Average Recurrence Interval of Event Precipitation in Real-time

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Abstract

As society and infrastructure become increasingly vulnerable and impacted by extreme precipitation, the requirement for timely, accurate and informative precipitation information is paramount to protecting property, saving lives and efficiently managing water resources. Accurate precipitation data are becoming widely available, but converting the data into meaningful information to support decisions is often difficult, especially in real-time. To make precipitation data more meaningful, an innovative technique for translating near real-time precipitation maps into "return period" maps has been developed for the first time. Knowing how much precipitation fell at a particular location during a certain amount of time is useful, but expressing the rarity of precipitation in terms of a "return period" provides an objective and useful perspective of the precipitation.

The "return period" has been criticized and has lead to confusion in the minds of decision makers and the public. Return period is sometimes misinterpreted as implying that the associated magnitude is only exceeded at regular intervals, and that they are referring to the elapsed time to the next exceedence. Therefore, to clarify the meaning and to be consistent with NOAA, the use of the term "average recurrence interval" or ARI is used. The ARI is the average number of years between exceedences of a given precipitation depth for a given duration at a specific point location. For example, the ARI of 3.63 inches of rain in 24 hours in Seattle, Washington is 50 years. In other words, Seattle can expect 3.63+ inches of rain in 24 hours to occur, on average, every 50 years.

Until now, calculating the ARI of a given precipitation event has been inefficient, generalized for an area based on a single observation and/or lacking reliable underlying data. Our methodology addresses each of these issues. In a highly computational GIS environment, event ARIs are computed using observed precipitation maps from the National Weather Service (NWS) and/or Weather Decision Technologies, Inc. (WDT) against official precipitation frequency maps published by the NWS.

An ARI map provides an objective determination of areas where observed precipitation exceed a certain threshold, for example a 100-year event for disaster assistance, 500-year for EAP activation or 1000-year for potential dam failure. An ARI map displays values in units of years, so for example, a 20 means that the observed 24-hour precipitation at that location occurs on average every 20 years. An ARI map indicates how typical or atypical the observed precipitation was for a specific duration. An overview of ARI maps, several examples and their unique capability to convey the magnitude of precipitation to dam owners will be presented. This paper will discuss this new and exciting technique and how it will help the dam safety community.

Introduction

As society and our aging infrastructure become increasingly vulnerable and impacted by extreme precipitation, the requirement for timely, accurate and informative precipitation information is paramount to protecting property, saving lives and efficiently managing water. Accurate precipitation data is becoming increasingly available, but converting it into meaningful information to support decisions is often difficult, especially in real-time. To make precipitation data more meaningful, an innovative technique for translating near real-time precipitation maps into "return period" maps has been developed. Knowing how much precipitation fell at a particular location during a certain amount of time is useful, but expressing the rarity of precipitation in terms of a "return period" provides an objective and useful perspective of the precipitation. This paper will discuss this new and exciting technology and how it will help the dam safety community.

Precipitation Frequency Estimates

The frequency and magnitude of precipitation is critically important to engineers, hydrologists and others involved in designing and operating structures, such as storm sewers, retention ponds, dams and levees. To meet this need, the Hydrometeorological Design Studies Center (HDSC), which is part of the Office of Hydrologic Development of National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) is, and has been since 1953, responsible for creating and publishing precipitation frequency estimates (e.g. 100-year 24-hour precipitation depth) for all locations in the United States. Since 2003, HDSC has been in the process of updating the old, out-dated precipitation frequency atlases published in the 1950s, 1960s and 1970s through NOAA Atlas 14. NOAA Atlas 14 is based on a much larger and longer sample of observed precipitation data than was available for previous atlases. (Bonnin, et. al., 2003) Eventually, different volumes of NOAA Atlas 14 will cover the entire United States. Figure 1 shows a map of current projects and areas included in future volumes of NOAA Atlas 14.

