Radar Rainfall Analysis
Toronto and Region Conservation Authority
Historical Rainfall Event
August 2014

Prepared for Toronto and Region Conservation Authority

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CERTIFICATION

Vieux and Associates, Inc. ensures that the Gauge Adjusted Radar Rainfall (GARR) values contained in this report are calculated based on the methodology described herein and are the result of a thorough analysis of meteorological data collected from both private and public sources. Our professionally trained hydrometeorologists employ a thorough quality-control and evaluation process, producing the most accurate and representative GARR over the defined study area. Vieux and Associates, Inc. reserves the right to amend reports at any time upon further review and/or discovery of additional data.



James Logan
Water Sector Leader

10/13/2026
Date

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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.

KBUF – Federal Communications Commission (FCC) call sign for the NEXRAD near Buffalo, NY.

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

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

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

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

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

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

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

Z-R relationship – An empirical relationship between radar reflectivity factor Z ($mm^6\ m^{-3}$) 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 [$Z = 300R^{1.4}$]

Overview

Vieux processed radar and rain gauge data for Toronto and Region Conservation Authority (TRCA). Radar and rain gauge data are quality controlled (QC) to produce QC gauge-adjusted radar rainfall (GARR) for a historical rainfall event that occurred on August 4, 2014. To produce QC GARR, both radar and rain gauge data are reviewed manually to remove inconsistent data. QC is performed to remove anomalous radar data and inconsistent rain gauges.

Radar data used in production of GARR is produced by the National Weather Service (NWS) Next Generation Radar (NEXRAD) system. NEXRAD Level II radar data are often referred to as Base Data and contain the full spatial/temporal/data resolution data from the radar. Level II radar data measures reflectivity in decibels of reflectance (dBZ), and at a spatial resolution of 0.5-degree by 0.25-km every 4 – 10 minutes with a data resolution of 0.5 dBZ amounting to 256 data levels of data. Level III Q0 radar data have the same data and temporal resolution, but a reduced spatial resolution of 1-degree by 1-km.

The primary radar data source used to process this period was Level II NEXRAD data from KBUF located near Buffalo, NY. The succession of data used gives priority to Level II followed by Level III products. If KBUF Level II NEXRAD data are unavailable, then KBUF Level III Q0 is substituted. In the event that all radar sources are unavailable or if the radar provides insufficient rainfall information, then a gauge-only product that spatially distributes point rainfall estimates is used. All radar data were processed into 5-minute increments.

Because the radar measures reflectivity in polar coordinates centered on the radar installation, the 1-degree azimuth increases in width as range increases from the radar. Range resolution of both Level II and III is 1-km and is measured out to 230-km from the radar. Due to the locations of KBUF in relation to the target area, the polar coordinates defining resolution range in width from 1.6 – 2.4 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 is defined by a 1-km^2 grid domain shapefile produced by Vieux, Inc., resulting in 1228 1-km^2 pixels encompassing the watersheds provided by TRCA.

Rainfall data from as many as 18 gauges were used to adjust the radar: 13 Halton and 5 Mississauga. Figure 1 depicts the spatial distribution of the rain gauge network and the 1-km^2 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-km^2 pixels were achieved using software developed at Vieux, Inc.

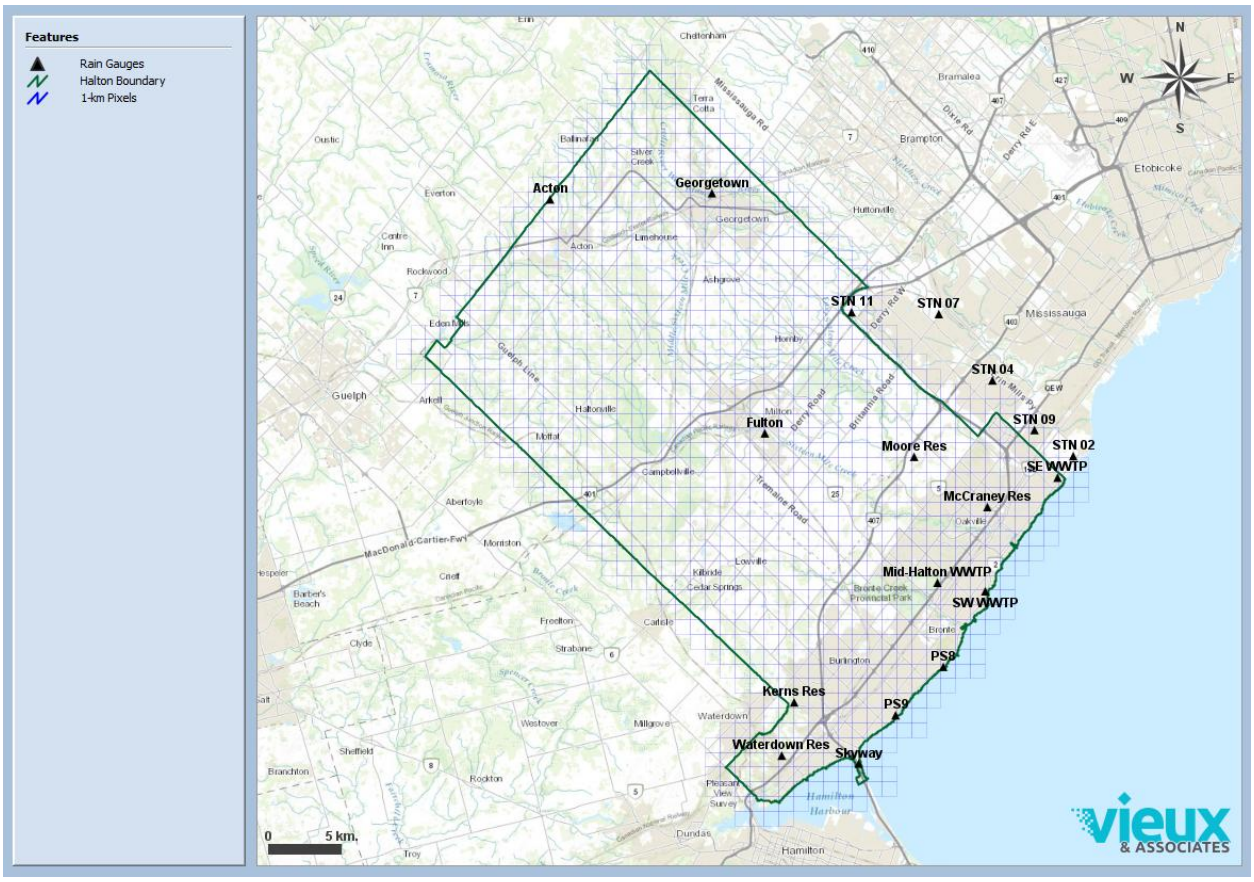


Figure 1. Spatial Distribution of the Rain Gauge Network and the 1-km^2 Pixels.

Table 1. Rain Gauge ID, Name and Source

Gauge ID	Gauge Name	Source
Acton	14386 Third Line	Halton
Fulton	161 Fulton St	Halton
Georgetown	68 John St	Halton
Kerns Res	2186 Kerns Rd	Halton
McCraney Res	Trafalgar Rd	Halton
Mid-Halton WWTP	2195 North Service Rd W	Halton
Moore Res	4115 Sixth Line	Halton
PS8	5390 Lakeshore Rd	Halton
PS9	3237 Lakeshore Rd	Halton
SE WWTP	2477 Lakeshore Rd E	Halton
SW WWTP	1385 Lakeshore Rd W	Halton
Skyway	1125 Lakeshore Rd	Halton
Waterdown Res	1376 Waterdown Rd	Halton
STN 02	Clarkson WWTP	Mississauga
STN 04	South Common Community Centre	Mississauga

Gauge ID	Gauge Name	Source
STN 07	Fire station #108	Mississauga
STN 09	Sheridan Villa	Mississauga
STN 11	Gary Morden Fire Training Centre	Mississauga

The 18 rain gauges and the one NWS NEXRAD radars are used to produce gauge-adjusted radar rainfall (GARR). The methodology used in the production of GARR is described below followed by a metadata section.

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 the 1-km^2 pixels using an area-averaged technique.

After bias correction, differences between rain gauge and radar rainfall accumulations can 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.

Relatively large calibrated average differences should not necessarily be interpreted as evidence that the GARR results are unreliable, particularly when gauge accumulations are small. Because radar precipitation is spatially averaged while rain gauges provide rainfall information at a point location, differences between the two are expected and can be substantial at times even when the GARR still provides a reasonable representation of precipitation across an area.

In addition, the local bias calibration approach limits the influence of localized radar–gauge differences on the results by accounting for spatially varying differences rather than allowing individual poor matches to affect the overall calibration. Therefore, large differences at individual locations can coexist with satisfactory overall performance of the GARR product.

Any additional details regarding the methodology are considered proprietary and will not be included in this report.

Metadata

Data accompanying this document provides a continuous rainfall record of the 1228 1-km^2 pixels for the following period:

2014/08/04 10:05 EST - 2014/08/04 22:00 EST

The data is provided in Excel format. A shapefile of the 1-km^2 pixels is located in the Shapefiles subfolder. The data file documentation follows:

Excel metadata:

- Excel file with IDs across the columns and time down the rows.
- Time stamps are in EST.
- Data values represent 5-min accumulation (mm) at end of interval.
- The pixel ID uses the “ID” field from the 1-km pixel shapefile.

Shapefile metadata:

- UTM 1983, Zone 17 (meters)

Gauge-Adjusted Radar Rainfall (GARR)

GARR was processed continuously at five-minute increments and covers the period from 2014-08-04 10:00 EST to 2014-08-04 22:00 EST. The GARR statistics for the event are listed in Table 2. The event was split into multiple sub-event periods to improve gauge-adjustment of the radar, resulting in a total of 5 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. 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).

