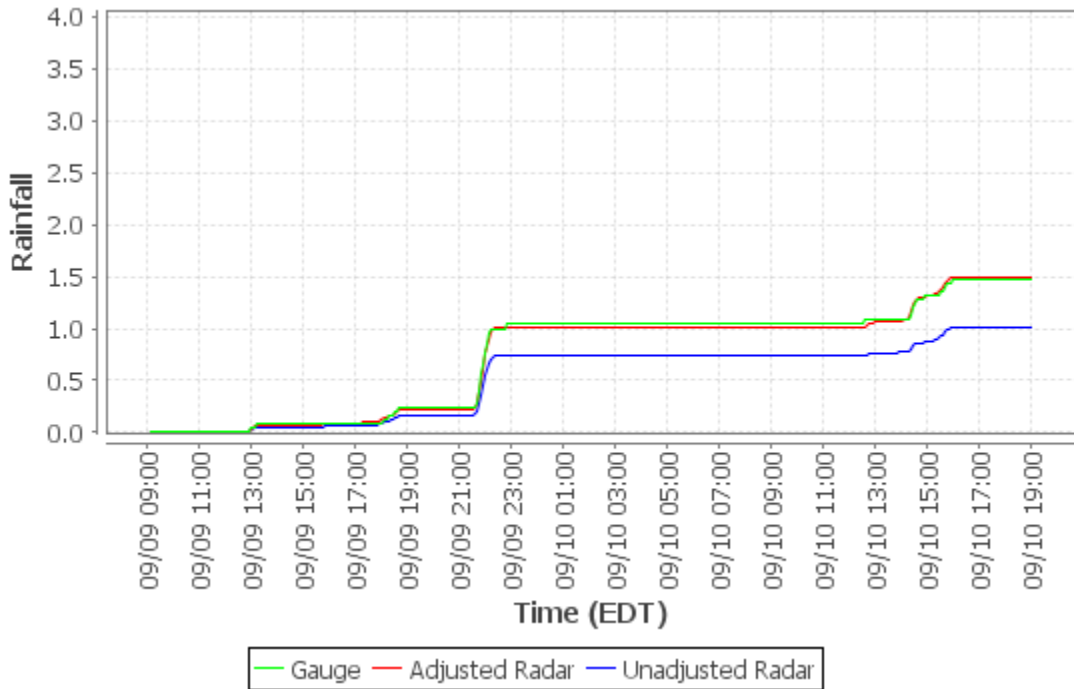
Cumulative Distribution Plot - Pulte/McLean (1300)



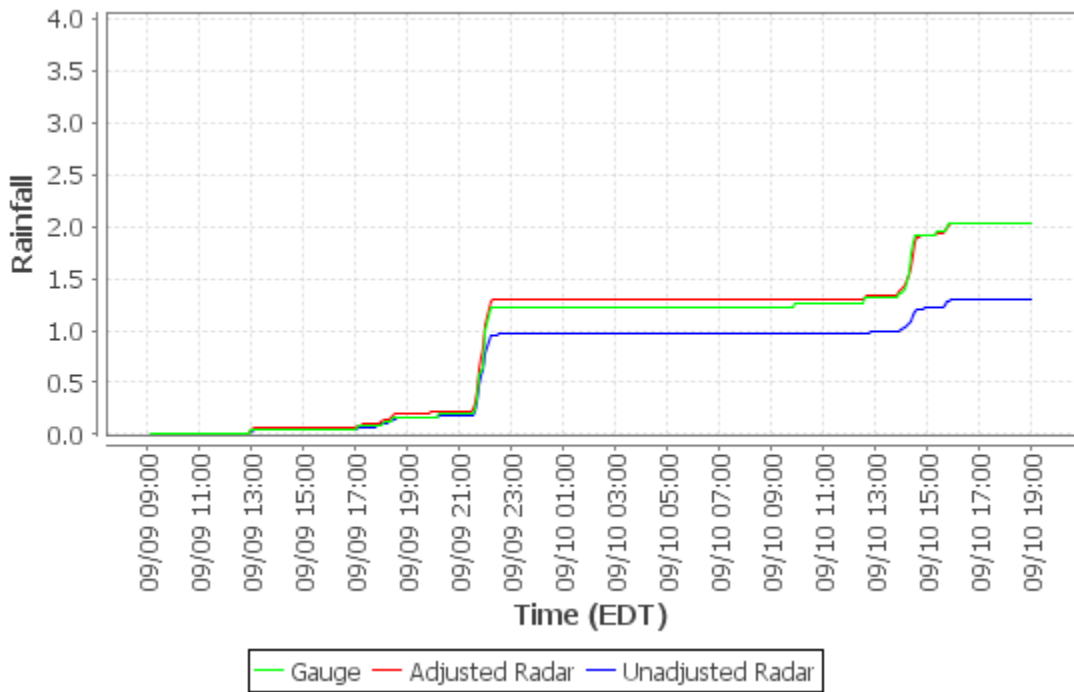
Cumulative Distribution Plot - Boothe Park (1350)



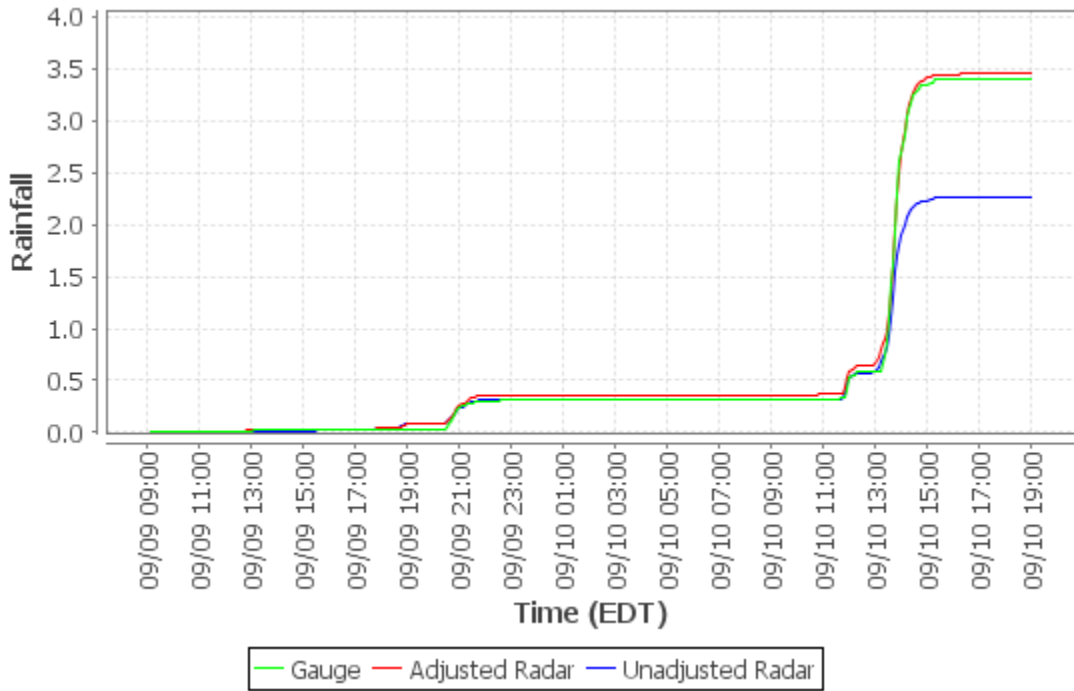
Cumulative Distribution Plot - Lake Accotink (FCPA) (1360)



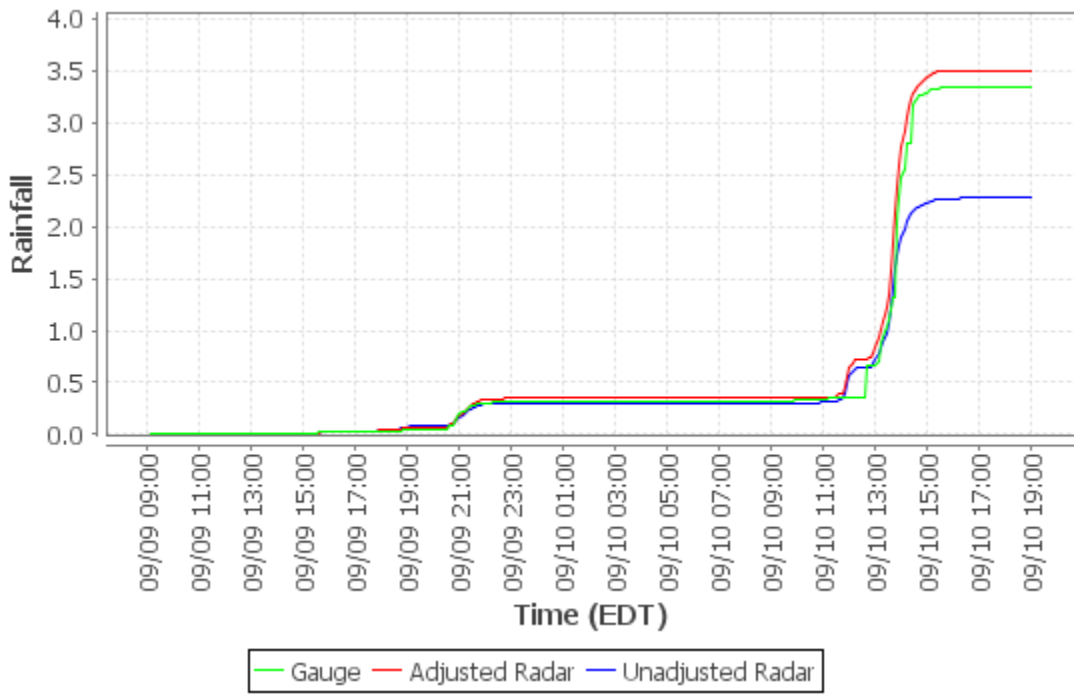
Cumulative Distribution Plot - Brookfield Park (1540)