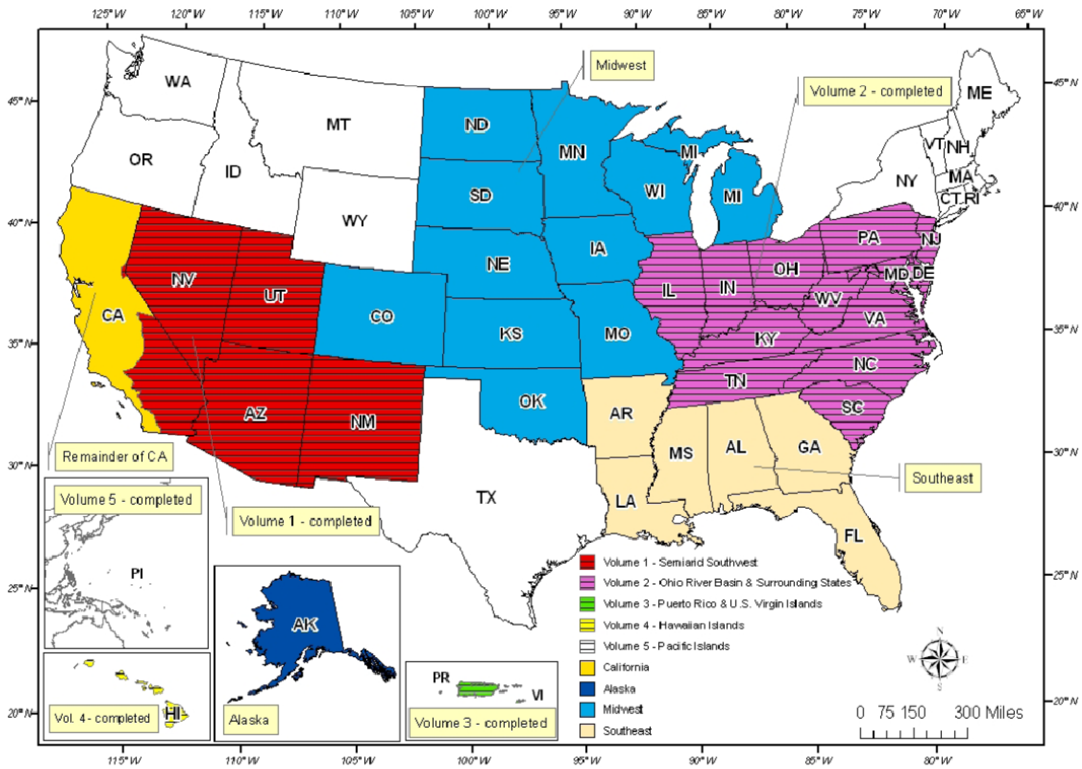

Figure 1 Map of current precipitation frequency projects and area already included in NOAA Atlas Volumes 1-5 as of May 2010. Hatched areas have updated precipitation frequency estimates. Colored areas will have updated precipitation estimates in 2011-2012.

NOAA Atlas 14 provides precipitation frequency relations (e.g. 100-year 24-hour) over a wide range of durations (5 minutes through 60 days) and recurrence intervals (1 year through 1,000 year). The large span of durations and frequencies is provided to meet the diverse needs for precipitation frequency information. More often than not, precipitation frequency estimates are not used in dam design, instead probable maximum precipitation (PMP) and the ensuing probable maximum flood (PMF) are used. Even so, and as this paper will demonstrate, precipitation frequency estimates can be effectively used in conjunction with rainfall for putting the rainfall magnitude into perspective for a number of applications.

Although current volumes of NOAA Atlas 14 are not available for the entire country, we patched together NOAA 14 gridded data (using a GIS) with older precipitation frequency atlases (e.g. Technical Paper 40, Technical Paper 49, NOAA Atlas 2) in order to create a seamless and continuous gridded coverage of the continental United States (CONUS). (U.S. Weather Bureau 1964; Hershfield, 1961; and Miller et. al., 1973). NOAA Atlas 14 is a web-based document available through the Precipitation Frequency Data Server (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html), so it is/was easy to obtain the GIS files. (Parzybok and Yekta, 2003) A sample NOAA Atlas 14 Volume 1 map is shown in figure 2.

