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USE OF RADAR-RAINFALL IN GIS-BASED SANITARY SEWER MODELING

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Abstract

Traditional inflow/infiltration (I/I) analysis relies on a few rain gauges and flow meters to evaluate excess inflow and infiltration into sanitary sewer systems. Typically the number of rain gauges used in monitoring programs is insufficient to adequately resolve the spatial distribution of rainfall over the targeted sewersheds. In addition, traditional inflow/ infiltration analysis often ignores timing and flow distribution dynamics throughout the sanitary sewer system. This paper presents a new technique for improving rainfall datasets by combining rain gauge data with NEXRAD weather radar data for use in analyzing sanitary sewer systems.

Introduction

Cities throughout the World are faced with the problem of extraneous water leaking into the sanitary sewer systems and overloading the facilities during rain events. The remediation of surface water (inflow) and groundwater (infiltration) entering the sewer system costs billions of dollars in the United States alone.

The impact of leakage into the sewer system is directly related to the rate, duration, and amount of rainfall occurring over the sewershed. Recent advances in radar technologies implemented by the US National Weather Service and by private meteorological information services provide new tools to describe the spatial distribution of rainfall for inflow and infiltration studies. These radar techniques give engineers the ability to "see" between rain gauges to improve the description of the areal distribution of rainfall and the true volumetric contribution of rainfall to the sewershed.

In several recent I/I studies conducted by the authors, radar rainfall estimates were combined with rain gauge observations to create improved descriptions of the spatial distribution of rainfall. These high-resolution rainfall data sets were used with detailed computer models of the sewer systems to simulate sewer response during the storms. Observed storm event hydrographs were compared to the simulated response to evaluate excess inflow/infiltration.

Rain gauges and radar are two fundamentally different tools used to estimate the volume of rain falling on a watershed. Rain gauges make direct measurements of rainfall at a point. Areal rainfall is indirectly determined by making assumptions regarding the amounts of rain falling between the gauges.

Conversely, radar is used to indirectly infer rainfall amounts from direct *areal* measurements over a 2 km x 2 km pixel - an area 123 million times larger than an 8 inch diameter rain gauge. Radar measurements are continuous over the entire watershed and speculation about the area-wide variability of rainfall is dramatically reduced. The objective of this study is to create an optimal estimate of the rainfall entering the subject watershed by merging rain gauge observations with radar estimates of rainfall. A merged data set utilizes the strength of rain gauges (i.e. direct point observation) and the strength of radar (i.e. direct areal estimates) to provide a highly resolved estimate of the timing and distribution of rainfall over the entire project area.

Project Approach

8-inch tipping bucket rain gauges with 0.01 inch resolution were distributed at four locations throughout the study area.

Table 1 shows the coordinates of the rain gauge locations and Figure 1 shows a street map with rain gauge locations. Data loggers at each site recorded the number of 0.01 inch bucket tips that occurred in one minute intervals.

Table 1: Lower White Rock Creek I/I Study Rain Gauge Locations

Gauge	Northing	Easting	Address
1398/8719	-58.693.32	70.673.74	Silberstien Elem Lawnview & Scyene
8717	-61.650.32	82.008.71	San Jacinto Elem, Buckner & Blossom
8750	-48.555.21	66.801.55	Samuel Grand Park, Lawnview & Samuel
8716	-53.976.28	80.037.41	Skyline H.S., Wimbleton & Forney Rd

