SITE-SPECIFIC PMP FOR NORTH TEXAS: BRINGING HMR 51 INTO THE 21ST CENTURY

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ABSTRACT

As part of an ongoing effort to evaluate continued performance of Tarrant Regional Water District (TRWD) dams, the TRWD Dam Safety Program is actively re-evaluating some of its aging infrastructure. Since design of some structures was completed in the 1920s, TRWD is comparing performance to modern standards and, if indicated, designing remedial measures. A geotechnical stability review and analysis is currently underway, and in 2009 an updated probable maximum flood (PMF) study was completed for one of the four reservoirs. The final component evaluated was the probable maximum precipitation (PMP) values. The PMP directly affects the resulting PMF and updated PMP values allow for PMF updates for all four TRWD basins.

In 1978 the National Weather Service (NWS) published Hydrometeorological Report No. 51 (HMR 51). The most recent storm used in HMR 51 to derive PMP values for the TRWD region occurred in 1954, so TRWD recognized the need for an updated PMP analysis. Due to limited funding and staffing, the NWS no longer produces PMP estimates. TRWD turned to Applied Weather Associates (AWA), a company with 17 years of experience producing site-specific, statewide, and regional PMP studies. For this study, AWA identified the most significant recent storms that have occurred over geographic regions that are topographically and climatologically similar to the TRWD basins. Several new extreme rainfall storms were identified, analyzed, and used along with storms in HMR 51 to determine PMP values for the TRWD basins. The study results reduced PMP compared to HMR 51 by as much as 21% for the TRWD basins. Study methods, process, data, and results are presented and discussed.

INTRODUCTION

This paper details the process and results associated with the development of the site-specific probable maximum precipitation (SSPMP) values for use in the computation of

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the probable maximum flood (PMF) for the four drainage basins comprising the Tarrant Regional Water District (TRWD); Lake Bridgeport, Eagle Mountain, Richland Chambers, and Cedar Creek (Figure 1.).

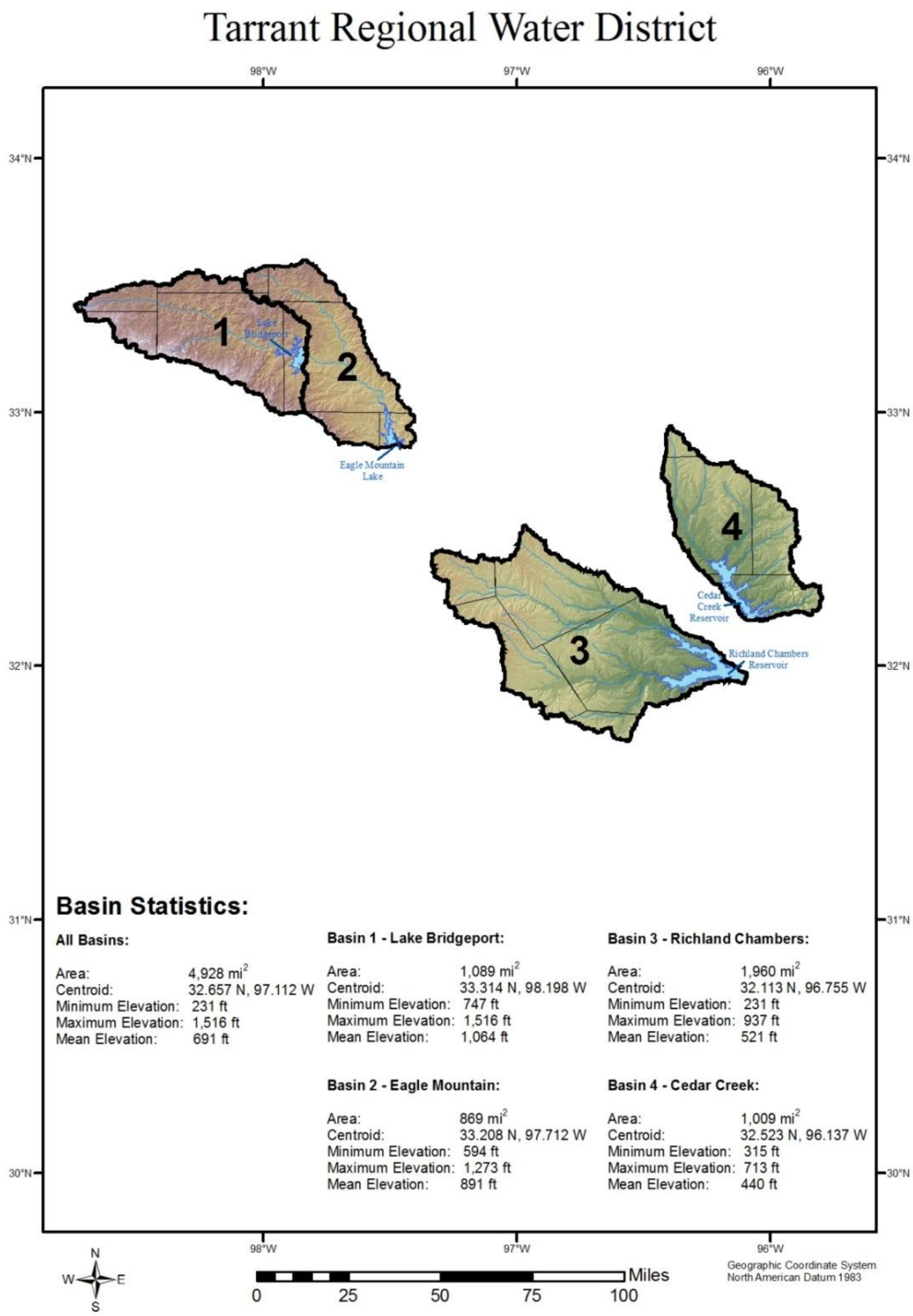

Figure 1. TRWD basins and relevant information used in this study

Background

Definitions of PMP are found in most Hydrometeorological Reports (HMRs) published by the National Weather Service (NWS). The definition used in the most recently published HMR (HMR 59, p. 5) is "theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year." Since the mid-1940s or earlier, several government agencies have been developing methods to calculate PMP in various regions of the United States. Until about 15 years ago, the NWS and the Bureau of Reclamation were the primary agencies involved in this activity. PMP values from their reports are used to calculate the PMF which, in turn, is often used for the design of significant hydraulic structures.