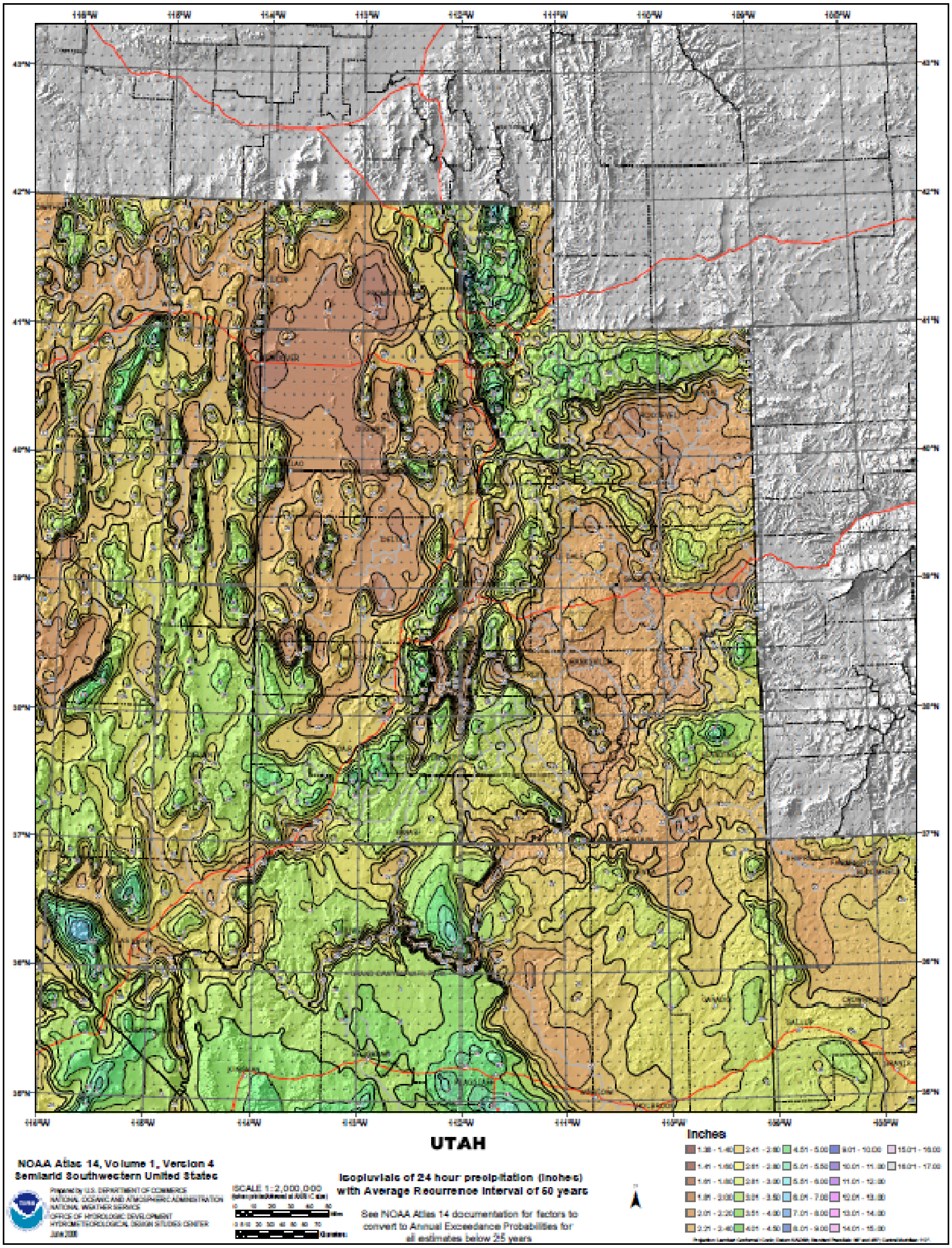

Figure 2 Sample (Utah, 50-year 24-hour) precipitation frequency map from NOAA Atlas 14 Volume 1.