Table 2. Storm Events and GARR Statistics

Event #	Source	Event Date	Start Time (EST)	End Time (EST)	Gauges Used (18)	Avg. Depth (mm)	Bias	AD (%)	CAD (%)
E1a	KBUF LII	2014-08-04	2014-08-04 10:05	2014-08-04 14:15	7	6.588	0.676	54.0	3.9
E1b	KBUF LII	2014-08-04	2014-08-04 14:20	2014-08-04 15:15	6	2.016	0.586	115.7	10.9
E1c	KBUF LII	2014-08-04	2014-08-04 15:20	2014-08-04 16:45	12	7.421	0.720	49.4	8.9
E1d	KBUF LII	2014-08-04	2014-08-04 16:50	2014-08-04 18:00	11	4.347	0.658	50.8	5.9
E1e	KBUF LII	2014-08-04	2014-08-04 18:05	2014-08-04 22:00	9	3.393	0.689	44.3	8.8

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 Appendix C. CDPs are useful for visualizing rain gauge performance. Figure 2 shows the rainfall accumulation at the 3237 Lakeshore Rd (PS9) gauge during the 2014-08-04 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.

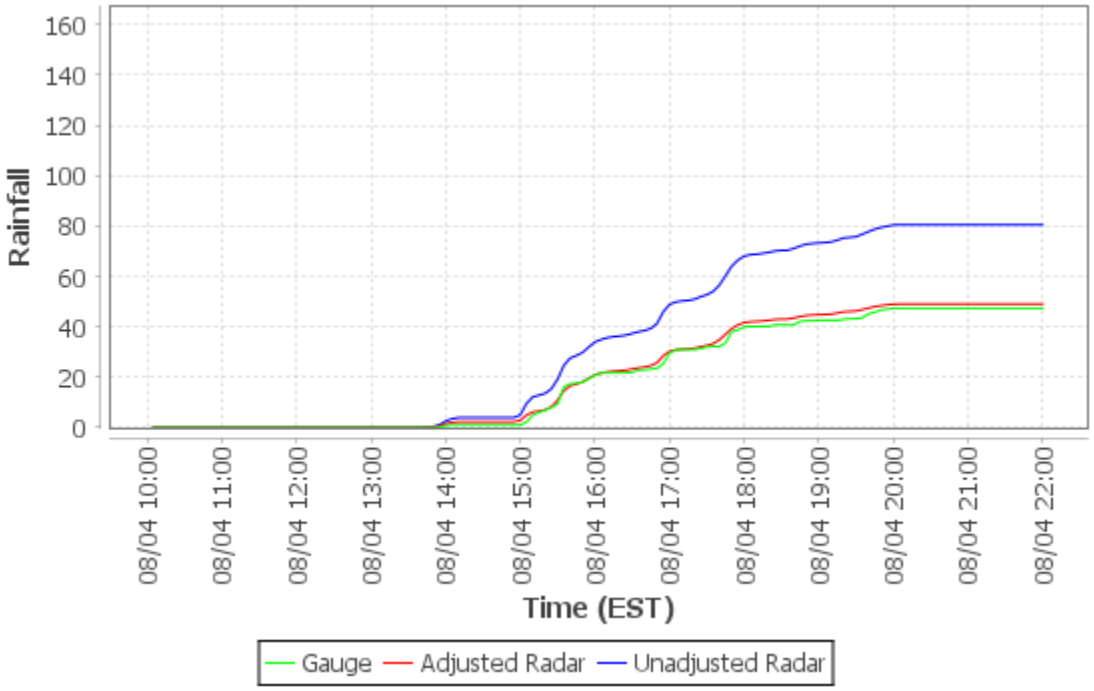


Figure 2. CDP Showing Rain Gauge Versus Unadjusted Radar Versus GARR

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>>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<<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: 2014-08-04

The analysis period was from 2014-08-04 10:00 EST to 2014-08-04 22:00 EST. The event was then split into five sub-event periods at 2014-08-04 14:15 EST, 2014-08-04 15:15 EST, 2014-08-04 16:45 EST and 2014-08-04 18:00 EST 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 - 10 summarize the results for each RG pair used for final radar adjustment, where G_i is the gauge estimate, R_i is the non-adjusted radar estimate, R_i* is the GARR estimate, and Diff* (%) is the percent difference between the gauge and GARR estimate. 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 - 7 show the scatter plots of the gauge-adjusted RG pairs. Those gauges not used to adjust the radar are shown in red. Figure 8 depicts the GARR storm total over the 1-km^2 pixels. The GARR amounts for the 1228 1-km^2 pixels range from 0.1 - 112.2 millimeters with a mean of 23.8 millimeters.

Table 5. GARR Statistics for Event 1

Event #	Radar	Event Date	Start Time (EST)	End Time (EST)	Gauges Used (18)	Avg. Depth (mm)	Bias	AD (%)	CAD (%)
E1a	KBUF LII	2014-08-04	2014-08-04 10:05	2014-08-04 14:15	7	6.588	0.676	54.0	3.9
E1b	KBUF LII	2014-08-04	2014-08-04 14:20	2014-08-04 15:15	6	2.016	0.586	115.7	10.9
E1c	KBUF LII	2014-08-04	2014-08-04 15:20	2014-08-04 16:45	12	7.421	0.720	49.4	8.9
E1d	KBUF LII	2014-08-04	2014-08-04 16:50	2014-08-04 18:00	11	4.347	0.658	50.8	5.9
E1e	KBUF LII	2014-08-04	2014-08-04 18:05	2014-08-04 22:00	9	3.393	0.689	44.3	8.8

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

Gauge ID	Name	G_i (mm)	R_i (mm)	R_i* (mm)	Diff* (mm)	Diff* (%)	Flag
McCraney Res	Trafalgar Rd	4.00	6.94	4.47	-0.47	-11.7	
SW WWTP	1385 Lakeshore Rd W	7.20	11.29	7.32	-0.12	-1.7	
STN 09	Sheridan Villa	4.60	6.71	4.61	-0.01	-0.2	
Kerns Res	2186 Kerns Rd	1.40	2.59	1.40	0.00	0.0	
Mid-Halton WWTP	2195 North Service Rd W	5.30	7.72	5.09	0.21	4.0	
Moore Res	4115 Sixth Line	10.80	14.39	10.30	0.50	4.6	
SE WWTP	2477 Lakeshore Rd E	3.80	5.24	3.60	0.20	5.3	
Acton	14386 Third Line	0.00	---	---	---	---	MSTT
Fulton	161 Fulton St	1.60	---	---	---	---	S
Georgetown	68 John St	0.00	---	---	---	---	MSTT
PS8	5390 Lakeshore Rd	0.00	---	---	---	---	Z

Gauge ID	Name	G_i (mm)	R_i (mm)	R_i* (mm)	Diff* (mm)	Diff* (%)	Flag
PS9	3237 Lakeshore Rd	1.00	---	---	---	---	MSTT
STN 02	Clarkson WWTP	3.80	---	---	---	---	O
STN 04	South Common Community Centre	1.60	---	---	---	---	O
STN 07	Fire station #108	0.00	---	---	---	---	MSTT
STN 11	Gary Morden Fire Training Centre	0.00	---	---	---	---	MSTT
Skyway	1125 Lakeshore Rd	0.00	---	---	---	---	MSTT
Waterdown Res	1376 Waterdown Rd	0.00	---	---	---	---	MSTT

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

Gauge ID	Name	G_i (mm)	R_i (mm)	R_i* (mm)	Diff* (mm)	Diff* (%)	Flag
Skyway	1125 Lakeshore Rd	1.40	4.94	1.83	-0.43	-30.7	
Mid-Halton WWTP	2195 North Service Rd W	5.20	7.45	5.68	-0.48	-9.2	
STN 11	Gary Morden Fire Training Centre	2.00	6.19	2.02	-0.02	-1.0	
Fulton	161 Fulton St	1.80	3.53	1.79	0.01	0.6	
SW WWTP	1385 Lakeshore Rd W	8.40	9.61	7.72	0.68	8.1	
PS9	3237 Lakeshore Rd	5.00	8.91	4.22	0.78	15.6	
Acton	14386 Third Line	0.00	---	---	---	---	MSTT
Georgetown	68 John St	0.00	---	---	---	---	MSTT
Kerns Res	2186 Kerns Rd	0.20	---	---	---	---	MSTT
McCraney Res	Trafalgar Rd	1.20	---	---	---	---	MSTT
Moore Res	4115 Sixth Line	0.60	---	---	---	---	MSTT
PS8	5390 Lakeshore Rd	1.40	---	---	---	---	O
SE WWTP	2477 Lakeshore Rd E	0.20	---	---	---	---	MSTT
STN 02	Clarkson WWTP	0.00	---	---	---	---	MSTT
STN 04	South Common Community Centre	1.00	---	---	---	---	MSTT
STN 07	Fire station #108	1.00	---	---	---	---	MSTT
STN 09	Sheridan Villa	0.40	---	---	---	---	MSTT
Waterdown Res	1376 Waterdown Rd	0.20	---	---	---	---	MSTT

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

Gauge ID	Name	G_i (mm)	R_i (mm)	R_i* (mm)	Diff* (mm)	Diff* (%)	Flag
SE WWTP	2477 Lakeshore Rd E	1.60	2.69	1.96	-0.36	-22.5	
Waterdown Res	1376 Waterdown Rd	3.40	6.22	4.01	-0.61	-17.9	
Mid-Halton WWTP	2195 North Service Rd W	2.70	6.15	3.14	-0.44	-16.3	
PS9	3237 Lakeshore Rd	17.20	26.49	18.06	-0.86	-5.0	
Moore Res	4115 Sixth Line	5.20	7.22	5.35	-0.15	-2.9	
Fulton	161 Fulton St	13.20	15.82	13.17	0.03	0.2	
SW WWTP	1385 Lakeshore Rd W	2.40	4.36	2.33	0.07	2.9	
McCraney Res	Trafalgar Rd	6.40	8.95	6.10	0.30	4.7	
Kerns Res	2186 Kerns Rd	18.40	25.25	17.07	1.33	7.2	
STN 04	South Common Community Centre	6.60	6.14	6.04	0.56	8.5	
STN 09	Sheridan Villa	1.60	1.71	1.45	0.15	9.4	
Skyway	1125 Lakeshore Rd	17.00	21.84	15.39	1.61	9.5	
Acton	14386 Third Line	0.00	---	---	---	---	MSTT
Georgetown	68 John St	0.00	---	---	---	---	MSTT
PS8	5390 Lakeshore Rd	17.60	---	---	---	---	S
STN 02	Clarkson WWTP	0.80	---	---	---	---	MSTT
STN 07	Fire station #108	1.00	---	---	---	---	MSTT
STN 11	Gary Morden Fire Training Centre	1.20	---	---	---	---	MSTT