The generalized PMP studies currently in use in the conterminous United States include HMR 49 (1977) for the Colorado River and Great Basin drainage; HMRs 51 (1978), 52 (1982) and 53 (1980) for the U.S. east of the 105th meridian; HMR 55A (1988) for the area between the Continental Divide and the 103rd meridian; HMR 57 (1994) for the Columbia River Drainage; and HMRs 58 (1998) and 59 (1999) for California. HMR 51 covers the largest portion of the U.S. and is considered a generalized PMP study. Figure 2. shows an example of a HMR 51 PMP map and its coverage, as it covers all of the U.S east of the Front Range of the Rocky Mountains.

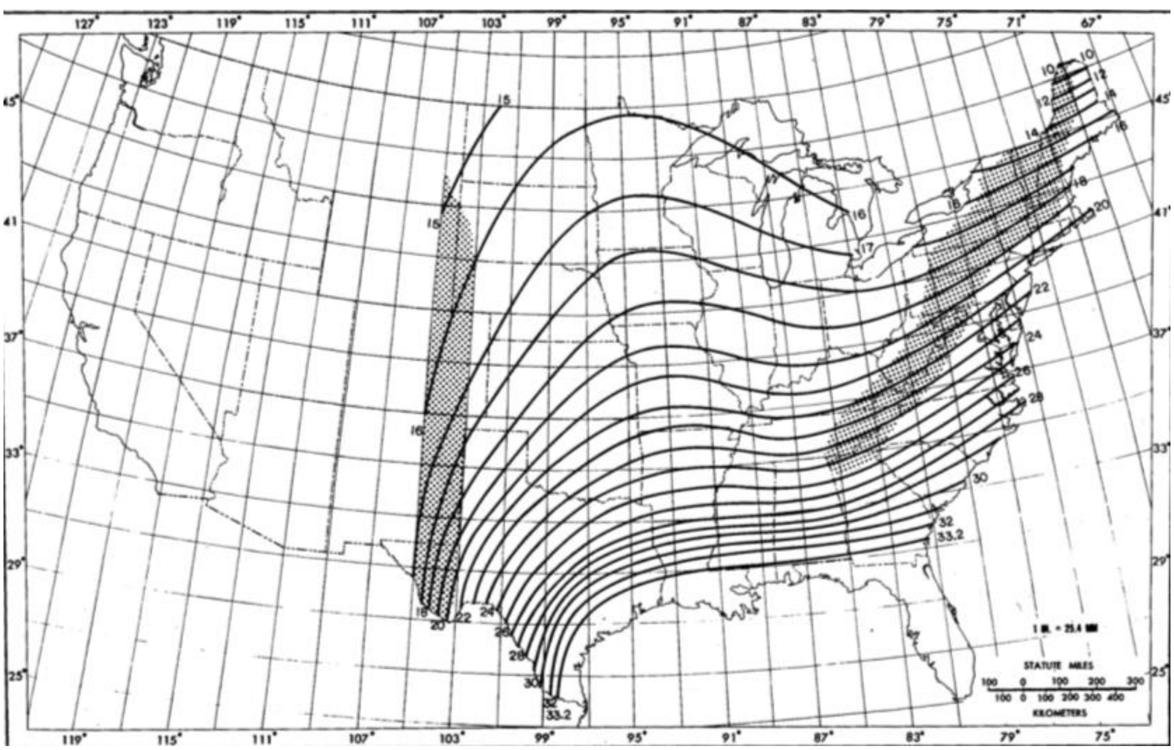

Figure 1. Example of a HMR 51 PMP map for 24-hour rainfall over 1,000 square miles (Schreiner and Riedel 1978)

A number of site-specific, statewide, and regional PMP studies augment generalized HMRs (Harriman Study-Yankee Atomic Energy Company, 1987; Tomlinson, 1993; Tomlinson et al., 2002; Tomlinson et al. 2003; Tomlinson et al., 2007; Tomlinson et al., 2008; Tomlinson et al., 2009; Tomlinson et al., 2010 and Tomlinson et al., 2011). These studies are for specific drainage basins, states, or regions within the large area addressed by HMR 51 as well as the other HMR documents. The meteorological conditions producing extreme rainfall events are significantly varied in different regions within this large geographic area covered by HMR 51. Along the Gulf Coast and much of the eastern seaboard, hurricanes are a major contributor. In much of the Midwest, extreme events are usually linked to either Mesoscale Convective Systems (MCSs) or synoptic storms with embedded convection. For the TRWD, all three storm types have an effect on the extreme rainfalls that can produce PMP. These include storms with remnant tropical moisture, synoptic frontal systems, and MCSs. Often, the extreme rainfalls associated with storms analyzed as part of this study are a combination of two of these storms types.

Although it provides generalized estimates of PMP values for a large, climatologically diverse area, HMR 51 recognizes that studies addressing PMP over specific regions can incorporate more site-specific considerations and provide improved PMP estimates. By periodically reviewing storm data and advances in meteorological concepts, PMP analysts can identify relevant new data and approaches for use in determining PMP estimates (HMR 51, Section 1.4.1).