The use of the term "return period" has been criticized for leading to confusion in the minds of decision makers and the public. "Return period" is sometimes misinterpreted as implying that the associated magnitude of a rain event is only exceeded at regular intervals. In other words, if a 100-year event occurred today, it is not true that another 100-year event will not occur for another 100-years. Therefore, to clarify the meaning and to be consistent with NOAA Atlas 14, the use of the term "average recurrence interval" or ARI is used. The ARI is the average number of years between exceedences of a given precipitation depth for a given duration at a specific point location. For example, the ARI of 3.63 inches of rain in 24 hours in Seattle, Washington is 50 years. In other words, Seattle can expect 3.63+ inches of rain in 24 hours to occur, on average, every 50 years. The "on average" part is critical because this means a 3.63 inch event, or larger, could happen again this year, next year, or any year. It does not mean one has to wait 50 years for a similar precipitation event to occur at the same location.

It is also very important to understand that rainfall ARI does not necessarily equate to a flood of the same ARI. Floods can be caused by heavy rain, spring snowmelt, dam/levee failure and/or limited soil absorption. The degree of flooding from heavy rainfall depends on the rainfall intensity, duration, topography, soil conditions, ground cover, basin size and infrastructure design among other factors. Rain associated with a 1 to 5 year ARI can cause significant urban flooding since most urban storm water systems are designed for 1 to10 year ARI rainfall events. ARIs for highway and other transportation infrastructure typically vary from 10 to 25. However, it is a near certainty that rainfall associated with ARIs greater than 100 year will cause major flooding. Dams and levees are generally designed for rainfall ARIs much larger than 500 years, but can be compromised during ARIs of 100 to 500+ year events.

Precipitation Data

Although the transformation of observed rainfall values into their equivalent ARI at gauge locations is possible, the focus of this paper is on the transformation of all points in a grid in order to produce an ARI map, therefore, maps/grids of rainfall data are needed. There are a growing number of sources of rainfall maps, including the National Weather Service (NWS) and Weather Decision Technologies, Inc. (WDT). A sample NWS rainfall map, from http://water.weather.gov/precip/, is shown in Figure 3. The precipitation-to-ARI conversion is especially sensitive to erroneous precipitation data, therefore it is important to have good quality rainfall data. Erroneous rainfall data will result in anonymously high ARI value and hence a "bulls eye" on the ARI map. It has only been within the past 5 years that gauge-adjusted radar-estimated rainfall has become reliable enough across the United States to support computations like ARI. The NWS radar data is available at a spatial resolution of 4 km by 4km, while data from WDT is available down to 1 km by 1 km. Both are available at a temporal resolution as short as 5-minutes, however reliable rainfall to ARI conversions are best made at durations of 1 hour or more.