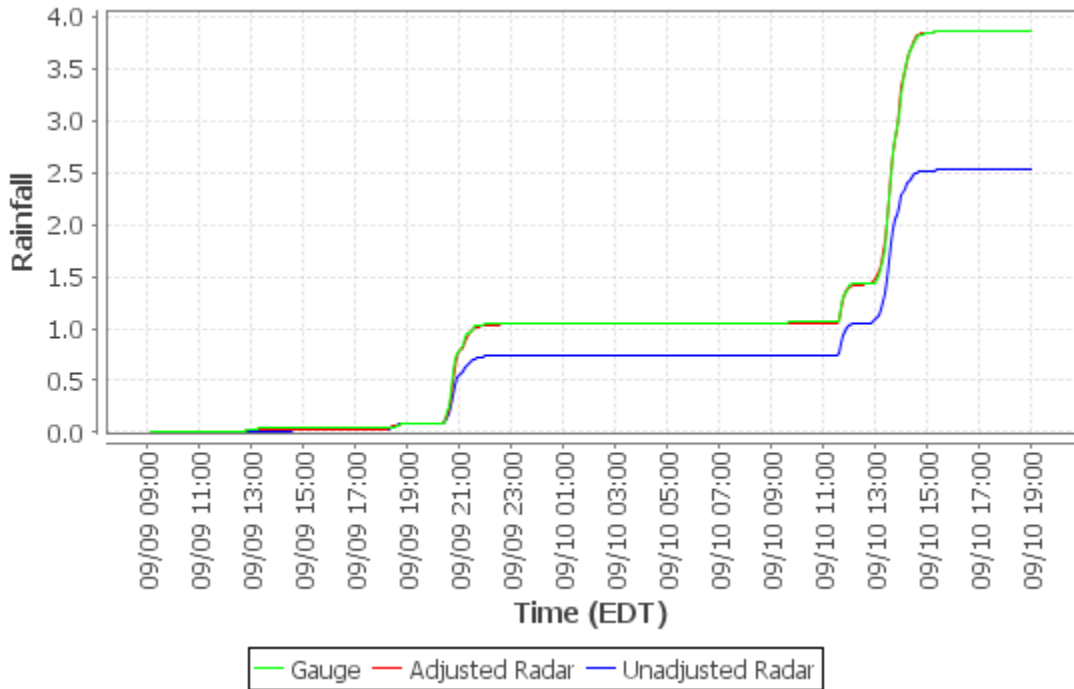
Cumulative Distribution Plot - RG-Brentwood (RG-Brentwood)



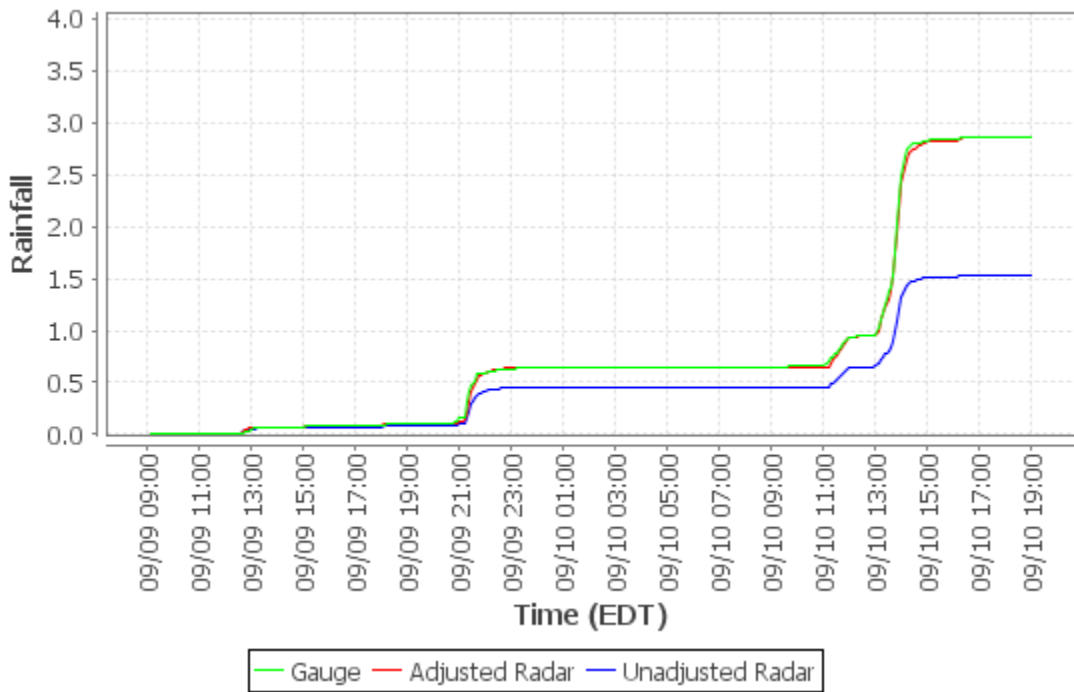
Cumulative Distribution Plot - RG-Bryant (RG-Bryant)



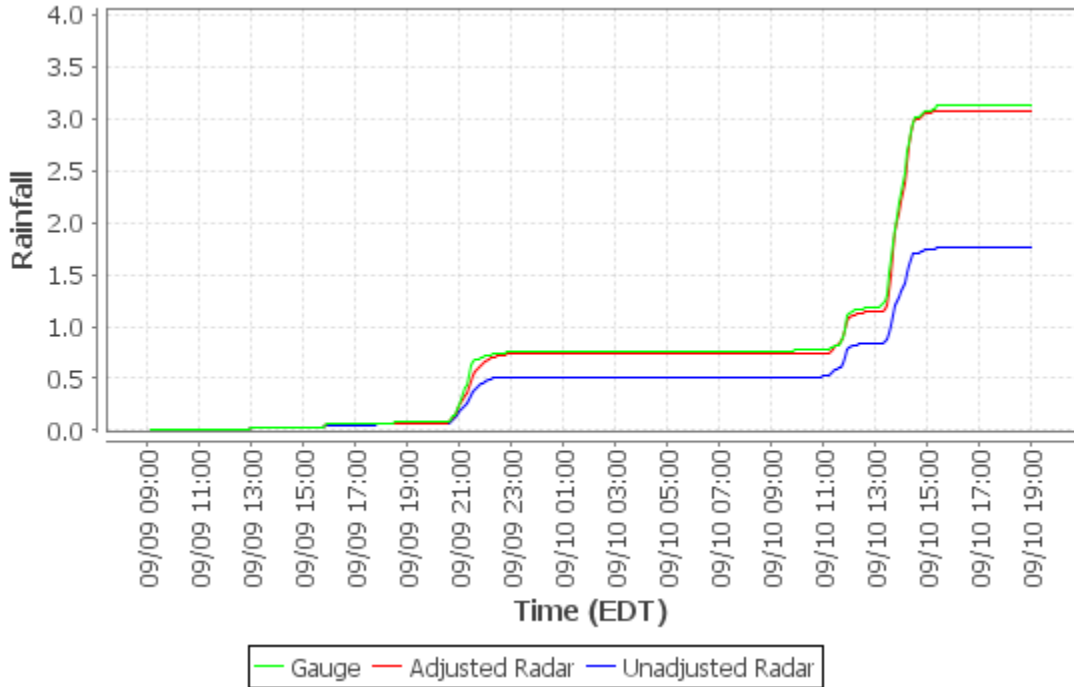
Cumulative Distribution Plot - RG-Main PS (RG-Main PS)



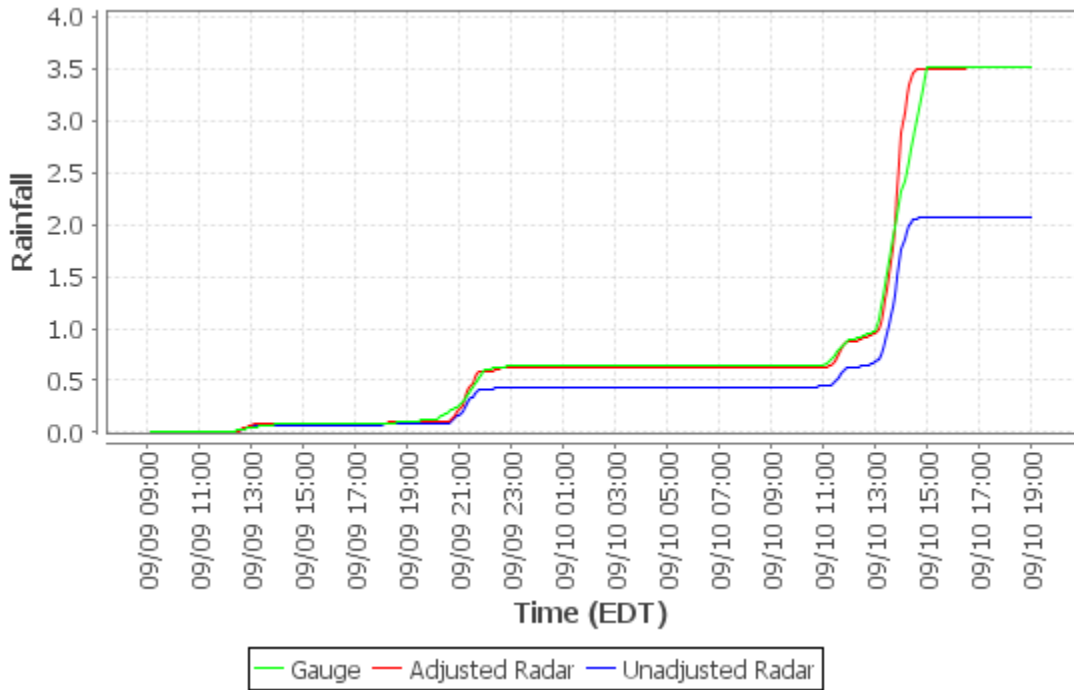
Cumulative Distribution Plot - FOURMILE RUN AT ALEXANDRIA (01652500)



Cumulative Distribution Plot - RG-RCPS (RG-RCPS)

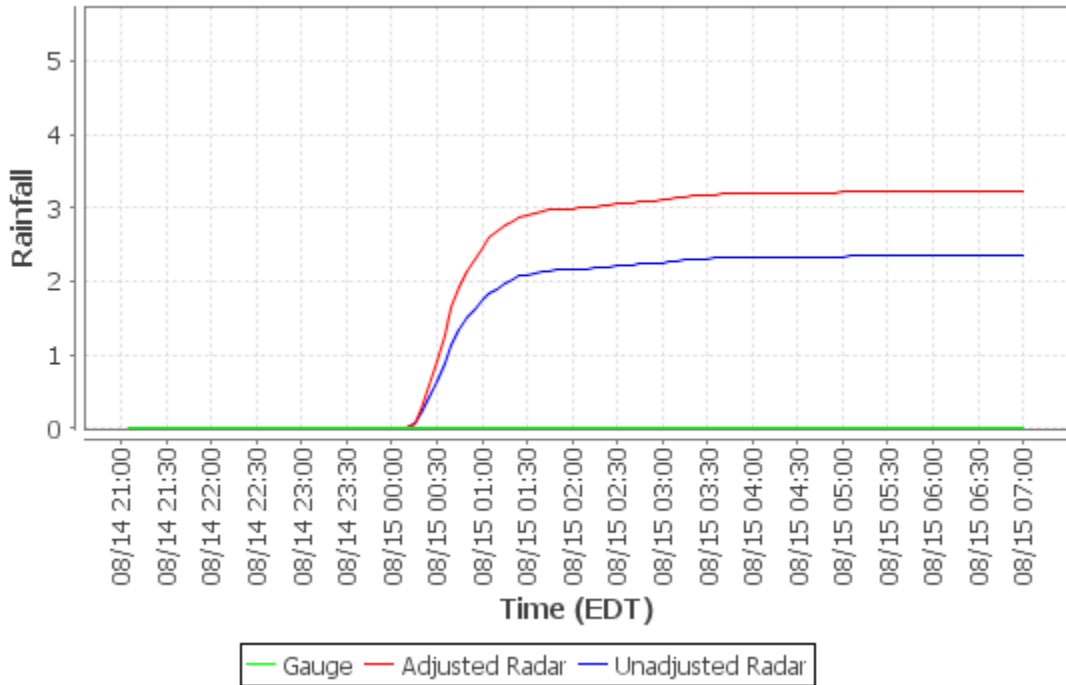


Cumulative Distribution Plot - Washington Reagan National Airport (KDCA)