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

Gauge ID	Name	G_i (mm)	R_i (mm)	R_i* (mm)	Diff* (mm)	Diff* (%)	Flag
STN 07	Fire station #108	3.40	5.87	3.83	-0.43	-12.6	
STN 02	Clarkson WWTP	3.00	4.06	3.26	-0.26	-8.7	
Mid-Halton WWTP	2195 North Service Rd W	4.90	9.48	5.18	-0.28	-5.7	
Kerns Res	2186 Kerns Rd	7.60	14.76	8.02	-0.42	-5.5	
STN 09	Sheridan Villa	3.80	4.79	3.90	-0.10	-2.6	
PS9	3237 Lakeshore Rd	16.80	28.73	17.12	-0.32	-1.9	
SW WWTP	1385 Lakeshore Rd W	7.20	12.77	7.10	0.10	1.4	
Moore Res	4115 Sixth Line	3.80	4.13	3.65	0.15	3.9	
Skyway	1125 Lakeshore Rd	1.60	2.46	1.51	0.09	5.6	

Gauge ID	Name	G_i (mm)	R_i (mm)	R_i* (mm)	Diff* (mm)	Diff* (%)	Flag
STN 04	South Common Community Centre	15.00	16.86	13.82	1.18	7.9	
SE WWTP	2477 Lakeshore Rd E	5.20	5.93	4.78	0.42	8.1	
Acton	14386 Third Line	0.40	---	---	---	---	MSTT
Fulton	161 Fulton St	1.00	---	---	---	---	MSTT
Georgetown	68 John St	0.40	---	---	---	---	MSTT
McCraney Res	Trafalgar Rd	0.00	---	---	---	---	MSTT
PS8	5390 Lakeshore Rd	1.00	---	---	---	---	S
STN 11	Gary Morden Fire Training Centre	0.80	---	---	---	---	MSTT
Waterdown Res	1376 Waterdown Rd	0.00	---	---	---	---	MSTT

Table 10. Summary of Individual RG Pairs for Event 1e

Gauge ID	Name	G_i (mm)	R_i (mm)	R_i* (mm)	Diff* (mm)	Diff* (%)	Flag
SE WWTP	2477 Lakeshore Rd E	4.20	7.66	5.33	-1.13	-26.9	
Mid-Halton WWTP	2195 North Service Rd W	7.20	9.30	7.83	-0.63	-8.7	
Moore Res	4115 Sixth Line	4.60	6.95	4.94	-0.34	-7.4	
Kerns Res	2186 Kerns Rd	8.60	17.54	8.84	-0.24	-2.8	
PS9	3237 Lakeshore Rd	7.40	12.46	7.37	0.03	0.4	
McCraney Res	Trafalgar Rd	7.40	9.02	7.01	0.39	5.3	
STN 04	South Common Community Centre	1.60	1.80	1.51	0.09	5.6	
SW WWTP	1385 Lakeshore Rd W	9.80	9.94	8.75	1.05	10.7	
STN 02	Clarkson WWTP	5.20	6.61	4.60	0.60	11.5	
Acton	14386 Third Line	0.00	---	---	---	---	MSTT
Fulton	161 Fulton St	0.20	---	---	---	---	MSTT
Georgetown	68 John St	0.00	---	---	---	---	MSTT
PS8	5390 Lakeshore Rd	0.00	---	---	---	---	Z
STN 07	Fire station #108	0.00	---	---	---	---	MSTT
STN 09	Sheridan Villa	0.40	---	---	---	---	MSTT
STN 11	Gary Morden Fire Training Centre	0.00	---	---	---	---	MSTT
Skyway	1125 Lakeshore Rd	0.00	---	---	---	---	MSTT
Waterdown Res	1376 Waterdown Rd	0.40	---	---	---	---	MSTT