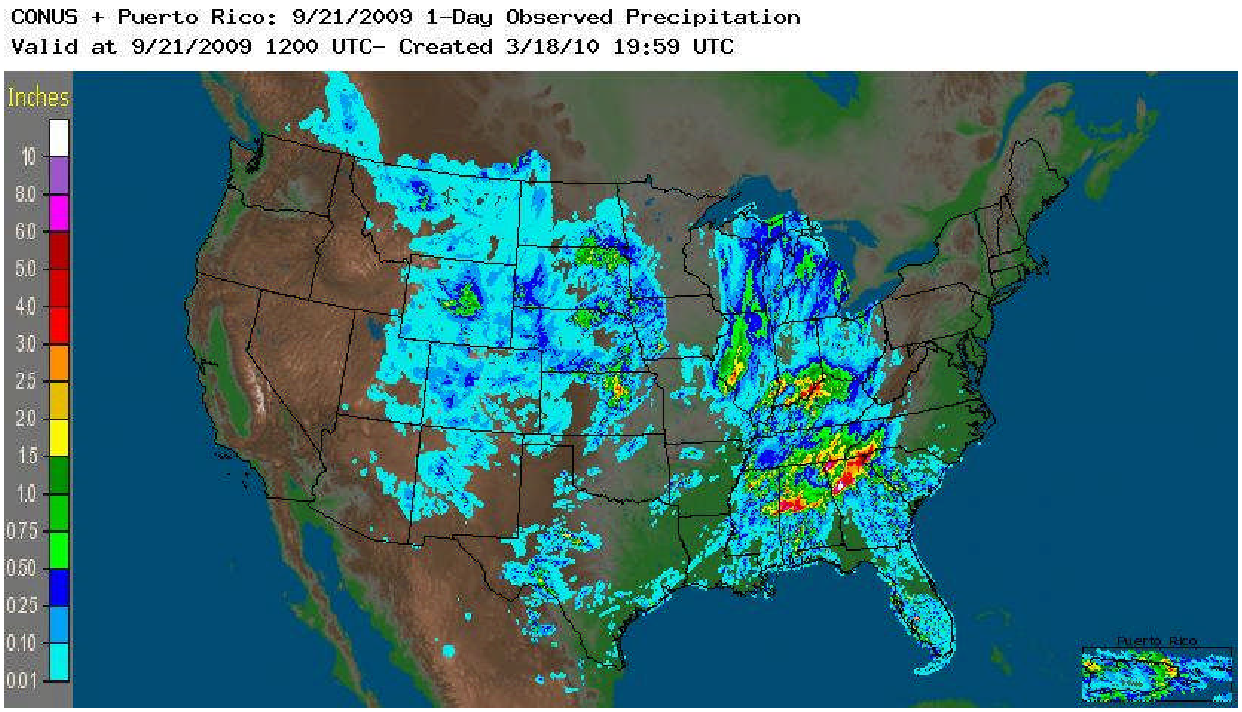

Figure 3 Sample NWS map of 24-hour observed rainfall ending on March 18, 2010 at 20 UTC.

Rainfall to ARI Conversion

The ARI grids/maps are created by translating each grid cell from the continental United States (CONUS) quantitative precipitation estimate (QPE) grid into an ARI. The rainfall to ARI conversion uses proprietary software, but the basic steps are outlined below. Given an observed rainfall amount, duration and location (e.g. 2.00 inches in 24 hours at Phoenix, Arizona) the corresponding ARI is computed as follows:

1. Obtain the precipitation frequency estimates from the appropriate, official precipitation frequency atlas. For our example, official precipitation frequency estimates for Phoenix, AZ are in NOAA Atlas 14 Volume 1 (Bonnin et. al., 2003).
2. Determine the bounding ARIs of the observed precipitation amount. For instance, according to NOAA Atlas 14, the ARI for a 24-hour 5-year ARI at Phoenix is 1.81” while the 10-year ARI is 2.14”.
3. Using the bounding ARI and precipitation frequency estimates, interpolate the ARI of the observed precipitation amount. In this example, a 2.00” rainfall event in 24 hours at Phoenix, AZ is equivalent to an ARI of 7.9 years.

The rainfall to ARI process is highly computational. Depending on the extent of rainfall across the CONUS, each CONUS ARI map is processed and created in 3-8 minutes on a multiple-processor Linux computer. The CONUS QPE grids are available at 12-14 minutes past each hour, so the ARI products are available at 15-23 minutes past the hour, valid through the last hour (Figure 4).