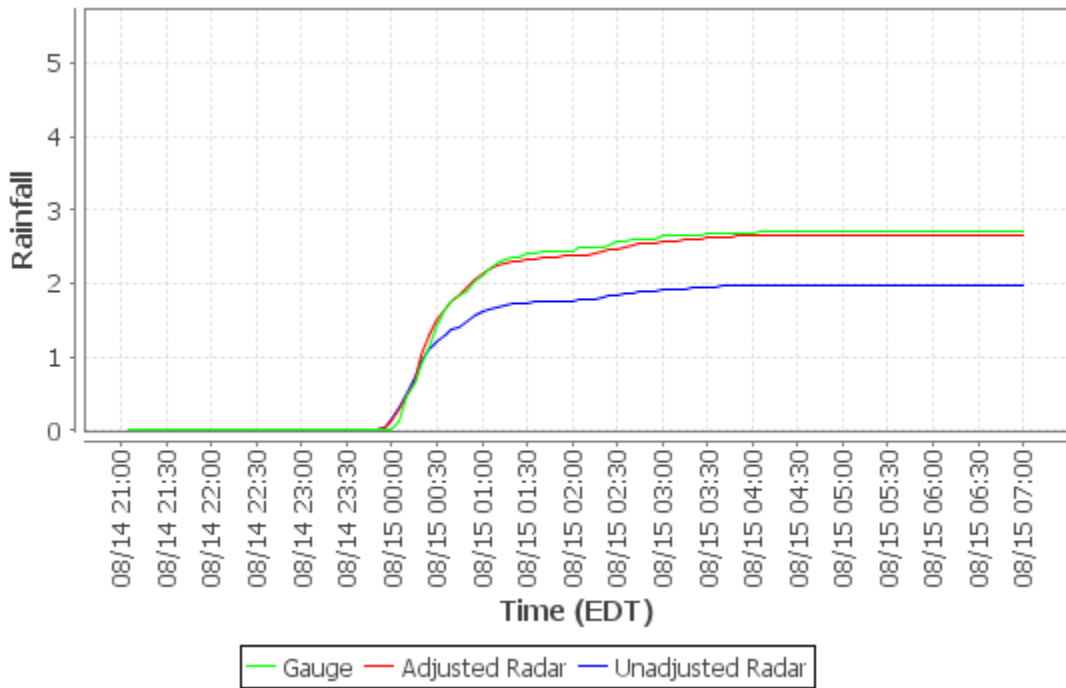


Appendix F - Event 4 (2021-08-15) CDPs

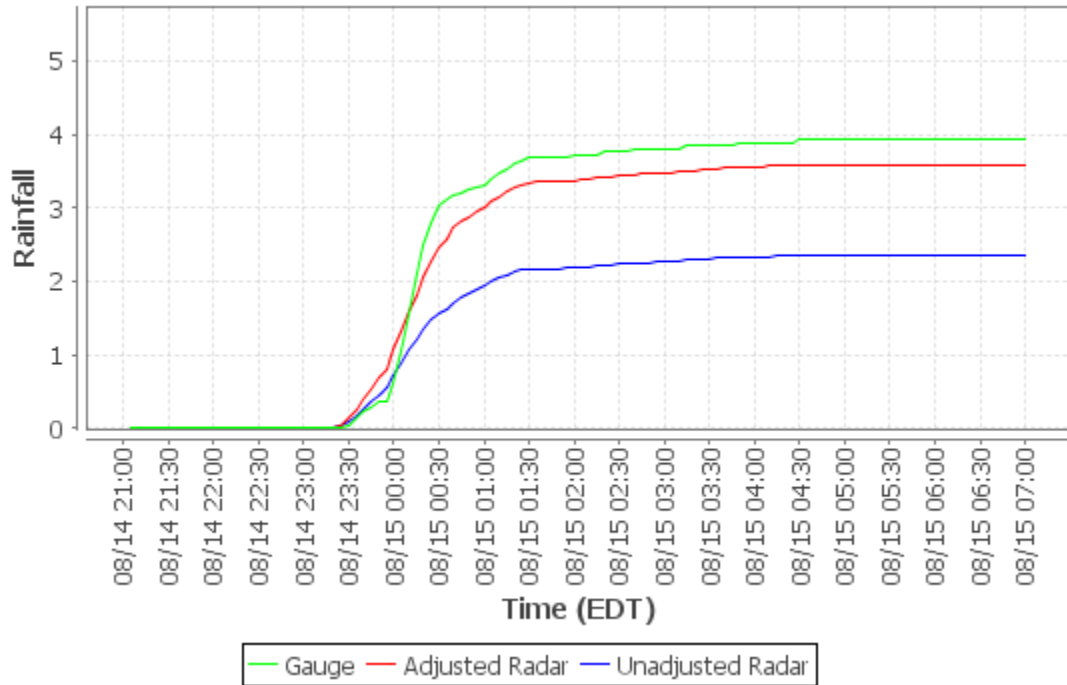
Cumulative Distribution Plot - Lake Barcroft (10001)



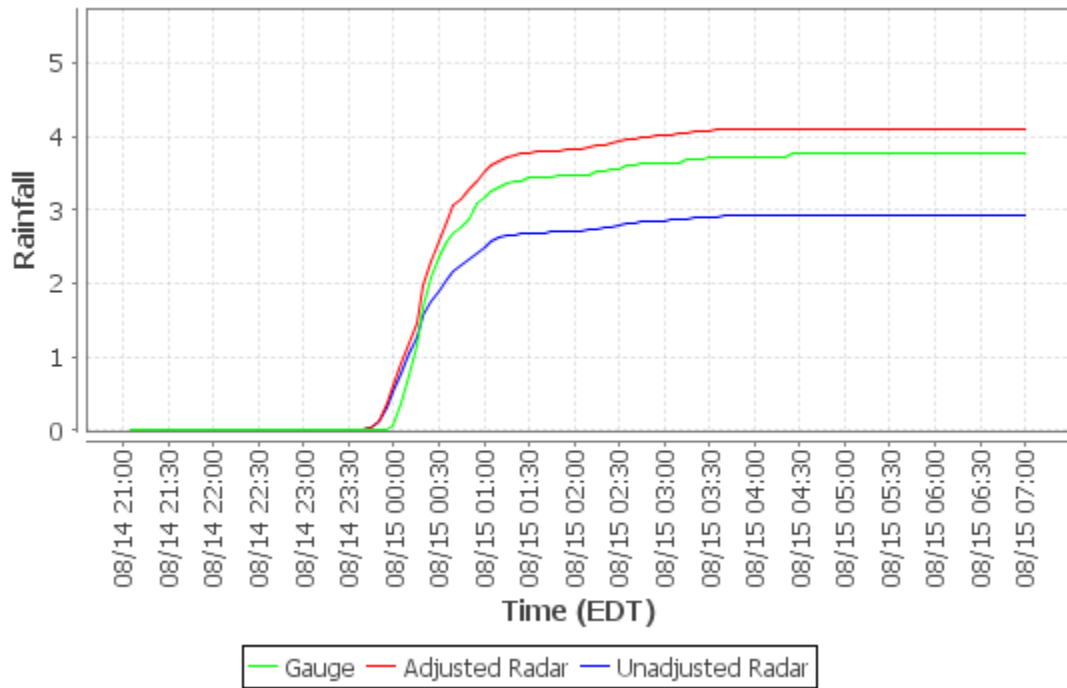
Cumulative Distribution Plot - Windmill Hill Park (20101)



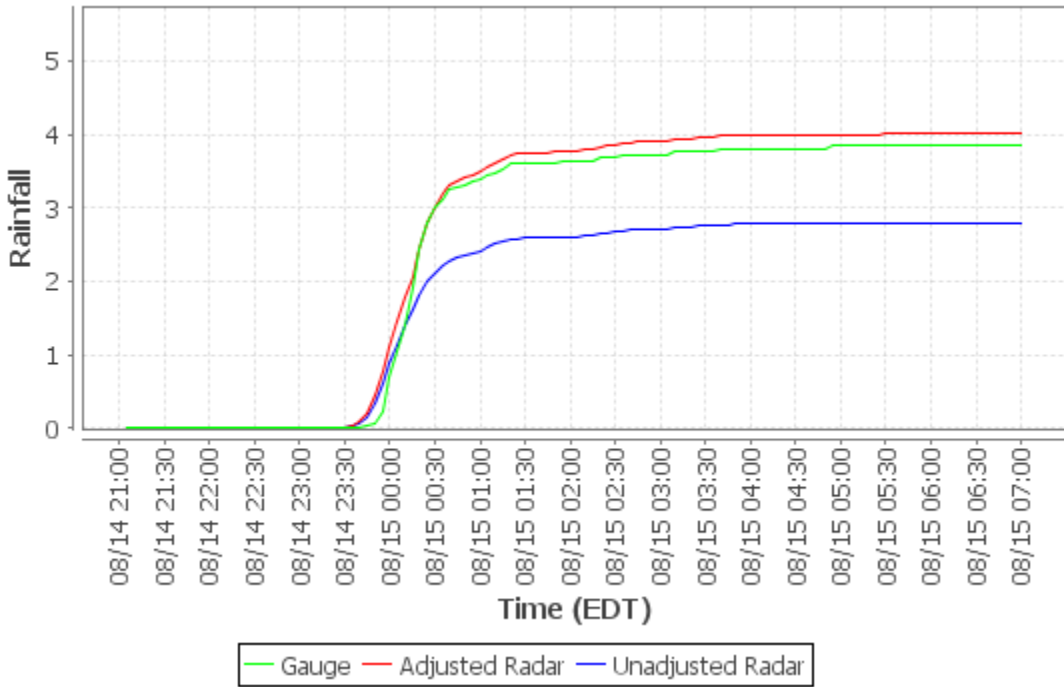
Cumulative Distribution Plot - Charles Barrett Elementary (20102)