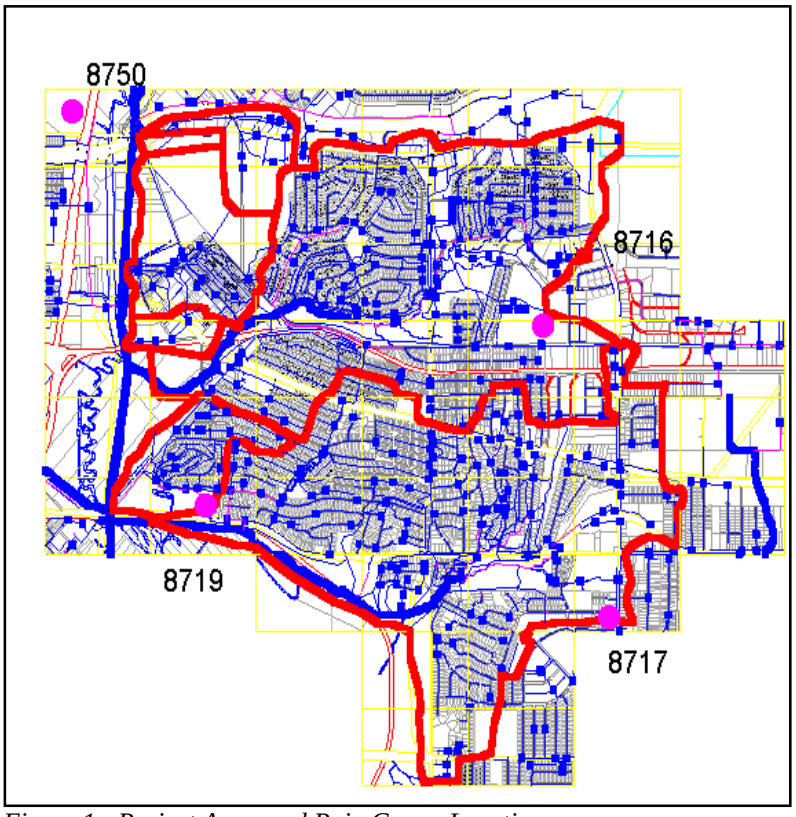

Figure 1 - Project Area and Rain Gauge Location

Radar-Rainfall Estimates

Radar-rainfall estimates were obtained from WSI Corporation, Billerica, MA in 15 minute increments with a spatial resolution of approximately 2 km x 2 km (~988 acres). WSI's radar-rainfall estimates are derived from composite images of radar reflectivity from the National Weather Service WSR-88D radars servicing the Dallas area. WSI is one of four vendors selected by the National Weather Service to provide value-added products directly from the NEXRAD data. WSI takes the NEXRAD data and enhances the dataset through the use of data scrubbing techniques and proprietary algorithms. Finally, WSI blends the data from all the radar sites into one contiguous, nationwide mosaic.

Radar Rain Gauge Comparisons

Rain gauges and radars are fundamentally different tools used to estimate rainfall. Unfortunately, direct comparison of rain gauge observations and radar estimates of rainfall is not straightforward. Radar estimates are estimates of the average rainfall over the entire 2 km x 2 km pixel. Rain gauges measure rainfall at a point. Within a given radar pixel, the rain gauge observation is a function of the gauge's location within the pixel. Figure 2 shows a hypothetical example of the "true" distribution of rainfall along one slice through a radar pixel. The radar estimate is the average across the entire pixel but the rain gauge measurement depends on the gauge's location along the slice. Both observations can be correct yet significantly different.

Gauge-Adjusted Radar-Rainfall Data

If there is just one pixel-gauge pair of rainfall estimates, there is no way of knowing whether or not the radar estimate is biased and in need of adjustment. However, if enough gauge observations are available, one can expect that some of the gauges would be in position to measure amounts higher than the radar estimated average and some gauges would measure lower than the radar estimated average. If the average of all gauge observations is approximately equal to the average of all the associated radar pixel estimates, the radar field is unbiased. If there is a significant difference between