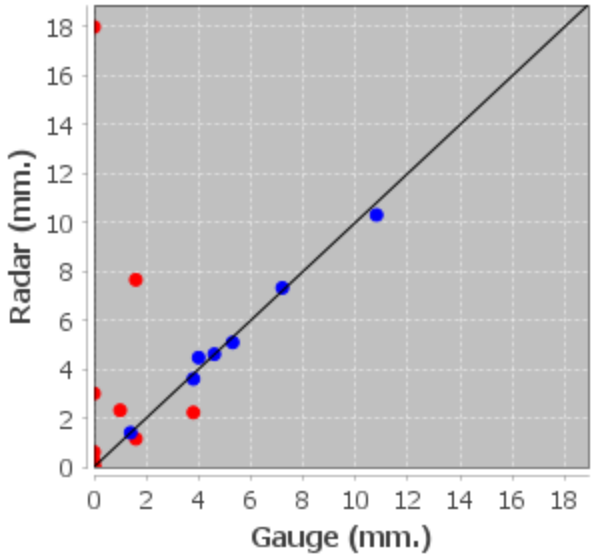


Figure 3. Scatter Plot of RG Pairs for Event 1a

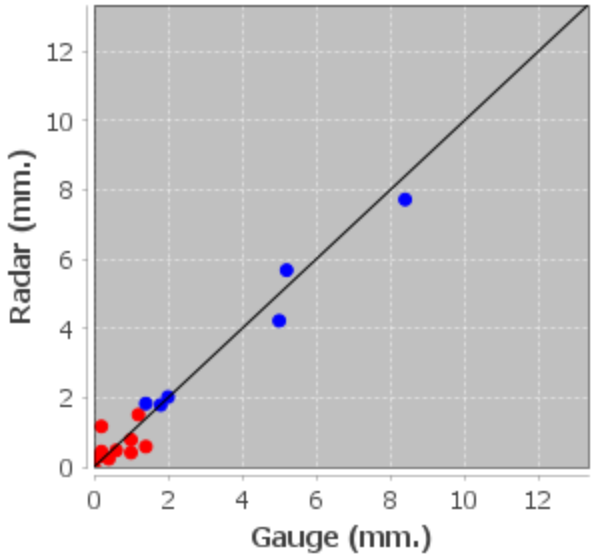


Figure 4. Scatter Plot of RG Pairs for Event 1b

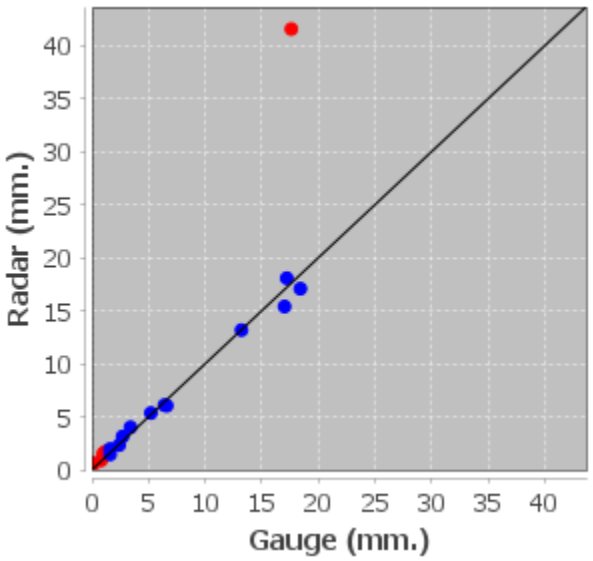


Figure 5. Scatter Plot of RG Pairs for Event 1c

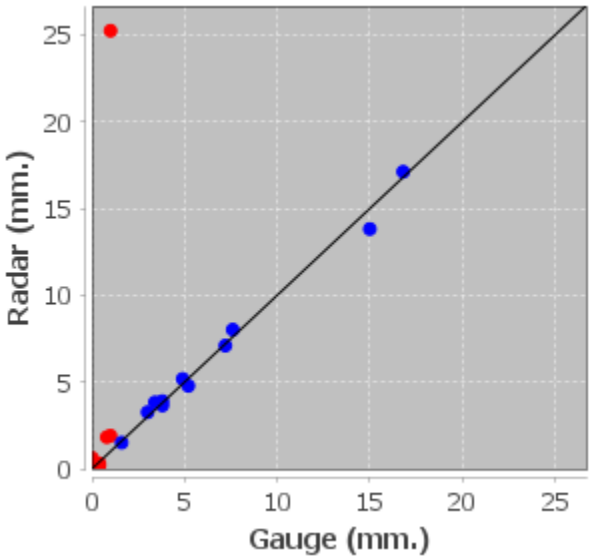


Figure 6. Scatter Plot of RG Pairs for Event 1d

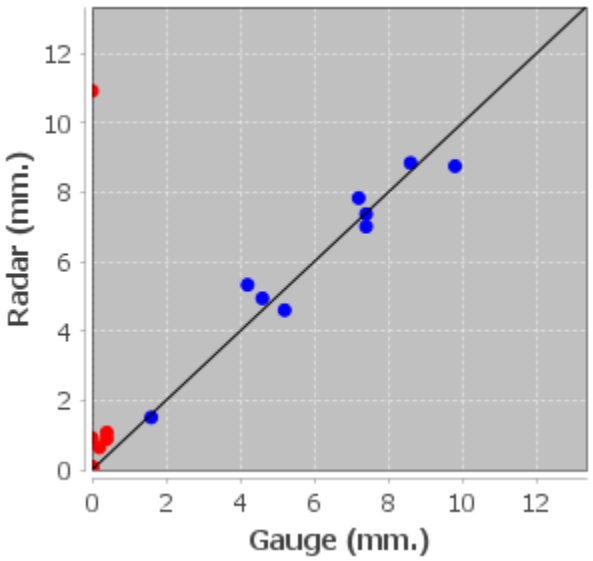


Figure 7. Scatter Plot of RG Pairs for Event 1e

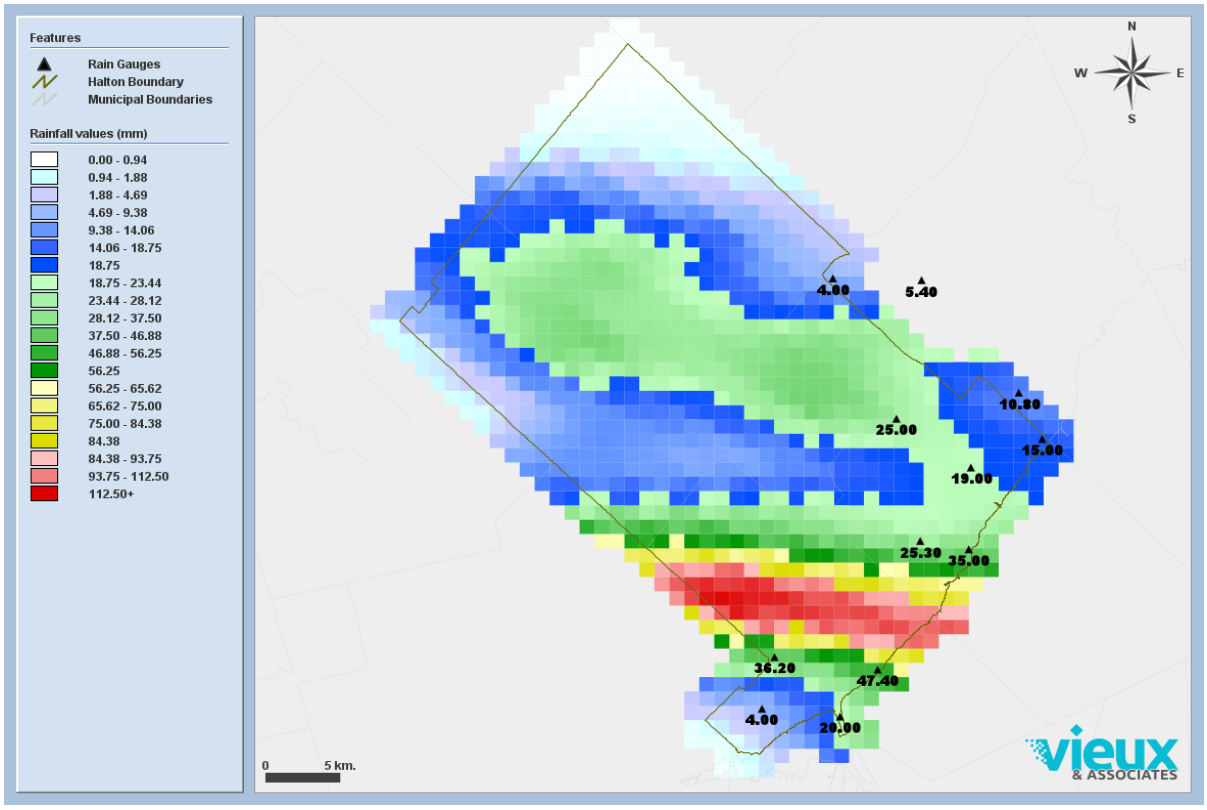


Figure 8. GARR Storm Total for Event 1

Appendices

Appendix A - Gauge Performance Exclusion Table
Appendix B - Gauge Statistical Criteria Exclusion Table
Appendix C - Event 1 (2014-08-04) CDPs

Appendix A - Gauge Performance Exclusion Table

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

Event #	E1a	E1b	E1c	E1d	E1e
Event Date	**2014-08-04**	**2014-08-04**	**2014-08-04**	**2014-08-04**	**2014-08-04**
Start Time (EST)	2014-08-04 10:05	2014-08-04 14:20	2014-08-04 15:20	2014-08-04 16:50	2014-08-04 18:05
End Time (EST)	2014-08-04 14:15	2014-08-04 15:15	2014-08-04 16:45	2014-08-04 18:00	2014-08-04 22:00
Acton					
Fulton	S				
Georgetown					
Kerns Res					
McCraney Res					
Mid-Halton WWTP					
Moore Res					
PS8	Z	O	S	S	Z
PS9					
SE WWTP					
SW WWTP					
Skyway					
Waterdown Res					
STN 02	O				
STN 04	O				
STN 07					
STN 09					
STN 11					

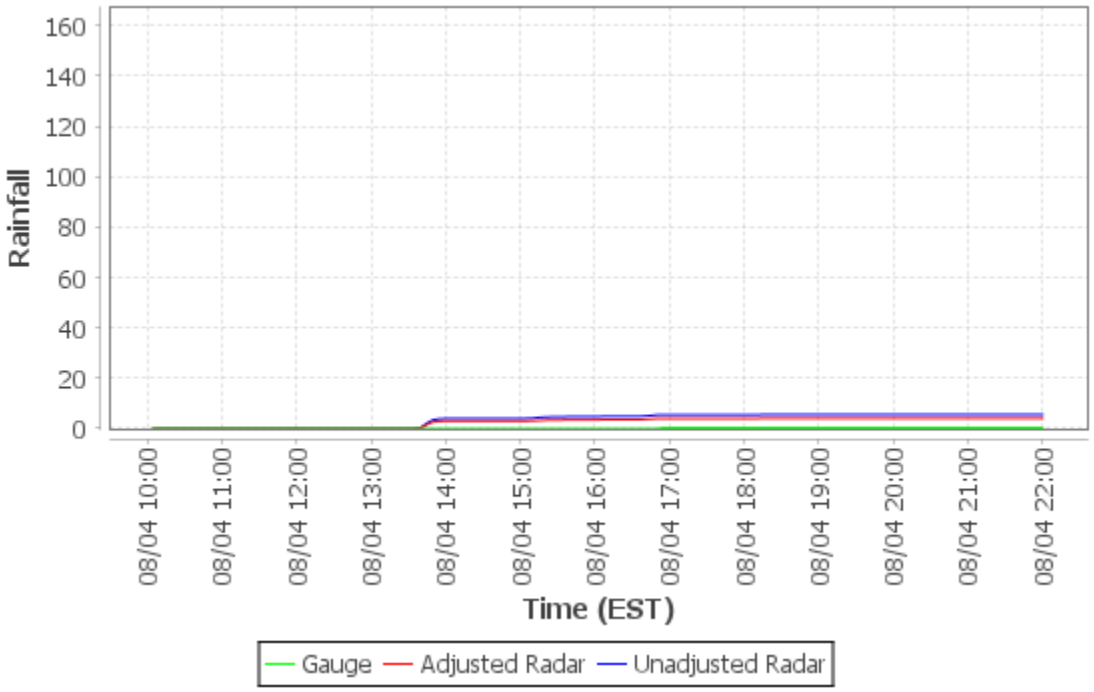
Appendix B - Gauge Statistical Criteria Exclusion Table

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>>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<<R)

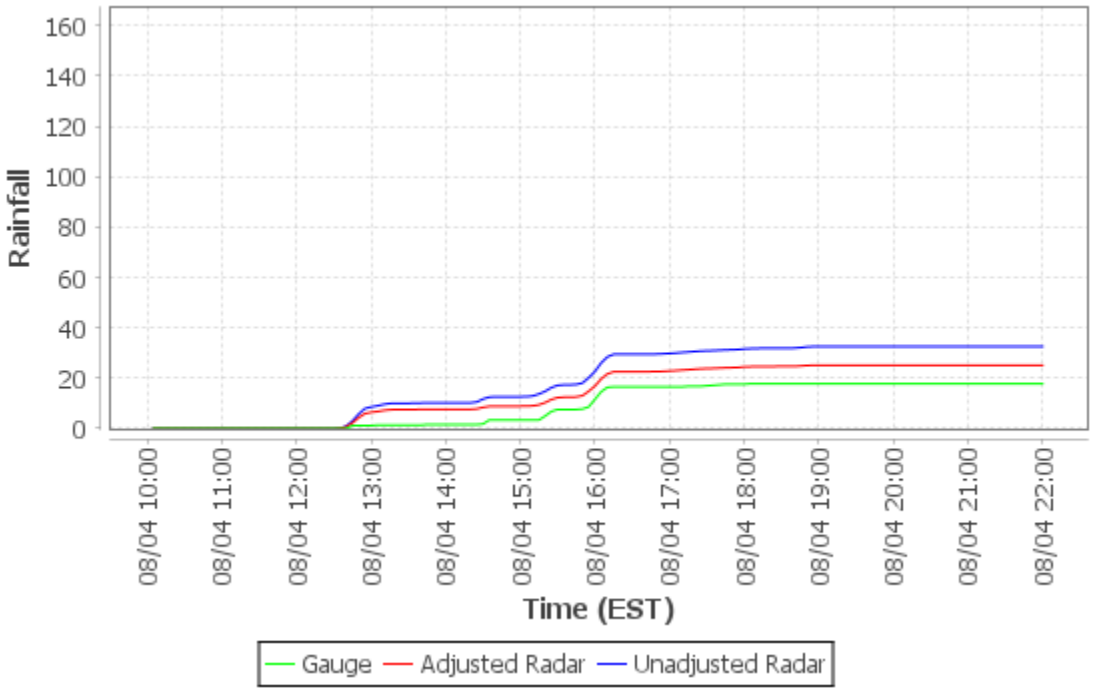
Event #	E1a	E1b	E1c	E1d	E1e
Event Date	**2014-08-04**	**2014-08-04**	**2014-08-04**	**2014-08-04**	**2014-08-04**
Start Time (EST)	2014-08-04 10:05	2014-08-04 14:20	2014-08-04 15:20	2014-08-04 16:50	2014-08-04 18:05
End Time (EST)	2014-08-04 14:15	2014-08-04 15:15	2014-08-04 16:45	2014-08-04 18:00	2014-08-04 22:00
Source	KBUF LII	KBUF LII	KBUF LII	KBUF LII	KBUF LII
Acton	MSTT	MSTT	MSTT	MSTT	MSTT
Fulton				MSTT	MSTT
Georgetown	MSTT	MSTT	MSTT	MSTT	MSTT
Kerns Res		MSTT			
McCraney Res		MSTT		MSTT	
Mid-Halton WWTP					
Moore Res		MSTT			
PS8					
PS9	MSTT				
SE WWTP		MSTT			
SW WWTP					
Skyway	MSTT				MSTT
Waterdown Res	MSTT	MSTT		MSTT	MSTT
STN 02		MSTT	MSTT		
STN 04		MSTT			
STN 07	MSTT	MSTT	MSTT		MSTT
STN 09		MSTT			MSTT
STN 11	MSTT		MSTT	MSTT	MSTT

