Radar data can be used for risk assessment and planning for sustainability in land development and infrastructure needs.

Use of Radar Data to Assess Water Infrastructure Resiliency and Sustainability

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An efficient and resilient water infrastructure is required for a healthy economy and social well-being. Any breakdown in this critical infrastructure can have serious short- to long-term cascading effects, as evidenced by recent catastrophic flooding in areas around the country. To ensure resilient and sustainable infrastructure, various engineering and scientific aspects need coordinated attention and solution.

Research and accurate data assessment are necessary to enable application of the best tools and knowledge to solve problems related to both current and future infrastructure conditions. Otherwise, today's engineering fixes may fail to address tomorrow's impacts.

Radar is an essential tool in the collection of meteorological data, which are used not only to provide weather forecasts but also to inform the planning and design of water infrastructure appropriate to both daily and storm-induced needs. Data collection and synthesis research programs are critical to the effective evaluation of risk and thus to the sustainability of hydrologic systems.

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FIGURE 1 Flooding due to high precipitation near Port Vincent, Louisiana, August 2016. Source: earthobservatory.nasa.gov.

Background

Global warming is associated with anticipated negative impacts on the boundary conditions assumed in the original engineering and design of various utilities and systems such as those for water delivery, sanitary sewer, flood control, and water quality enhancement, among others.

These impacts include the occurrence at ports and waterways of rising tide levels during storms and related hydraulic phenomena such as a sudden rise and fall of water levels (e.g., storm surges). In addition, many cities use combined sewer systems, in which sanitary sewage and storm runoff are designed to occasionally share piping system elements. Under many global warming scenarios of possible elevated water levels, these combined sewer systems may be negatively impacted by elevated outlet hydraulic conditions that may reduce overall discharge and cause overflows.

To address these and other impacts, planning and design need to anticipate where the target concerns will be so that the engineering design arrives positioned to handle future demands—much like running to where the soccer ball will be rather than running after it. Effective preparation requires accurate data and analysis, and radar is a principal tool in the acquisition of such data for water management.

Water-related engineering and planning technical fields of great importance include water distribution, sanitary sewer systems, flood control, water quality enhancement, and others involved in infrastructure resiliency. Water-related concerns in these areas are being transformed by changes in population, development, habitat, facility use, and the environment, among other stresses. Figure 1 illustrates an environmental stress, as populated US coastal and other low-lying areas have been subject to more frequent severe flooding in the past 25 years (USGCRP 2014).

This paper reviews a case study that is relevant to growing communities and their water infrastructure management: flood control in the severe storm environment of arid regions such as the southwestern United States. We estimated storm size (i.e., aerial extent) for the arid watersheds of California's San Bernardino County (SBC), the largest land-area county in the United States (Hromadka et al. 2018). We analyzed 18 years of rain gauge data and Doppler radar data to develop storm size characteristics as they relate to precipitation quantities of high intensity and associated rare return frequencies. This effort was carried out under the direction of the County of San Bernardino as part of its water resources planning and risk analysis efforts.

Doppler: The Radar of Choice for Meteorology

Radar technology helps meteorologists provide timely and useful rainfall and other forecasts. Ever since radar was first used in the Second World War to detect aircraft, its application for predicting weather phenomena (in particular, precipitation) has been fast maturing, with advances in both the equipment used at radar stations and the data processing software that analyzes the scanned radar data and processes them to yield precipitation estimates.