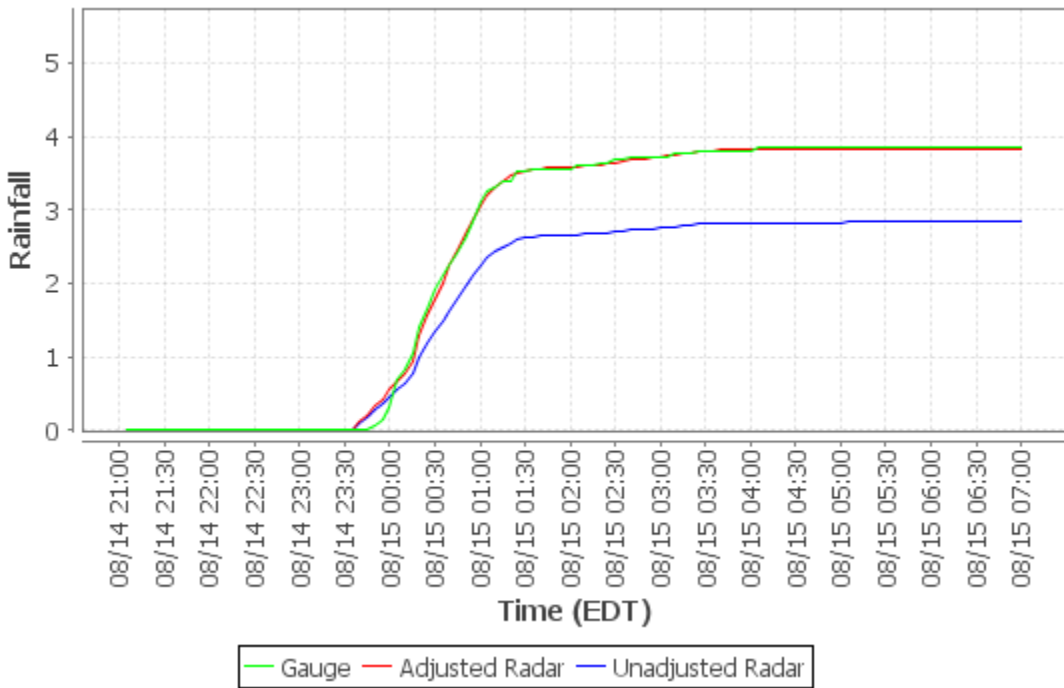
Cumulative Distribution Plot - Beach Park (20103)



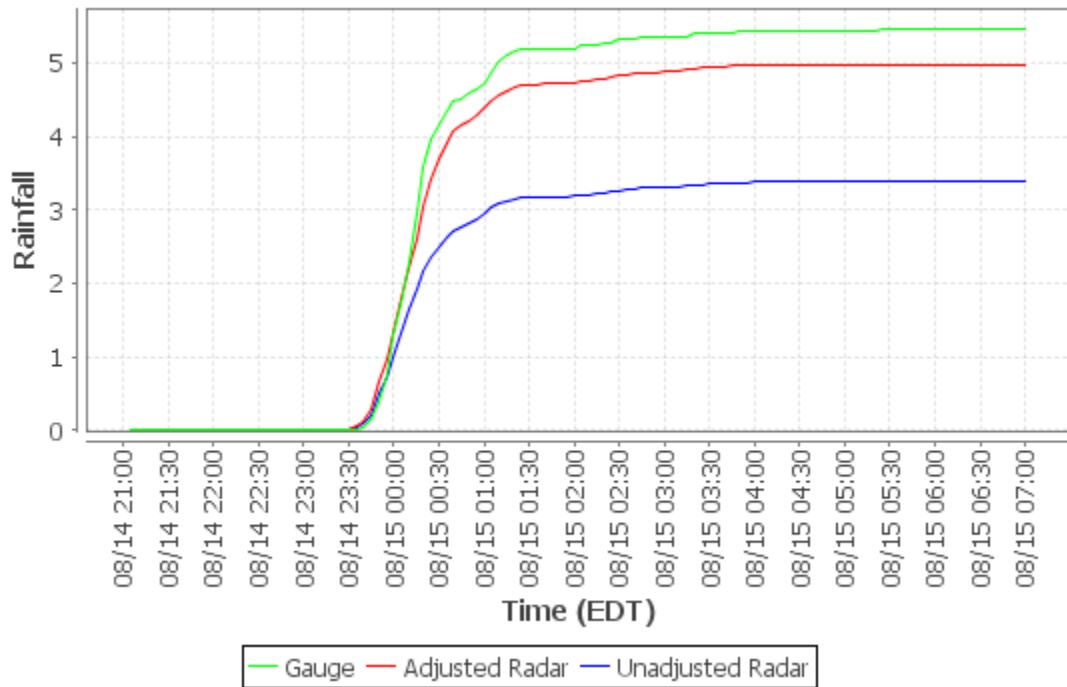
Cumulative Distribution Plot - Mount Vernon Elementary (20104)



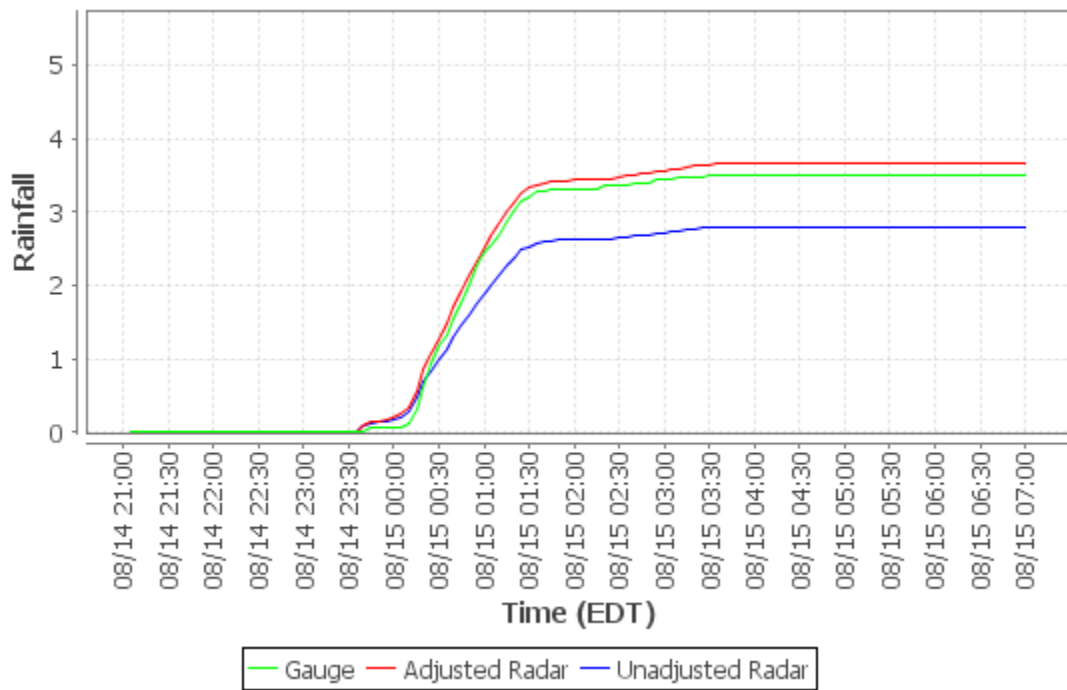
Cumulative Distribution Plot - Francis Hammond Middle School (20105)



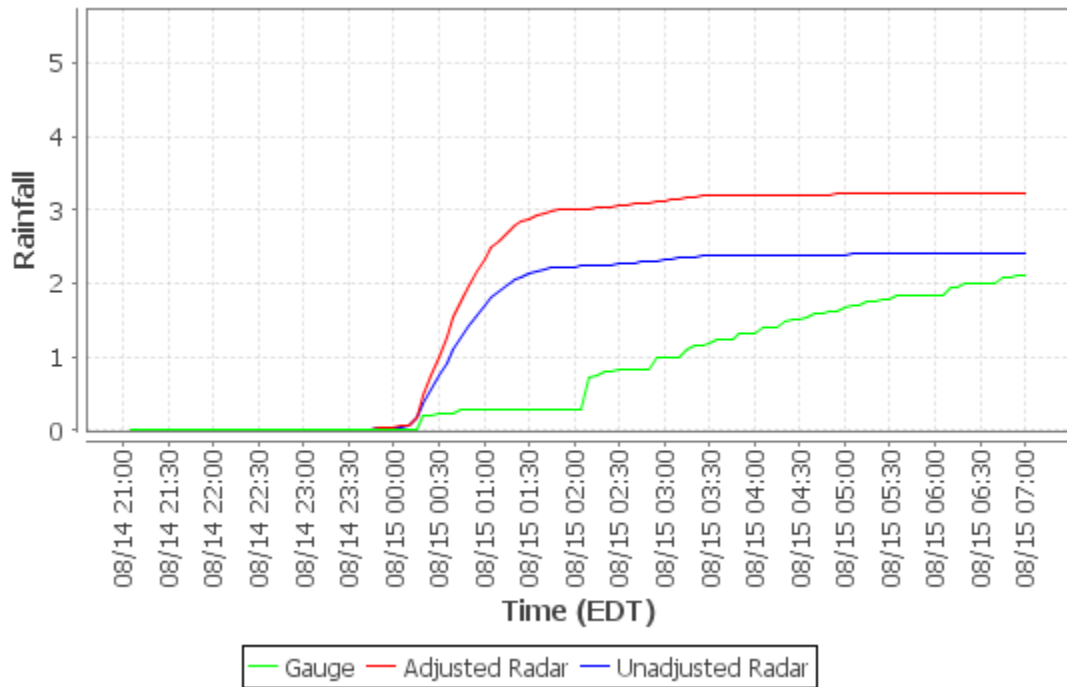
Cumulative Distribution Plot - George Mason Elementary (20106)



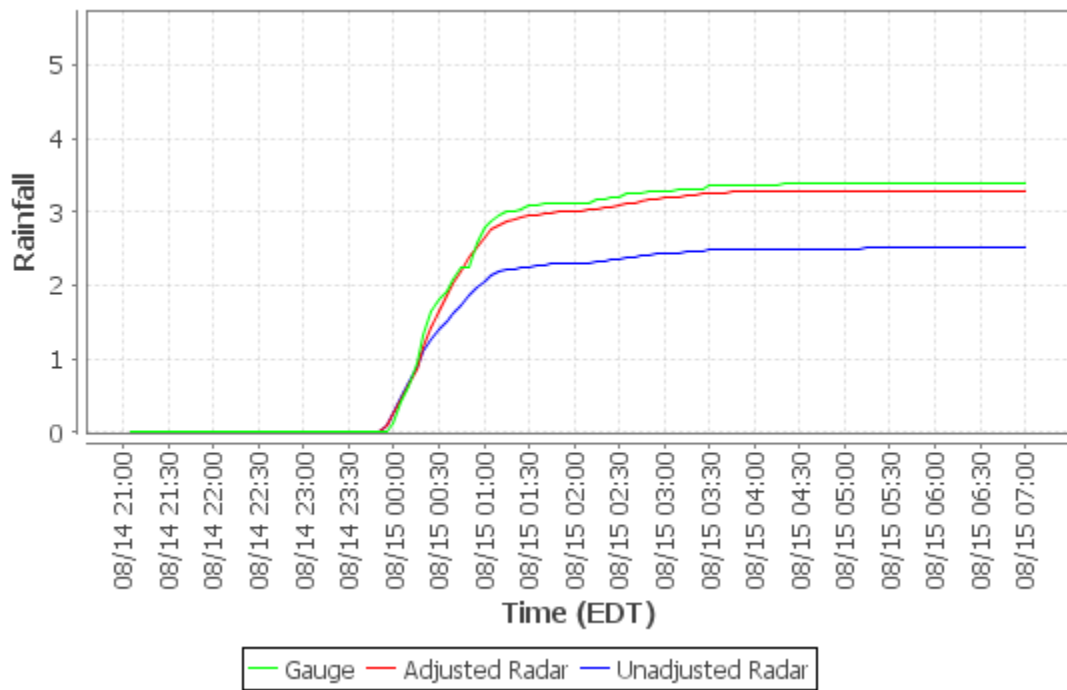
Cumulative Distribution Plot - Holmes Run @ Van Dorn (20116)