Several SSPMP studies have been completed within the region covered by HMR 51; the Upper Deerfield River drainage above Harriman Dam in Vermont (Board of Consultants to New England Power Company 1987), the Upper and Middle Dams drainage basin in Maine (Tomlinson 2002), the Great Sacandaga Lake drainage basin in New York (Tomlinson 2003), the Woodcliff Lake drainage basin in New Jersey in 2007 (Tomlinson et al. 2007), the Blenheim Gilboa drainage basin in New York in 2008 (Tomlinson et al. 2008), the Tuxedo Lake drainage basin in New York in 2009 (Tomlinson et al. 2009), the Lake Wanahoo drainage basin in Nebraska (Tomlinson et al. 2008), and the Brassua Dam basin n Maine (Tomlinson et al. 2011), Ohio statewide PMP (in progress), Wyoming statewide PMP (in progress). Additionally, a regional study for the two state regions of Wisconsin and Michigan, managed by the Electric Power Research Institute (EPRI) was completed in 1993 (Tomlinson 1993) and the statewide study for Nebraska was completed in 2009 (Tomlinson et al.). These are good examples of PMP studies that explicitly consider the meteorology and topography of the basins along with characteristics of historic extreme storms over climatically similar regions surrounding the basins. Resulting updated PMP values replace HMR 51 values for those studies and have been used in computing the PMF for individual watersheds.

Objectives

The objective of this study was to perform a site-specific study to determine reliable estimates of PMP values for the Lake Bridgeport, Eagle Mountain, Richland Chambers, and Cedar Creek watersheds comprising the TRWD watersheds. The most reliable methods and data currently available have been used, with new techniques and data used where appropriate.

Approach

The approach used in this study follows the same basic procedures that were used in the development of the HMRs. These procedures were applied considering the meteorological and topographic characteristics of the TRWD watershed.

The study maintains as much consistency as possible with the general method used in HMR 51 and the numerous site-specific, statewide, and regional PMP studies AWA has completed over the past 17 years. Deviations are incorporated where justified by developments in meteorological analyses and available data. The basic approach identifies major storms that occurred within the central United States from Kansas east to the Mississippi River south to approximately Interstate 10 in Texas and to within 50 miles of the Gulf Coast line from Louisiana through Georgia (Figure 2.). The moisture content of each of these storms is maximized to provide an estimate of the maximum rainfall for each storm at the location where it occurred. This is accomplished by computing the ratio of the *maximum* amount of atmospheric moisture that could have been entrained into the storm at that time of year to the *actual* atmospheric moisture entrained into the storm as it occurred. After maximization, the storms are transpositioned to each appropriate basin throughout the TRWD watershed to the extent supportable by similarity of meteorological conditions and topography. Maximum precipitation values are enveloped for each basin to provide PMP estimates for various area sizes and durations.

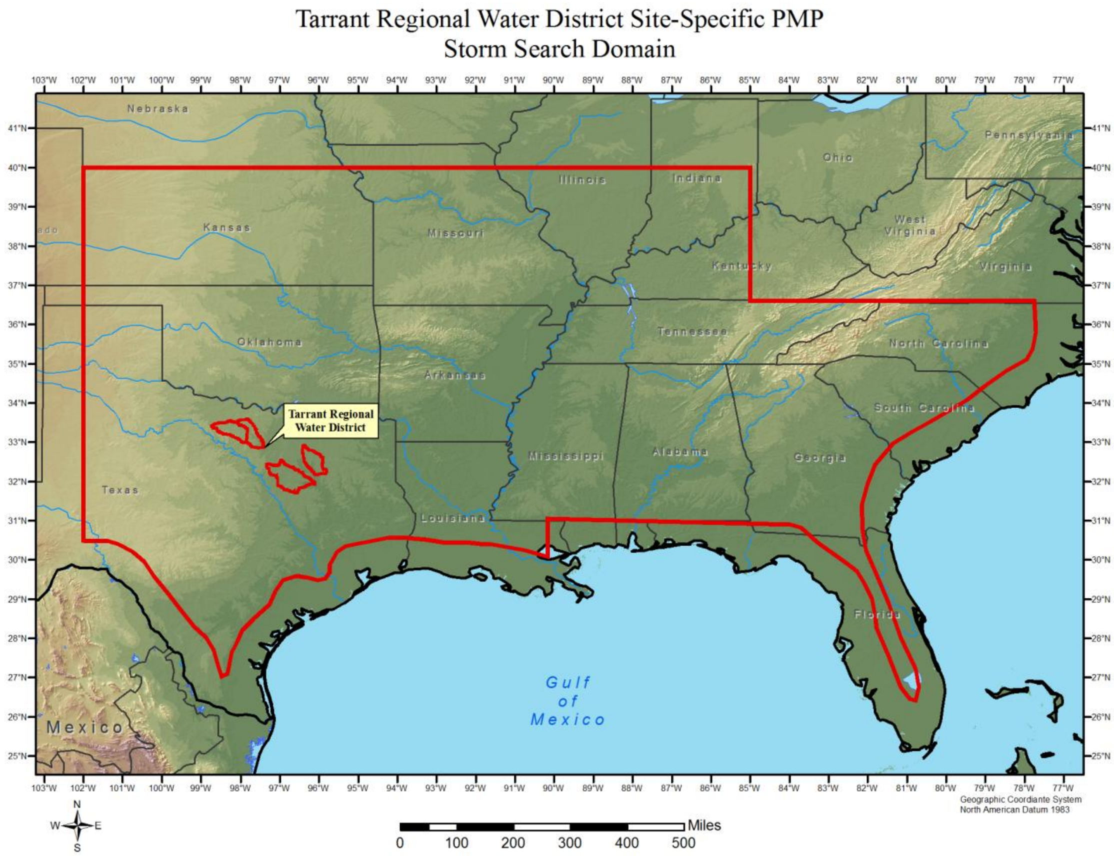

Figure 1. TRWD storm search domain

For some parts of the process used to derive the PMP values, this study applied standard methods (e.g. WMO Operational Hydrology Report No. 1, 1986), while for others, new techniques were developed. Advanced computer-based technologies, Weather Service Radar WSR-88D NEXt generation RADar (NEXRAD), and HYSPLIT model trajectories were used for storm analyses along with new meteorological data sources. New technology and data were incorporated into the study when they provided improved reliability, while maintaining as much consistency as possible with previous studies. This approach provides the most complete scientific analysis compatible with the engineering requirements of consistency and reliability for credible PMP estimates.