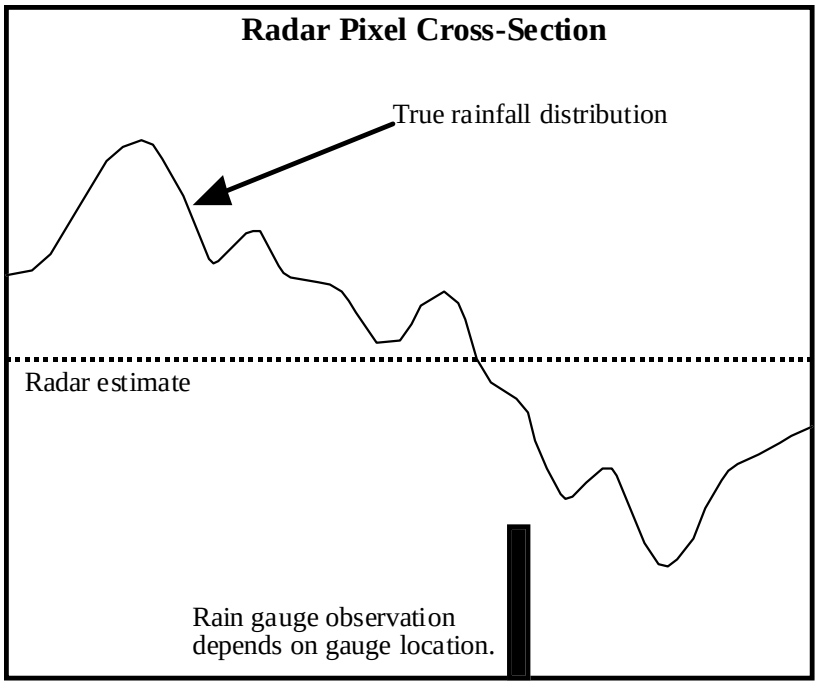

Figure 2 Radar Pixel Cross-Section

the average gauge value and the average radar pixel estimate, the radar field is assumed to be biased on average. The bias can be corrected by applying a "mean-field" field adjustment factor to each pixel in the radar field.

The mean field adjustment factor used in this study is defined as the ratio of the average rain gauge observation and the average radar-rainfall estimate for the pixels associated with each rain gauge location every 15-minutes.

The mean field adjustment factor was developed from pixel-gauge pairs located in and near the target watershed. Using the mean field adjustment factor derived from local rain gauges reduces the potential impacts of any performance variations in the radar data set that are a function of location. (Ground clutter, anomalous propagation, and other artifacts may affect rainfall estimation in some parts of the area but not others.) By keeping the area used to develop the mean field adjustment factors to a minimum, the mean field adjustment factors are more representative of radar performance in the target watershed.

Rainfall Estimation Results

After applying the mean field adjustment to each radar pixel, the *volume of rainfall as represented by the radar pixels* associated with rain gauges is ***exactly*** the same as *the volume of rain represented by the rain gauge observations* (This can be shown mathematically).

As far as the gauge-pixel *pairs* are concerned, the two data sets are equivalent. However, the advantage of the gauge-adjusted radar-rainfall data set is that the radar data set provides a more natural view of what occurred between the gauges than other available methods for distributing rainfall such as Thiessen or other rainfall weighting schemes.

Conceptually, the raw radar data is simply used as a template to describe the areal variability of rainfall over the watershed in space and time. Merging the radar template with the rain gauge observations yields a highly representative areal distribution of rainfall that's consistent volumetrically with the point rain gauge observations.

Even though the *average* gauge-adjusted radar-rainfall estimate matches the *average* rain gauge value, there is still considerable variation in the *individual* gauge-pixel pairs. A Radar-Rain Gauge scatter diagram comparing the individual gauge and radar pixel values will show a scatter of data points that is normal and expected.

The most significant benefit of using radar-rainfall data is the ability of the radar to define the rainfall occurring "between" the rain gauges. The radar can actually quantify the variability. Other methods such as Theissen Polygons or Least-Squared Distance are mathematically correct, but actually provide no information to define the real world conditions.

Radar-rainfall uses the strength of one rainfall measurement technique to compensate for the weakness of the other. The spatial capability of the radar is enhanced by the quantitative accuracy of the rain gauges. The result allows for dramatically better data resolution using fewer physical rain gauges.

Figure 3 shows maps of storm totals for significant rainfall events in the Project Area during the monitoring period. The color coded rectangular shaped areas in the maps represent rainfall estimates corresponding to each radar pixel in the study area.