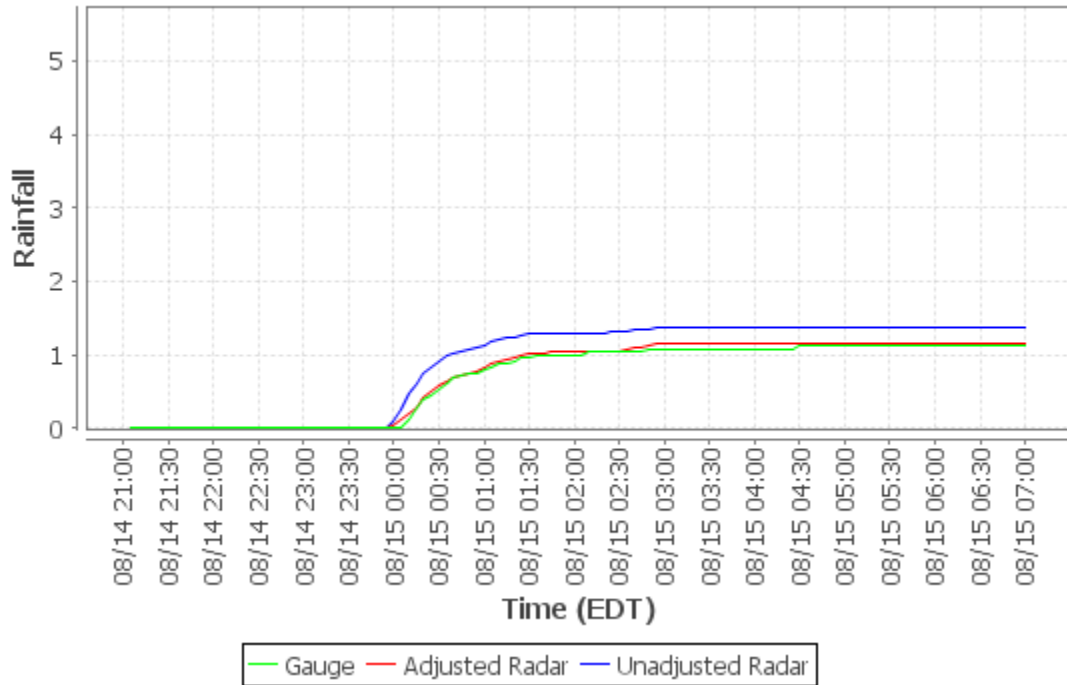
Cumulative Distribution Plot - Holmes Run Parkway (20117)



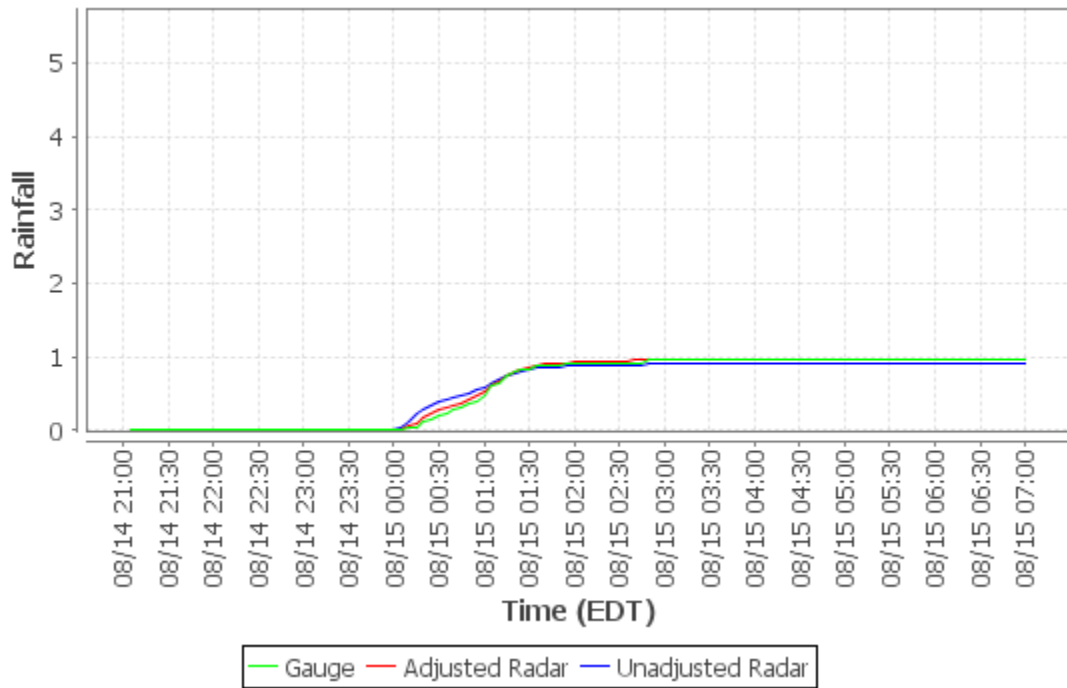
Cumulative Distribution Plot - Huntington Levee - Ponding Area (980)



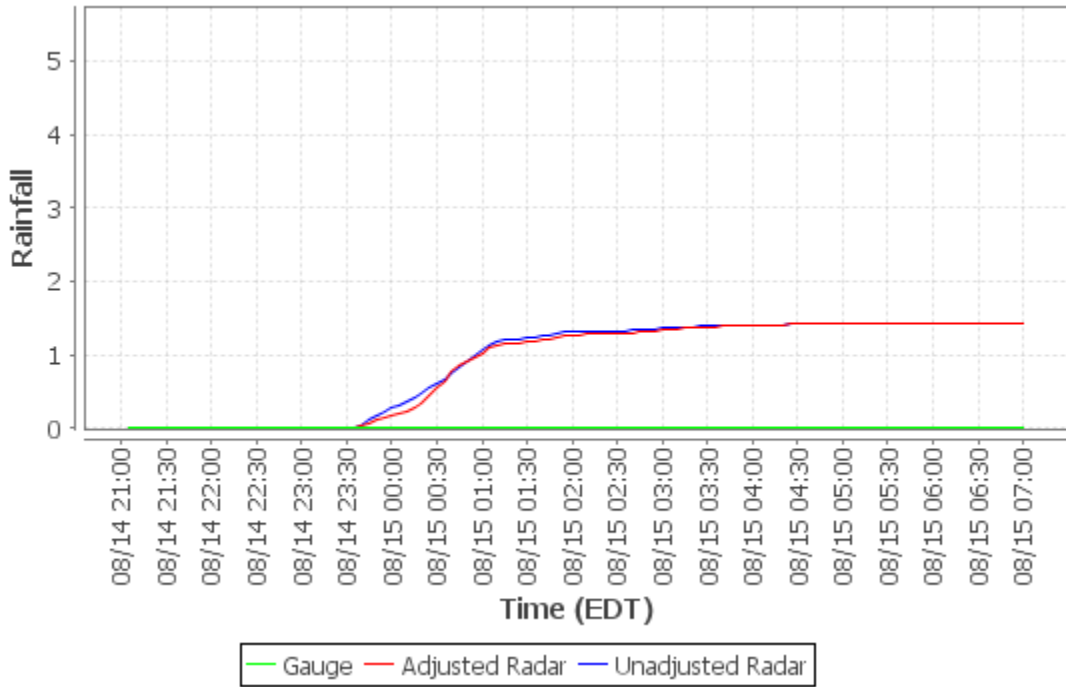
Cumulative Distribution Plot - Huntsman Lake (1000)



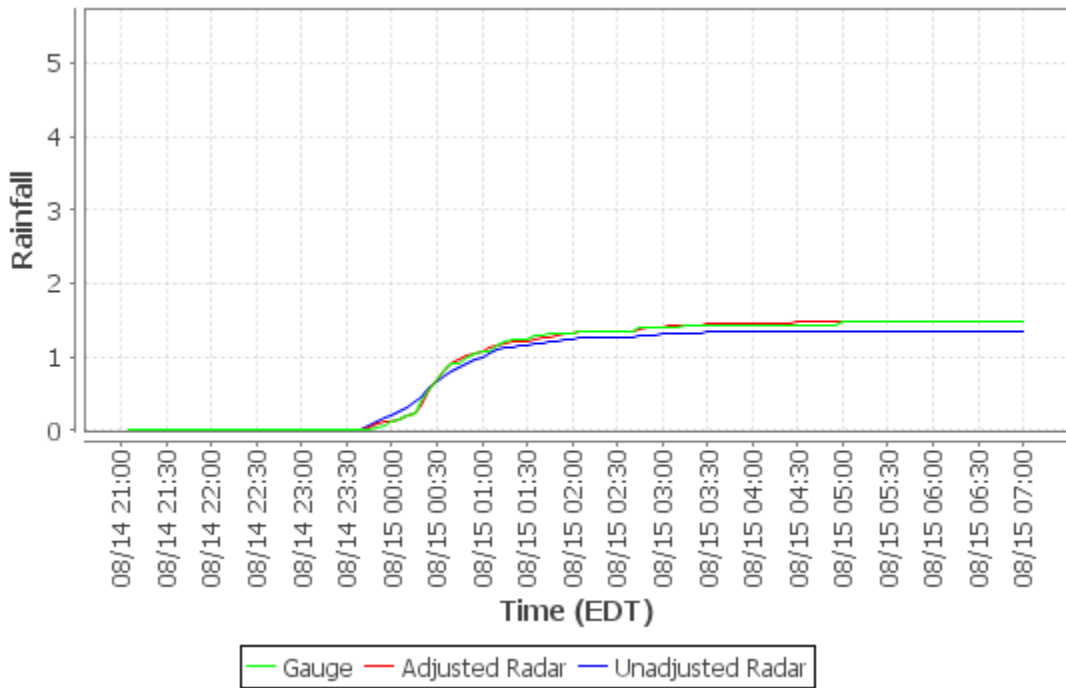
Cumulative Distribution Plot - Lake Mercer (1030)