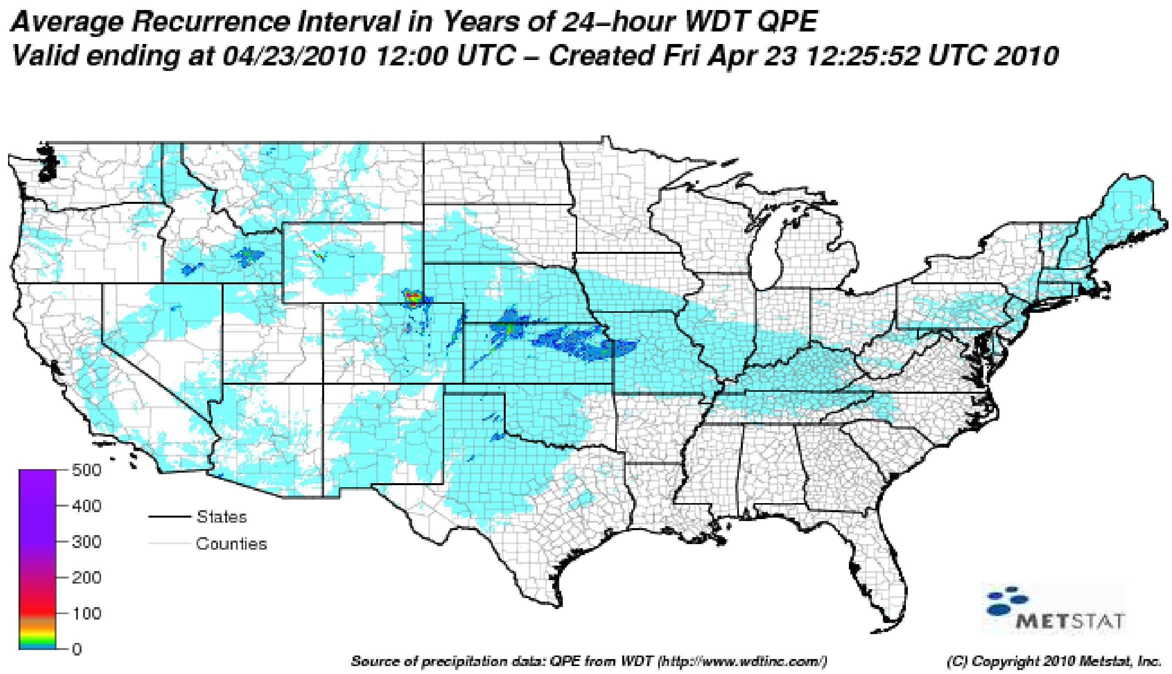

Figure 4 Sample CONUS ARI map valid for 24-hour rainfall ending on April 23, 2010 1200 UTC.

Although based on the best available data, the underlying precipitation frequency data and observed rainfall both inherently carry different degrees of uncertainly, therefore the ARIs should be considered estimates.

Sample Cases

Now that we can visualize the ARI of events across the U.S. it is apparent that rare rainfall events occur almost daily, somewhere in the country. A couple of widespread, extreme events during the past year provided excellent examples of the ARI map concept. The first event occurred in January 21-23, 2010 across central Arizona. A very moist storm system produced up to 10 inches of rain during a 24 hour period to parts of central Arizona. These rainfall amounts equated to ARIs of 100+ years in areas (Figure 5).