Appendix C - Event 1 (2014-08-04) CDPs

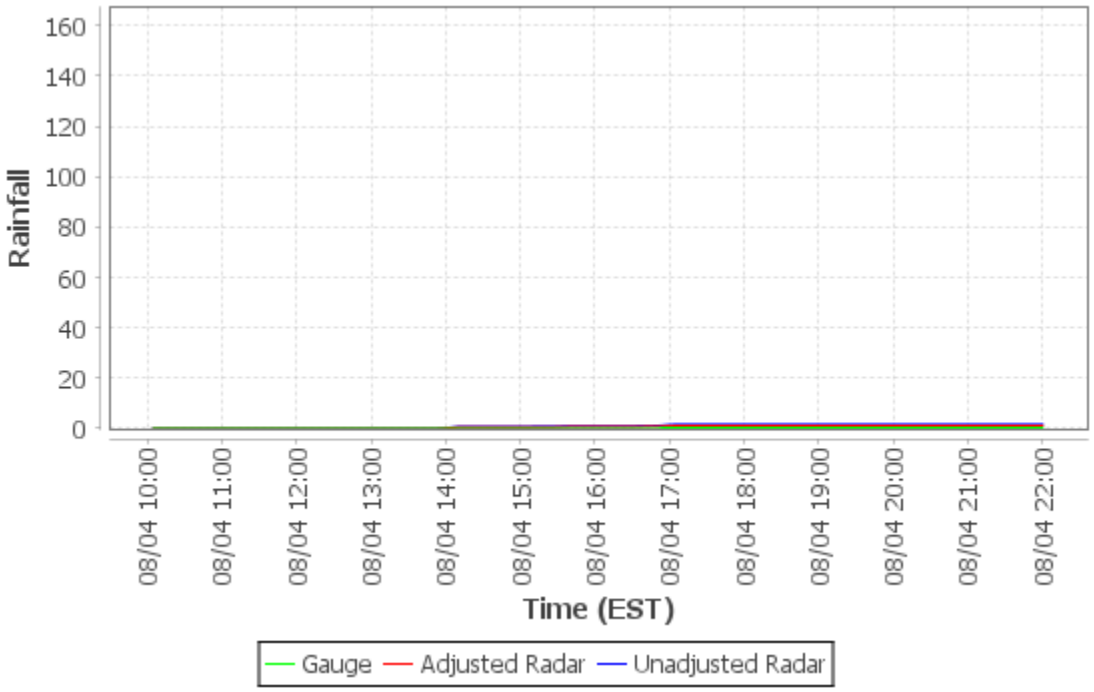
Cumulative Distribution Plot - 14386 Third Line (Acton)



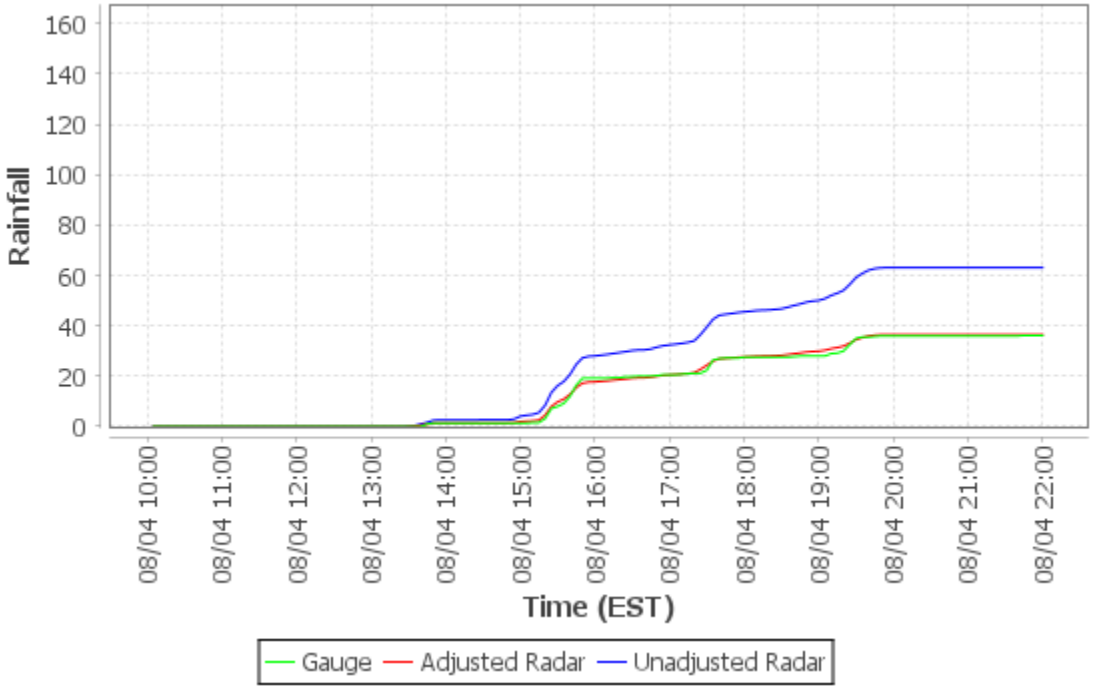
Cumulative Distribution Plot - 161 Fulton St (Fulton)



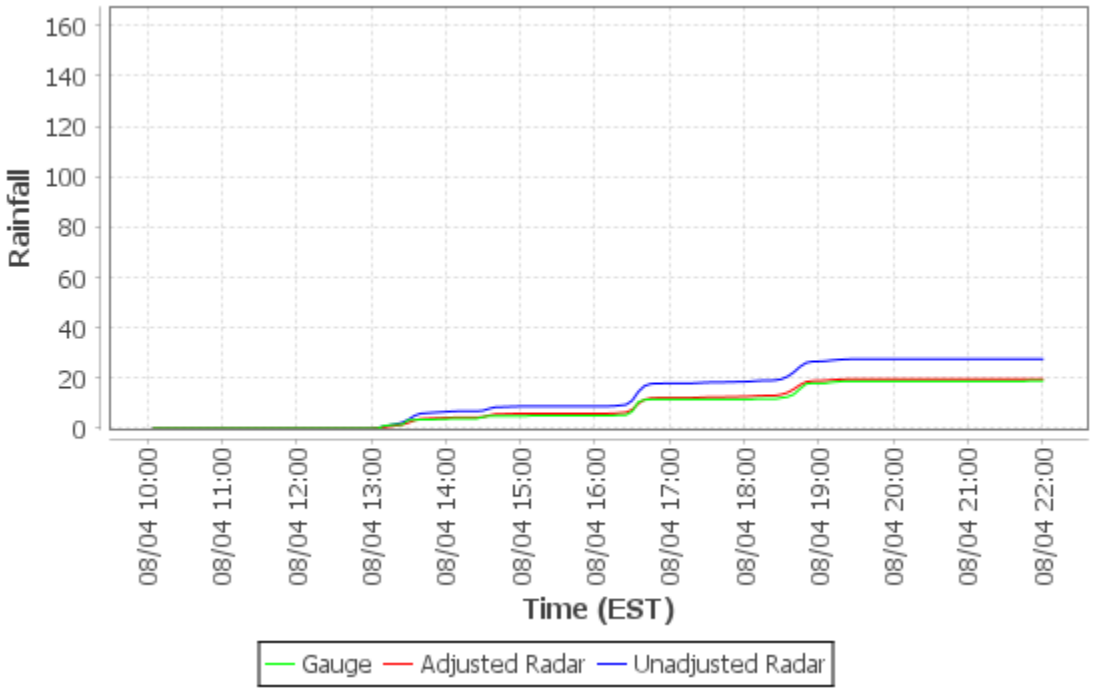
Cumulative Distribution Plot - 68 John St (Georgetown)