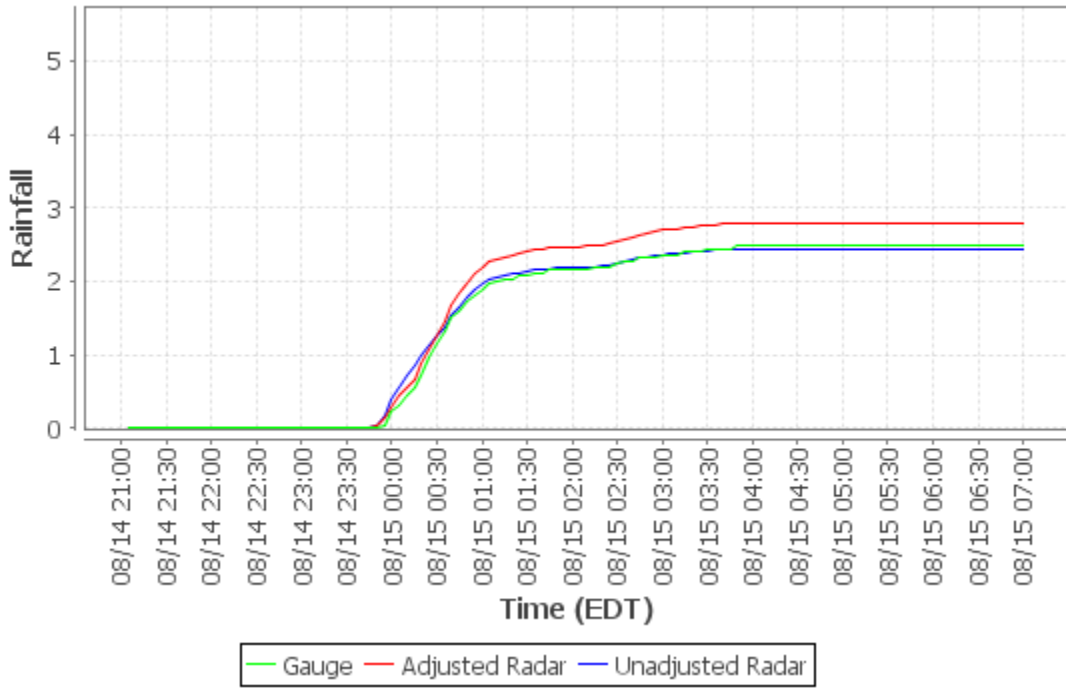
Cumulative Distribution Plot - Royal Lake (1040)



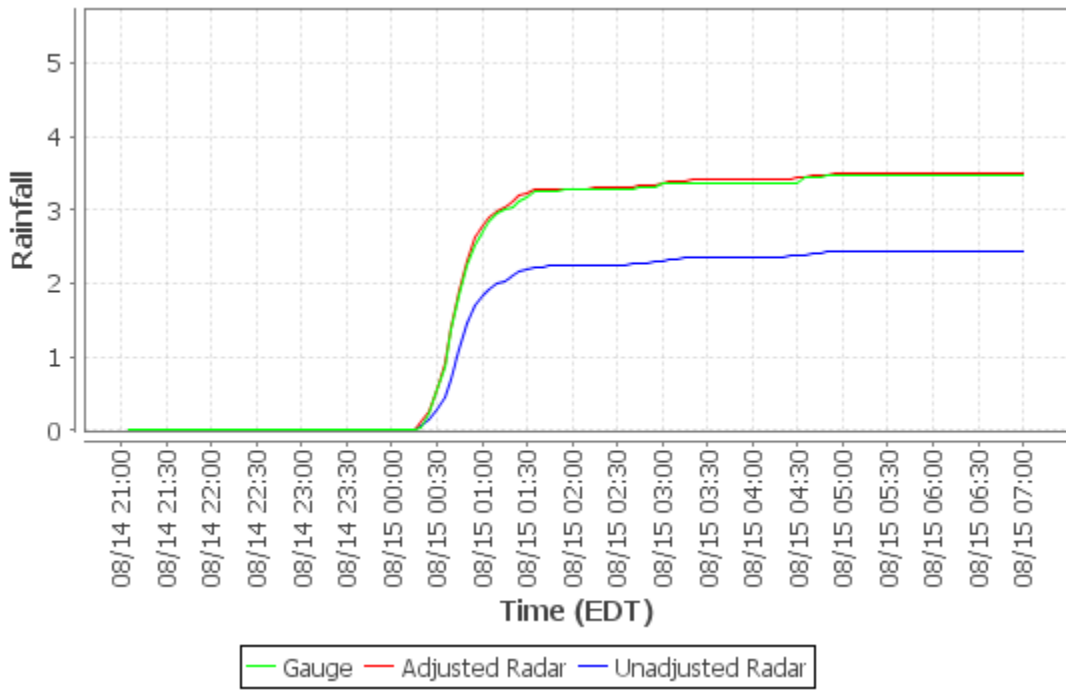
Cumulative Distribution Plot - Lake Braddock (1050)



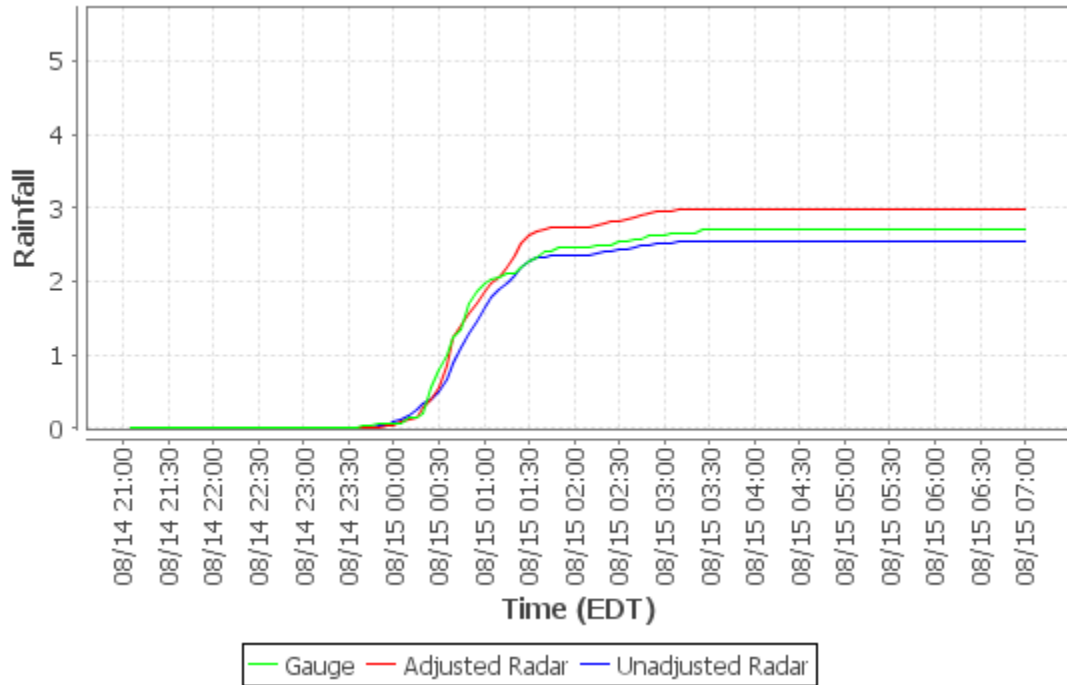
Cumulative Distribution Plot - Pump Station (1070)



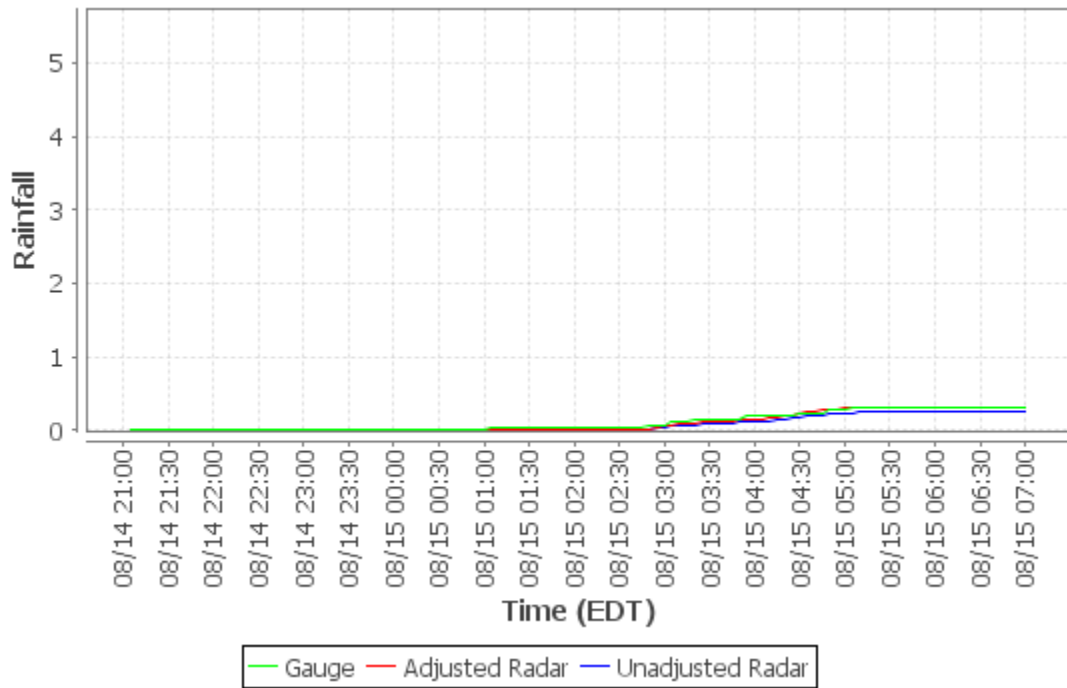
Cumulative Distribution Plot - Fairview Lake (1090)