Weather Surveillance Radar (WSR-88D) is the technical name for the 159 high-resolution S-band Doppler weather radars (installed during 1990–96), part of the Next Generation Radar (NEXRAD) network operated by the National Weather Service (NWS; figure 2). The

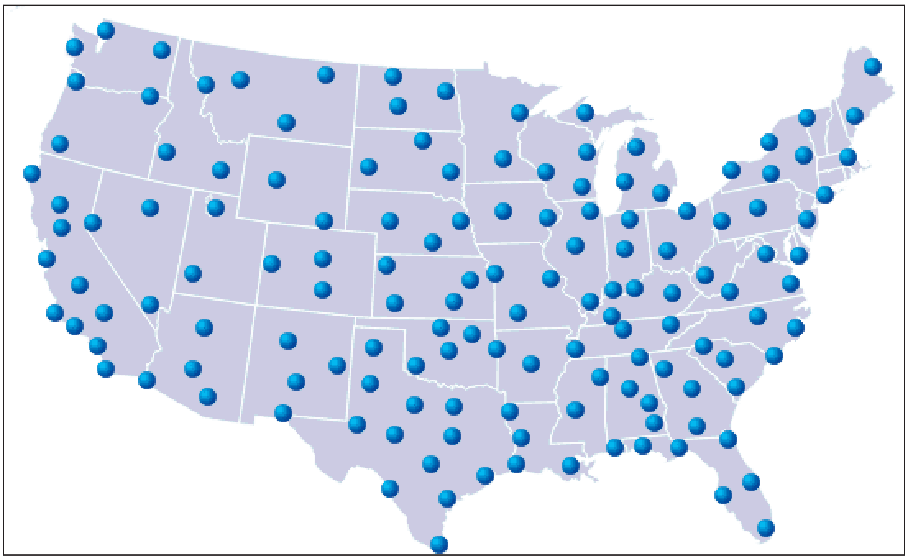

FIGURE 2 Locations of WSR-88D sites in the contiguous United States. Source: radar.weather.gov.

WSR-88D operates by sending and receiving microwave pulses in the 2–4 GHz range, known as the S band. Because the WSR-88D can estimate precipitation at high spatial and temporal resolution, it has great potential for hydrometeorological assessment and use in meteorological and hydrological modeling (Austin 1987; Fulton et al. 1998; Serafin 1996; Smith et al. 1996).

Advances in understanding of the science behind precipitation events led to the upgrading in 2011–12 of the WSR-88D to dual polarization, allowing for enhancements in data quality and addressing some reported limitations (Bringi and Chandrasekar 2001; Collier 2016; Vaccarono et al. 2016). Whereas the originally designed WSR-88D transmits and receives radio waves along a single horizontal polarization, dual polarization radars transmit and receive signals across both horizontal and vertical polarizations. The availability of reflected power and phase details along two directions enables the calculation of additional parameters that can be used to improve precipitation estimates, including better differentiation between heavy rain, hail, snow, and sleet.

Errors in Radar-Estimated Precipitation Values

Studies show, however, that, although Doppler radar has contributed significantly to the understanding and assessment of storm precipitation and related weather phenomena, radar precipitation estimates are subject to various errors and challenges.

Villarini and Krajewski (2010) provided a detailed examination of some errors in radar-estimated precipitation values, and before that Hunter (1996) presented an in-depth discussion of various precipitation estimation errors and potential remedies. Krajewski and colleagues (2010, p. 92) quantified some of the uncertainties in radar precipitation estimates and concluded that, although radar estimates improved over the last two decades, "comprehensive characterization of uncertainty of radar-rainfall estimation has not been achieved."

Berne and Krajewski (2013) discussed some of the challenges for the use of weather radar in hydrology (i.e., in validation studies, precipitation forecasting, mountainous precipitation, error propagation in hydrological models). They noted that the use of weather radar for precipitation measurements in mountainous regions has major limitations—such as interference due to ground clutter, beam shielding, and large vertical variability—that strongly affect the accuracy of estimates.

Thus radar data and outcomes still require careful interpretation and assessment to achieve a desired level of accuracy. In particular, in many areas of engineering and planning Doppler radar remains the primary measurement tool for the assessment of precipitation quantities, so it is important to examine and understand the uncertainty involved in its use.