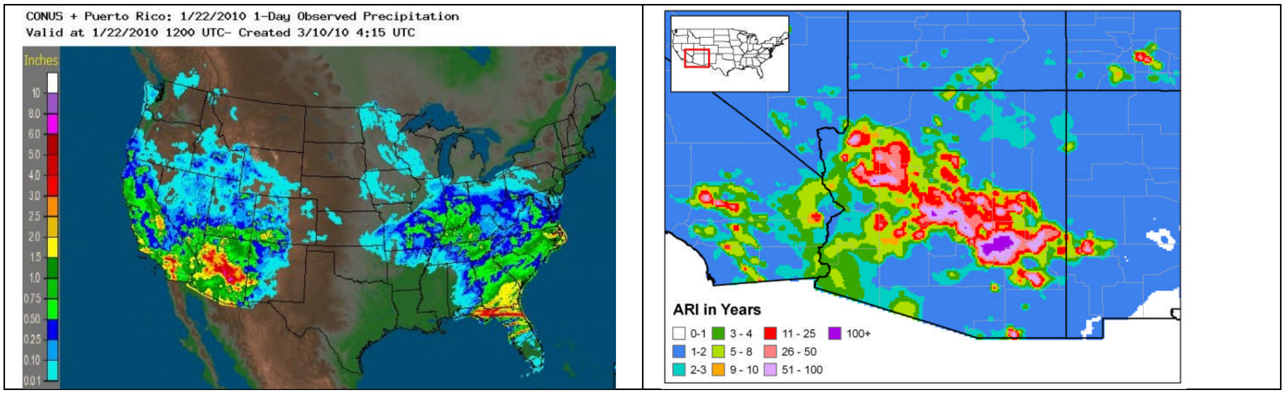

Figure 5 NWS observed rainfall (left) and corresponding ARI (right) for 24-hour period ending January 22, 2010 1200 UTC.

Another noteworthy event occurred over the Tennessee Valley during the period May 2-4, 2010, where over 12 inches of rain fell. The ensuing floods claimed 30 lives and caused more than $1 billion in damage. The ARI indicated this was a 100-year event across parts of western Tennessee and western Kentucky (Figure 6).

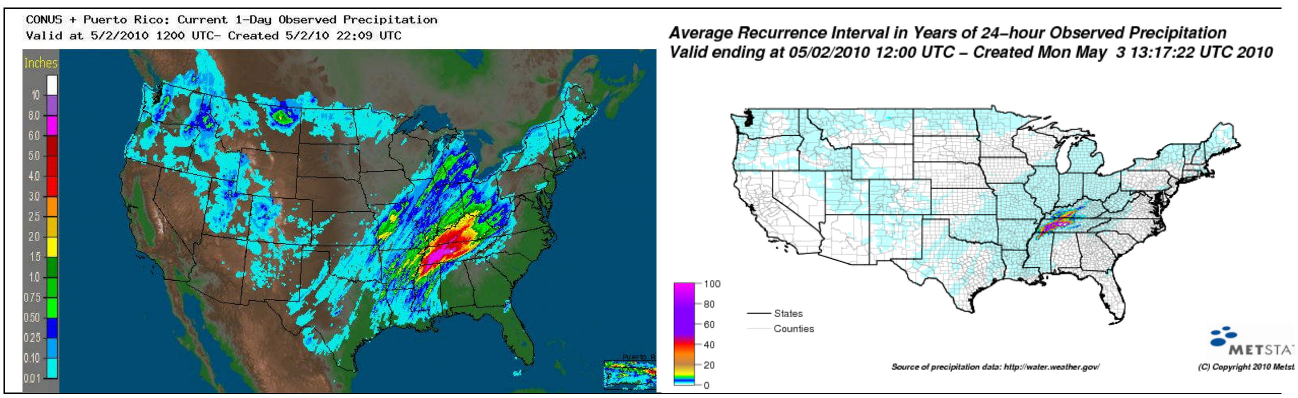

Figure 6 NWS observed rainfall (left) and corresponding ARI (right) for 24-hour period ending May 2, 2010 1200 UTC.

Conclusions

Until now knowing the ARI of a given rainfall event has been difficult to compute, generalized for an area based on a single observation and/or lacking reliable underlying data. ARIs can now be objectively computed using official precipitation frequency atlas's in conjunction with observed precipitation grids/maps for every location in the United States, in near real-time.

ARI maps provide a new and exciting way to visualize rainfall data that has never been avaialbe to decision makers before. It has a wide range of applications, for example activation of EAPs, rainfall monitoring guidance to dam owners/operators and issuance of flood warnings. A coarse (4km x 4km) resolution 24-hour ARI map of the continental United States based on gauge-adjusted radar precipitation data from the NWS is available by visiting http://www.metstat.com.

Efforts are underway to expand to Puerto Rico and Hawaii as well as adding additional durations and variables (e.g. snow). Plans are in place to also provide forecast ARI products, thereby giving clients an idea of how significant (in terms of ARI) a rainfall event is expected to be.

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