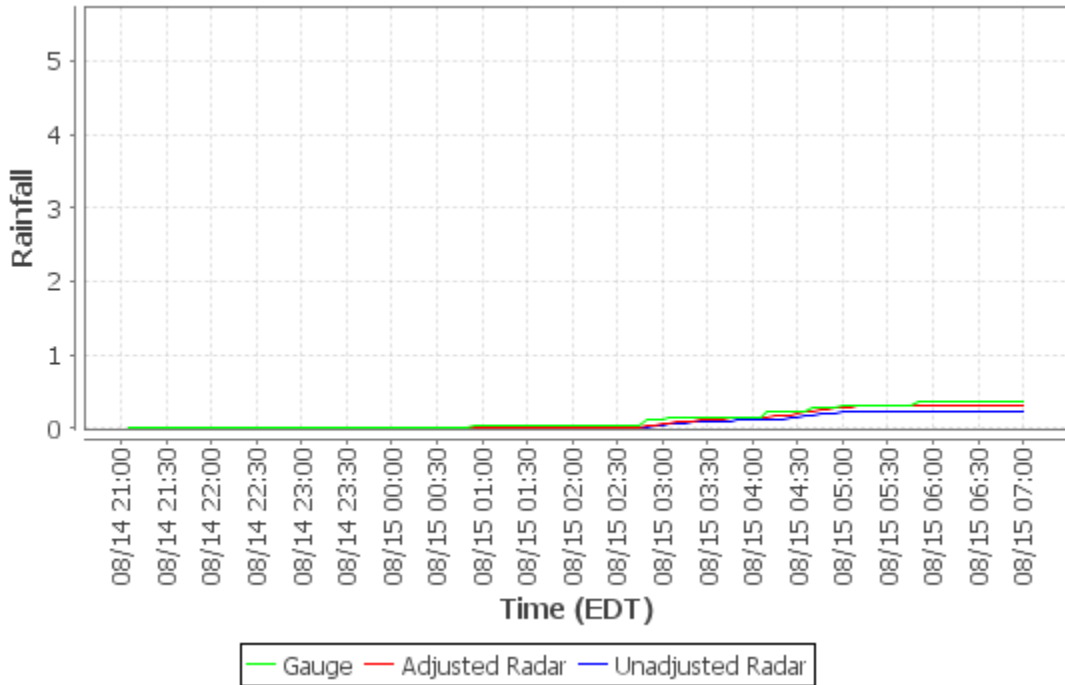
Cumulative Distribution Plot - Kingstowne Regional Pond 4 (1270)



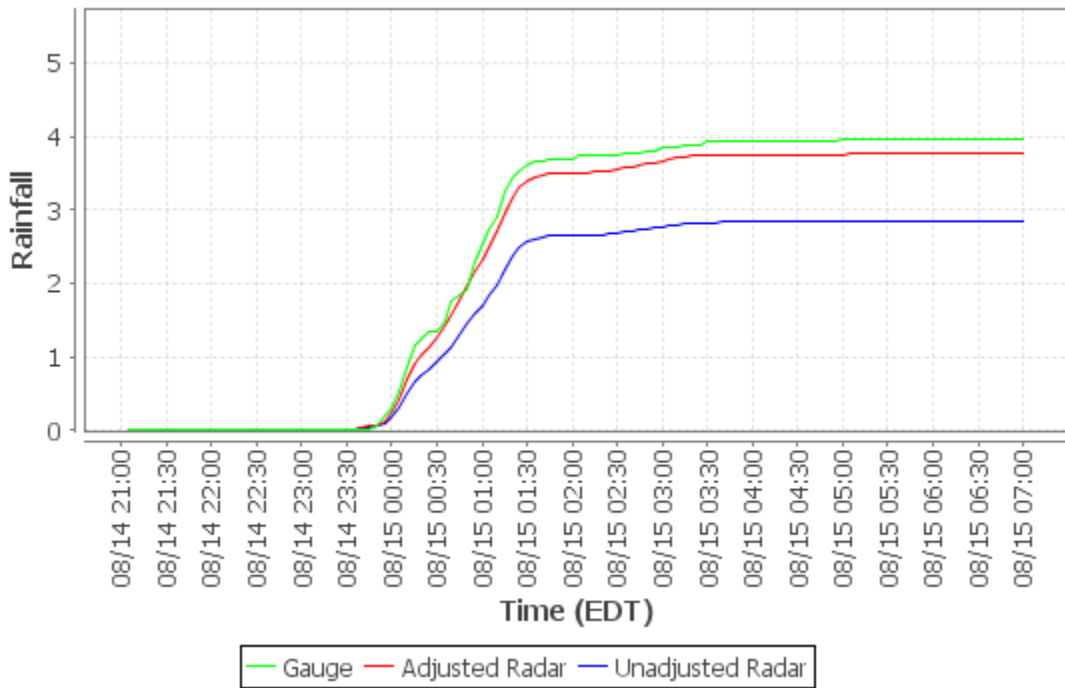
Cumulative Distribution Plot - Carrington (1280)



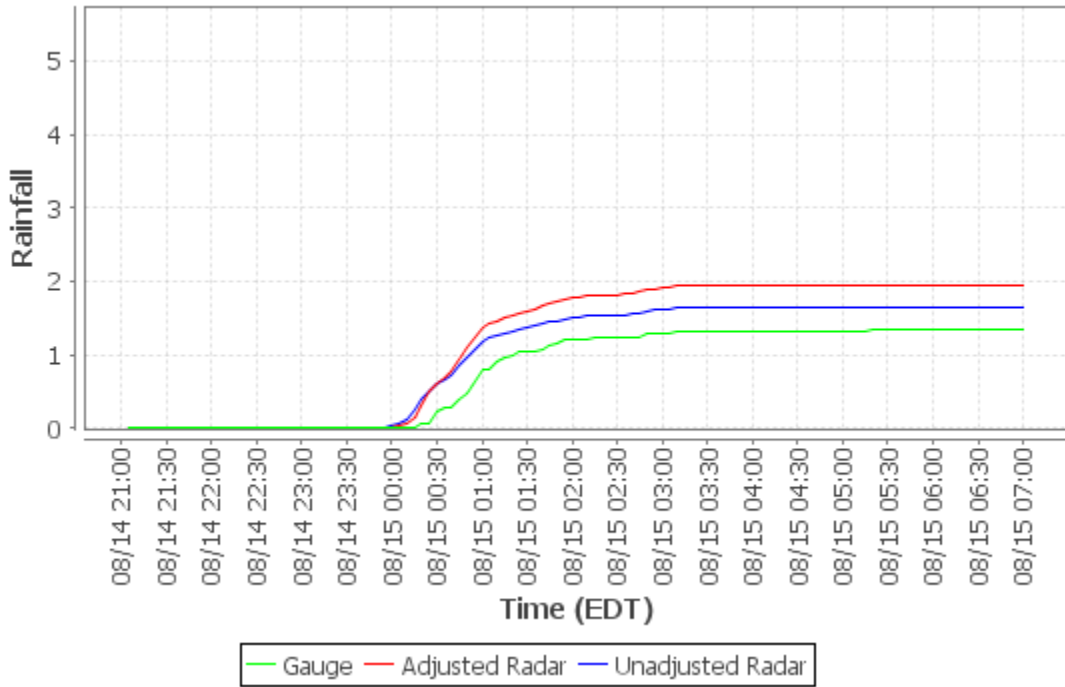
Cumulative Distribution Plot - Pulte/McLean (1300)



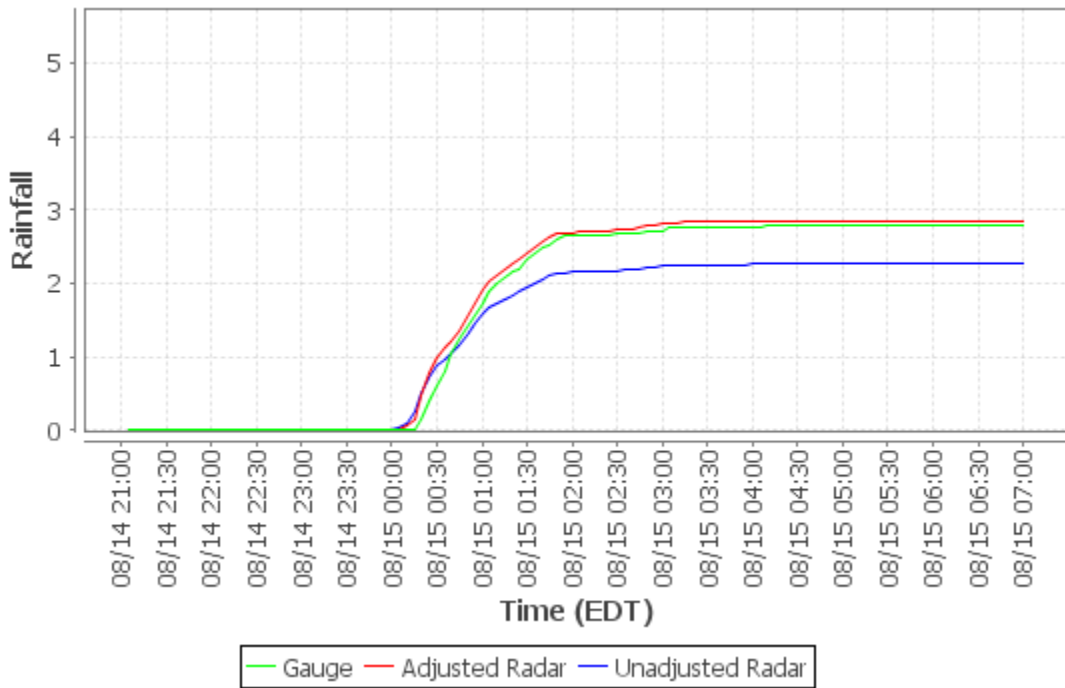
Cumulative Distribution Plot - Boothe Park (1350)



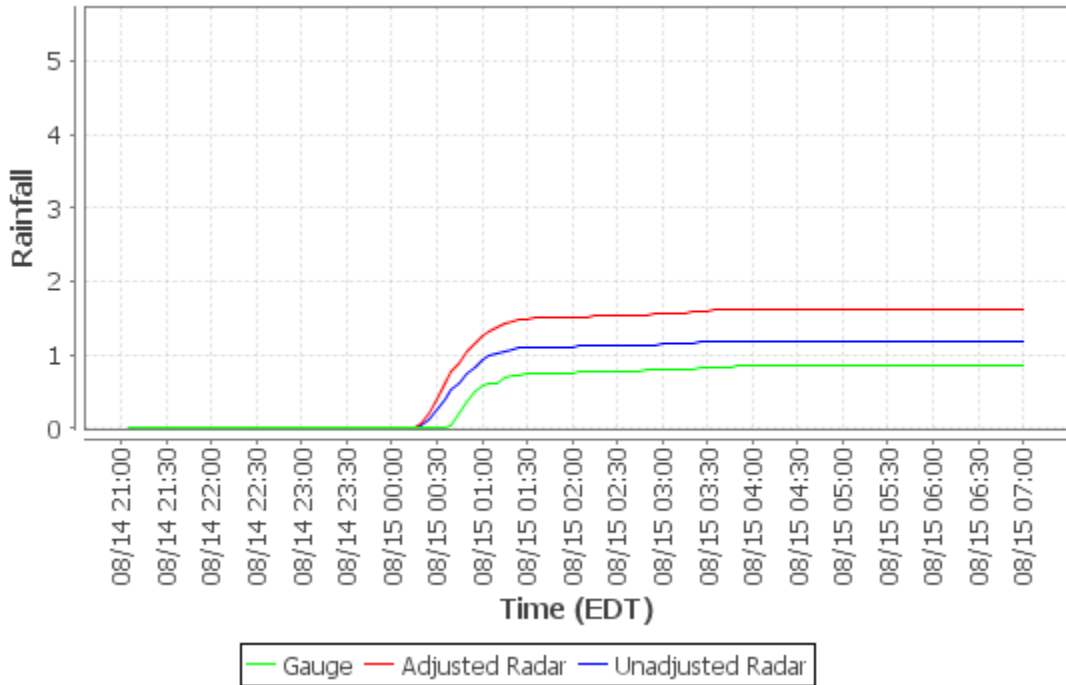
Cumulative Distribution Plot - Lake Accotink (FCPA) (1360)