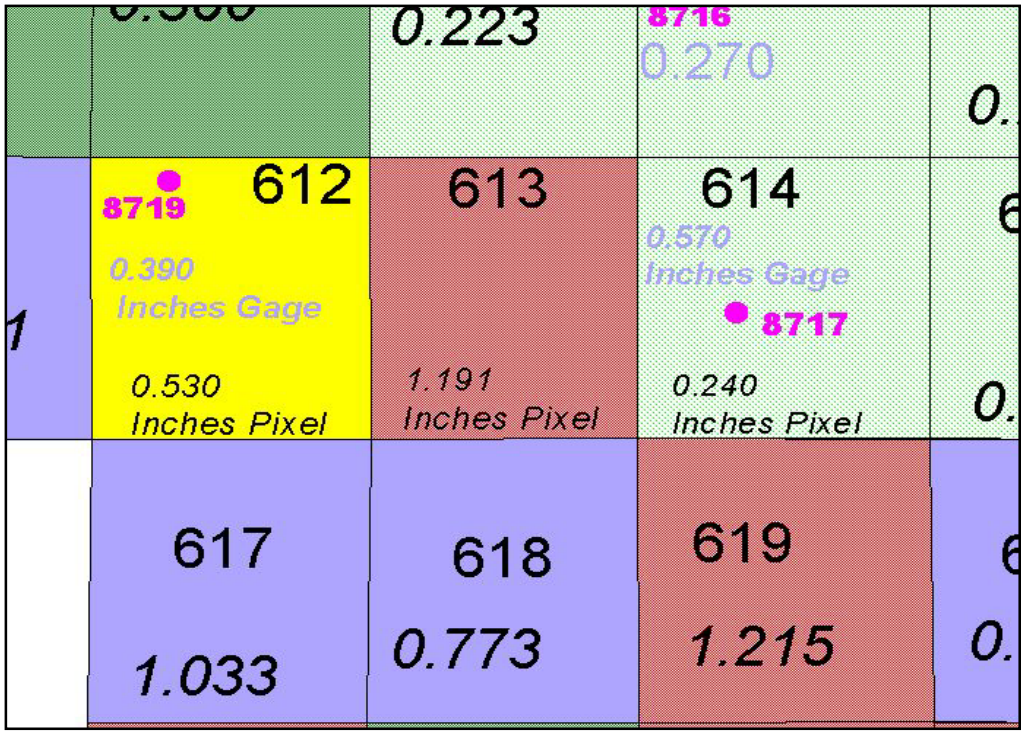

Figure 3 - Pixel and Rain Gauge Rainfall Rates

Note the rain gauge values of Gauge 8719 (Pixel 612) is 0.390 inches, and Gauge 8717 (Pixel 614) is 0.570 inches. However, the adjusted radar-rainfall amounts for Pixels 612 and 614 are considerably different that the rain gauge values. More significantly, the radar-rainfall amount of the pixel between the two gauges (Pixel 613) shows the actual rainfall between the gauges was considerably higher than the rain gauge at either gauge location. Traditional rainfall isohyetograph methods would have resulted in an estimated rainfall amount of approximately 0.48 inches, as compared with the estimate from radar-derived rainfall techniques of 1.191 inches, or a difference of almost 250 percent.

Application To Sewer Analysis

The analysis of sewer systems during storm events centers around determining how much inflow entered the sewer system at the source (yards, manhole covers, etc.). Flow meters can help to measure inflow, however since they are located at the basin outlet, time-delays and rainfall variability upstream prevents directly correlating flow meter data with source flows. Analysis is even more difficult in larger systems where time delays and rainfall variability are greater.

This approach for sewer analysis used the spatial, temporal radar-rainfall data to define the variability of the rainfall. A computer model of the sewer system was used to account for time delays within the sewer system, flow accumulation, and rainfall/inflow relationships. The amount of inflow injected is adjusted until the simulated flows at the basin outlet produced by the computer model matched the actual flows as measured that the flow metering equipment. At that point, a reasonable approximation of the actual source flows was determined.

Another benefit for using radar-rainfall is the ability to better detect when “design storms” occur. Many regulatory agencies use design storms as a benchmark for measuring whether sewer overflows are permitted. Overflows that occur when the recorded rainfall did not reach design storm amounts may trigger enforcement by the regulatory agencies. If only rain gauges are used, then the sewer agency only knows how much rain fell at the rain gauges. Chances are the highest amount of rainfall did not happen to occur exactly where the rain gauge was located. If parts of the sewer system indeed received a design storm rainfall event and overflows occurred, the design storm rainfall would be undetected by the rain gauges. The Agency would incorrectly determine that overflows were caused by less than a design storm event.

Conclusions

Radar-rainfall provides a greatly improved method of determining spatial and temporal distribution of rainfall over large service areas. By combining the radar data with the rain gauge data, a calibrated and contiguous set of data can be geo-registered and used for a variety of purposes in addition to sewer system analysis. As the use of spatial, temporal rainfall data increases, rainfall events will be viewed and analyzed as three dimensional events rather than single point events.

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