Moisture analyses by the NWS, Bureau of Reclamation, and Corps of Engineers have historically used monthly maximum observed 12-hour persisting dew points to quantify atmospheric moisture. Maximum dew point values are provided by *Climatic Atlas of the United States,* published by the Environmental Data Services, Department of Commerce (1968). This study, however, used an updated maximum dew point return frequency analysis. This dew point analysis incorporated data sets with longer periods of record than were available for use in HMR 51 and the EPRI study. Twenty-year, 50-year and 100-year return frequencies for maximum average dew point values for 6-hour, 12-hour and 24-hour duration periods were produced. A Geographic Information System (GIS) was used extensively in the development of the new maximum dew point climatology.

For storms where the moisture source originated over the Gulf of Mexico, surface based dew points were not available. In these cases, a sea surface temperature (SST) procedure was used in-place of dew point temperatures. This follows the same procedure used in HMR 57 and HMR 59 and previous SSPMP studies completed by AWA. As part of this study, an updated SST climatology was developed replacing the Marine Climate Atlas of the World (U.S. Navy, 1981) that was used in the HMRs. This updated climatology dataset included monthly mean and 2-sigma maps for the entire Gulf of Mexico and the western Atlantic Ocean basin (NCDC 2011, Kent et al. 2007, Reynolds et al. 2007, and Worley et al. 2005). In conjunction with the climatology maps, daily SST maps based on ship and buoy reports as well as satellite data (after 1979) were produced and used in deriving the storm representative SST values for each storm event where the moisture source originated over the water.

A reanalysis of transposition limits was completed that evaluated the average elevation of each storm's isohyetal pattern versus the average elevation of each of the four TRWD basins. It was determined from this analysis that storms should not be transpositioned more than +/- 1000 feet in elevation from their original storm elevations and/or +/- six degrees in latitude. This follows similar guidelines provided in HMR 51, 55A, 57, and 59. These criteria only affected two storms at both Richland Chambers and Cedar Creek which were not transpositioned into those basins: 1) Albany, TX August 1978, AWA storm number 78; and 2) Clyde, TX October 1981, AWA storm number 68. This procedure provided precise guidance and constraints on the regions of influence for individual storms.

Basin Location and Description

The four watersheds of TRWD extend from Lake Bridgeport and Eagle Mountain reservoirs to the northwest of the Dallas-Ft. Worth Metroplex to the southeast at Cedar Creek and Richland Chambers reservoirs (Figure 1. above). The northern border of Lake Bridgeport and Eagle Mountain is around 33.5°N latitude with the southern boundaries of the Richland Chambers basin extending just south of 32°N latitude. The western most boundary extends to near 99°W longitude as part of the Lake Bridgeport watershed, while the eastern most edge of the Cedar Creek boundary reaches to 95.5°W longitude. Figure 3. shows the regional setting of the TRWD basins. TRWD's location in north central Texas allows for a variety of weather patterns and extreme storm types that produce heavy rainfall in the four basins.