Doppler Radar Assessment Update for Arid Regions of San Bernardino County

A case study of Doppler data for arid SBC areas sought to determine correlations between the Doppler aerial coverage and precipitation gauge data corresponding to selected storm events. The area is approximately 20,000 square miles and monitored by 77 precipitation gauges with hourly (or shorter-duration) data (excluding daily gauges). Based on the data from these 77 gauges, 156 storm dates with return frequencies estimated (using NWS data) at more than 10 years were identified between 1997 and 2015.

In addition to the arid region of SBC, radar sites in Yuma (KYUX), Edwards (KEYX), Santa Ana (KSOX), Las Vegas (KESX), and San Diego (KNKX) were analyzed for storm events. Once the storms of interest were identified, the relevant NEXRAD data were downloaded from the National Oceanic and Atmospheric Administration (NOAA) website (www.ncdc.noaa.gov/nexradinv/) and used in the creation of a Doppler animation for the 156 storm events. From these animations, 3-hour, 2-hour, 1-hour, 30-minute, and 15-minute peak rainfall durations were identified and, based on the intensities of each peak duration interval, the 11 most significant storms were selected for further analysis.

The Doppler data were used to calculate average rainfall quantity (precipitation depth) for each target peak duration, and the resulting values enabled computation of an average normalized estimated precipitation depth for each interval. The aerial extent versus estimated average precipitation depth for a given interval was plotted (figure 3), together with the published depth area reduction factor (DARF) curves for the county. The DARF takes into account the size of the watershed: a smaller one may have a relatively uniform rainfall over its entire area than a larger watershed. The larger the watershed, the smaller the DARF.

The similarity between the DARF curves and the graphs developed from the radar data suggests that continued monitoring is necessary for all the relevant water recourses variables as well as hydrometeorology variables, particularly as changes occur with new understanding of the variables.

Conclusions

The planet's hydrometeorological responses are continually changing as urbanization spreads and global temperatures rise. Data show evidence of extremely severe and rare precipitation events associated with floods and the failure of engineered systems such as flood control channels, dams, and others.