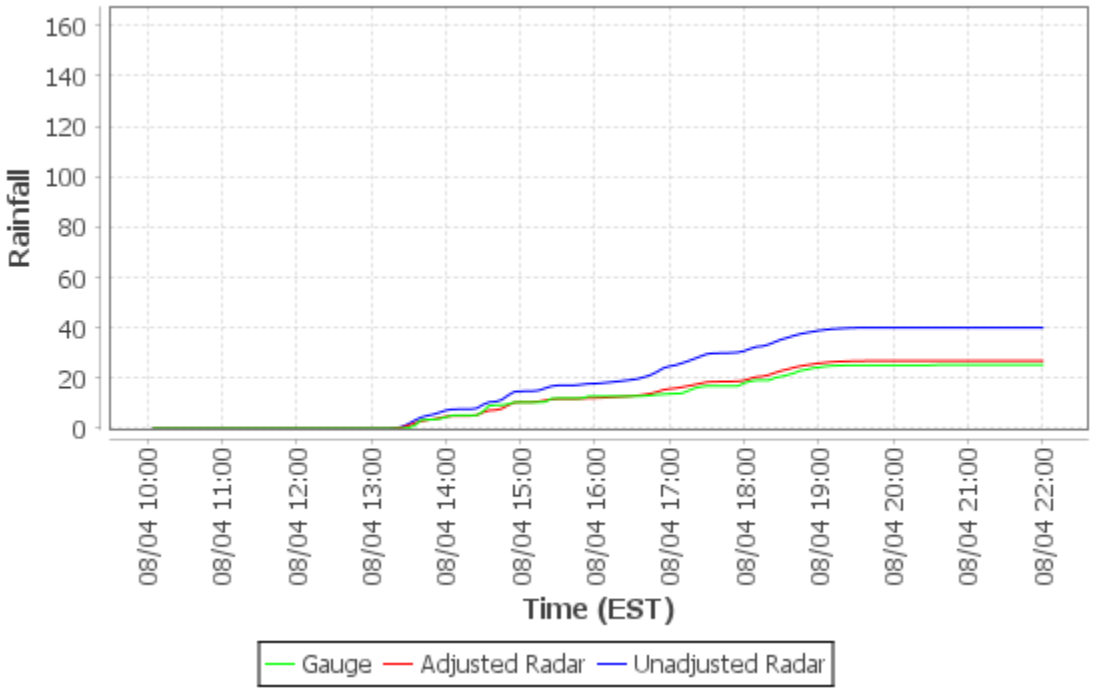
Cumulative Distribution Plot - 2186 Kerns Rd (Kerns Res)



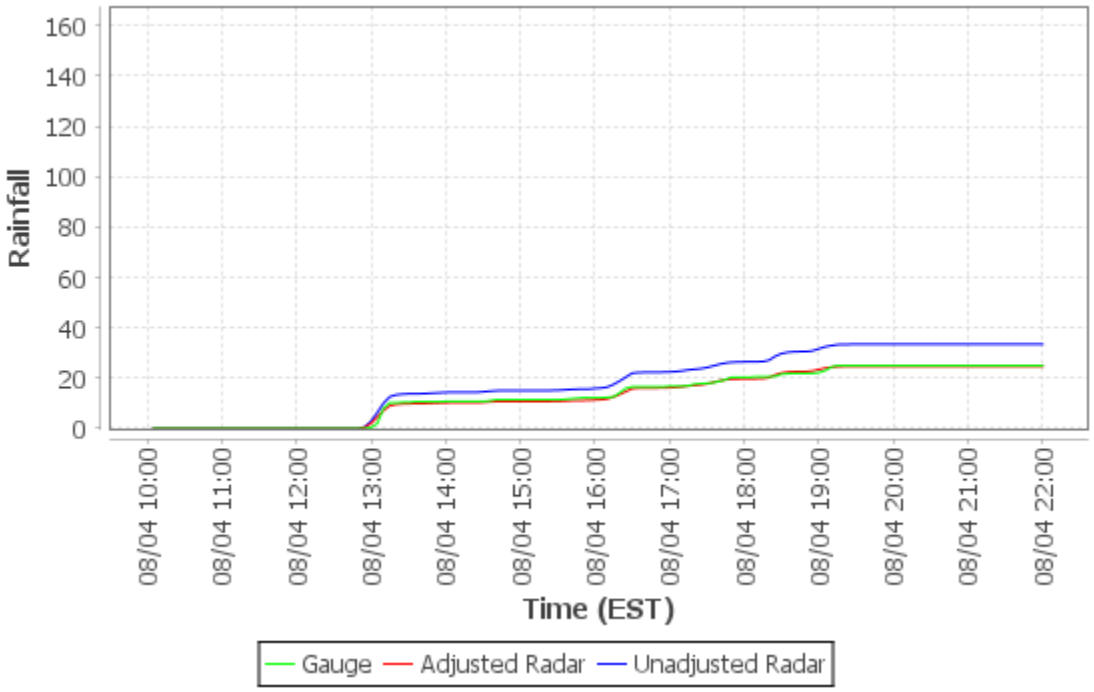
Cumulative Distribution Plot - Trafalgar Rd (McCraney Res)



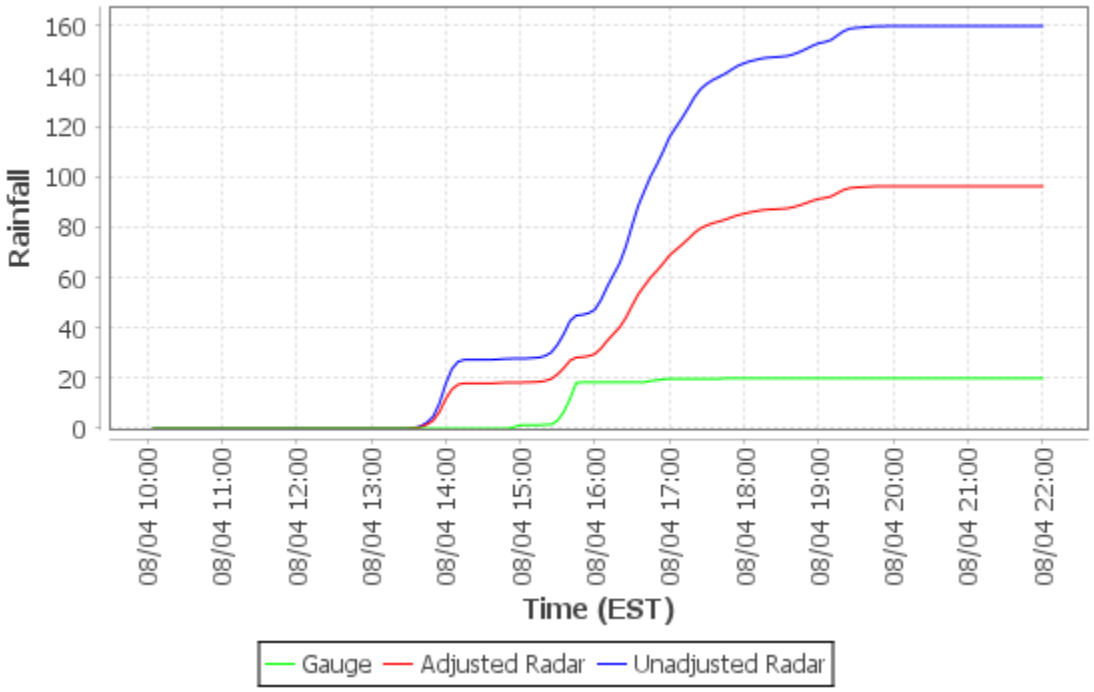
Cumulative Distribution Plot - 2195 North Service Rd W (Mid-Halton WWTP)



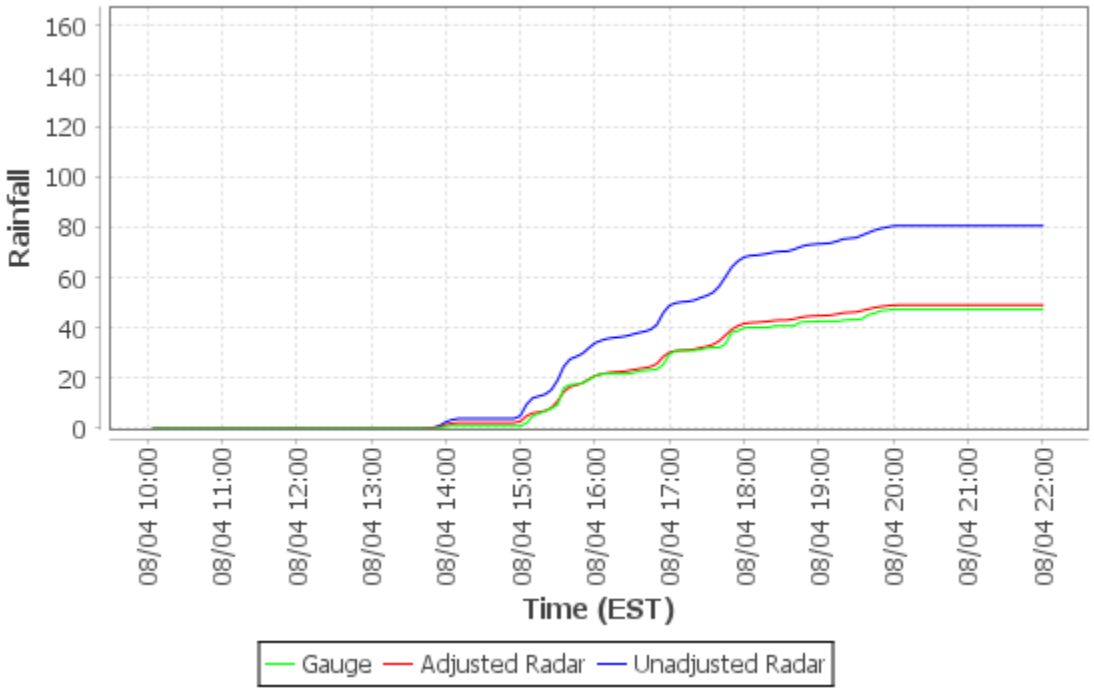
Cumulative Distribution Plot - 4115 Sixth Line (Moore Res)