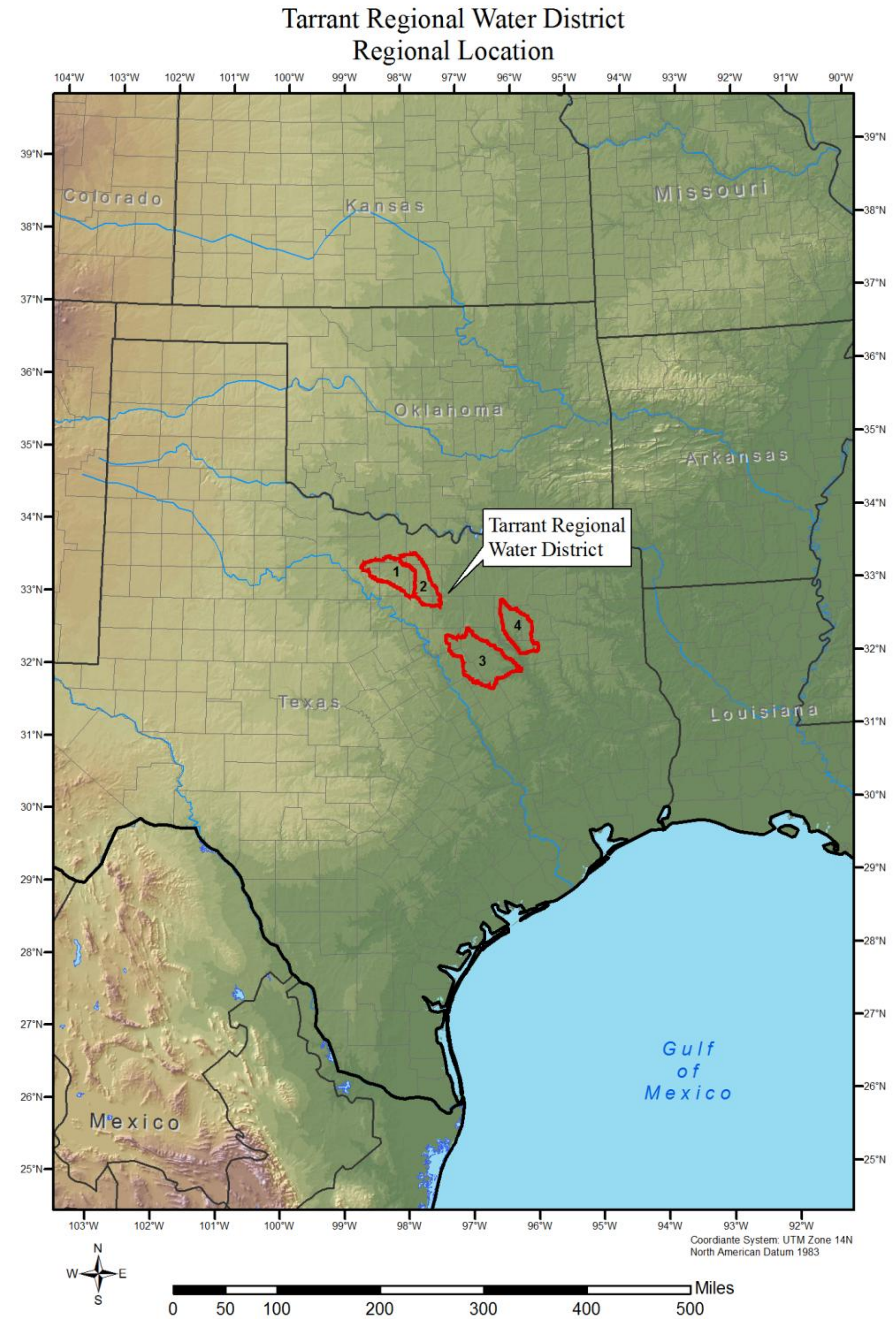

Figure 3. TRWD regional setting

Elevation changes across Texas range from sea level along the Gulf Coast to 8,749 feet at Guadalupe Peak east of El Paso in western Texas (Figure 4.). Although the elevation changes seem gradual moving from south to north and east to west across the state, this large elevation change has a profound effect on moisture availability and storm dynamics. This is especially prominent as moisture encounters the Balcones Escarpment and Edwards Plateau regions. Therefore, storms considered transpositionable to any of the four TRWD basins were limited to elevation below 1500 feet. This ensured storms where orographics significantly contributed to the resulting rainfall were not included in the PMP analysis for any of the four basins. This eliminated storms such as the center around Medina, TX in 1978, Vic Pierce, TX 1954, and Mountain Home, TX 1932. Several other storms were not considered transpositionable because of distance from the region and/or direct influences from the Gulf of Mexico. Examples include Edgerton, MO 1965 and Elba, AL 1929.

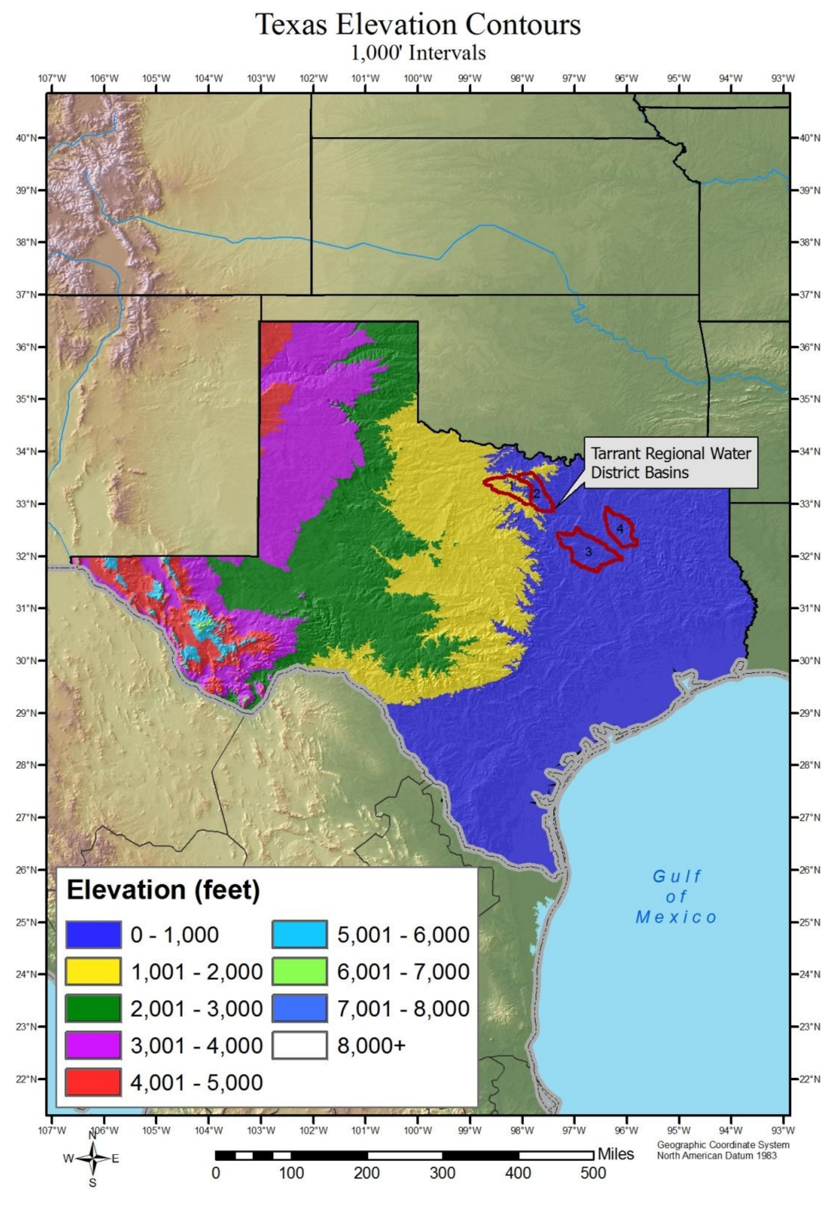

Figure 4. Elevations contours across the state of Texas at 1,000 foot intervals

EXTREME STORM TYPES AND WEATHER PATTERNS

The region surrounding the TRWD watershed has a very active and varied weather regime throughout the year. Consequently heavy rainfall events at both short and long durations are common. By far, the largest amount of moisture available for precipitation over the region comes from the Gulf of Mexico. Additional moisture is sometimes drawn up around the semi-permanent area of high pressure over the eastern Pacific Ocean, especially at the middle and upper levels of the atmosphere. The major types of extreme precipitation events in the region are produced by Mesoscale Convective Systems (short durations and small area sizes), synoptic events/fronts (large areas sizes and longer durations), remnant tropical systems, and/or a combination of two of these.

Short List of Storms Used to Derive the Site-Specific PMP Values

The final short storm list used to determine the SSPMP values for each of the four TRWD basins was derived using the results of AWA's storm search and analyses. Initial storm search results included over 1,000 events which occurred within our storm search domain and were greater than the 100-year return frequency value at an individual station's location. These initial results were scrutinized to determine which events would truly affect the SSPMP values at any area size or duration for the four basins analyzed.

New Storm Analysis. The results of the storm search and evaluation led to seven new storms being identified as important for development of SSPMP values at one or more durations and area sizes for one or more of the TRWD basins. None of these seven storm events had been previously analyzed as part of HMR 51 or other HMRs) and therefore required a full Storm Precipitation Analysis System (SPAS) (Parzybok and Tomlinson 2006) storm analysis to be completed to develop the storm depth-area-duration (DAD) values. The SPAS analysis produced all the necessary data required to evaluate and utilize the storm in the SSPMP derivation process. The seven new storms identified and used in the PMP derivation are given in Table 1.

Table 1. SPAS storm analyses completed for the TRWD site-specific PMP study

Storm Name	State	AWA Storm Number	Lat	Lon	Year	Month	Day	Total Rainfall in Inches	SPAS Storm Number
GLADEWATER	TX	104	32.537	-94.943	1966	4	27	25.33	SPAS 1181
ENID	OK	86	36.400	-97.883	1973	10	11	20.00	SPAS 1034
ALBANY	TX	78	32.726	-99.350	1978	8	3	32.50	SPAS 1179
CLYDE	TX	68	32.479	-99.479	1981	10	10	23.23	SPAS 1184
CORRIGAN 2 E	TX	38	30.260	-94.890	1994	10	15	30.90	SPAS 1185
NEW BRAUNFELS	TX	27	29.700	-98.117	1998	10	17	30.00	SPAS 1180
LARTO LAKE	LA	10	31.220	-92.130	2008	9	1	23.31	SPAS 1182

These comparisons and final analyses resulted in a final short storm list which included 18 storms (Figure 5. and Table 2.).

Each of these storms was evaluated in detail including development of storm isohyetals and DADs (if not already available), elevation adjustments, maximization, and transposition to each basin. These evaluations were completed to develop SSPMP values for each of the four TRWD basins. Analysis of the resulting Depth-Area (DA) and Depth-Duration (DD) values at each of the standard area sizes and durations presented in HMR 51 and at the specific total basin area size of each of the four TRWD basins was completed. The elevation difference between these two storms and the average elevation of each of the basins was greater than 1,000 feet and therefore the storm dynamics and moisture available had these storms been moved to these two basins would be significantly different than what was analyzed in-place.

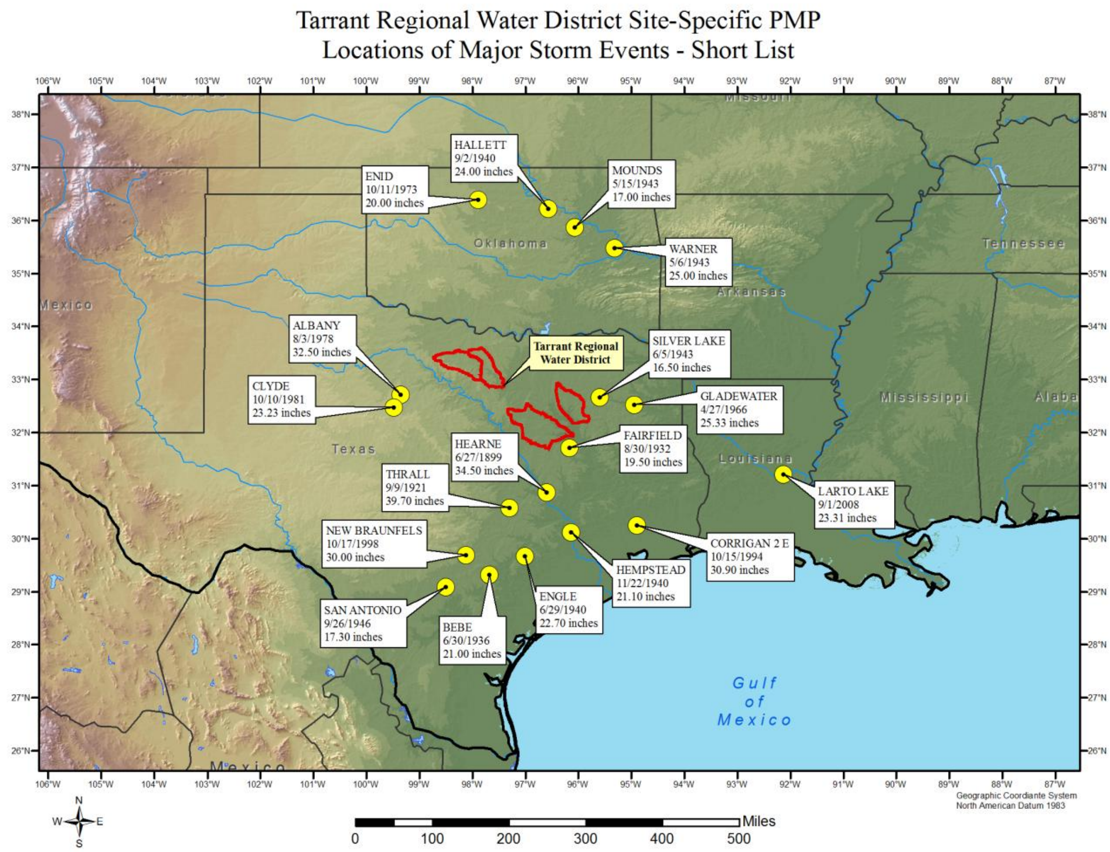

Figure 5. Storm locations of the short storm list relative to the four TRWD basin locations

Table 2. TRWD short storm list ranked in chronological order, precipitation values in inches

Storm Name	State	AWA Storm Number	Lat	Lon	Year	Month	Day	Total Rainfall in Inches	Rainfall Analysis Source
HEARNE	TX	180	30.879	-96.593	1899	6	27	34.50	GM 3-4
THRALL	TX	162	30.591	-97.297	1921	9	9	39.70	GM 4-12
FAIRFIELD	TX	153	31.725	-96.165	1932	8	30	19.50	GM 5-16A
BEBE	TX	145	29.332	-97.682	1936	6	30	21.00	GM 5-6
ENGLE	TX	140	29.681	-97.009	1940	6	29	22.70	GM 5-11
HALLETT	OK	139	36.230	-96.570	1940	9	2	24.00	SW 2-18
HEMPSTEAD	TX	138	30.133	-96.133	1940	11	22	21.10	GM 5-13
WARNER	OK	135	35.490	-95.310	1943	5	6	25.00	SW 2-20
MOUNDS	OK	209	35.877	-96.061	1943	5	15	17.00	SW 2-21
SILVER LAKE	TX	211	32.670	-95.596	1943	6	5	16.50	SW 3-3
SAN ANTONIO	TX	128	29.100	-98.500	1946	9	26	17.30	GM 5-24
GLADEWATER	TX	104	32.537	-94.943	1966	4	27	25.33	SPAS 1181
ENID	OK	86	36.400	-97.883	1973	10	11	20.00	SPAS 1034
ALBANY	TX	78	32.726	-99.350	1978	8	3	32.50	SPAS 1179
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LARTO LAKE	LA	10	31.220	-92.130	2008	9	1	23.31	SPAS 1182

DEVELOPMENT OF PMP VALUES FOR THE TRWD BASINS

Storm maximization and transposition provide an indication of the maximum amount of precipitation that a particular storm could have produced over the TRWD basins. Use of these values alone does not ensure that PMP values are provided for all area sizes and durations since some of the maximized and transpositioned values could be less than the PMP. By enveloping the rainfall amounts from all the major storms, rainfall values indicative of the PMP magnitude are produced (WMO, 1986). The standard process for deriving DAD values at each of the four TRWD basin centroid's was used in the project.

Envelopment Procedures and DAD Derivation

Enveloping is a process for selecting the largest value from a set of data. This technique provides continuous smooth curves based on the largest precipitation values from the set of maximized and transpositioned storm rainfall values. The largest precipitation amounts provide guidance for drawing the curves.

During the enveloping process, values which are not consistent (are either high or low) are re-evaluated to insure reliability. High values are enveloped unless an explanation can be provided to justify undercutting the value. No undercutting of rainfall values was done in this study. Low values are also re-evaluated for reliability and then enveloped to maintain consistency with surrounding values. This enveloping procedure addresses the possibility that for certain area sizes and durations, no significantly large storms have been observed that provide large enough values after being maximized and transposed to represent PMP at a particular area size and/or duration. The result of this procedure is a set of smooth curves that maintain continuity among temporal periods and areal sizes.

The envelopment process was used in PMP determination for this study, following the same procedures used for envelopment in the derivation of PMP in the HMRs and all previous AWA PMP studies. Once the total storm adjusted rainfall values at each basin were determined, they were plotted on individual DA charts for analysis. Envelopment was applied to each DA curve for all durations. The DA curves were drawn to produce smooth curves to provide continuity in space. Figure 6. is an example of a DA chart with the envelopment curve for the 72-hour duration at the Lake Bridgeport basin.

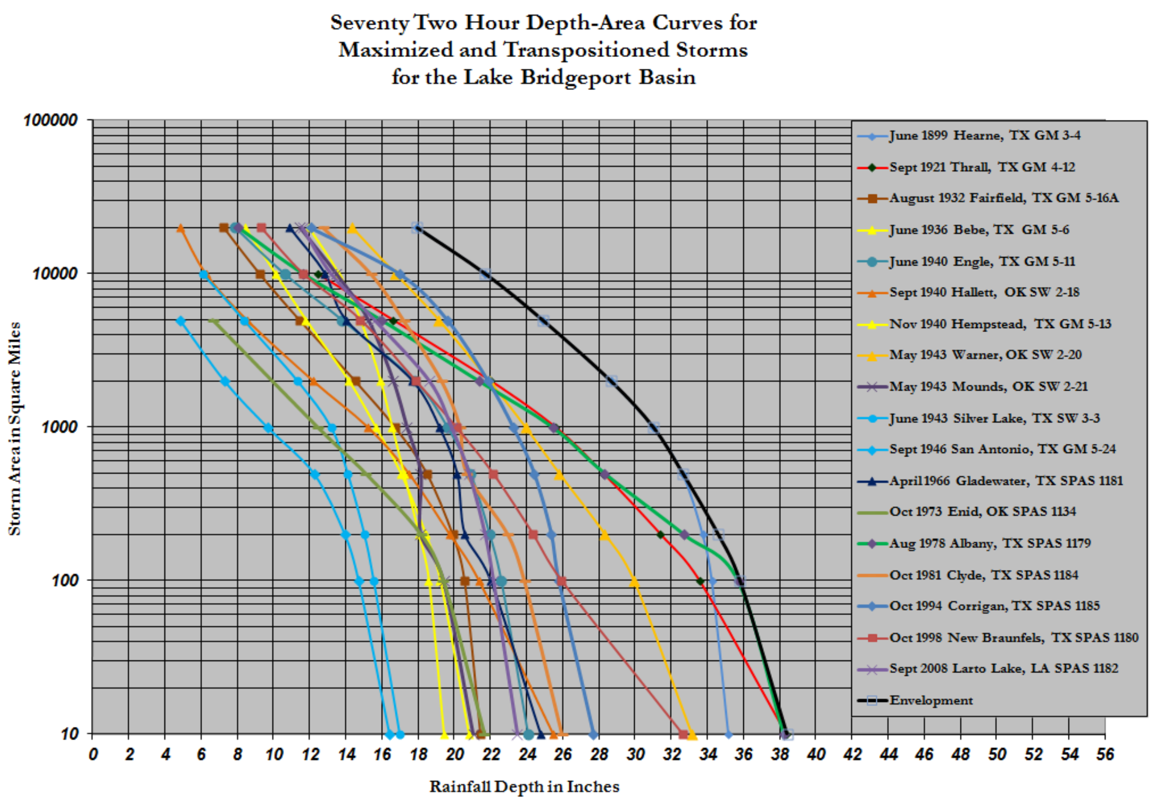

Figure 6. 72-hour DA curves for the Lake Bridgeport basin

The second application of the envelopment process was used with the DD curves at each area size. Curves for each of the area size were constructed using results from the DA analysis described above. The DD curves were drawn to produce smooth curves that provide continuity in time. Figure 7. gives an example of the DD curves for the Lake Bridgeport basin.

The final set of DD curves for all durations at each basin defines the SSPMP values for each of the TRWD basin in this study. The envelopment of the adjusted storms together with the curve smoothing process insured that all storm data were included and that the resulting set of PMP values provides rainfall values that are consistent spatially and temporally.

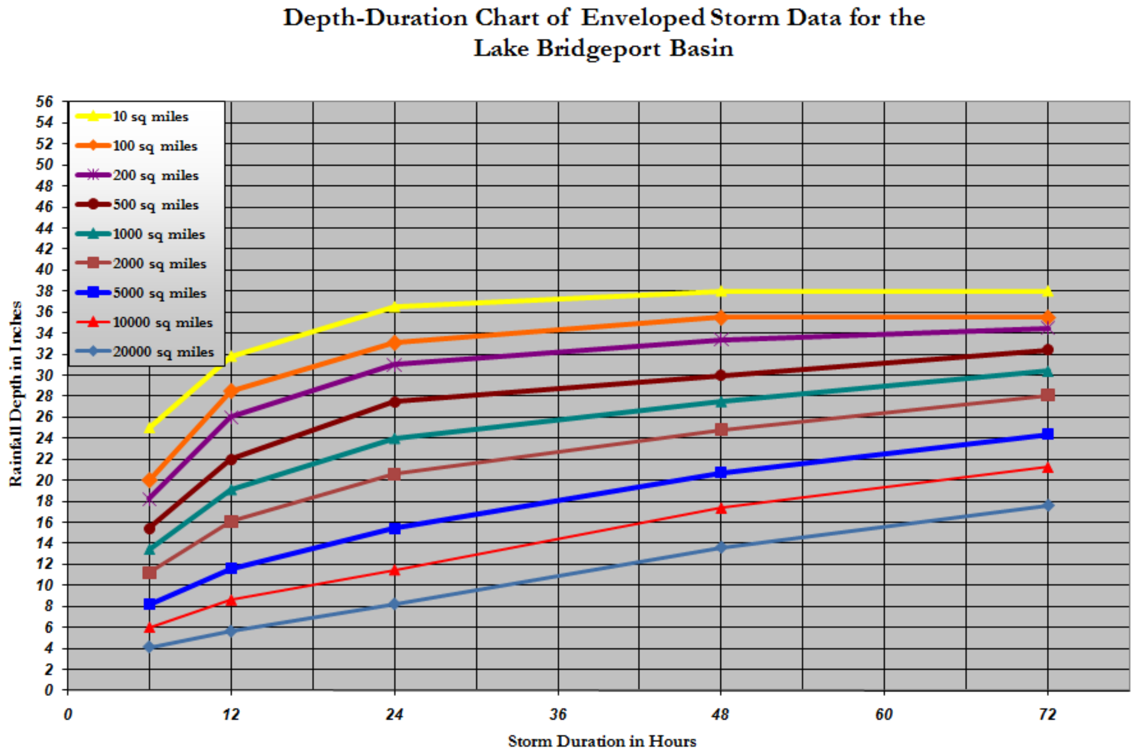

Figure 7. Depth-Duration curves for the Lake Bridgeport basin

CONCLUSION

The results of this study provided updated site-specific PMP values for the four TRWD basins. These values supersede the values in HMR 51, and are being used to update the design PMF for each of the basins. Tables 3 through 6 below display the results of this analysis. Each table shows the updated SSPMP values for each basin. They are displayed for the total basin area size at each of the standard HMR 51 durations. Reductions from HMR 51 PMP values were achieved at each of the basins, with the largest reductions at the 6- and 12-hour durations. These updated SSPMP values will help to lower potential remediation and construction costs at each of the basins. Further, the results of this study incorporated the latest understanding of precipitation processes and included the most up-to-date data set available, thereby providing the highest level of confidence possible in the PMP values used to compute the design PMF.

Table 3. Site-specific PMP values for the Lake Bridgeport basin and comparison with HMR 51 values

Lake Bridgeport Site-Specific PMP vs HMR 51 PMP at 1,089 square miles					
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
Lake Bridgeport PMP Values in Inches	13.4	19.1	24.0	27.5	30.4
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
HMR 51 PMP values in Inches	15.8	20.4	24.9	28.6	31.9
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
% Reduction from HMR 51	15%	6%	4%	4%	5%

Table 4. Site-specific PMP values for the Eagle Mountain basin and comparison with HMR 51 values

Eagle Mountain Site-Specific PMP vs HMR 51 PMP at 869 square miles					
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
Eagle Mountain PMP Values in Inches	14.2	19.8	25.2	28.3	31.4
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
HMR 51 PMP values in Inches	16.0	21.4	25.6	29.8	33.4
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
% Reduction from HMR 51	11%	7%	2%	5%	6%

Table 5. Site-specific PMP values for the Richland Chambers basin and comparison with HMR 51 values

Richland Chambers Site-Specific PMP vs HMR 51 PMP at 1,960 square miles					
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
Richland Chambers PMP Values in Inches	11.9	16.6	21.6	26.8	30.3
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
HMR 51 PMP values in Inches	15.1	20.0	25.7	30.2	33.4
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
% Reduction from HMR 51	21%	17%	16%	11%	9%

Table 6. Site-specific PMP values for the Cedar Creek basin and comparison with HMR 51 values

Cedar Creek Site-Specific PMP vs HMR 51 PMP at 1,009 square miles					
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
Cedar Creek PMP Values in Inches	14.2	19.9	25.6	29.3	32.8
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
HMR 51 PMP Values in Inches	16.8	22.0	27.5	32.0	35.1
	6-Hour	*12-Hour*	*24-Hour*	*48-Hour*	*72-Hour*
% Reduction from HMR 51	15%	10%	7%	8%	7%

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