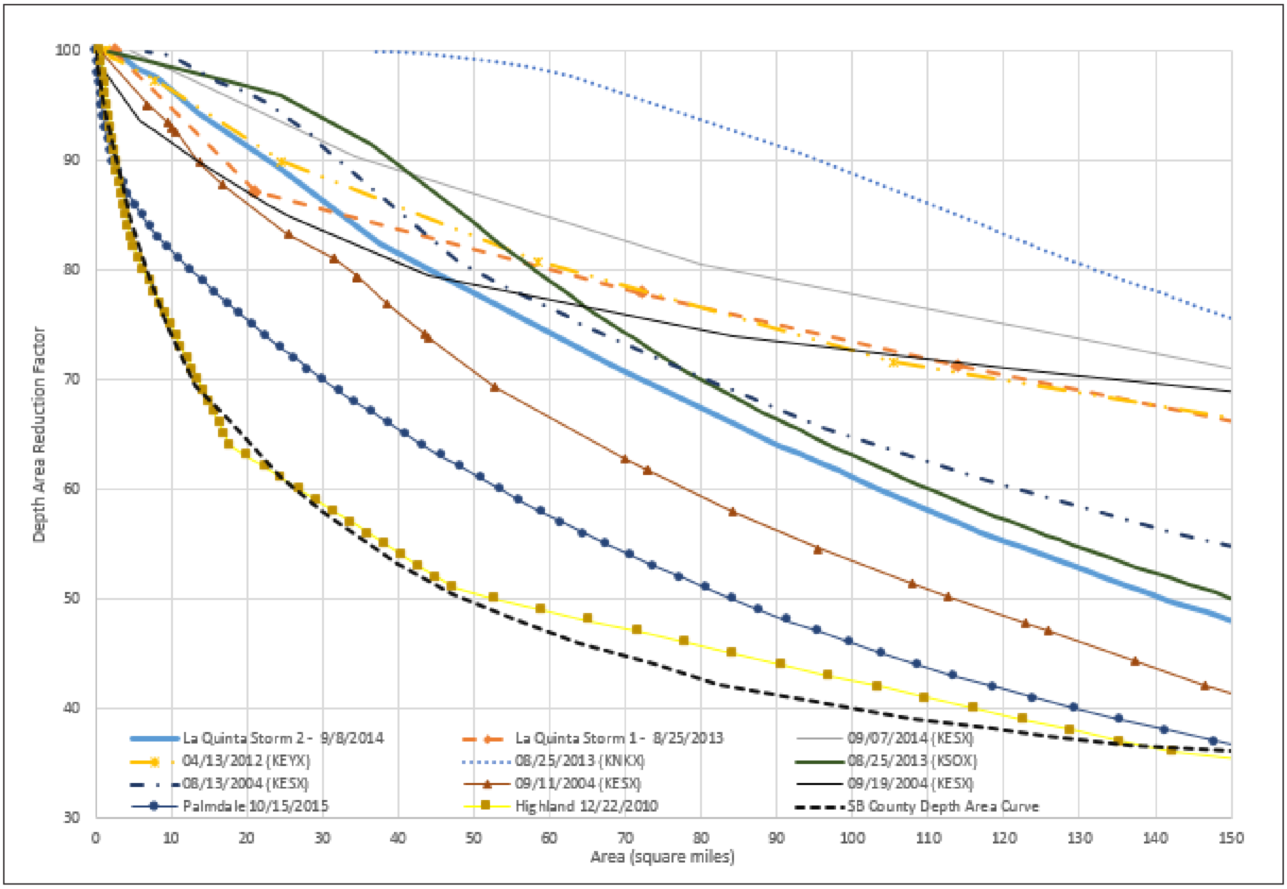

FIGURE 3 Comparison of depth area reduction factor (DARF) curves and Doppler radar (KESX, KEYX, KNKX, KSOX) synthesized graphs for selected storms in San Bernardino County (CA) and adjacent regions, 2004–15. KESX = Las Vegas; KEYX = Edwards Air Force Base; KNKX = San Diego; KSOX = Santa Ana. Reprinted with permission from Hromadka et al. (2018).

Analysis of storms that occurred in 1997–2015 in the County of San Bernardino, based on data from precipitation gauges and Doppler radar, has resulted in valuable information that can be used for a variety of investigations in engineering and planning. Important applications include predictions of risk assessment and sustainability for land development and infrastructure needs in these and other increasingly populated arid regions.

Given the possibility of major impacts from overarching conditions such as anticipated global warming effects, this ongoing data collection program and analysis provide crucial information for infrastructure designers and planners about an important aspect of storm risk analysis, particularly the DARF used in estimating storm size for analysis of storm events and their impacts.

Effective and reliable infrastructure performance and risk reduction require continuous relevant data collection, synthesis, and statistical assessment to evaluate risk with respect to performance goals and sustainability. These methods are only as effective as the data obtained, although advanced statistical and computational methods can also enhance accuracy in the assessment and understanding of hydrometeorological patterns and trends.

Although the focal point of our analysis is the characteristics of storms in arid areas, other hydrometeorological factors—such as weather patterns, watershed characteristics, and hydrological preconditions—need to be carefully measured, monitored, and evaluated to determine trends and patterns. Information about these trends and characteristics is necessary for urban infrastructure planners to make knowledgeable decisions about the vulnerability of regions to anticipated changing conditions. Those decisions can then be incorporated in assessments of risk and sustainability and used to guide planning and decisions about infrastructure maintenance and upgrades.

Note from the Funding Agency

This research was an academic exercise to understand the relationship between radar data and rainfall rates and must not be used for design considerations. The County of San Bernardino Flood Control District, which provided partial funding for this study, has embarked on an aggressive program to install more rain gauges in the arid regions of the county, and these will provide more localized rainfall data for future research.

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