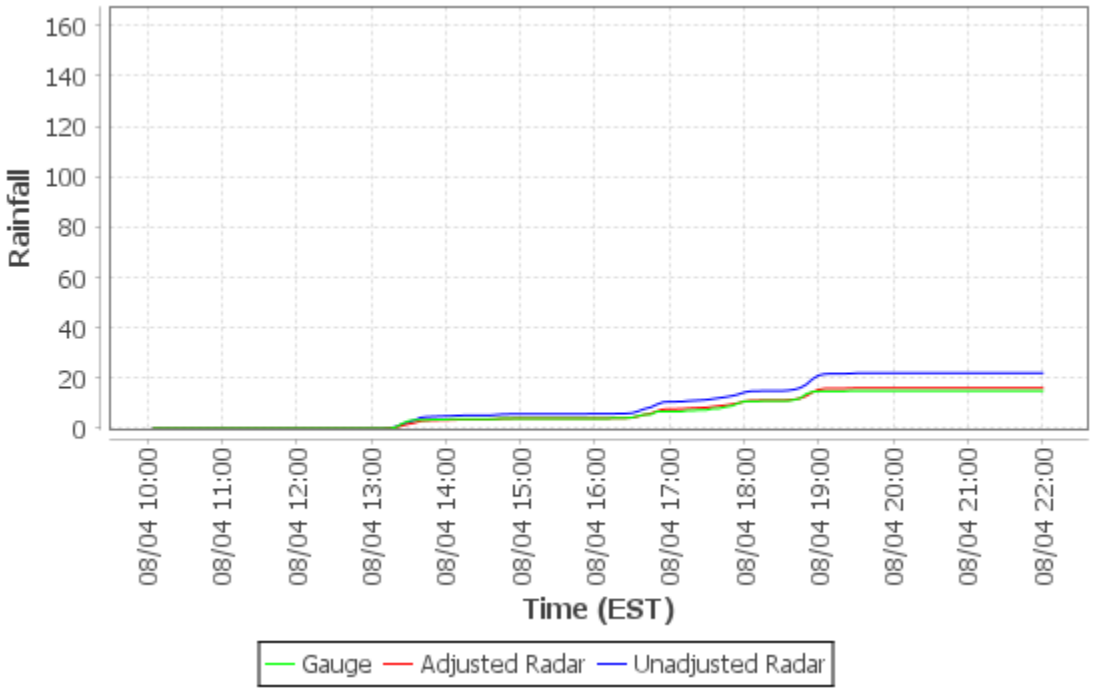
Cumulative Distribution Plot - 5390 Lakeshore Rd (PS8)



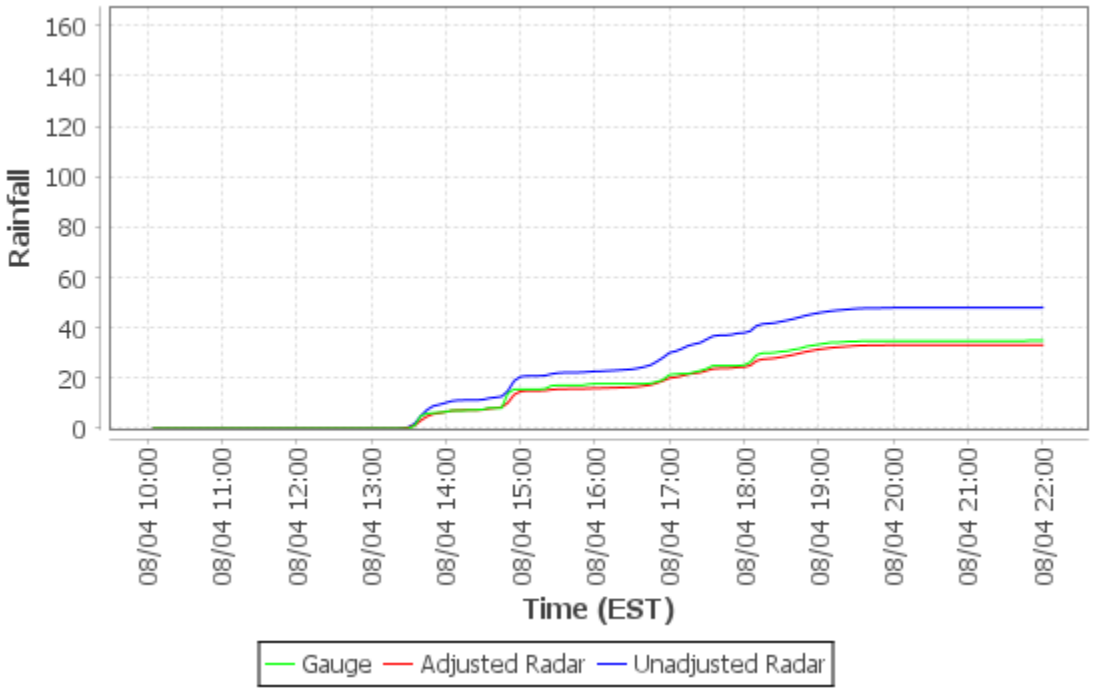
Cumulative Distribution Plot - 3237 Lakeshore Rd (PS9)



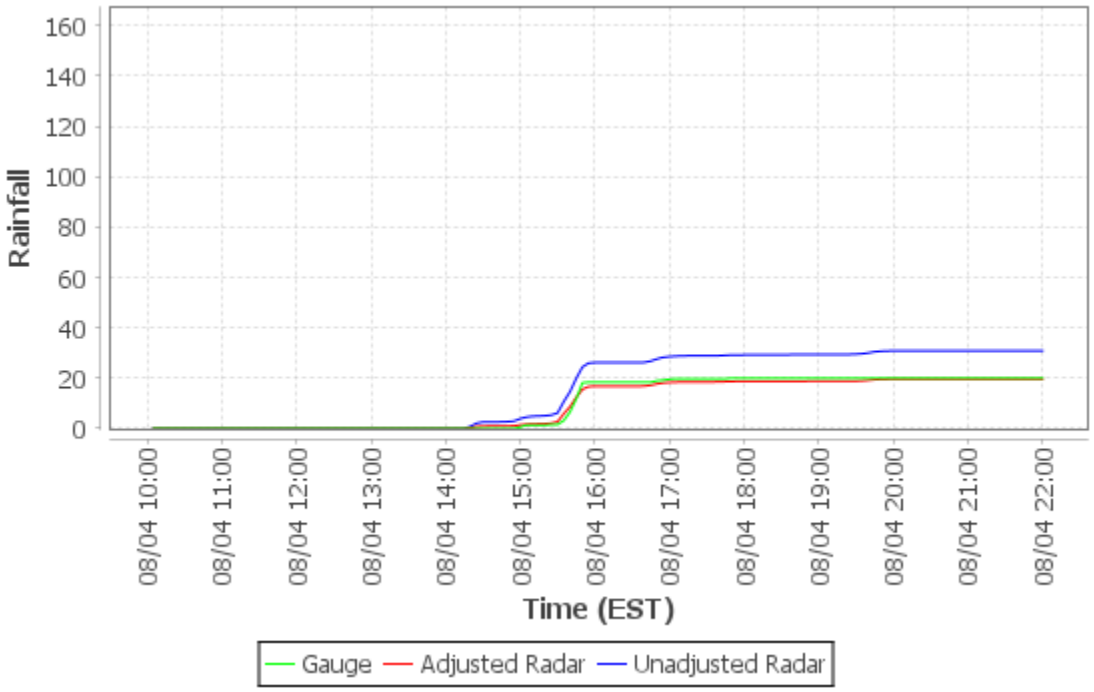
Cumulative Distribution Plot - 2477 Lakeshore Rd E (SE WWTP)



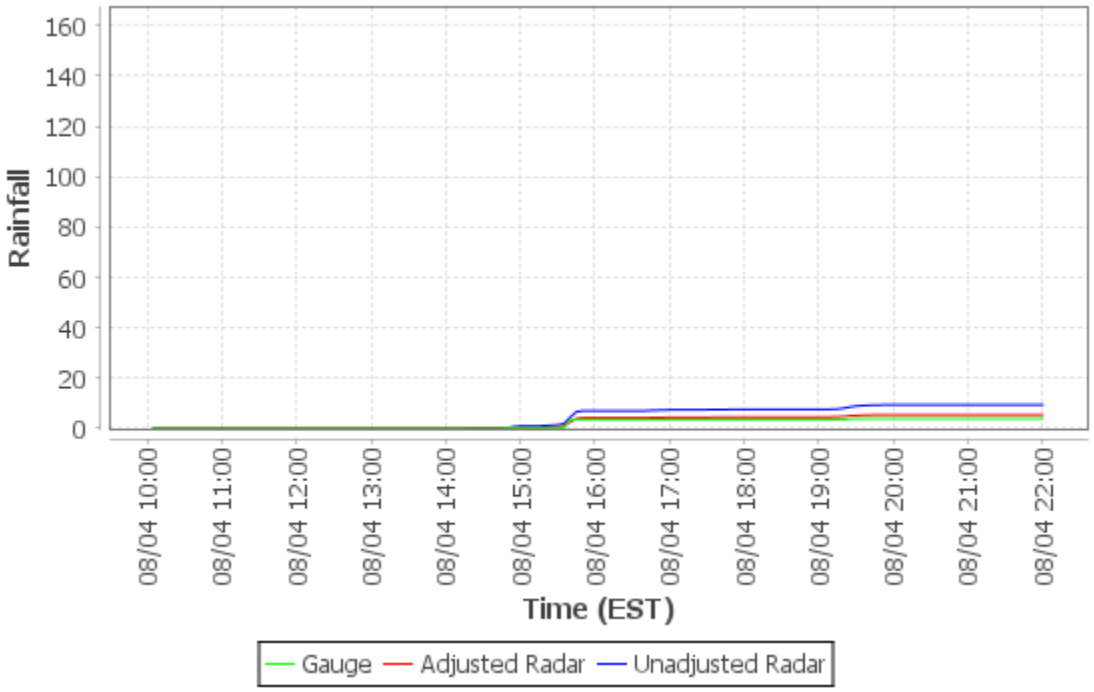
Cumulative Distribution Plot - 1385 Lakeshore Rd W (SW WWTP)



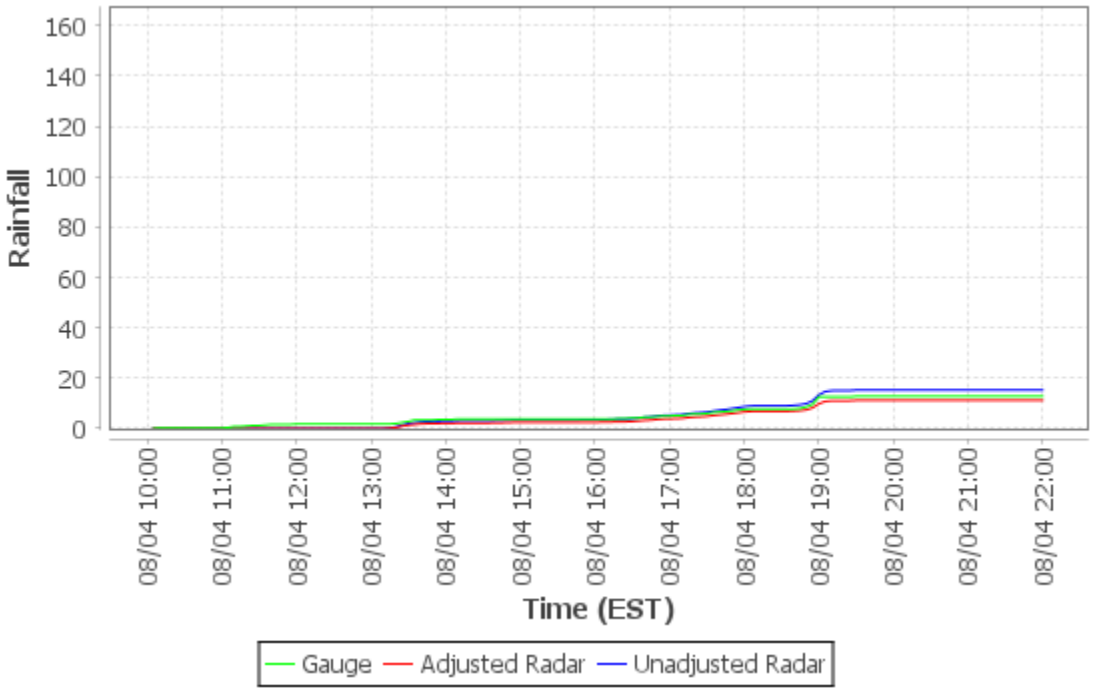
Cumulative Distribution Plot - 1125 Lakeshore Rd (Skyway)



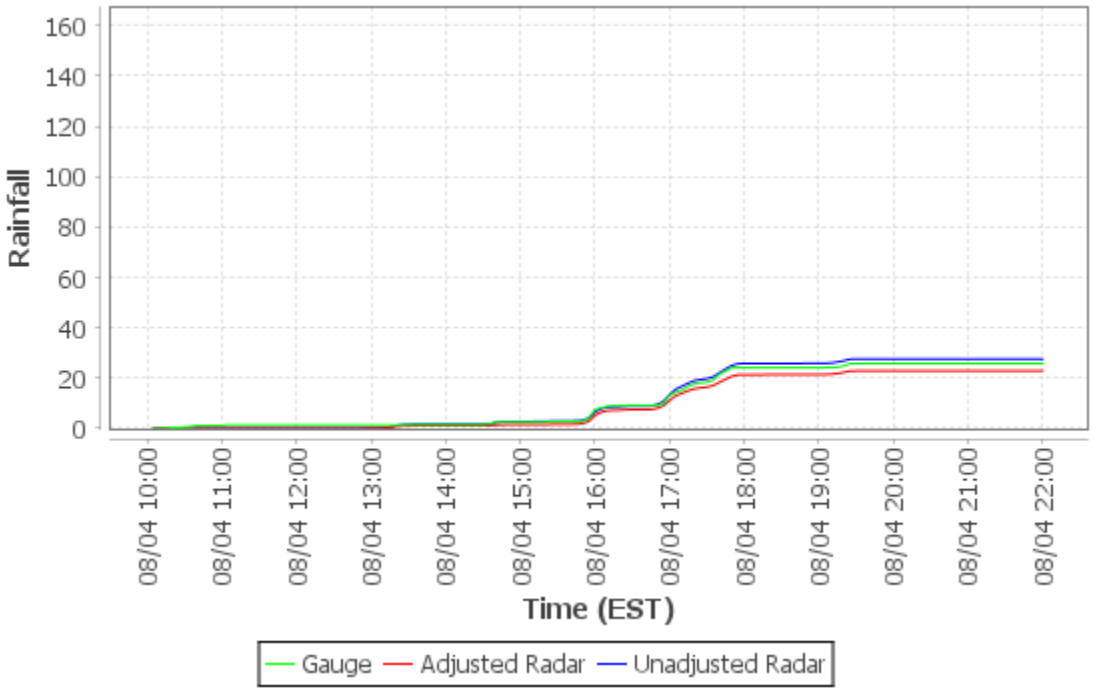
Cumulative Distribution Plot - 1376 Waterdown Rd (Waterdown Res)



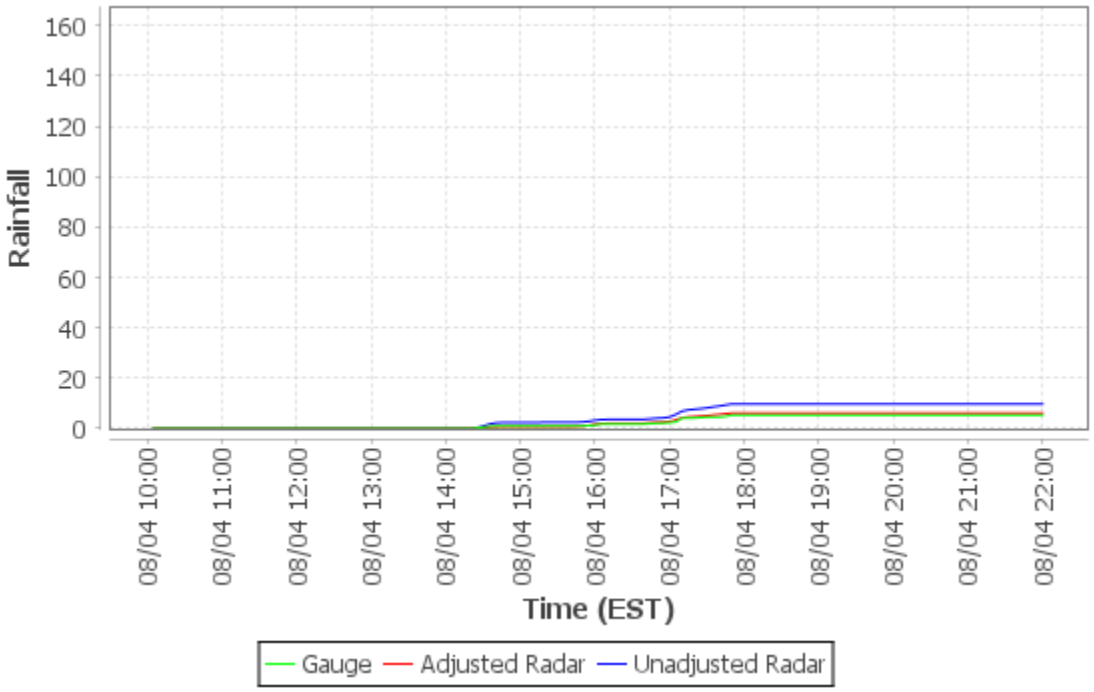
Cumulative Distribution Plot - Clarkson WWTP (STN 02)



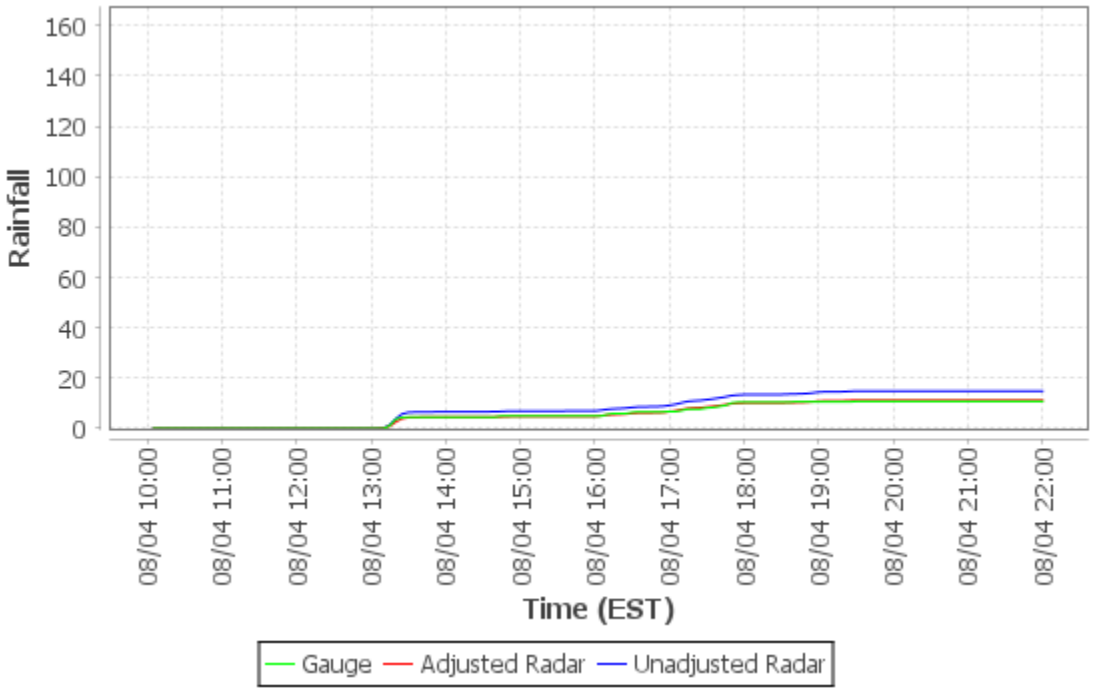
Cumulative Distribution Plot - South Common Community Centre (STN 04)



Cumulative Distribution Plot - Fire station #108 (STN 07)



Cumulative Distribution Plot - Sheridan Villa (STN 09)



Cumulative Distribution Plot - Gary Morden Fire Training Centre (STN 11)