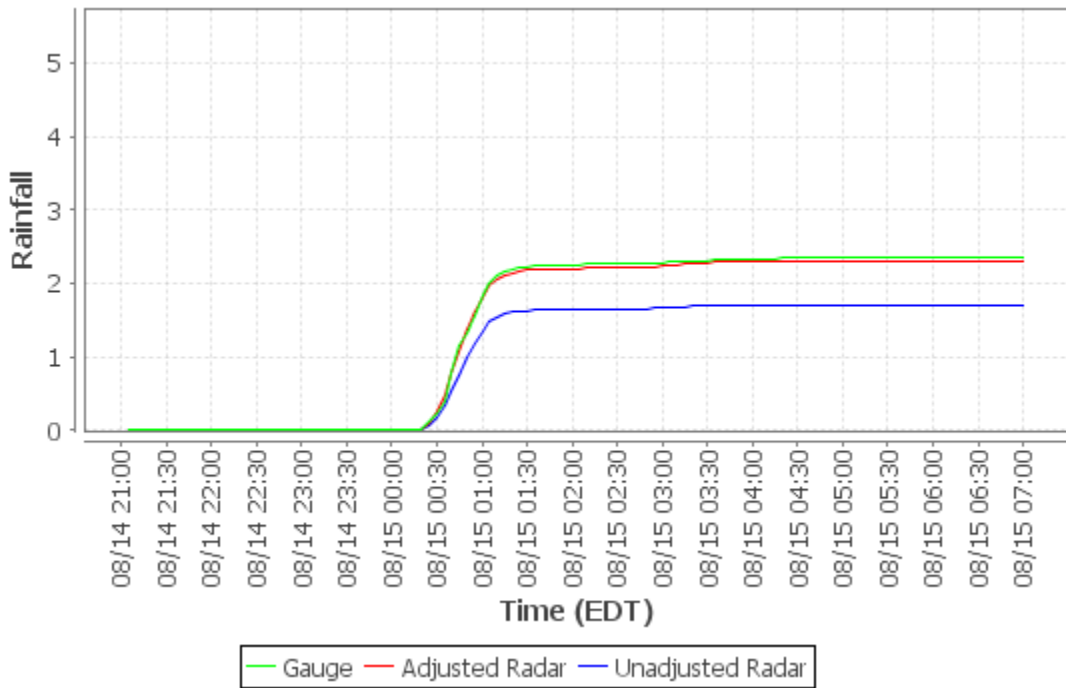
Cumulative Distribution Plot - Brookfield Park (1540)



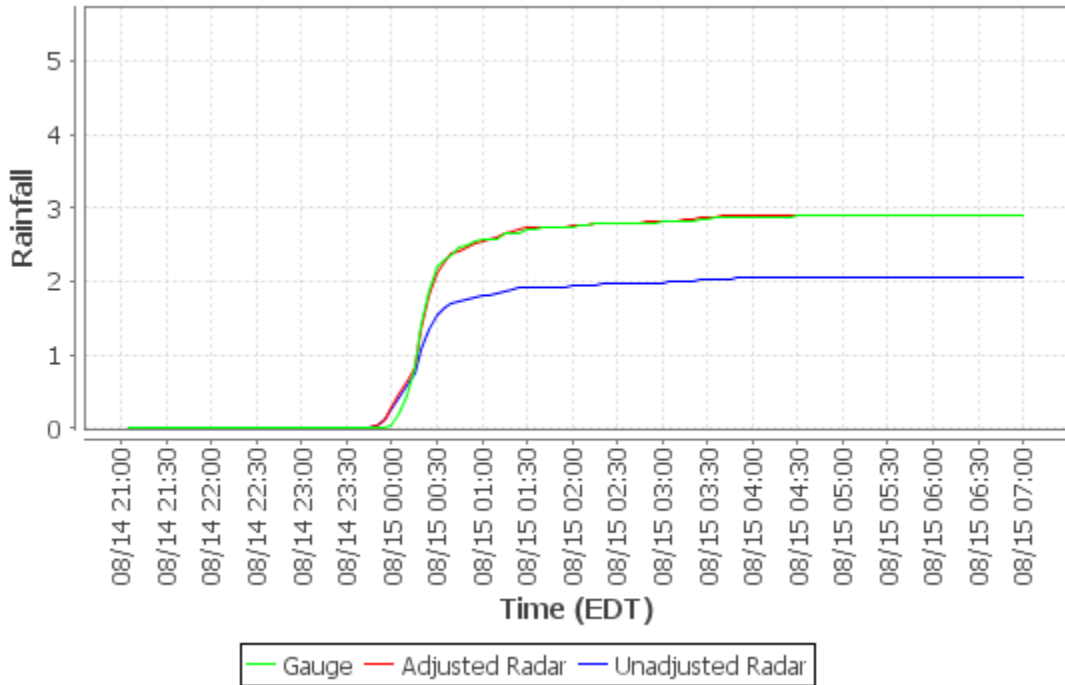
Cumulative Distribution Plot - RG-Brentwood (RG-Brentwood)



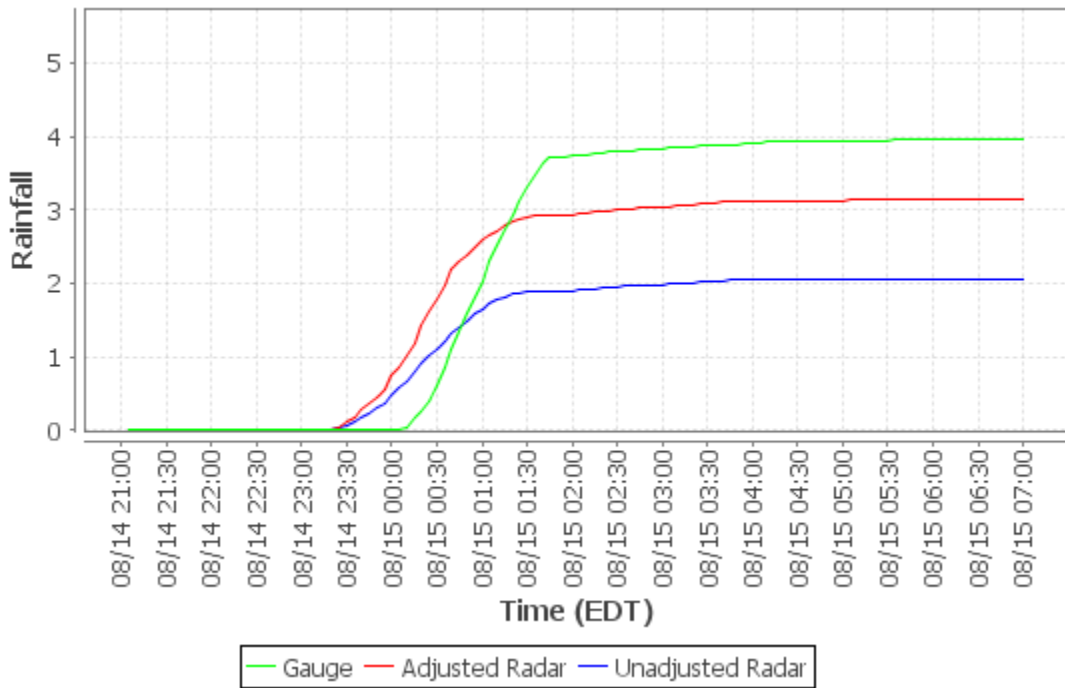
Cumulative Distribution Plot - RG-Bryant (RG-Bryant)



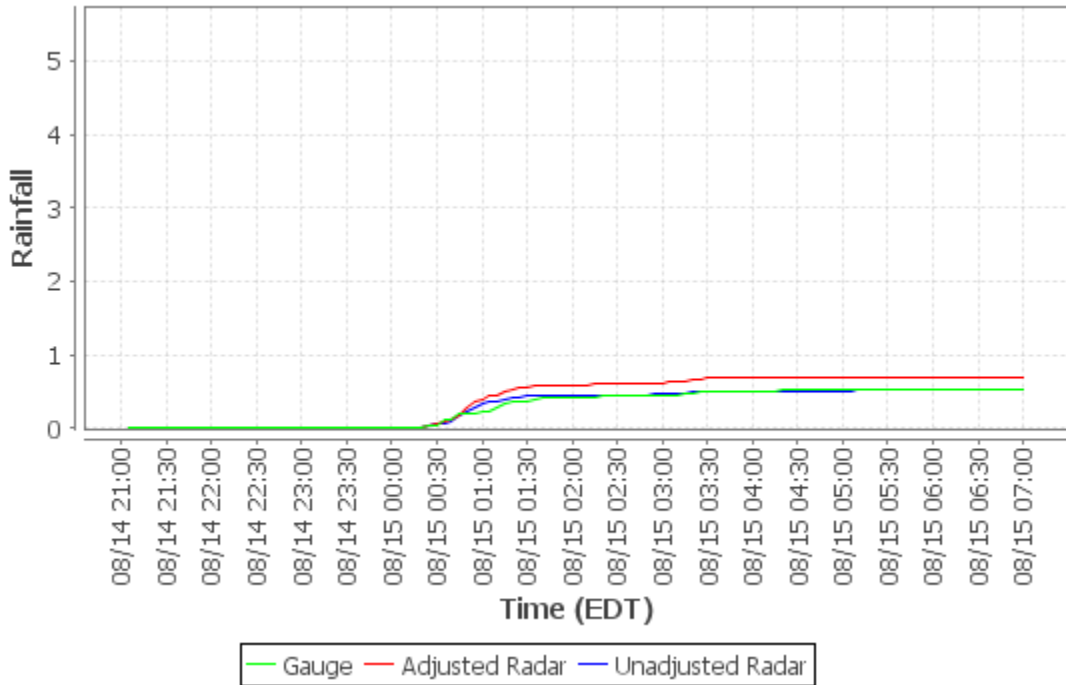
Cumulative Distribution Plot - RG-Main PS (RG-Main PS)



Cumulative Distribution Plot - FOURMILE RUN AT ALEXANDRIA (01652500)



Cumulative Distribution Plot - RG-RCPS (RG-RCPS)



Cumulative Distribution Plot - Washington Reagan National Airport (KDCA)

