Creation of Rainfall Areal Reduction Factors from the Basin-Averaged Rainfall Record at the Lower Mississippi River Forecast Center

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1.0 INTRODUCTION

At the National Weather Service (NWS) Lower Mississippi Forecast Center (LMRFC), the rainfall archive with the longest period of record is based upon gauge-only data converted to basin mean areal precipitation (MAP) with the Thiessen Polygon method. This period of record is over 60 years in length and continues to grow. These data are used for the calibration of every modeled subbasin in the LMRFC region. Subbasins in the LMRFC area range from approximately 2.5 mi^2 to approximately 2200 mi^2.

Starting in 1997, a gridded method was introduced where MAPs were created from bias-corrected, radar-based estimates (MAPX). This gridded method is anticipated to improve estimates of basin-averaged rainfall especially where the precipitation is widely varying in time and space (such as with convection) because the Thiessen polygon method will tend towards overestimation where storms cross over a gauge location but miss most of the remainder of the basin, and vice versa. Although generally considered to be more accurate, the MAPX method has too short of a period of record to be used for effective calibration of hydrologic models at the LMRFC because of the high variation in rainfall-runoff responses of modeled subbasins.

Because of the differences in the two rainfall estimation techniques and because of the fact that the hydrologic models are calibrated to the older non-radar method, it is important to identify potential biases in the rainfall database. Such identification is especially important for higher-end rainfall events that are causative inputs to a majority of flooding events in the LMRFC region. One means to check for biases at the higher magnitude end of the MAP dataset is to perform a frequency analysis in order to compare rainfall amounts from specific average recurrence intervals (ARIs) to values that would be expected to occur for a basin of that size. This paper presents the methodology for performing such a comparison and discusses uncertainties and limitations found during the analysis.

2.0 METHODOLOGY

2.1 Obtaining Precipitation Frequency Data

Providing quantitative precipitation estimates (QPE) or quantitative precipitation forecasts (QPF) in terms of an ARI is a helpful way of putting values in the context of climatology for a given location. This concept is already used widely in hydrology to describe a streamflow crest (such as a “100-year event”) and is also used to convey risk for insurance purposes (such as the Federal Emergency Management Agency’s [FEMA] 100-year or 1% floodplain). In addition, this concept is sometimes used to describe rainfall events. Typically this information is used by engineers to design bridges, culverts, and structures to handle stormwater, however there have been examples of this information being compared to areas impacted by flooding (Lincoln W. S., 2014; Lincoln W. S., 2014; Parzybok, 2011).

The Hydrologic Design Studies Center (HDSC) of the NWS has recently undertaken an effort to update the rainfall frequency data for most states in the continental United States (CONUS); the results of this effort are presented in both print and digital formats as NOAA Atlas

14 (Perica, et al., 2013). NOAA Atlas 14 contains a series of tables and maps indicating the estimated rainfall depth that would correspond to a particular ARI. This updated data from NWS HDSC has an increased number of gauges, a longer period of record from which to calculate the extreme value distributions, improved output resolution, and output in geographic information system (GIS) compatible formats (when compared to previous rainfall frequency analyses). The rainfall frequency data was downloaded in GIS format (http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html) for use on this analysis and other projects.

2.2 Converting Point-Based Rainfall Frequency Data to Areal Rainfall Frequency Data

One caveat with using rainfall frequency data is that it is valid only for a given point location and applicability is lacking for areas. This causes an issue in hydrologic forecasting because most modeling approaches utilize watersheds with widely varying dimensions and areally-averaged parameters. To find the corresponding rainfall amount valid for an area at a given ARI, the use of areal reduction factors (ARFs) is required (Dingman, 1994; Miller, Frederick, & Tracey, 1973).

One commonly used set of ARFs are the ones published in NOAA Atlas 2 (Miller, Frederick, & Tracey, 1973). This set of ARFs was intended to be non-specific to any particular region or ARI, but did vary by storm duration (Figure 1). A review of the scientific literature, however, found widely varying ARFs (Asquith W. H., 1999; Stanescu, Engineering Hydrology Chapter 10: Urban Hydrology, 2006). Not only was this variance found to occur across studies, but sometimes within a single study the ARFs could vary by region, season, and individual ARI being studied. Because of this uncertainty, ARFs will be discussed in a later section.

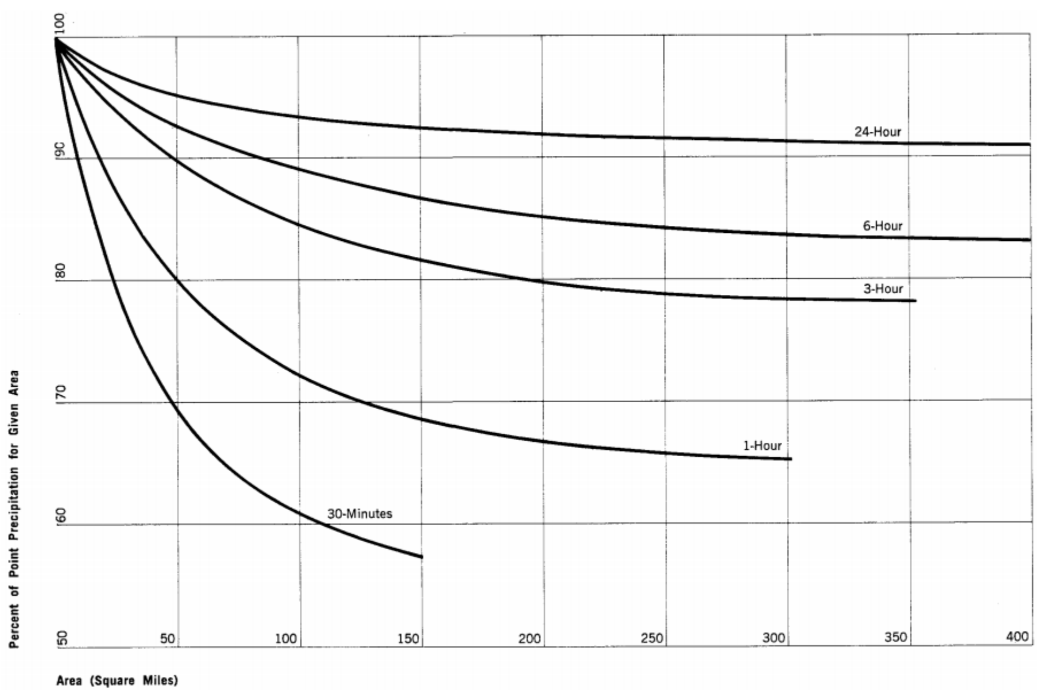

Figure 1. Areal reduction factors from NOAA Atlas 2 Figure 14 (Miller, Frederick, & Tracey, 1973).

2.3 Performing Frequency Analysis on LMRFC MAP Data

The gauge-only MAP used at the LMRFC has areal average rainfall for each subbasin computed on a 6 hour time step is determined using the Thiessen Polygon method. In 2013, LMRFC completed a depth-duration-frequency analysis on the 6-hour estimates to improve situational awareness during flood events. The goal was to provide forecasters a list of the highest MAP values as well as an estimate of values at several ARIs so that current events could be put into context of past events. At the time of the analysis, data for the January 1950–December 2012 period was available.

For each subbasin, the top five 6-hour MAP depth were determined for January 1950–December 2012, as well as the maximum 6-hour depth for every calendar year. The maximum calendar year 6-hour MAP values were then ordered using the Weibull Plotting Position method to calculate empirical exceedance probability. A Log-Pearson Type III distribution (Figure 2) was fit to the data to provide the formal estimate of annual exceedance probability (AEP). AEP is converted to ARI by:

ARI (yr) = 100.0 / AEP (%)

Values were extracted from the logarithmic-fitted data for the 2, 5, 10, 25, 50, and 100 year ARI (50%, 20%, 10%, 4%, 2%, 1% annual chance, respectively) to be used along with the top five by forecasters.

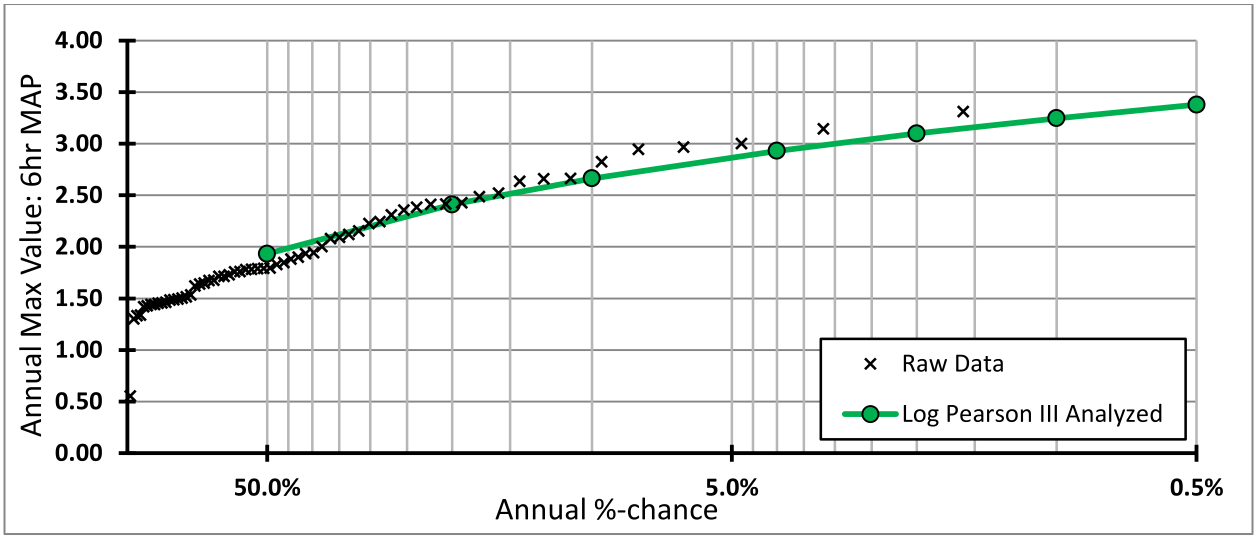

Figure 2. Example probability plot indicating the chance of a particular 6-hour MAP value occurring in a given year. The “X” markers indicate values derived from the ordering of annual maximum values using the Weibull Plotting Position and the circles indicate values derived from the raw data fitted to a Log-Pearson Type III distribution.

One issue with the LMRFC MAP frequency analysis data is the bias introduced by fixed-interval observations. Rainfall recording intervals are tied to an arbitrary time step, for this data it was a 6-hour timestep. To properly determine the maximum 6-hour rainfall over the course of a year, the optimal approach would be to use a moving window with an hourly or sub-hourly time step and aggregate up to 6 hours, otherwise storms that occur near the beginning/end of a 6 hour period will be split in half and bias the statistics lower. This optimal approach is not applicable to our situation, however, as we estimated ARIs for events of a 6-hour duration and the available MAP data was also on a 6-hour timestep. Asquith (1998) as well as table 13-10 in Hydrology for Engineers (1982) provide a fixed interval correction factor for this issue. Because only one time increment fits within the analyzed duration, the maximum adjustment of 1.13 was required; data was adjusted by multiplying by this adjustment factor.

2.4 Comparing LMRFC MAP data to NOAA Atlas 14

Next, the spatial averages of the cells for NOAA Atlas 14 grids were computed for the 2, 5, 10, 25, 50, and 100 year ARI for each study basin. A ratio of the LMRFC MAP ARI values to the NOAA Atlas 14 data was then calculated. To reduce the noise in the data, the data were averaged within eight (8) separate bins, each with approximately the same number of basins. For the purposes of this report, these bin-averaged ratios will be referred to as the “LMRFC MAP ARFs” for this study. It was noted that the LMRFC MAP ARFs generally decrease as ARI increases. The 2 year (50% annual chance) event was an outlier to this trend (Figure 3; Figure 4), which could be attributed in part to estimation bias of the median maxima (William H. Asquith, personal communication, November 2015). The fact that the ARFs for a given area decrease with increasing ARI is likely a manifestation of high rainfall intensities generally being more spatial restricted as real storms track across the landscape (William H. Asquith, personal communication, November 2015).

It was expected that when plotted as a function of area, the LMRFC MAP ARFs would have similar shape to that of other published ARFs. We would expect that very small basins with an area approaching 0.0 mi^2 would have very similar rainfall values to a point location for a given ARI (ARF of ~1.0) and basins with larger areas should have smaller rainfall values for the same ARI (ARF < 1.0). This trend was indeed noted in the LMRFC MAP ARFs but it was difficult to determine which published ARFs would be most applicable to our dataset. The LMRFC MAP ARFs were compared to the following areal reduction relationships found from our literature review (Figure 5):

1. The NOAA Atlas 2 relation (Miller, Frederick, & Tracey, 1973).
2. Allen & DeGaetano relation for North Carolina (Allen & DeGaetano, 2005).
3. Fruhling relation (Vladimirescu, 1984). As published in Virtual Campus in Hydrology and Water Resources’ (VICAIRE’s) online module “Engineering Hydrology” (Stanescu, Engineering Hydrology Chapter 10: Urban Hydrology, 2006).
4. Leclerc & Schaake relation (Leclerc & Schaake, 1972). As published in VICAIRE’s online module “Engineering Hydrology” (Stanescu, Engineering Hydrology Chapter 10: Urban Hydrology, 2006).

5. Stanescu relation (Stanescu, 1995). As published in VICAIRE's online module "Engineering Hydrology" (Stanescu, Engineering Hydrology Chapter 10: Urban Hydrology, 2006).
6. Woolisher & Schwalen relation (Woolisher & Schwalen, 1959). As published in VICAIRE's online module "Engineering Hydrology" (Stanescu, Engineering Hydrology Chapter 10: Urban Hydrology, 2006).

Although the smallest LMRFC basins tended to have the highest variability in ARFs, the bin average was very similar to ARFs published by Leclerc & Schaake (1972) and Woolisher & Schwalen (1959). For basins of approximately 100–400 mi^2 in size, the LMRFC ARFs generally paralleled values published previously in NOAA Atlas 2 (1973) and by Allen & DeGaetano (2005). For basins of approximately 400–2,000 mi^2 in size, the LMRFC ARFs generally paralleled values published by Allen & DeGaetano (2005). The LMRFC MAP ARFs were virtually incomparable for any basin area to ARFs from the Fruhling relation (Vladimirescu, 1984) nor those published by Stanescu (1995). The Fruhling and Stanescu ARFs both appear to be substantial departures from the other published ARFs and will thus be no longer considered for this study.

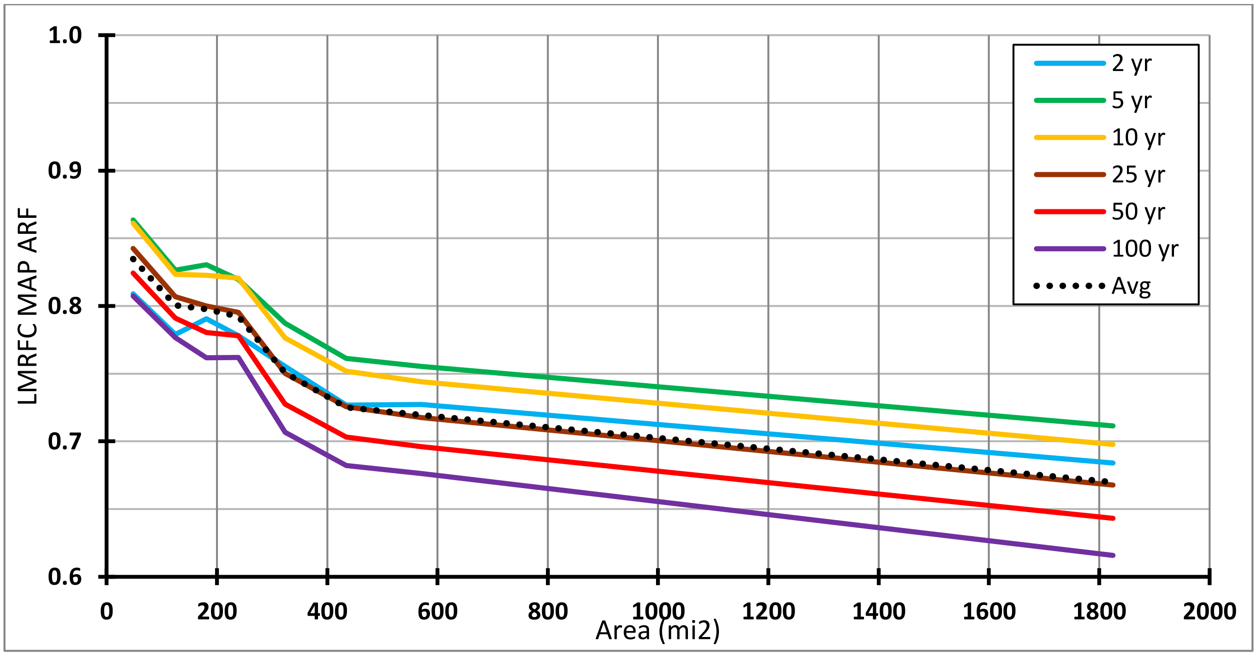

Figure 3. "LMRFC MAP ARFs" by basin area, plotted separately for each ARI, and also for all ARIs combined.

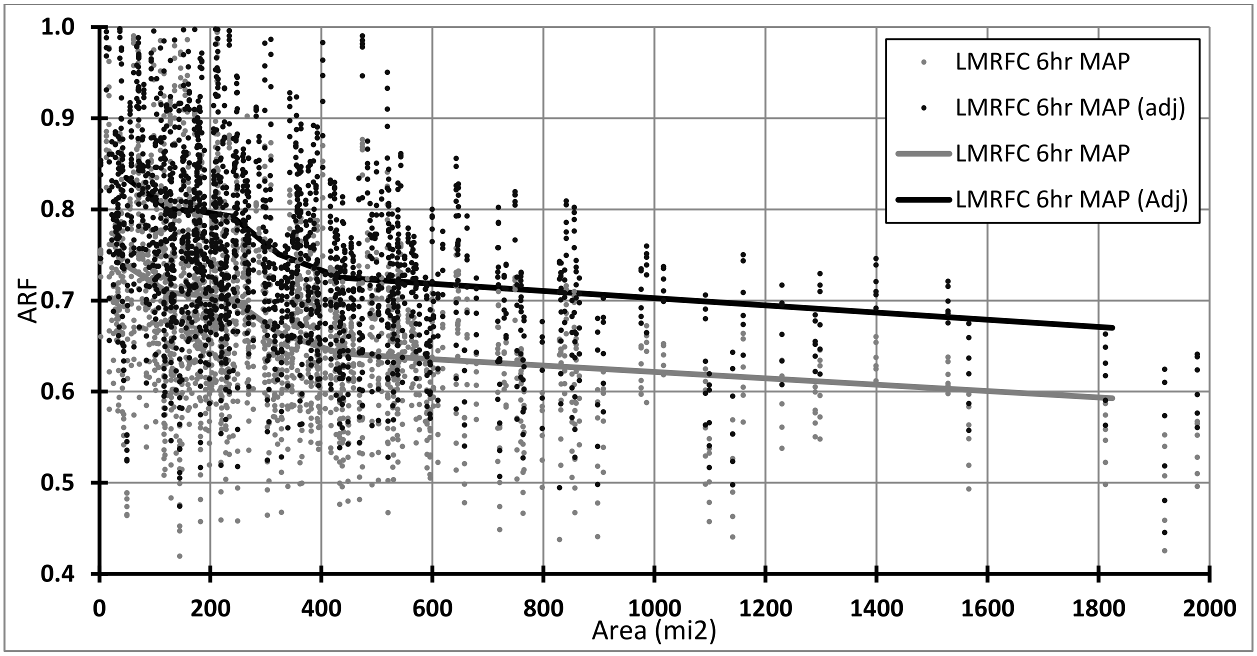

Figure 4. “LMRFC MAP ARFs” by basin area for all (2, 5, 10, 25, 50, and 100 year) ARIs combined. The raw data from the analysis (gray) was adjusted to account for the fixed-interval bias (black). Lines indicate a smoothing of the point data by binning (equal number of basins per bin).

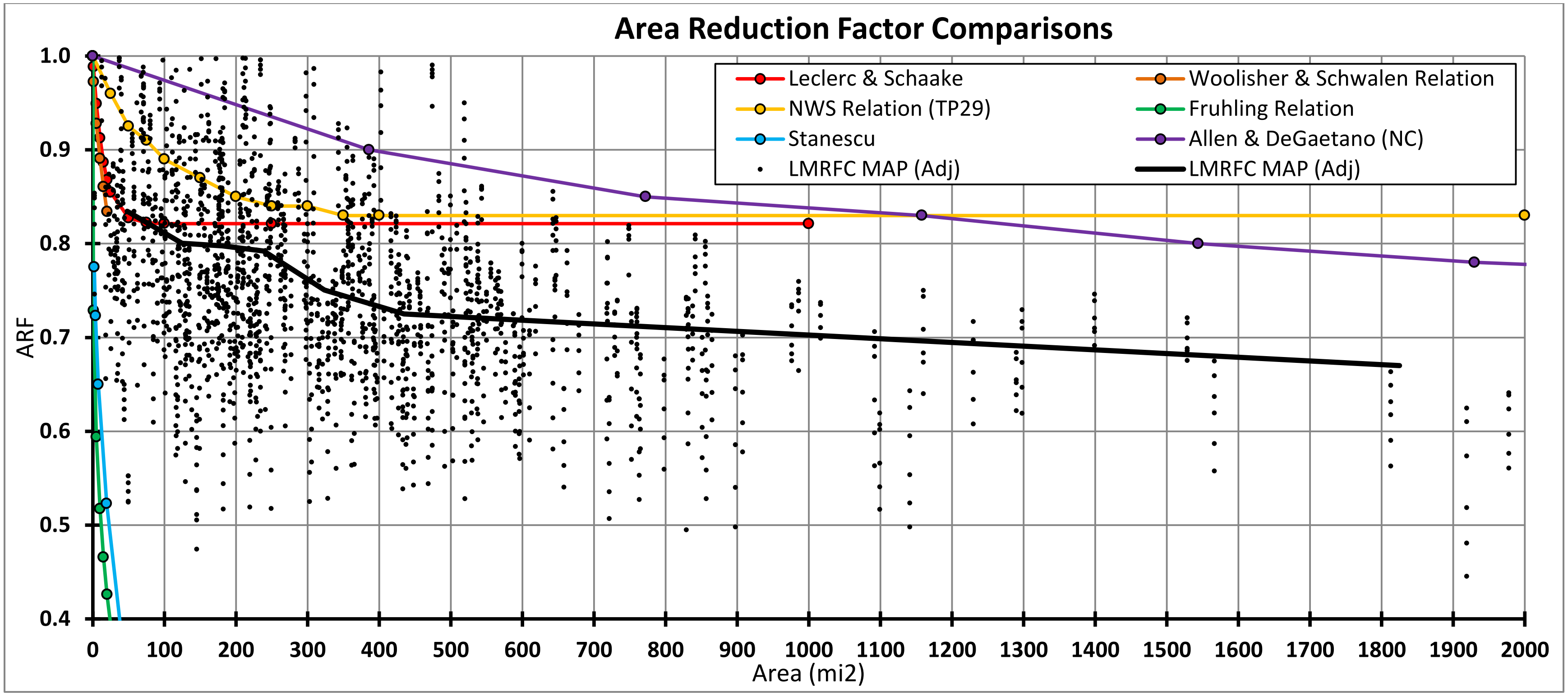

Figure 5. Comparison of the “LMRFC MAP ARFs” to other published areal reduction relationships.

3.0 DISCUSSION & CONCLUSIONS

There are a few different ways to utilize the data created by this analysis. The DDF data from NOAA Atlas 14 could be used along with a suitable ARF to create the hypothetical “correct” rainfall amounts for each basin and each ARI. These rainfall amounts could then be compared to the rainfall amounts produced by the LMRFC MAP frequency analysis to see if any biases exist, and if so, where along the frequency curve are they found (extreme events, or more common events). Unfortunately, as seen in section “***2.4 Comparing LMRFC MAP data to NOAA Atlas 14***,” published ARFs vary substantially. This makes it quite difficult to determine the accuracy of the LMRFC MAP data, because proper correction (reduction) for basin area is required. A “proper correction” might be elusive because a “proper definition” of an ARF is lacking. There is no one definition that fits all potential applications of ARFs in either synthetic hydrology (design computations) or rainfall-runoff model calibrations (William H. Asquith, personal communication, November 2015).

Another way to utilize the data created by this analysis is to take the reduction factors produced by comparing the LMRFC MAP against the NOAA Atlas 14 data and use them to produce areal reduction factors based upon our data. Unfortunately, there are many caveats to this. The frequency analysis performed on the LMRFC 6-hour MAP data was simple. The gauge network in many parts of the LMRFC area is not as dense as those in published ARF studies, which will cause basins within a single Thiessen polygon to basically be assigned the rainfall frequency values of a single point location (the gauge) and not an area. The Log-Pearson Type III distribution was used in this analysis, but the authors were informed by a peer reviewer that the Gumbel Distribution may have been more applicable (William H. Asquith, personal communication, November 2015). This may yield uncertainty that was not quantified.

Regardless of the mentioned issues with this analysis, the output of our analysis is consistent in some areas with other ARF studies. It has been shown in previous studies that the ARFs may be different for specific ARIs. In Allen & DeGaetano (2005), a steady decrease in ARFs was found as the ARI increased, with this difference most notable with larger areas. Our analysis showed a similar behavior (Figure 3), although the 2 year (50% annual chance) event was an outlier by being lower than the 5 year (20% annual chance) event. Also, in virtually all published ARF studies, the ARF trend increases rapidly toward 1.0 as basin sizes decrease to zero (0). Although the available LMRFC basin sizes and the binned-averaging process make it difficult to determine the ARF trend for very small basin sizes, we do see a similar trend. We also evaluated using the median value for each bin rather than the mean based upon a peer review suggestion; this change yielded negligible differences.

After careful consideration and analysis of our data in context of other published ARFs, we have decided to present our analysis as an independent, that is alternative, ARF. One assumption with ARFs is that rainfall ARIs for areas of near 0.0 mi^2 should be approximately the same as for a single point ARI (ARF value of near 1.0). This is not evident in our binning method because the bin for the smallest areas is an average of ARFs from basins ranging from 2.5 mi^2 to 96 mi^2 in size. Thus, we have chosen to present two different ARFs based upon our data, one derived from the binning method (hereafter “Binned Method”) shown previously and another with a power best-fit regression (hereafter “Regression Method”), the latter of which would have an ARF value of approximately 1.0 at an area of 0.0 mi^2. The Regression Method can be expressed by:

$$ARF = (1.09)(\,a^{\,-0.0667})$$

where a is the area and ARF is the areal reduction factor to multiply by the point-based ARI value. The LMRFC ARFs are shown by Figure 6 and Table 1.

Because of the issues with widely ranging values in different published ARFs and the simplicity of our analysis, the LMRFC MAP derived ARFs are subject to uncertainty and attendant questions of applicability. These ARFs may not be suitable for all data types in all geographic regions. At the present time, the ARFs are likely to be most valid for locations within the LMRFC forecast area and for areas within the size range of our forecast basins. The authors recognize that these reduction factors were not derived with as robust of a methodology when compared to other studies, and should be used with caution.

4.0 ACKNOWLEDGEMENTS

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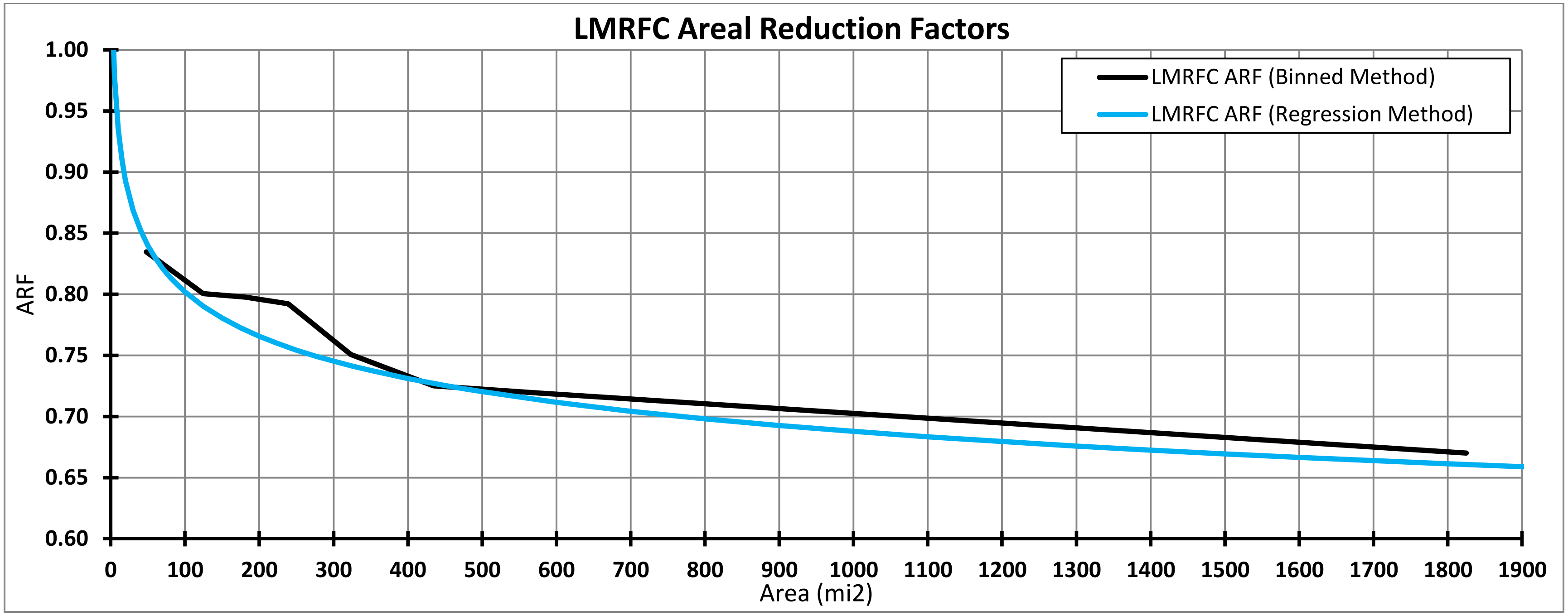

Figure 6. Areal Reduction Factors derived from the LMRFC MAPs. The Binned Method was derived from bins of equal numbers of subbasins. The Regression Method was derived from a power best-fit regression to the raw data.

Table 1. Summary of ARFs derived from the LMRFC MAPs. The Binned Method was derived from bins of equal numbers of subbasins. The Regression Method was derived from a Power best-fit regression to the raw data. Area values correspond to the mid-point of each range of areas in the Binned Method.

Area (mi^2)	ARF (Binned Method)	ARF (Regression Method)
48	0.83	0.84
125	0.80	0.79
181	0.80	0.77
239	0.79	0.76
323	0.75	0.74
435	0.73	0.73
571	0.72	0.71

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