

Extreme Precipitation Analysis Tool (EPAT)

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BIOGRAPHICAL SKETCH

Rob Rahrs is a Meteorologist and the GIS Coordinator with eight years of professional experience. He graduated from the University of Nebraska - Lincoln in 2000 with a Bachelor of Science degree in Meteorology/Climatology. Rob joined HDR as a Meteorologist over 6 years ago as part of the developing Atmospheric Science Group. He has experience in numerous projects dealing with extreme flooding reconstructions, forensics, flood warning systems, water supply forecasting, flash flood forecasting, probable maximum precipitation studies, and the development of design storm for hydrologic modeling.

While working on these projects, Rob recognized the depth and capabilities of GIS to streamline many of the hydro-met projects. In 2005, he seized the opportunity to pursue a graduate degree in this field. He graduated with his Masters of Engineering – Geographic Information Systems (GIS) from the University of Colorado – Denver in December 2007. The main focus of the Masters of Engineering – GIS program was the incorporation of GIS applications into the engineering arena.

ABSTRACT

In general, Probable Maximum Precipitation (PMP) estimates are an attempt to determine the physically possible greatest amount of precipitation for dam spillway size which is required for by the regulatory agency dam licensing. The goal of these estimates is to define the greatest volume of precipitation in the watershed upstream of the dam location that could naturally happen and hazard the capacity and spillway capability of the dam. A series of Hydrometeorological Reports (HMR) were developed by representatives of the Corps of Engineers, National Weather Service, and Bureau of Reclamation to develop a common standard of practice for the country in determining PMP. In recent decades the HMR-based PMP estimates have been supplemented and to a large degree superseded by both site-specific (SSPMP) and regional (RPMP) basin-specific studies.

The primary differences of these studies from the HMR-PMP estimates are: (1) SSPMP and RPMP are storm-based studies and incorporate recent research on storm characteristics while HMR studies provide more general and overly conservative estimates of PMP potential; and (2) SSPMP and RPMP studies consider the characteristics of specific basins while HMR studies rely on a general consideration of topographic impacts on precipitation.

Currently, SSPMP and RPMP studies have no designated standard of practice. Due to this problem, HDR with help from the Colorado Division of Water Resources developed an Extreme Precipitation Analysis Tool (EPAT).

The EPAT is an ArcGIS-based developed software that provides an automated objective application of accepted SSPMP and RPMP analysis techniques to a specific basin based on analyses of state approved extreme precipitation event climatology. This tool was created by using ArcObject programming functions.

The application works by inputting a basin into the software in shapefile format. The software then runs a number of calculations using stored historical storms over that basin based on location and elevation of the basin. In the end, the application determines the controlling storm that creates the greatest amount of volume due to the elevation change and spatial extent of the storm in the basin.

The EPAT essentially takes the guess work out of SSPMP and creates reproducible results. The output of the EPAT gives the user the watershed peak rainfall amounts, total volumes, and temporal distributions for both local storms and general storms. It also allows the user to save the controlling storms in shapefile format. The EPAT tool has become the new standard of practice for the State of Colorado for elevations above 5500 feet.

Extreme Precipitation Analysis Tool (EPAT)

*An alternative to Site Specific
Probable Maximum Precipitation
Studies and
Insights into Flood
Retarding Structures
using Design Storm*

*Robert Rahrs, CFM
Mike McMahon
HDR Engineering Inc.*

HDR Team members

- John Henz, C.C.M.
- Robert Rahrs, C.F.M., GIS
- Greg Gagliano, GIS Programmer
- William Badini, C.F.M, Radar, Storm Library
- Mike McMahon, Storm Library



HDR and Extreme Precipitation

- EPAT – Automated GIS Software for PMP
- Design Storm – GIS Basin Delineation for South Boulder Creek
- Water Supply and Climate Variability



Motivation

- Levees – floods
- Dams – floods
- Water Supply - Droughts

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Introduction

The HMR 55A states that Probable Maximum Precipitation (PMP) 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.”

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PMP HISTORY

- Research by USBR, COE, and NWS in the 1970's determined the worst case scenario flood that could physically occur upstream of dam needed to be found.
- This flood was termed: Probable Maximum Precipitation (PMP)
- HMR-PMP method
 - Generally considered to overestimate the rainfall especially over the higher terrain.
 - cost: millions of extra dollars in spillway resizing.
- Site Specific Probable Maximum Precipitation (SSPMP)
 - has become the leading methodology in determining the worst case flood scenario
 - takes into account the topographic basin characteristics
 - acknowledges that storm sizes are specific to certain geographic locations.
 - Flaws:
 - no designated standard of practice for PMP storm choice



Introduction

- Knowledge of storm behavior and precipitation continues to evolve since the HMRs were last updated for Mountainous States.

The HMR 49 (p.2) states:

“We recognize there are yet unknowns in the complicated atmospheric processes responsible for extreme rainfalls. Thus, methods used for deriving PMP include making judgments based on record storms and meteorological processes related to them.

Results of studies are considered estimates because changes are likely as our understanding increases.”



EPAT Birth

- HDR Engineering, with funding from the Colorado Division of Water Resources (CDWR), developed the Extreme Precipitation Analysis Tool (EPAT).
- Backlog of smaller watershed dams needing re-hab in Colorado.
- Most watersheds < 500 sq mi in size.
- HMR PMP's result in unrealistically large PMP values and site-specific, peer-reviewed PMP's are costly and can drag on for 12-18 months or more.
- An alternative, state-of-practice was investigated that emulates the best of the other PMP alternatives.



EPAT

The Extreme Precipitation Analysis Tool (EPAT) produces a storm-and-observation based maximization of extreme precipitation events that are both climate and terrain consistent for the basin.

It is user friendly and physically consistent with the state of storm science. Its results are reproducible.

Its prime objective is to produce the most physically possible extreme precipitation event that could stress the dam or flood retarding structure, its basin and subsequent design.

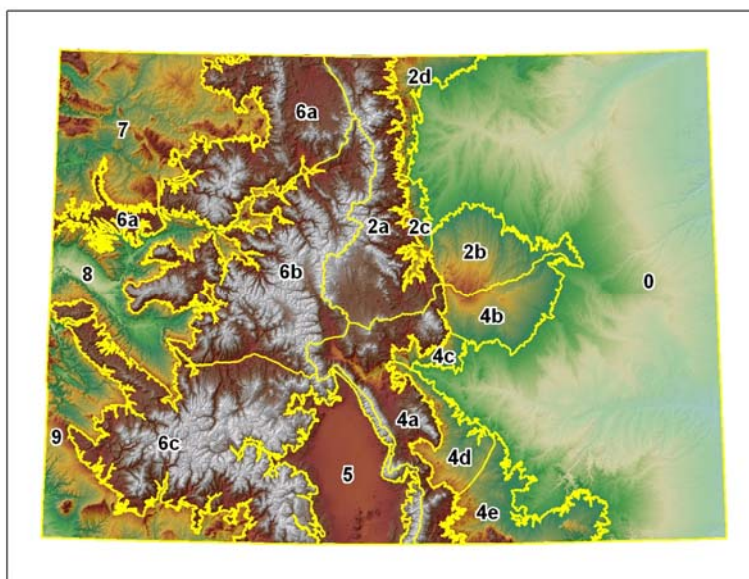


Extreme Precipitation Analysis Tool

- Automated GIS-Based Software creating scientifically reproducible results.
- First release for Colorado. New Mexico version is currently being created.
- EPAT developed with ESRI ArcGIS 9.1 and 9.2's ArcObjects using Visual Basic.Net programming.
- Uses observed storm rainfall points and patterns and not probability based risk analysis.
- Only allows historical storms that developed in the same geographic region to be used when determining the PMP for basins that reside in those similar regions

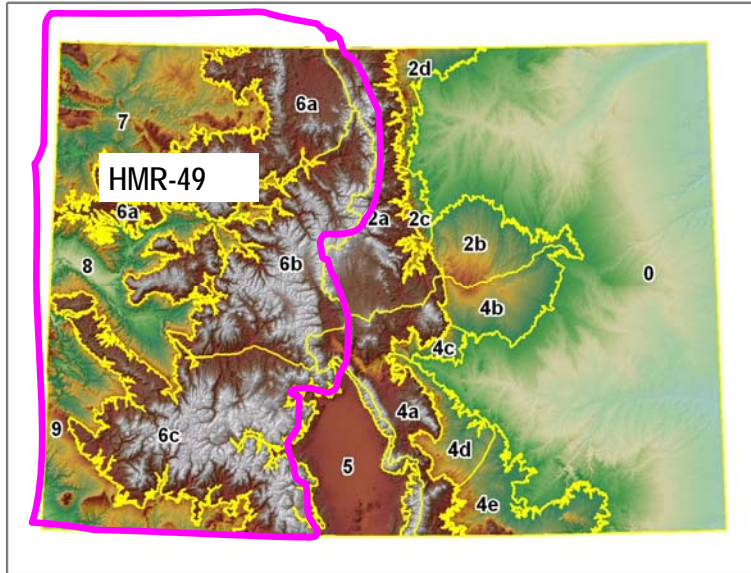
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Refined Colorado Extreme Precipitation Regions



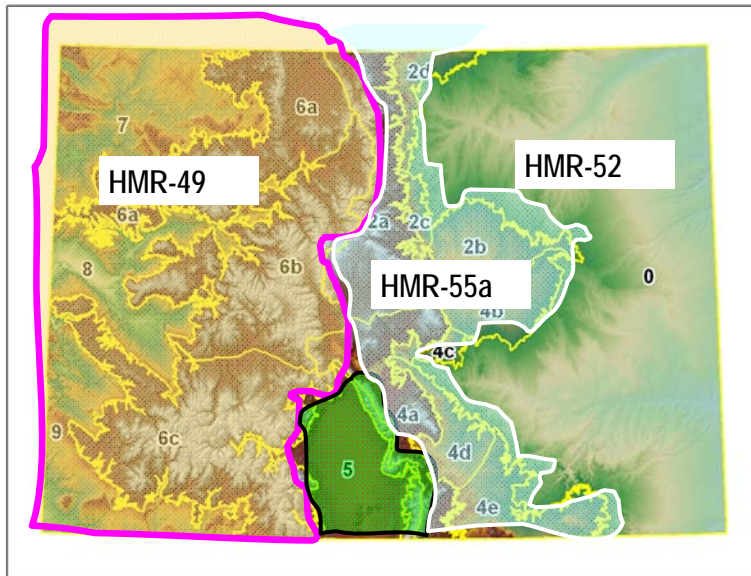
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EPATS: West of the Cont. Divide



FDR

EPATS: East of the Cont. Divide



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EPAT SSPMP/HMR Process

1. **Develop Historical Extreme Precipitation Event Evaluation (Storm Library)**
2. **In-place moisture maximization of the event and Seasonal adjustment (15 days to warmer)**
3. **Transposition factor**
4. **Elevation-Adjusted Maximized Precipitation**
5. **Storm Placement**
6. **Spatial Point Reduction**



STEP BY STEP EXPLANATION FOR EPAT

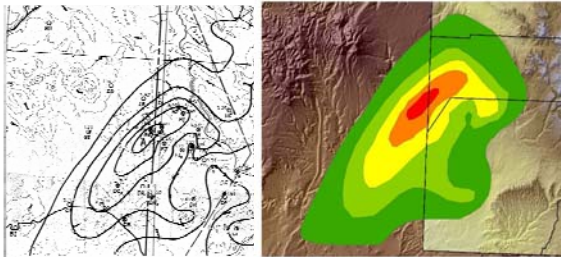
Step 1 - Historical Extreme Precipitation Event Evaluation

- Creates a catalog of extreme precipitation events, or historical storms. There are numerous resources used to find these storms:
 1. Hydro-Meteorological Reports
 2. National Weather Service – Stormdata
 3. Bureau of Reclamation – Regional office
 4. NRCS, COE, USGS
 5. State Climatologist's office
 6. State Historical Library



STEP BY STEP EXPLANATION FOR EPAT

Step 1 - Historical Extreme Precipitation Event Evaluation



Digitized Paper Map

For Old paper maps -- scans were created and saved as tiff images.

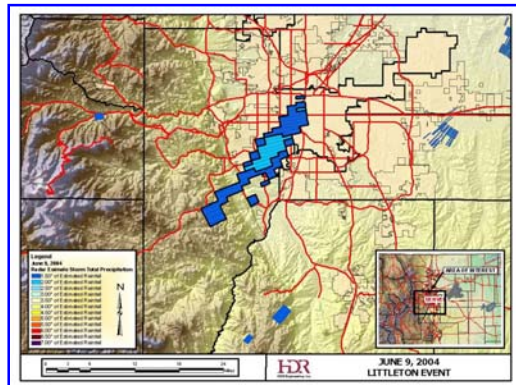
The tiff images could be brought into a GIS system.

The geo-reference GIS application was used to match similar control points on the paper map to layers in GIS, and a new shapefile was created.



STEP BY STEP EXPLANATION FOR EPAT

Step 1 - Historical Extreme Precipitation Event Evaluation



The NWS Doppler radar provides excellent spatial coverage of storms and is available in shapefile format from the National Climate Data Center (NCDC).



STEP BY STEP EXPLANATION FOR EPAT

Step 1 - Historical Extreme Precipitation Event Evaluation

- The National Weather Service (NWS) has derived an automated way of relating rainfall to Doppler radar reflectivity in real-time which is termed Storm Total Precipitation (STP).
- However, the algorithm used to determine this rainfall in real-time has several flaws in it.

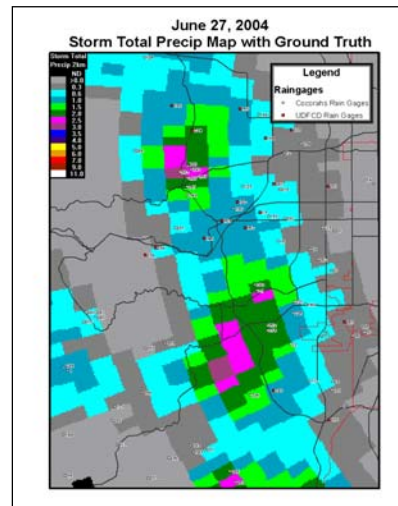
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STEP BY STEP EXPLANATION FOR EPAT

Step 1 - Historical Extreme Precipitation Event Evaluation

Each STP product is scrutinized to make sure that the estimates are accurate by using ground observations.

If a discrepancy existed, a rainfall reconstruction was performed to correct it.



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STEP BY STEP EXPLANATION FOR EPAT

Step 1 - Historical Extreme Precipitation Event Evaluation



Point Rainfall Reports

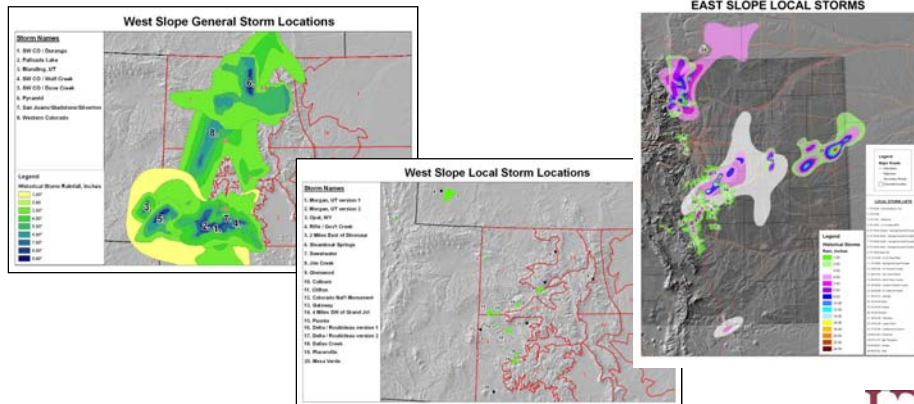
- Historical reports of extreme flooding with only one observation associated with the event.
 - Typically from ranchers or observers who reported a rainfall amount recorded in something other than a rain gage.
 - Termed point rainfalls
 - Included due to the extensive amount of flooding reported with them.
 - Placed into a GIS system by use of a point shapefile from the recorded latitude and longitude.



STEP BY STEP EXPLANATION FOR EPAT

Step 1 - Historical Extreme Precipitation Event Evaluation

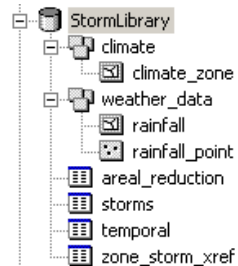
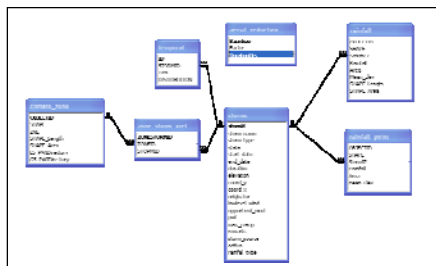
- Once all of the storm shapefiles were created in ArcMap, they were stored into a geodatabase named "Storm Library." Notice the location of extreme storm events versus the surface topography



STEP BY STEP EXPLANATION FOR EPAT

Step 1 - Historical Extreme Precipitation Event Evaluation

- The Storm Library geodatabase is the foundation of the EPAT, and all the programming was focused around its design.
- The other tables in the geodatabase store additional information about the storms. These tables are labeled aerial reduction, storms, temporal, and zone storm xref. They are tied together with a primary key.

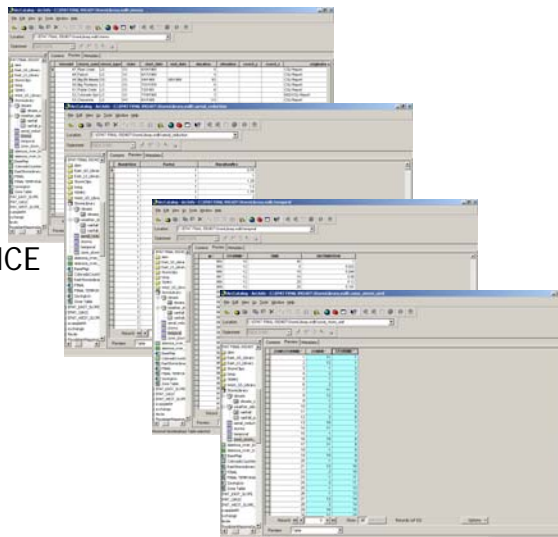


STEP BY STEP EXPLANATION FOR EPAT

Step 1 - Historical Extreme Precipitation Event Evaluation

FOUR TABLES

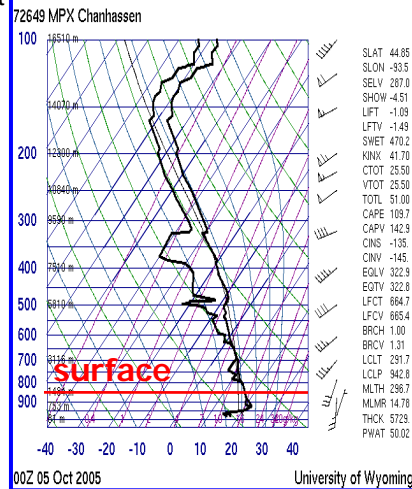
- SPATIAL REDUCTION
- STORMS
- TEMPORAL
- ZONE STORM REFERENCE



STEP BY STEP EXPLANATION FOR EPAT

Step 2 – In-Place Maximization Step

- Determines what the surface dewpoint was at the elevation and location where the original storm developed.
- The surface dewpoint is used to saturate the entire atmosphere along the saturated mixing ratio.
 - from 150 millibars (top of the atmosphere) to 1000 millibars (sea-level)
 - Use of a Skew-T diagram.
- