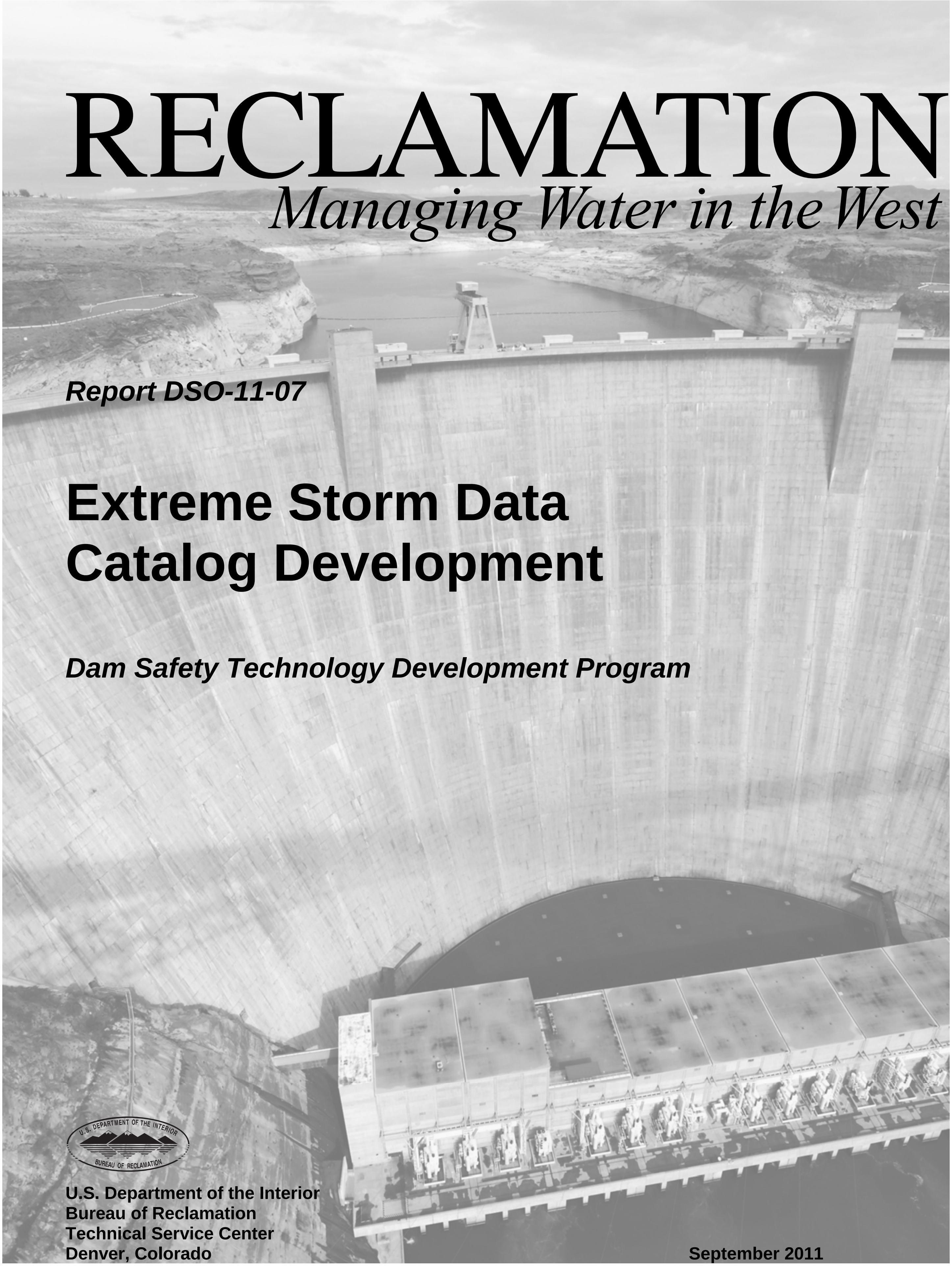

RECLAMATION

Managing Water in the West

Report DSO-11-07

Extreme Storm Data Catalog Development

Dam Safety Technology Development Program

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2011

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Extreme Storm Data Catalog Development

Dam Safety Technology Development Program

prepared by

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Bureau of Reclamation
Technical Service Center
Water and Environmental Resources Division
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Denver, Colorado

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The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies energy to power our future.

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BUREAU OF RECLAMATION
Dam Safety Technology Development Program
Flood Hydrology and Emergency Management Group, 86-68250

DSO-11-07

Extreme Storm Data Catalog Development

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Contents

1.0 Introduction and Background

Historical storm-based precipitation is a key input parameter into hydrologic models. Specifically, storm-based precipitation is the dominant forcing variable for the generation of extreme floods in rainfall-runoff models. The majority of the historical storm data, however, exists only in paper-format, and is not stored in a logical manner or in a central archive. In this format, storm data are inaccessible and are not usable for rainfall-runoff modeling. The process in which to convert the historical data into electronic formats for direct use in the hydrologic models is time-consuming and expensive. Additionally, there are no current procedures to update storm data sets with storms post-1973 from a storm catalog (USACE, 1973), or document those used in the Hydrometeorological Reports (HMR) for Probable Maximum Precipitation (PMP), with storms up to 1986. Storm events are lacking for events after 1986 (e.g. Corrigan et al., 1999). As such, dam safety hydrologic hazard assessments are arduous and involve substantial resources; historical storm estimates must be assembled and current precipitation estimates must be developed as part of each individual project. Overall, the end result is high costs for Dam Safety Issue Evaluation and Corrective Action Studies.

Methods for estimating extreme storm probabilities, up to and including the PMP, are also currently lacking. Yet, extreme storm probability estimates are needed for dam safety assessments, risk analysis, and to better understand extreme flood processes. In particular, regional precipitation frequency analyses are key inputs to the Stochastic Event Flood Model (SEFM), the Australian Rainfall-Runoff Model (ARR) approach, and other watershed models used for Dam Safety Issue Evaluations and Corrective Action Studies (described in Swain et al., 2006).

2.0 Objectives

There are three objective of this research:

1. to create a comprehensive electronic database of historical extreme storm events in a Geographic Information System (GIS);
2. to investigate and document methodologies and datasets that could be used to process storms outside of the historical database; and
3. to develop in-house capabilities and programs to calculate regional precipitation frequencies up to the PMP in a format suitable for flood runoff models.

A new electronic database (objective 1) is presented in Section 3. This database has already been put to use on several recent hydrologic hazard issue evaluation studies for Dam Safety. New storm data processing methodologies are described in Section 4. The regional precipitation frequency programs are presented in Section 5.

3.0 Electronic Database of Historical Extreme Storm Events

Storm data are needed for nearly every Dam Safety Issue Evaluations and Corrective Action Studies that utilize a rainfall-runoff model to estimate the hydrologic hazard curve. All meteorological inputs for the rainfall-runoff model (e.g. storm seasonality, storm duration, spatial distribution, temporal distribution) are determined from observed and documented storm events. Due to the lack of storm analyses in the past 30 years, it is obligatory to utilize historical storm studies, primarily available in paper-format only, to determine these inputs. Collecting new storm information (Section 4) will also provide meteorological inputs.

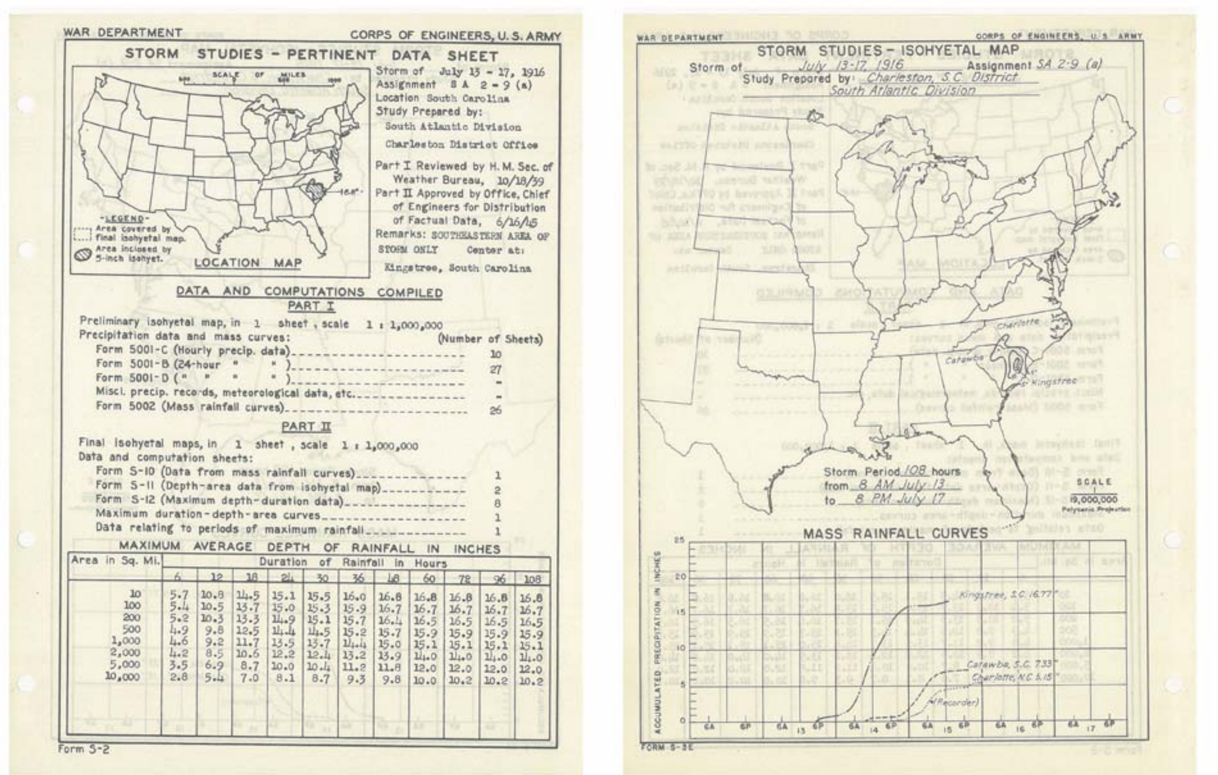
Since each Dam Safety Issue Evaluation and Corrective Action Study is site-specific, it is necessary to assemble all storm data pertinent to the region of interest for each and every study. It is especially laborious and expensive to assemble paper copies of historic storm data. Moreover, once the data are amassed, then they must be converted from a paper document to a more useful electronic format. This additional procedure to convert the data between formats requires further resources.

The creation of an electronic database of historical extreme storm events is designed to relieve some of the effort to assemble the storm data for a region and to have addressed the need to convert the paper document to electronic format. Additional conveniences attained from creating an electronic database include a central repository for storm information, data accessibility for information sharing, and data compatibility with GIS and spreadsheet software for combination with other datasets. The electronic database can also act as a preservation mechanism to safeguard the historical paper-only storm summaries.

This chapter of the report is segmented into multiple subsections. Section 3.1 discusses the historical methodology used to analyze storms and the resultant datasets. Section 3.2 explains which storms were included within the storm database. Section 3.3 describes the database, and Section 3.4 reiterates the importance and utility of the database.

3.1 Historical Methodology and Resulting Datasets

Historically, storms were studied by conducting bucket surveys: storm assessments completed in the field by meteorologists (or hydrologists) with emphasis on raw data collection, interviewing witnesses and observing the aftermath first hand. Meteorologists would generate mass curves of storm-based precipitation (i.e. charts of time vs. accumulated precipitation) at multiple locations from the gathered data. A map of the sites where mass curves were produced provides the spatial distribution of the storm, and the mass curves themselves depict the depth (i.e. amount) and duration of the precipitation. These three elements were combined into a depth-area-duration (DAD) table and storm summary (pertinent data) sheet to succinctly summarize the storm event (Figure 1). Further details of the storm data collection and bucket survey process are described in USWB (1946) and Cudworth (1989).



Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	72	96	108
10	5.7	10.8	14.5	15.1	15.5	16.0	16.8	16.8	16.8	16.8	16.8
100	5.4	10.5	13.7	15.0	15.3	15.9	16.7	16.7	16.7	16.7	16.7
200	5.2	10.3	13.3	14.9	15.1	15.7	16.4	16.5	16.5	16.5	16.5
500	4.9	9.8	12.5	14.4	14.5	15.2	15.7	15.9	15.9	15.9	15.9
1,000	4.6	9.2	11.7	13.5	13.7	14.4	15.0	15.1	15.1	15.1	15.1
2,000	4.2	8.5	10.6	12.2	12.4	13.2	13.9	14.0	14.0	14.0	14.0
5,000	3.5	6.9	8.7	10.0	10.4	11.2	11.8	12.0	12.0	12.0	12.0
10,000	2.8	5.4	7.0	8.1	8.7	9.3	9.8	10.0	10.2	10.2	10.2

Figure 1. Example of historic storm information including DAD table and mass curves.

Prior to 1972, it was commonplace to summarize extreme events in DAD tables. A collection of these summaries may be found in the U.S. Army Corps of Engineers (USACE) Storm Catalog, and the most significant of these events were reprinted in the National Weather Service (NWS) HMRs and used in the establishment of PMP procedures for regions across the nation (USACE, 1973; Schreiner and Riedel, 1978; Hansen et al., 1982; Hansen et al., 1988; Corrigan et al., 1999). After 1972, selected storms were documented within individual HMRs, including HMRs 55A, 57 and 59. Very few contributions were made to storm study data collection and research since 1986, after HMR 59 was completed.

3.2 Storms included within the Electronic Database

The USACE Storm Catalog includes hundreds of DAD summaries from storms occurring prior to 1972; only those storms considered ‘significant’ were included in the electronic database. Storms were considered ‘significant’ if they were included within an HMR. The HMRs, as mentioned above, reprinted DAD tables of storms that the authors deemed extraordinary to a region, and in some cases, reanalyzed older storms and documented selected newer events. The DAD tables for the storms referenced in HMRs 51, 52, 55A, 57 and 59 were converted to a digital table format and archived in the database.

Each HMR corresponds to a distinct region of the United States and contains DAD tables of significant storms for that region. Figure 2 is a map of these regions. By selecting the aforementioned HMRs, most of the significant historic storms that occurred in the continental United States are included within the electronic database.

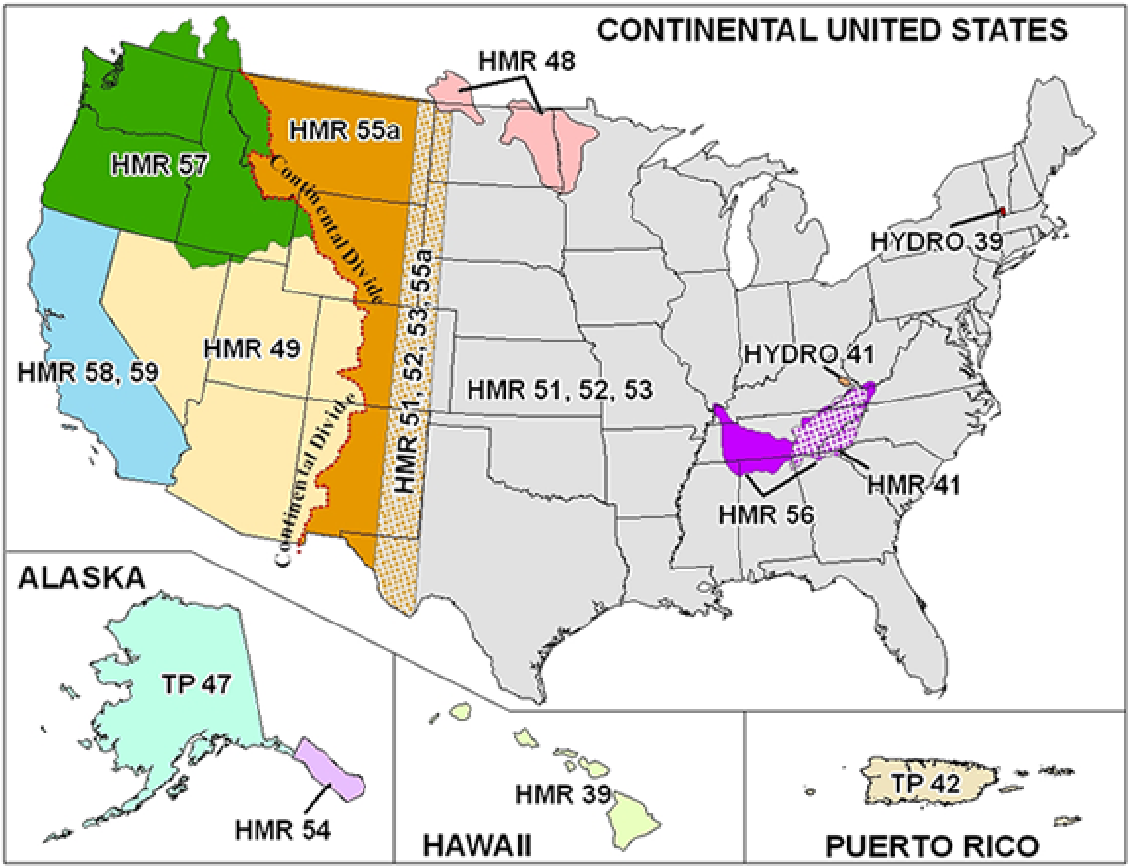


Figure 2. Map depicting the regions discussed in the Hydrometeorological Reports (source: http://www.weather.gov/oh/hdsc/studies/pmp.html).

Figure 3 is a map showing the location of the 563 storms that are included in the electronic database. Note that a few storms are located in Canada and Mexico; these storms were deliberately analyzed by the NWS for incorporation in the HMRs because of their large storm magnitudes and their possible effects on the U.S. states that border these countries. Also note the area void of data in the southwestern United States. This area corresponds to HMR 49. HMR 49 was prepared in an unusual format in comparison to the other HMRs based on DAD data (HMRs 51, 55A, 57, and 59) and does not directly provide a list of significant storms.

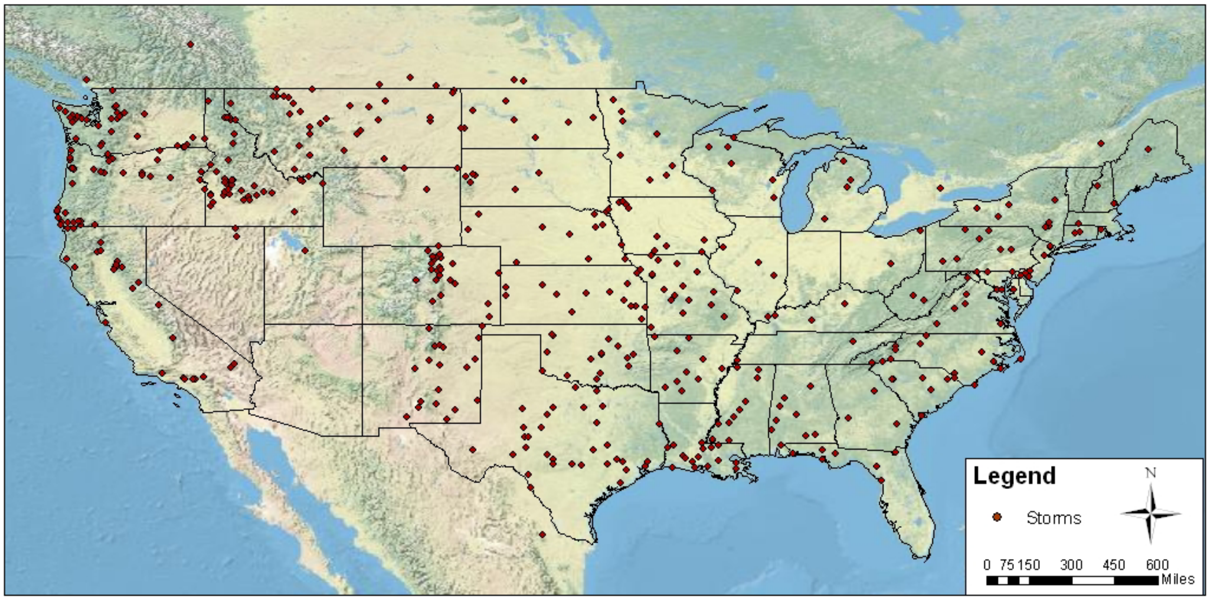


Figure 3. Map depicting the extreme storms in the electronic database.

Several storms are referenced in multiple HMRs. To avoid duplication of a storm in the master storm list, the storm is presented as it appears in the most recently published HMR only. Appendix A is a directory of the duplicate storms; it also includes the HMRs in which the storm is listed.

3.3 Electronic Database

The electronic database is an amalgamation of numerous files, consisting of ArcGIS shapefiles and Microsoft Excel spreadsheets. The database was developed by generating digital files for each HMR individually. Once all of the HMRs were considered (HMRs 51, 52, 55A, 57, and 59), then a master file was created. The following subsections discuss the formats of the shapefiles and spreadsheets that compose the database and provide an overview of the files that compose the database.

3.3.1 Shapefiles

The database has one ArcGIS shapefile for each HMR. These shapefiles contain a list of the storms that were described in the HMR and associated metadata about each storm. Since all HMRs differ slightly in format and content, the storm metadata that is presented in each shapefile will vary as appropriate for each HMR (Table 1).

There are two shapefiles associated with HMR 57: HMR 57 all storms, and HMR 57 DAD. The 'HMR 57 all storms' shapefile includes a listing of all storms that were critical in the creation of HMR 57 and the metadata appears similar to all other HMR shapefiles. The 'HMR 57 DAD' shapefile, on the other hand, discusses a storm in terms of latitude and longitude of the storm as opposed to location and state. This methodology was used because the authors analyzed multiple storm centers for each storm. For simplicity, only the 'entire storm' center was included in the database. Users are directed to HMR 57 to view the other storm center analyses.

Table 1. Storm metadata contained by each HMR shapefile.

	HMR 51	HMR 52	HMR 55A	HMR 57	HMR 59
HMR Storm Number	X		X	X	X
Reference Number	X		X	All storms	
Importance of Storm	X				
Storm Dates	X	X	X	X	X
Start Date	X	X	X	X	X
End Date	X	X	X	X	X
Location	X	X	X	All storms	X
State	X	X	X	All storms	X
Latitude	X	X	X	X	X
Longitude	X	X	X	X	X
Total Area (sq mi)	X	X	X	DAD storms	X
Total Duration	X	X	X	DAD storms	X
D24 A10	X		X	DAD storms	X
DT A10	X		X	DAD storms	X
D24 A100	X		X	DAD storms	X
D24 A1000		X			
Moisture Adjustment	X		X		
Orientation	X		X		
Elevation				DAD storms	X
DAD Data	X		X	DAD storms	
Provided in HMR 33	X				

The master storm list, depicted in Figure 3, is an assemblage of all the HMR storm lists. Duplicate storms have been removed so that the storm in the master storm list is represented by the most recent HMR only (see Appendix A). Only pertinent data to the storms, provided in the below bulleted list, are included as metadata in this file.

- HMR (the most recent HMR to examine the storm)
- HMR Storm Number (the storm number given to the storm in the above HMR)
- Storm Dates (the time interval in which the storm occurred)

- Start Date
- End Date
- Location (closest city)
- State
- Lat
- Lon
- Area mi^2 (the total area on the storm, in square miles)
- Duration hr (the total duration of the storm, in hours)
- D24 A10 (the largest amount of precipitation that fell in 24 hours at 10 square miles)
- DT A10 (the largest amount of precipitation that fell during the total duration of the storm at 10 square miles)
- D24 A100 (the largest amount of precipitation that fell in 24 hours at 100 square miles)
- DAD (whether or not the HMR contains a DAD table for the storm)
- Ref (reference number of the storm given by the agency who conducted the bucket survey)

The master storm list is designed to guide users to the location of additional data. From the master storm list, the user is able to easily identify which HMR discusses the storm and whether or not DAD data are available. The master storm list is not intended to provide all storm metadata.

3.3.2 DAD Tables

Electronic DAD tables were created for all storms with DAD data using Microsoft Excel. For each storm, there is a single workbook. Within each workbook are two worksheets: the first worksheet, named ‘Data,’ contains metadata about the storm, and the second worksheet, aptly called ‘DAD table,’ provides the DAD table associated with the storm.

3.3.3 Files Composing the Electronic Database

The organization for the file directory of the electronic database is presented below (the symbol 🗀 represents a directory). For a complete listing, including all .xls and shapefiles, please refer to Appendix B.

- 🗀 Extreme Storm Data Catalog
    - EXTRE.mxd (ArcGIS document)
    - 🗀 Master Storm List
    - 🗀 HMR 51
        - 🗀 HMR 51 DAD
        - 🗀 HMR 51 GIS

- HMR 52
    - HMR 52 GIS
- HMR 55A
    - HMR 55A DAD
    - HMR 55A GIS
- HMR 57
    - HMR 57 DAD
    - HMR 57 GIS
- HMR 59
    - HMR 59 DAD
    - HMR 59 GIS

3.4. Application of the Electronic Database

The database has already proven to be extremely valuable for ongoing Reclamation Dam Safety hydrologic hazard studies, including critical Issue Evaluation studies. For the Red Willow Dam Issue Evaluation study (Novembre et al., 2010), the interactive map depicting the master storm list was consulted to determine the historic storms affecting the Red Willow watershed and surrounding area. The watershed was superimposed on the map, and it was clearly evident that the largest historic storm to have occurred in the area was an event at Hale, CO. Moreover, the metadata for the storm was found in the map's attribute table, so all pertinent information was found in a single location. It will become common practice to consult this map for storm information in future hydrologic hazard studies.

The GIS map is not designed to be a closed-box data repository; a user may continually add storm data to the map. Thus, as additional storms are analyzed or further historic storms become available electronically, these data can readily be added to the GIS map. As such, the Extreme Storm Data Catalog Data Research Project laid the foundation for a database that can be expanded and updated as needed.

Furthermore, the GIS map (Figure 3) visually presents the storm data, so users can plainly see the large areas of the country that lack storm data. This is useful information; the map clearly illustrates which areas need to supplemented with additional storm data. Identifying which regions have a need for data (e.g., Southwestern states and Wyoming) is the first step toward solving the issue of limited data availability.

4.0 Methodologies to Investigate New Storms

As previously stressed, the USACE (1973) storm database essentially ends in year 1972, and there are limited storms in the period 1973-1986 listed within HMRs 55A, 57 and 59. Thus, there is a great need to update the database. New record events continue to be observed, but are not systematically documented and archived. Moreover, greater storm record length would increase confidence in extreme storm probability estimates. Thus, it is of great importance to study these events, document the results, add the results to the extreme storm database, and begin incorporation of the results in Dam Safety hydrologic hazard studies.

Traditional methods to compute depth-area-duration (DAD) relationships involve the collection of point precipitation data at multiple sites to generate storm total and incremental duration plots of isohyets for determination of area sizes and areal precipitation amounts. Recent technological advances have allowed the incorporation of modern methodologies and datasets in the calculation of DAD.

Two methods, both of which utilize the multisensor precipitation estimate (MPE) product available from the National Weather Service River Forecast Centers (RFCs), are presented here. The first method was developed by the Army Corps of Engineers, and the other method was developed in-house by Reclamation.

4.1. Storm Analysis, Developed by the Army Corps of Engineers

The USACE provided Reclamation with a copy of their storm analysis model during a visit to their Omaha office in late July, 2010 (Clemetson and Melliger, 2010). The model was presented in two forms: one which analyzes storms by examining radar images from WSI for the time period 1998-2005, and another method that utilizes a 24-hour incremental MPE product provided by the NWS for the years 2006-present. The model creates DAD tables from the 24-hr input data using ArcGIS files and spreadsheets.

There are limitations to the USACE storm analysis model. The time increment for the analysis is 24-hours. If the storm occurred within six of the 24-hours, then this model would not accurately capture the duration of the storm. Additionally, if a storm were to occur in 24-hours, but over two of the 24-hour data windows, then the storm would not accurately be modeled. Furthermore, the model analyzes radar images from WSI for the time period 1998-2005; this is not actual data but image files. The use of an image in lieu of data is a questionable practice because image files are typically at coarse resolution and may not fully represent actual storm magnitudes from the event.

The basic concepts for generation of the DAD tables in this model are of great interest. The model identifies area of equal precipitation amounts to define the storm spatial pattern. Since the data is gridded, a DAD table may be created by counting the cells of equal precipitation amount. This underlying concept is the foundation of the storm analysis model developed in-house by Reclamation that is discussed below.

4.2. Storm Analysis, Developed by Reclamation

An hourly MPE product is generated at the RFCs and is available on a 4 x 4 km grid. Satellite, radar, and gauge data are blended to create the MPE, depending on the spatial and temporal availability of each in a given hour. Bias corrections are applied based on comparisons between the in situ measurements (i.e., satellite and radar) and ground truth (i.e., gauges). In addition, hydrometeorologists at the RFC perform additional manual quality control on the hourly grids. The hourly MPE grids are available since the mid-1990s over various parts of the country, but consistently available since the early 2000s at all RFCs. The MPE grids are served to the public in a variety of formats, including: netCDF, xmrg, and shapefile. Fortunately, the availability of open source software allows an inexpensive and computationally efficient method for processing these data types.

A new methodology for processing MPE was investigated for storm analysis purposes. Tropical Storm Erin over south-central Oklahoma in 2007 was used as a test case. Erin is of importance as the storm passed within 50-100 km of Altus Dam, and a hydrologic hazard study for the Altus Dam Corrective Action Study is in progress. This storm, and the procedures to analyze it (as well as others), will be of critical importance to the Altus study. While the heaviest precipitation (> 10 inches) was observed to the east of Altus, its close proximity will allow the storm to be used as a critical storm input to the rainfall-runoff model. The following sections describe the data collected, software developed, and initial results of the DAD calculations.

4.2.1 Data

The Arkansas-Red River Basin RFC (ABRFC) provided hourly MPE files in xmrg format for the period 00 UTC 17 August through 23 UTC 19 August 2007. The xmrg format is a gridded format used by the National Weather Service and is referenced to the Hydrologic Rainfall Analysis Project (HRAP) grid. The HRAP grid ensures a 4 x 4 km resolution across the contiguous United States.

4.2.2 Methodology

Processing of the MPE grids to DAD relationships involves the incorporation of several open source software packages and libraries. An overview of the processing steps can be seen in the flow chart from Figure 4. The following paragraphs describe the methodology in detail with the primary software requirements for each step provided in square brackets.

The NWS offers a program in the C programming language to convert xmrg to an ASCII grid [xmrgtoasc.c]. The ASCII grid is in the native HRAP projection and requires transformation to a geographic coordinate system (e.g., World Geodetic System 1984 (WGS84)) for use in available processing tools [gdalwarp]. The xmrg files are then processed to ASCII text files with longitude (x), latitude (y), and precipitation (p) as columns using a combination of Python and the Geospatial Data Abstraction Library (GDAL) in a Linux environment [gdal2xyz.py]. Individual hourly xyp files are then concatenated by column and accumulated by row and across columns at various durations (e.g., 1h, 6h, 12h, 24h, 72h, and storm total) using Linux shell scripts. Generation of shapefiles [xyz2shp.py] and tagged image file format (tiff) grids [xyz2gdal.py] is performed so that the output from the software may be visually inspected (Figure 5). These outputs are in WGS84 coordinates and are transformed back to a Universal Transverse Mercator (UTM) coordinate system to allow direct computation of appropriate area sizes in metric units (e.g., square kilometers). In the final step before the DAD calculations, statistics are generated for each of the tiff-formatted grids [gdalinfo], including the maximum and mean areal precipitation for each duration grid [shell].

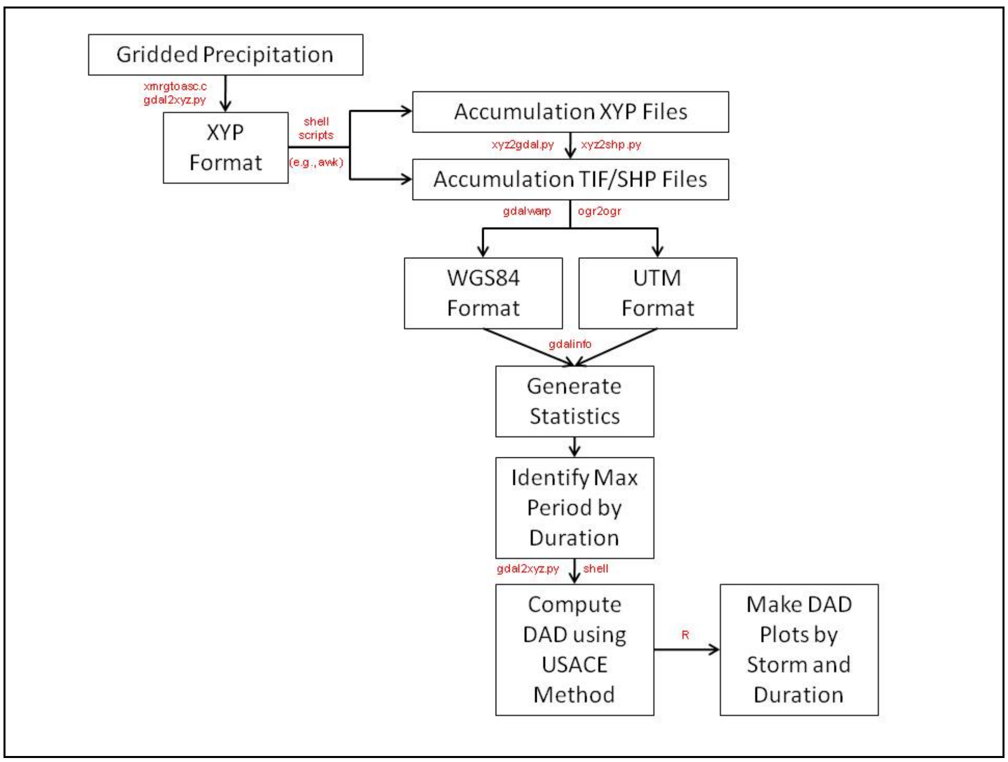


Figure 4. Flow chart of the procedures to generate DAD from gridded MPE files. Red text indicates the primary software required to complete each step.

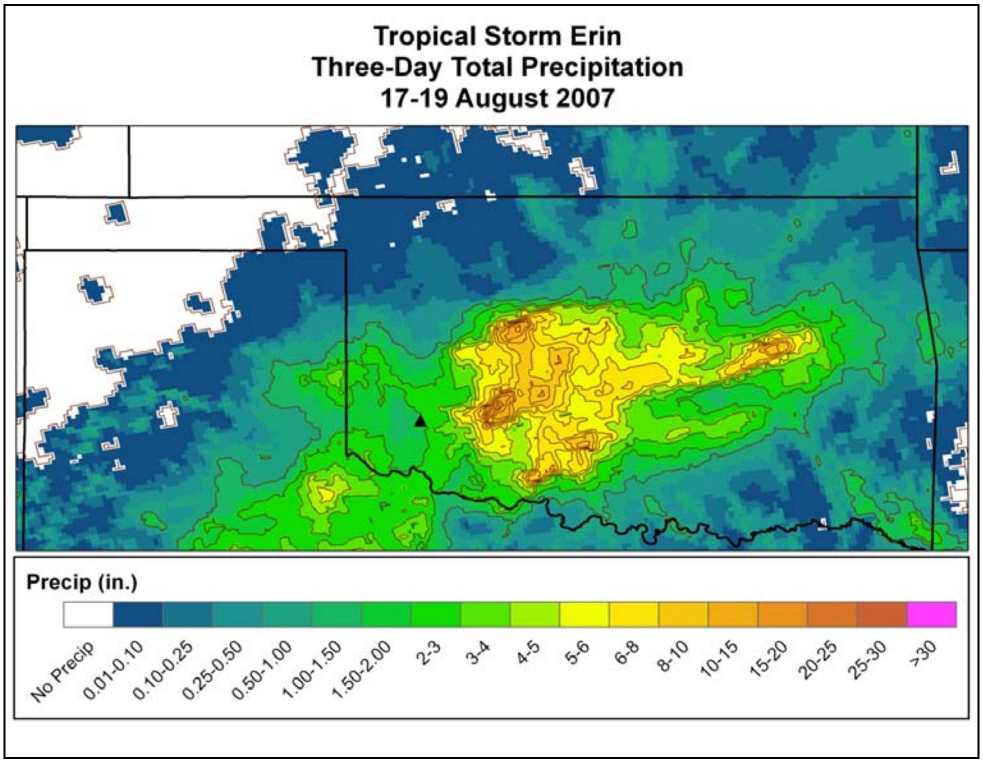


Figure 5. Storm total/72-hour accumulated MPE over Oklahoma from TS Erin (00 UTC 17 August to 23 UTC 19 August). One-inch isohyets (brown) are shown.

The USACE developed a methodology using ESRI ArcMap and Microsoft Excel to generate DAD relationships from gridded data (see Section 4.1; Clemetson and Melliger, 2010). The method involves the development of isohyets, or lines of equal precipitation amounts, from the various duration grids that can be used to define the spatial patterns. Using the isohyets, the number of cells within that isohyet and the average of those cells can be calculated for use in developing the DAD. This is equivalent to counting the cells with values above that precipitation amount and taking the average of the precipitation values for those same cells. As such, we first converted the UTM grids to xyp format, where x and y are now easting and northing, respectively, and p represents the precipitation amount [gdal2xyp.py]. Shell scripts are used to perform the DAD calculations for all available grids. Using the statistics output from the earlier steps, the start hour of the maximum mean precipitation for each duration grid is determined manually. The respective files are then ingested in the R statistical software package for plotting of DADs by storm and by duration (Figure 6). The DAD values are calculated irrespective of specific area sizes as the number of cells with precipitation values above a particular threshold vary depending on the duration and start time of that duration. The values are also in metric units; hence, the R scripts use a linear interpolation scheme and conversion factor to generate the DAD values at 10, 200, 1000, 5000, 10000, and 20000 square miles in inches (see Figure 6; Table 2). This allows ease of comparison with DAD tables from the NWS HMRs.

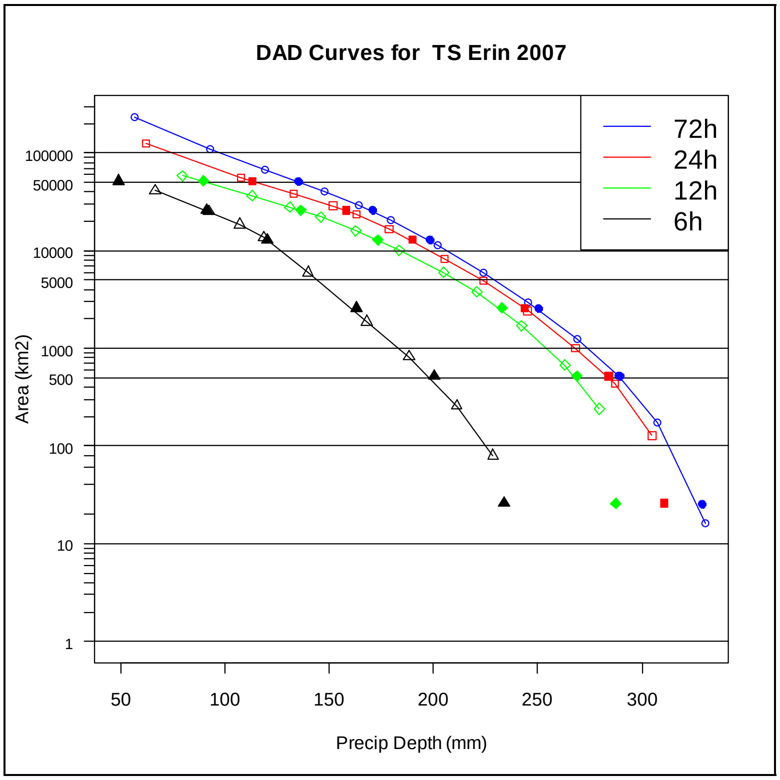


Figure 6. DAD curves for TS Erin. Lines with hollow points indicate the DAD computed using shell scripts. Solid points are generated using linear interpolation to specific area sizes.

Table 2. DAD values in inches for each duration.

	Duration (hrs)			
Area (sq mi)	6	12	24	72
10	9.21	11.32	12.24	12.94
200	7.89	10.59	11.19	11.38
1000	6.42	9.17	9.59	9.85
5000	4.73	6.83	7.48	7.81
10000	3.59	5.37	6.22	6.71
20000	1.92	3.53	4.45	5.32

While not shown in the flow chart in Figure 4, mass curves can also be developed from the MPE grids [xyz-vs-gdal.py]. Using a set of designated points, the precipitation accumulation values from the running total grids can be extracted and concatenated at each hour during the storm duration. Using this time series of precipitation, plots are then made using R (Figure 7). As a proof of concept, the maximum grid cell in the 72-hour running total grid from TS Erin was identified and used for the extraction process. At that grid point, the highest rainfall rates occurred between hours 48 and 80 when 298 mm (~11.73”) fell (Figure 7). By performing this process at multiple points and for multiple storms, a representative temporal distribution of rainfall may be determined for application in rainfall-runoff models for hydrologic hazard studies.

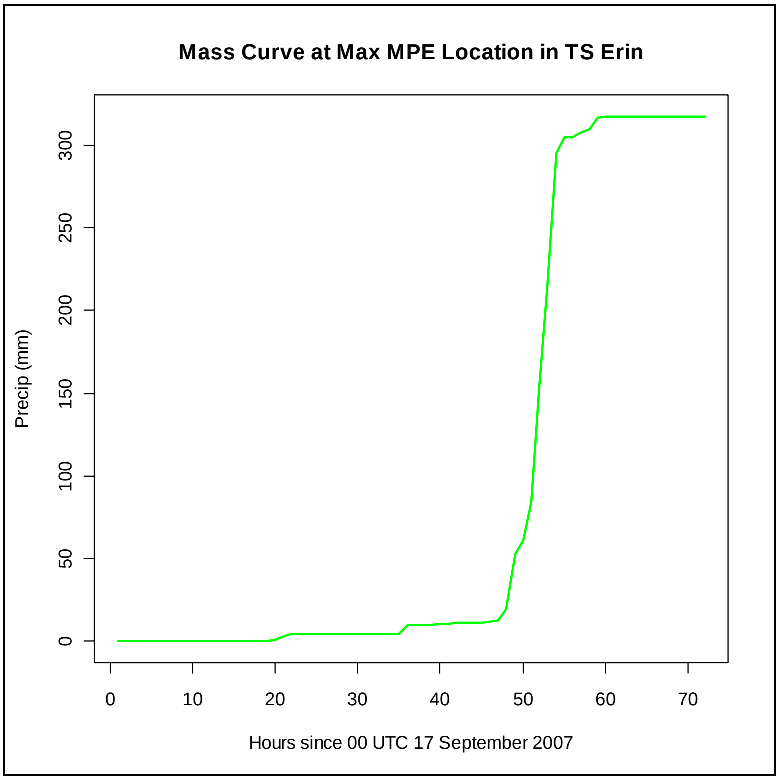


Figure 7. Mass curve for TS Erin at the location of maximum precipitation based on MPE. Most precipitation fell during a 12-hour period from Hour 48 to 60, when total accumulation increased from 19.6 to 317.5 mm.

4.2.3 Discussion

The use of gridded precipitation datasets provides the advantage of increased spatial and temporal resolution of existing point precipitation data; however, the data may be limited by inaccuracies in the radar-estimated precipitation (Caldwell et al., 2011). TS Erin was selected as a test due to its proximity to Altus Dam and potential implications in an upcoming dam safety evaluation. Based on the mass curve at the location of maximum rainfall based on MPE alone, the majority of rainfall fell during a 12 hour period. During the maximum 12-hour time period, the 8-inch isohyet enclosed a total area of approximately 3800 km^2 square kilometers. At 72-hours, the same isohyet incorporated 6000 km^2. These areas approach the area size of the Altus watershed and would most likely require consideration of both peak and volume considerations in assessing risk at Altus.

The methodology developed here is easily translated to other regions and basins, but at present does not include any consideration for adjustment of the storms based on moisture maximization, transposition, or orographics. Using this procedure, individual storm processing can be performed on additional storms in the future for inclusion in an extreme storm database.

5.0 Regional Precipitation Frequency

L-moments regional precipitation frequency methods (Hosking and Wallis, 1997) are used to create the precipitation frequency curve for a watershed, with PMP as the upper limit of the curve. The L-moments method utilizes a ‘space for time’ substitution, whereby data at nearby rain gauges are pooled into a large dataset to estimate a distribution that represents an entire region. L-moments provides the key precipitation input to the Stochastic Event Flood Model that is used for Issue Evaluation and Corrective Action Studies (Swain et al., 2006).

Until recently, regional precipitation frequency analyses using L-moments have been completed by contractors, including analyses for A.R. Bowman, Minidoka, and most recently Trinity and Whiskeytown Dams. As part of this research project, Reclamation developed and improved software and methodologies for L-moments calculations. From these efforts, L-moments regional precipitation frequency analyses are now completed in-house and calculations can be thoroughly checked. Moreover, regional precipitation frequency analyses are now commonplace in the Hydrologic Hazard studies of Dam Safety Issue Evaluations and Corrective Action Studies.

The following sub-sections describe the accomplishments of Reclamation staff that made the statistical procedure successful in-house, the studies that have already utilized the L-moments methodology, and a brief examination of a contractor’s software.

5.1 Completion of the L-moments Methodology

The L-moment Methodology Outline that was developed as part of this project is attached as Appendix C. This outline is the step-by-step procedure used by Reclamation to estimate a precipitation frequency curve using the L-moments regional precipitation frequency method for a watershed. This method includes a collection of various Fortran computer programs, data sets in specified formats, and analyses using a GIS. As noted by the number of steps and computer routines listed in Appendix C, the method is complex.

As part of this research project, several pieces of computer code necessary to link the existing statistical code together, and to complete the calculations, were written. The Methodology Outline in Appendix C documents the process and components. The outline is a guide for those within Reclamation who wish to learn and implement the L-moments procedures on projects. In addition, a brown bag presentation was given so that hydrology technical checkers and peer-reviewers might better understand the meteorology descriptions and results provided in L-moments calculations for Dam Safety hydrologic hazard reports. The powerpoint slides used in the brown bag presentation (Appendix D) were created as a stand-alone instruction guide.

5.2 L-moments Precipitation Frequency Curves in Dam Safety Studies and Beyond

L-moments statistics have already been used by Reclamation staff to estimate regional precipitation frequency curves for Dam Safety studies, including East Park Dam (Dworak et al., 2011), Red Willow Dam (Novembre et al., 2010), and Anderson Ranch Dam (draft report). An example precipitation frequency curve estimated using L-Moments is shown in Figure 8. L-moments will play a role in several crucial upcoming studies for Reclamation Dam Safety: Altus Dam, Boise River Diversion Dam, El Vado Dam, and Island Park Dam. L-moments statistics are rapidly becoming standard practice in Reclamation to produce precipitation frequency curves.

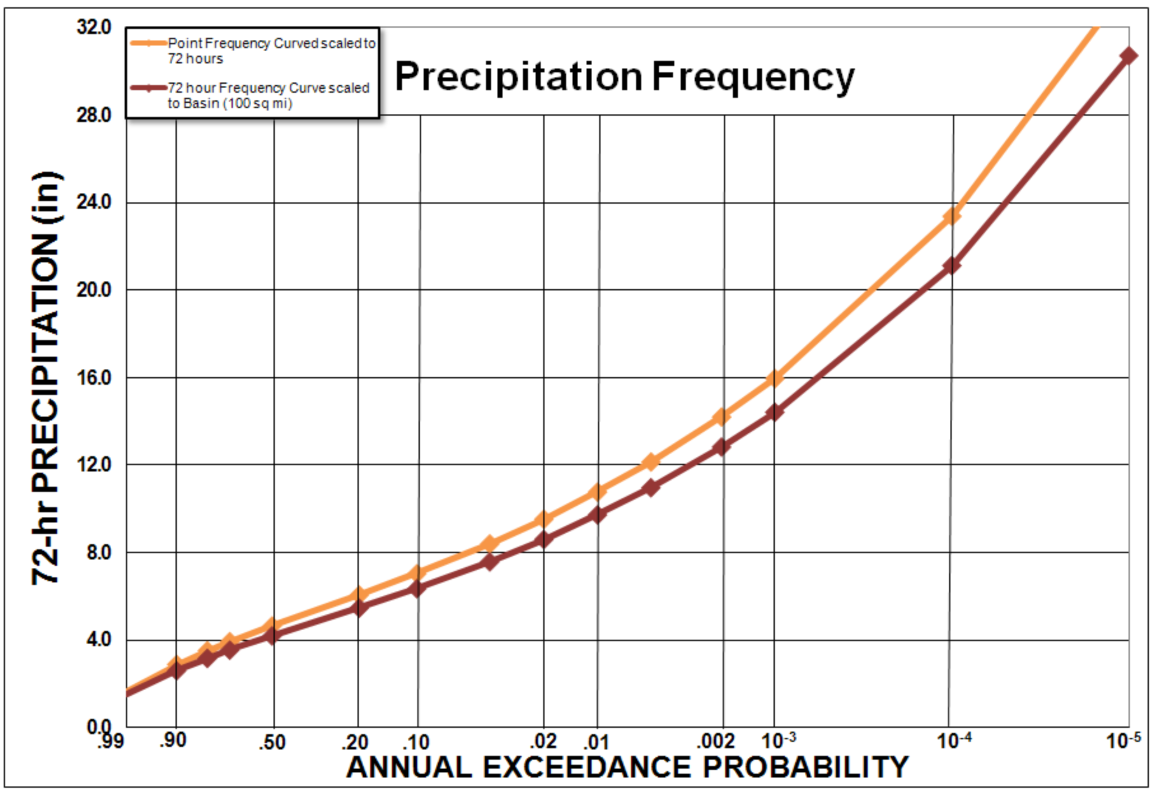


Figure 8. Precipitation frequency curves for East Park Dam, CA. The point frequency curve scaled to 72 hours is shown in orange, and the 72-hour frequency curve scaled to the basin is shown in red.

The L-moments regional precipitation frequency method has been presented by Reclamation to other agencies to demonstrate its utility. A poster was presented at the American Meteorological Society Annual Conference, Conference on Hydrology, in January, 2011 (Sankovich and England, 2011), which displayed the results from East Park Dam, CA, hydrologic hazard study (Dworak et al., 2011). Additionally, L-moments regional precipitation frequency methods were presented and discussed at the Hydrologic Hazard Training Course with the Federal Energy Regulatory Commission, Tennessee Valley Authority, and Reclamation employees on August 24-26, 2011.

5.3 L-Moments Software Alternatives

As stated above, regional precipitation frequency with L-moments was once completed by contractors for Reclamation. MGS Engineering Consultants have created a software program, called L-RAP, to calculate L-moments (MGS Software, 2011). The software is a Microsoft GUI and executable; source code is not provided.

L-RAP was acquired by Reclamation for testing purposes. Since it is provided in a GUI format, it may be easier and more straightforward to use as opposed to Reclamation's collection of code. At this time, Reclamation has obtained the software but has not yet fully tested the software or evaluated its capabilities for use on projects.

6.0 Summary

Extreme storm data research was completed in three main areas:

1. a comprehensive electronic database of historical extreme storm events in GIS was developed;
2. methodologies and datasets that could be used to process new storms based on Multisensor Precipitation Estimates were investigated and documented; and
3. in-house capabilities and programs to calculate regional precipitation frequencies up to the PMP in a format suitable for flood runoff models were developed.

The results from this research were applied to several critical hydrologic hazard studies for the Reclamation Dam Safety Program, including Red Willow Dam and East Park Dam. The methodologies will also be applied on ongoing projects such as Friant, Altus and Island Park Dams.

Based on the research and tools developed, there are several areas in need of continuing work. These would include: collection of new extreme storm data and processing of these storms; development of uncertainty estimates for L-moments regional precipitation frequency curves, and collaborating with other Federal agencies on a new national extreme storm data set and archive procedure.

7.0 References

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Appendix A: Duplicate Storms in the Master Storm List

Name	State	Date	Appearing in HMRs	Listed as HMR
Jefferson	OH	09/10-13/1878	51, 52	51
Ward District	CO	05/29-31/1894	52, 55A	55A
Wellsboro	PA	05/30-06/01/1889	51, 52	51
Greeley	NE	06/04-07/1896	51, 52	51
Lambert	MN	07/18-22/1897	51, 52	51
Hearne	TX	06/27-07/01/1899	51, 52	51
Jewell	MD	07/26-29/1897	51, 52	51
Wakeeney	KS	09/20-24/1902	52, 55A	55A
Paterson	NJ	10/07-11/1903	51, 52	51
Boxelder	CO	05/01-03/1904	52,55A	55A
Spearfish	SD	06/02-05/1904	52,55A	55A
Rociada	NM	09/26-30/1904	52,55A	55A
Medford	WI	06/03-08/1905	51, 52	51
Warrick	MT	06/06-08/1906	51, 55A	55A
Knickerbocker	TX	08/04-06/1906	51, 55A	55A
Meeker	OK	10/19-24/1908	51, 52	51
Bowen	MT	10/10-11/1911	55A,57	57
Arnegard	ND	04/11-14/1912	52, 55A	55A
Clayton	NM	04/29-05/02/1914	52, 55A	55A
Hazelton	ND	06/25-28/1914	52, 55A	55A
Onida	SD	02/12-14/1915	52, 55A	55A
Sun River Canyon	MT	06/19-22/1916	55A, 57	57
Altapass	NC	07/15-17/1916	51, 52	51
Meek	NM	09/15-17/1919	51, 55A	55A
Vale	SD	05/09-12/1920	52, 55A	55A
Penrose	CO	06/02-06/1921	52, 55A	55A
Springbrook	MT	06/17-21/1921	52, 55A	55A
na	na	12/09-12/1921	57, 59	59
Savageton	WY	09/27-10/01/1923	52, 55A	55A
Eagle Pass	TX	05/27-29/1925	52, 55A	55A
Belvidere	SD	05/05-09/1927	52, 55A	55A
Kinsman Notch	NH	11/02-04/1927	51, 52	51
Berthold	ND	07/05-08/1928	52, 55A	55A
Elba	AL	03/11-16/1929	51, 52	51
Gallinas	NM	09/20-23/1929	52, 55A	55A
Porter	NM	10/09-12/1930	52, 55A	55A
Abilene	TX	09/05-07/1932	52, 55A	55A
Cheyenne	OK	04/03-04/1934	51, 55A	55A
Simmesport	LA	05/16-20/1935	51, 52	51
Cherry Creek	CO	05/30-31/1935	51, 55A	55A
Hale	CO	05/30-31/1935	51, 55A	55A
Hector	NY	07/06-10/1935	51, 52	51

Broome	TX	09/14-18/1936	52, 55A	55A
Ragland	NM	05/26-30/1937	52, 55A	55A
Circle	MT	06/11-13/1937	52, 55A	55A
Loveland	CO	08/30-09/04/1938	52, 55A	55A
Snyder	TX	06/19-20/1939	51, 55A	55A
Hallett	OK	09/02-06/1940	51, 52	51
McColleum Ranch	NM	09/20-23/1941	52, 55A	55A
Kanton	OK	04/17-21/1942	52, 55A	55A
Rancho Grande	NM	08/29-09/01/1942	52, 55A	55A
Big Meadows	VA	10/11-17/1942	51, 52	51
Warner	OK	05/06-12/1943	51, 52	51
Colony	WY	06/02-05/1944	52, 55A	55A
Plentywood	MT	08/10-13/1947	52, 55A	55A
Del Rio	TX	06/23-24/1948	51, 55A	55A
Yankeetown	FL	09/03-07/1950	51, 52	51
na	na	10/26-29/1950	57, 59	59
Vic Pierce	TX	06/23-28/1954	52, 55A	55A
Westfield	MA	08/17-20/1955	51, 52	51
na	na	11/21-24/1961	57, 59	59
Sombreretillo	Mex	09/19-24/1967	51, 55A	55A
Zerbe	PA	06/19-23/1972	51, 52	51
na	na	12/24-26/1980	57, 59	59

Appendix B: Files Composing the Extreme Storm Database

- Extreme Storm Data Catalog
  - EXTRE.mxd (ArcGIS document)
  - HMR 51
    - HMR 51 DAD
      - Storm_1.xls
      - Storm_2.xls
      - Storm_3.xls
      - Storm_4.xls
      - Storm_6.xls
      - Storm_7.xls
      - Storm_8.xls
      - Storm_11.xls
      - Storm_13.xls
      - Storm_14.xls
      - Storm_16.xls
      - Storm_17.xls
      - Storm_20.xls
      - Storm_22.xls
      - Storm_26.xls
      - Storm_29.xls
      - Storm_31.xls
      - Storm_33.xls
      - Storm_36.xls
      - Storm_37.xls
      - Storm_38.xls
      - Storm_42.xls
      - Storm_44.xls
      - Storm_47.xls
      - Storm_49.xls
      - Storm_50.xls
      - Storm_51.xls
      - Storm_53.xls
      - Storm_54.xls
      - Storm_56.xls
      - Storm_57.xls
      - Storm_59.xls
      - Storm_65.xls
      - Storm_67.xls
      - Storm_68.xls
      - Storm_69.xls
      - Storm_71.xls
      - Storm_74.xls
      - Storm_76.xls
      - Storm_77.xls
      - Storm_78.xls
      - Storm_80.xls
      - Storm_82.xls
      - Storm_85.xls
      - Storm_86.xls
      - Storm_87.xls
      - Storm_88.xls
      - Storm_90.xls
      - Storm_91.xls
      - Storm_93.xls
      - Storm_97.xls
      - Storm_99.xls
      - Storm_100.xls
    - HMR 51 GIS
      - HMR51_Storms.dbf
      - HMR51_Storms.prj
      - HMR51_Storms.sbn
      - HMR51_Storms.sbx
      - HMR51_Storms.shp
      - HMR51_Storms.shx

HMR51_Storms.shp.xml

HMR 52

HMR 52 GIS

HMR52_MajorStorms.dbf
HMR52_MajorStorms.prj
HMR52_MajorStorms.sbn
HMR52_MajorStorms.shp.xml
HMR52_MajorStorms.sbx
HMR52_MajorStorms.shp
HMR52_MajorStorms.shx

HMR 55A

HMR 55A DAD

Storm_1.xls
Storm_6.xls
Storm_8.xls
Storm_10.xls
Storm_13.xls
Storm_20.xls
Storm_23.xls
Storm_25.xls
Storm_27.xls
Storm_30.xls
Storm_31.xls
Storm_32.xls
Storm_38.xls
Storm_44.xls
Storm_46.xls
Storm_47.xls
Storm_53.xls
Storm_56.xls
Storm_58.xls
Storm_60.xls
Storm_68.xls
Storm_71.xls
Storm_75.xls
Storm_76.xls
Storm_77.xls
Storm_78.xls
Storm_79.xls
Storm_86.xls
Storm_101.xls
Storm_105.xls
Storm_108.xls
Storm_111.xls
Storm_112.xls
Storm_114.xls
Storm_116.xls

HMR 55A GIS

HMR55A_Storms.dbf
HMR55A_Storms.prj
HMR55A_Storms.sbn
HMR55A_Storms.shp.xml
HMR55A_Storms.sbx
HMR55A_Storms.shp
HMR55A_Storms.shx

HMR 57

HMR 57 DAD

Storm_5.xls
Storm_12.xls
Storm_29.xls
Storm_32.xls

Storm_38.xls
Storm_40.xls
Storm_59.xls
Storm_60.xls
Storm_66.xls
Storm_74.xls
Storm_78.xls
Storm_80.xls
Storm_82.xls
Storm_88.xls
Storm_106.xls
Storm_126.xls
Storm_133.xls
Storm_143.xls
Storm_147.xls
Storm_149.xls
Storm_151.xls
Storm_155.xls
Storm_156.xls
Storm_157.xls
Storm_165.xls
Storm_168.xls
Storm_175.xls
Storm_179.xls

HMR 57 GIS

HMR57_AllStorms.dbf
HMR57_AllStorms.prj
HMR57_AllStorms.sbn
HMR57_AllStorms.shp.xml
HMR57_AllStorms.sbx
HMR57_AllStorms.shp
HMR57_AllStorms.shx

HMR57_DADStorms.dbf
HMR57_DADStorms.prj
HMR57_DADStorms.sbn
HMR57_DADStorms.shp.xml
HMR57_DADStorms.sbx
HMR57_DADStorms.shp
HMR57_DADStorms.shx

HMR 59

HMR 59 DAD

Storm_40.xls
Storm_88.xls
Storm_126.xls
Storm_149.xls
Storm_156.xls
Storm_165.xls
Storm_175.xls
Storm_508.xls
Storm_523.xls
Storm_525.xls
Storm_544.xls
Storm_572.xls
Storm_575.xls
Storm_630.xls
Storm_1000.xls
Storm_1002.xls
Storm_1003.xls
Storm_1004.xls
Storm_1005.xls
Storm_1006.xls
Storm_1007.xls
Storm_1008.xls
Storm_1010.xls
Storm_1011.xls
Storm_1012.xls
Storm_1013.xls
Storm_1014.xls
Storm_1015.xls
Storm_1016.xls
Storm_1017.xls

Storm_1018.xls

HMR 59 GIS

HMR59_Storms.dbf
HMR59_Storms.prj
HMR59_Storms.sbn
HMR59_Storms.shp.xml
HMR59_Storms.sbx
HMR59_Storms.shp
HMR59_Storms.shx

Master Storm List

Master_storm_list.dbf
Master_storm_list.prj
Master_storm_list.sbn
Master_storm_list.shp.xml
Master_storm_list.sbx
Master_storm_list.shp
Master_storm_list.shx

US_states.dbf
US_states.prj
US_states.sbn
US_states.shp.xml
US_states.sbx
US_states.shp
US_states.shx

Appendix C: L-Moment Methodology Outline

Important: do not overwrite files. Each step that creates a file needs to create a NEW file for future use.

1. **Define the storm transposition region.** Refer to NOAA Atlas 2/14 or TP 40, NWS climatological divisions, and PRISM annual precipitation maps.

2. In GIS, open the SOD_all_COOP shapefile in:
H:\8200\8250\Flood_Files\8250 Meteorology\NCDC
This file will show the location of all the COOP stations. Highlight all of the stations within the storm transposition region and export into a text editor.

3. Eliminate all information except for the 6-digit station ID. Format the file so that there is one station ID per line, essentially a list of the stations in which you require data.

4. Run Sankovich's **specify_COOP.f**
This code reads in the list of stations created in Step 3 and the raw NCDC COOP data (which is organized by state, so if the storm transposition region straddles multiple States, you will have to run the program multiple times). The raw NCDC COOP data is found on Victoria's external hard drive. The output is all the raw NCDC COOP data for the selected stations within the storm transposition area. Note: the filenames are hardwired into the program. It is necessary to change these. Furthermore, the 'DO loops' also have a hardwired number of iterations. Change these as appropriate as well.

If the State of interest is not located on the hard drive, then refer to the end of this document for instructions to create a State file.

5. Run Mel Schaefer's **PPTDailyMax.exe**
No code is available, only the executable. This code is the reason that the data be in the specific format of the hydrosphere data. The purpose of this code is to find the annual maximum precipitation amount (either 1 or 3 day amount) at each station for each year the station was in existence. Inputs include the following:

> *ANNMAX.dat – states the input and output filename, collection year, and number of days in desired accumulation period
> *Stainfo.prn – there is a master Stainfo.prn on Victoria's external hard drive. However, because this code does not read the entire station ID when processing data (it reads the final 4 digits, the station ID, and ignores the first two digits, the state ID, even though stations located in different states may share the same station ID) you must process only

one State at a time, if the data straddles multiple states. Thus, from the master file, extract only one state in a .prn file, and be sure to have the same state in the data input file. This file also requires the header information.
*data – the station data from all the stations within the storm transposition area, split by State

6. If needed, combine all the separate states in one file.

7. Run Stodt's **readannmax.f**

This program attaches the station name to each line of data. The input is the output from PPTDailyMax.exe, the combined State file. If errors are noted upon compiling, a possibility could be in the elevation of the stations: if **** is noted as the elevation, then the program will not execute. Replace **** with 9999 or look up station elevation.

8. Remove header information in TextPad now that the station name is attached to each individual line of data.

Sort:	First Key (state sort)	From 108, Length 2
	Second Key (station name)	From 80, Length 25
	Third Key (observation number)	From 1, Length 4

9. Sort data by year, can also be completed in TextPad

Sort:	First Key (year sort)	From 43, Length 4
	Second Key (month)	From 50, Length 2
	Third Key (day)	From 46, Length 2

10. Run Stodt's **annmaxevents.f**

This program finds the unique storms in a given year. Input is the data sorted by year (from Step 9), output is independent storms.

11. (optional yet beneficial). Sort annmaxevents.f output by year, month, and day in a text editor to list data in chronological order.

12. Run Sankovich's **max_station_precip.f**

Program to find the greatest precipitation event at all stations. Input is the file with header information removed, the file created in Step 8)

13. Check the highest precipitation data against Climatological Data for consistency (2 files: the output from Step 12 and from Step 11). Edit the original data (the input into Step 5) to match Climatological Data. Document any inconsistencies, use Climatological Data as truth. If uncertain, contact the respective state's climatologist for assistance.

14. Repeat steps 5-13 if changes were made (average is about 3 iterations).

15. Output of the above was to obtain the annual maximum precipitation values for each station, the top events in the dataset, and to do some QA/QC. There is another code written by Mel(?) that will do some quality checking. It's called **QualityCheck.exe**. Here would be an appropriate time to run that code. John England would be a good reference to decipher the output.

16. At this point, it is helpful to map the top events so that spatial distribution is known. (When creating a homogeneous region later, you will want to attempt to include the stations that reported top events.).

17. Run Sankovich's **lmom_input.f**
The purpose of this program is to reformat the final, quality-assured, annual maximum precipitation data (i.e. the output from Step 5) into something readable for the L-moments code. The input, again, is the output from Step 5.

18. Run England's **streamstats_lmoms14.f**
The input is the output from Step 17. This program will compute the L-moment statistics for each rain gauge station.

19. Map the L-Cv, L-skewness, and the mean in GIS.

From here forth, the assumption is made that a single homogeneous region about the watershed will be found.

20. **Define the homogeneous region**. The spatial distribution of these parameters in addition to the location of the extreme events will define the (first attempt) homogeneous region. Choose an area about the watershed where the rain gauge stations share a similar L-Cv and L-skewness. Include as many of the top events as possible. This area should be large (around 100 stations) as the next steps will refine the region. If there is a gradient of a statistic across the watershed, be sure to capture this gradient. Note the stations that are going to comprise your homogeneous region.

21. In the output file created in Step 18, remove the rain gauge stations that are not included in the homogeneous region. Also, remove all of the intermediate calculations - keep only the resultant statistics and header (Site No., Nobs, L-1, L-CV, t3, t4, t5, DateMax, QpeakMax, Mean, Std.Dev, Skew, Lag-1, Serial Correl). Give the file some title information (above the header). Between the title and header, add another line which includes the number of stations and the basin name, example below:

109 (then two spaces) EastPark

22. Run Hosking's **xtest.f**

This code calculates the discordancy values for each station within the homogeneous region. Those stations that are most unlike the group will be noted with stars. Additionally, the parameters for any regional distribution that fits reasonably well to the data will be given.

23. Put data into **1Region.xls**

This spreadsheet creates a chart of the ratio L-skewness vs. L-kurtosis in relation to a number of regional frequency distributions. The chart will show the mean of the ratio as well as the scatter about the mean and help determine which of the regional frequency distributions most closely describes the dataset. Fill in the 'Lmom&Hvalues_from_Xtest tab with the output from xtest.f (careful to replicate exactly), and the chart should appear in the LCS_LK tab.

24. **Analyze the stations with high discordant values**. GIS and the L-skewness vs L-kurtosis chart will help. Most of the stations with high discordant values will need to be removed from the dataset in order to create a true homogeneous region. However, if a station reports a top event or reports a relatively high mean precipitation value, then attempt to keep the station within the dataset. Additionally, if a station lies within the watershed or close to it, then attempt to keep the station within the dataset.

25. Remove appropriate stations with high discordant values.

26. Repeat Steps 22 and 24 until a homogeneous region and desirable regional frequency distribution is found. This may take numerous iterations.

27. Calculate the regional precipitation frequency using the appropriate distribution. Equations for the distributions are found in the appendices of Hosking's **Regional Frequency Analysis** textbook. In EP_freq_curve.xls, the Freq_curve tab may be helpful.

28. Scale the regional growth curve to the at-site mean, where the at-site mean is the mean annual precipitation representative of the entire watershed. The at-site mean can be found by calculating an inverse-distance areal average of several rain gauges within and surrounding the watershed.

29. Determine the storm duration and scale the at-site growth curve appropriately. To find the storm duration, consult the respective HMR and check the duration of the historical extreme storms. The USACE Storm Catalog may also be helpful. Furthermore, check the design storm report and latest PMP/PMF report. Once the storm duration is found, scale the at-site growth curve. Again, consult the respective HMR to see if there is a predetermined ratio (HMR 59 includes ratios). If not, then a ratio will need to be calculated from historical extreme storms:

ratio the calculated storm duration precipitation amount (i.e. at 72-hours the precipitation was 24") to the 24-hour precipitation amount. Ideally, repeat for a few storms and take the average.

30. Scale the growth curve to the areal extent of the basin. Currently, the growth curve is scaled to the at-site mean, or a representative 10 mi^2 point. The HMRs provide a ratio to convert the 10 mi^2 point to a larger areal value.

31. Plot the precipitation frequency. **EP_testcurves.xls** may be helpful.

To Create a State File

1. The raw data is found on NCDC SOD CDs. The format (for the 1948-2001 CD) is such that there is a directory for each state, then, within that directory, is a file for each station. Output all of these station filenames within the state directory into a text file. (Using linux, use the command 'ls > station_files.txt' without the quotes where station_file is the name of the file where the list of file names will be output.)

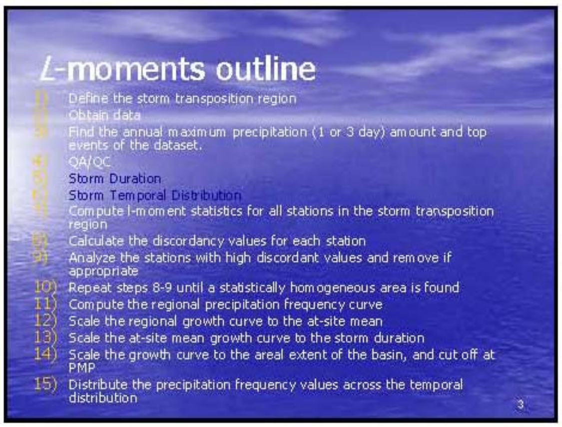
2. The above list of filenames will be one of the inputs into Sankovich's **ncdc_to hydro.f** This allows the program to loop over all the files stored within the list. The other input is the CD itself. As the program loops over all of these files, ncdc_to_hydro.f will extract all of the PRCPHI data (this is the summary of the day precipitation data; the program will ignore temperature, wind speed, etc.) and format the data to look like the hydrosphere data (which is needed to run Mel Schaefer's codes later). ncdc_to_hydro.f is heavily commented, but the input and output filenames are hardwired. Please change as needed.

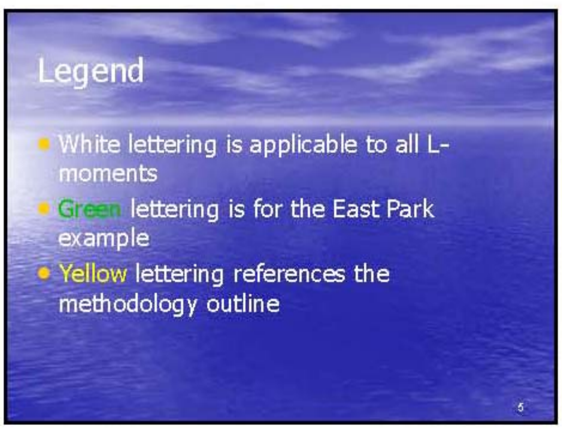
3. Repeat steps 1 and 2 for the 2002-2006 CD. This will be more difficult because the data is not just split by state, but by state and year, so that you'll have to create a file for California-2002, California-2003, California-2004, etc.

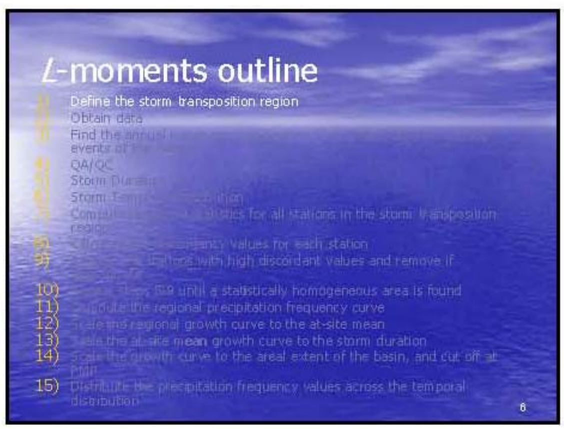
4. Combine all of the data into one master State file. Can be easily sorted in TextPad, sort first by station, then put into chronological order.

Sort:	First Key (for station sort):	From 6, Length 4, Ascending Order
	Second Key (for chrono.):	From 18, Length 6, Ascending Order

Appendix D: L-moments Technical Check Guide







Storm Transposition Region I

- Initial delineation of the storm transposition region
- All rain gauges within this region may be considered in the statistical analysis
- Determined by NWS climatological divisions, PRISM annual precipitation maps, NOAA Atlas 2/14 or TP 40 (Step 1)

7

Storm Transposition Region II

- Explanation of the region delineation should be included within the project report (Section 4.3)

The geography of the East Park watershed is rather complex, since it is located on the eastern slope of the Coastal Range. As such, a region that is climatologically similar must also exhibit highly orographic characteristics. To aid in the delineation of this region, PRISM mean annual precipitation maps (Oregon Climate Center, 2000), *NOAA Atlas 2* regions (Miller et al., 1973), and the National Weather Service (NWS) Climatological Divisions were consulted. Additionally, a 300-ft elevation threshold was applied in the likeness of the Folsom Dam report (Schaefer and Barker, 2005) to be sure that the lowland, non-orographic area between the Coastal Range and the Sierra Mountains was not included in the climatologically similar region. This low-lying area is situated at elevations much lower than the average elevation of the East Park watershed. A map of this climatologically similar region may be found in Figure 4.4A.

8

L-moments outline

1) Define ...
2) Obtain data
3) Find the ... events ...
4) QA/QC
5) Storm Duration
6) Storm Temporal Distribution
7) Compute ... statistics for all stations in the storm transposition region
8) ... values for each station
9) ... stations with high discordant values and remove if ...
10) ... steps 6-9 until a statistically homogeneous area is found
11) Compute the regional precipitation frequency curve
12) Scale the regional growth curve to the at-site mean
13) Scale the at-site mean growth curve to the storm duration
14) Scale the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

9

Obtain Data I

- Data may be obtained from any observational network within the storm transposition region
- Important to understand the data quality, time of observation, etc.
- Networks used in previous studies include NWS COOP, RAWS, SNOTEL (Steps 2-4)

10

Obtain Data II

- Explanation of data should be included within the project report (Section 4.3)

The precipitation observations used as input for this study were acquired primarily from the one-day (approximately 24-hour) precipitation totals from the NWS Cooperative Network (COOP) rain gauge network. This data was augmented by observations from various other networks, including: Remote Automatic Weather Stations (RAWS), gauges operated by the U.S. Army Corps of Engineers, a precipitation gauge at Indian Valley operated by the Yolo County Flood Control and Water Conservation District, and a precipitation gauge operated by the California Department of Water Resources.

11

L-moments outline

1) Define ...
2) Obtain data
3) Find the annual maximum precipitation (1 or 3 day) amount and top events of the dataset.
4) QA/QC
5) Storm Duration
6) Storm Temporal Distribution
7) Compute ... statistics for all stations in the storm transposition region
8) ... values for each station
9) ... stations with high discordant values and remove if ...
10) ... steps 6-9 until a statistically homogeneous area is found
11) Compute the regional precipitation frequency curve
12) Scale the regional growth curve to the at-site mean
13) Scale the at-site mean growth curve to the storm duration
14) Scale the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

12

Top Events I

- Codes to determine annual max and top events:
  - PPTDailyMax.exe: finds the annual maximum 1 or 3 day amount (Step 5)
  - Readannmax.f: attaches metadata to each line of data (Step 7)
  - Annmaxevents.f: finds the unique storms in a given year (Step 10)
  - Max_station_precip.f: finds the greatest precipitation event at all stations (Step 12)

13

Top Events II

- Not included within project report
- Files not very organized
- Not part of technical check at this point

14

L-moments outline

Define …
Obtain data
Find the …
events …
QA/QC
Storm Dur…
Storm …
Comp… …istics for all stations in the storm transposition region
… …cordancy values for each station
… …tions with high discordant values and remove if …
10) … until a statistically homogeneous area is found
11) …the regional precipitation frequency curve
12) … regional growth curve to the at-site mean
13) … the at-site mean growth curve to the storm duration
14) … the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

15

QA/QC

- Check the highest precipitation amounts against Climatological data (Steps 13)
- Remove/fix inconsistencies
- Repeat Top Events programs (Step 14)
- QualityCheck.exe (Step 15) results are confusing

16

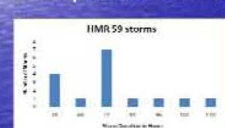
L-moments outline

Define …
Obtain data
Find the …
events …
QA/QC
Storm Duration
Storm …
Comp… …istics for all stations in the storm transposition region
… …cordancy values for each station
… …tions with high discordant values and remove if …
10) … until a statistically homogeneous area is found
11) …the regional precipitation frequency curve
12) … regional growth curve to the at-site mean
13) … the at-site mean growth curve to the storm duration
14) … the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

17

Storm Duration

- Needed to scale frequency curve later
- Process should be outlined in report (Section 4.1)
- Uses previous studies, storms in the HMRs



Storm Date	Storm Duration (hours)
[illegible]	108
[illegible]	120
[illegible]	72
[illegible]	144
[illegible]	120*
[illegible]	36
[illegible]	30
[illegible]	144*
[illegible]	120*
[illegible]	72
[illegible]	96*
[illegible]	144*
[illegible]	72
[illegible]	36
[illegible]	

18

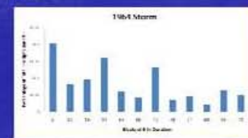
L-moments outline

1) Define ...
2) Obtain data
3) Find the annual ... events of the ...
4) QA/QC
5) Storm Duration
6) Storm Temporal Distribution
7) Compute ... statistics for all stations in the storm transposition region
8) ... discordancy values for each station
9) ... stations with high discordant values and remove if ...
10) ... Steps 8-9 until a statistically homogeneous area is found
11) Compute the regional precipitation frequency curve
12) Scale the regional growth curve to the at-site mean
13) Scale the at-site mean growth curve to the storm duration
14) Scale the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

19

Storm Temporal Distribution

- Needed to distribute frequency curve later
- Process should be outline in report (Section 4.2)
- Uses previous studies



20

L-moments outline

1) Define ...
2) Obtain data
3) Find the annual ... events of the ...
4) QA/QC
5) Storm Duration
6) Storm Temporal Distribution
7) Compute l-moment statistics for all stations in the storm transposition region
8) ... discordancy values for each station
9) ... stations with high discordant values and remove if ...
10) ... Steps 8-9 until a statistically homogeneous area is found
11) Compute the regional precipitation frequency curve
12) Scale the regional growth curve to the at-site mean
13) Scale the at-site mean growth curve to the storm duration
14) Scale the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

21

L-moments

- lmom_input.f: reformats the final, quality-assured, annual maximum precipitation data (Step 17)
- streamstats_lmoms14.f: compute the L-moment statistics for each rain gauge (Step 18)

22

Begin checking files here

Lmomout_result.txt

Result of Step 18

For all stations in the storm transposition region, this file includes:
- Site No.
- Number of observations
- L-1 (mean)
- L-CV (std. dev.)
- t3 (skew)
- t4, t5
- Date of maximum precip
- Maximum precip
- Mean
- Std. dev.
- Skew
- Lag -1
- Serial Correlation

23

L-moments outline

1) Define ...
2) Obtain data
3) Find the annual ... events of the ...
4) QA/QC
5) Storm Duration
6) Storm Temporal Distribution
7) Compute ... statistics for all stations in the storm transposition region
8) Calculate the discordancy values for each station
9) ... stations with high discordant values and remove if ...
10) ... Steps 8-9 until a statistically homogeneous area is found
11) Compute the regional precipitation frequency curve
12) Scale the regional growth curve to the at-site mean
13) Scale the at-site mean growth curve to the storm duration
14) Scale the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

24

Discordancy I

- Xtest.f: calculates the discordancy for each station in the dataset, provides the regional distribution parameters (Step 22)

Discordancy = quantitative value of how different an individual station is in comparison to the dataset as a whole

25

Discordancy II

- There were 185 stations in the storm transposition region. An elevation threshold was applied (explained in report) which reduced the dataset to 109 stations. These stations were removed from Lmomout_result.txt
- Input to **xtest.f** is EastP_highlands_v1.txt
- Notice the slight reformat, Step 21
- Output is EastP_highlands_v1_out.txt

26

Discordancy III

- The output provides the input again, then reformats and includes the discordancy values, then provides the distribution parameters
- Check that the number of stations matches the input
- One star means discordant, two stars means highly discordant

27

L-moments outline

1) Define th...
2) Obtain data
3) Find the annual ... events of ...
4) QA/QC
5) Storm Dur...
6) Storm Temp...
7) Comp... statistics for all stations in the storm transposition regio...
8) ... values for each station
9) Analyze the stations with high discordant values and remove if appropriate
10) ... 8-9 until a statistically homogeneous area is found
11) Compute the regional precipitation frequency curve
12) Scale the regional growth curve to the at-site mean
13) Scale the at-site mean growth curve to the storm duration
14) Scale the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

28

Analyze discordant stations

- Not usually included in project report
- Notes can be found in a meteorology technical document
- Discordant stations not always immediately removed (Step 24)
  - 5 years of data or less, then removed
  - Is the gage located within the watershed?
  - Does the gage record contain one of the top precipitation events?

29

L-moments outline

1) Define th...
2) Obtain data
3) Find the annual ... events of ...
4) QA/QC
5) Storm Dur...
6) Storm Temp...
7) Comp... statistics for all stations in the storm transposition regio...
8) ... values for each station
9) ... stations with high discordant values and remove if ...
10) Repeat steps 8-9 until a statistically homogeneous area is found
11) Compute the regional precipitation frequency curve
12) Scale the regional growth curve to the at-site mean
13) Scale the at-site mean growth curve to the storm duration
14) Scale the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

30

Scale to At-Site Mean I

- The at-site mean is the mean maximum annual precipitation representative of the entire watershed
- May be calculated by finding the inverse-distance areal average of several gauges within and surrounding the watershed in ArcGIS (Step 28)

37

Scale to At-Site Mean II

- Explanation normally provided in project report (Section 4.4)

The regional growth curve was next scaled to the at-site mean. The at-site mean is the annual maximum daily (approximately 24-hour) precipitation observation representative of the entire watershed. This was found by identifying the mean value of the annual maxima daily (approximately 24-hour) precipitation observations for several rain gauges surrounding the watershed, then applying an inverse-distance weighting scheme to compute an area average. Figure 4.6 is a map showing the East Park watershed, the eight rain gauges surrounding the watershed, and their respective mean annual maxima daily (approximately 24-hour) precipitation observation. The area average for the watershed is 2.80 in.

38

Scale to At-Site Mean III

- Need meteorology.mxd to check the average value
- In spreadsheet (EP_freq_curve.xls)
  - Check that average was input correctly
  - Make sure that equation is correct

$$Q_i(F) = \hat{\mu}_i q(F)$$

39

L-moments outline

1) Define
2) Obtain data
3) Find the annual ... events
4) QA/QC
5) Storm Duration
6) Storm ...
7) Compute ... statistics for all stations in the storm transposition region
8) ... discordancy values for each station
9) ... stations with high discordant values and remove if ...
10) ... until a statistically homogeneous area is found
11) ... the regional precipitation frequency curve
12) ... regional growth curve to the at-site mean
13) Scale the at-site mean growth curve to the storm duration
14) ... growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

40

Scale to Storm Duration I

- ..this is why storm duration is mentioned above...
- Because the data corresponds to 24-hour precipitation observations, the current frequency curve represents 24-hour precipitation observations
- But if the storm duration is different (Step 29):
  - Scale factors found in some HMRs
  - Scale factor can also be determined by analyzing several storms

41

Scale to Storm Duration II

- Explanation found in project report (Section 4.4)

Based on the historical record of storms in the vicinity of the East Park watershed (discussed in Section 4.1), the storm that would be most devastating to the area would be a 72-hour storm. To account for a 72-hour storm, the 24-hour at-site mean frequency curve was scaled by a factor of 1.75, provided in HMR 59 (Corrigan et al., 1999). In Figure 4.8, this is the orange curve.

42

Scale to Storm Duration III

- Can check appropriate HMR for value or the storm analysis
- In spreadsheet (EP_freq_curve.xls)
  - Check that scale factor was input correctly
  - Make sure that equation is correct

43

L-moments outline

1) Define t
2) Obtain data
3) Find the annu events of the
4) QA/QC
5) Storm Durati
6) Storm Tem
7) Com tistics for all stations in the storm transposition regio
8) dancy values for each station
9) stations with high discordant values and remove if
10) steps 8-9 until a statistically homogeneous area is found
11) the regional precipitation frequency curve
12) the regional growth curve to the at-site mean
13) the at-site mean growth curve to the storm duration
14) Scale the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

44

Scale to Basin Extent I

- Because the data corresponds to a point precipitation observation, the current frequency curve represents point precipitation observation
- But the watersheds are usually larger (Step 30):
  - Scale factors found in some HMRs

Explanation found in project report (Section 4.4)

For the frequency curve to be representative of the East Park watershed (as opposed to a 10 mi² point), another scale factor was applied to transform the curve from 10 mi² to approximately 100 mi², in accordance with the size of the watershed. This value (0.9025) was also derived from HMR 59 (Corrigan et al. 1999).

45

Scale to Basin Extent II

- Can check appropriate HMR for value
- In spreadsheet (EP_freq_curve.xls)
  - Check that scale factor was input correctly
  - Make sure that equation is correct

46

Scale to Basin Extent III

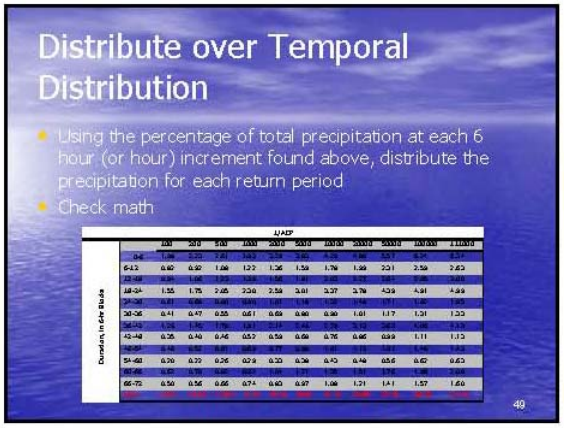
- Check PMP
  - Did the frequency curve end at the PMP?
  - Was the PMP used correct?

47

L-moments outline

1) Define t
2) Obtain data
3) Find the annu events of the
4) QA/QC
5) Storm Durati
6) Storm Tem
7) Com tistics for all stations in the storm transposition regio
8) dancy values for each station
9) stations with high discordant values and remove if
10) steps 8-9 until a statistically homogeneous area is found
11) the regional precipitation frequency curve
12) the regional growth curve to the at-site mean
13) the at-site mean growth curve to the storm duration
14) the growth curve to the areal extent of the basin, and cut off at PMP
15) Distribute the precipitation frequency values across the temporal distribution

48


Distribute over Temporal Distribution
Using the percentage of total precipitation at each 6 hour (or hour) increment found above, distribute the precipitation for each return period
Check math
49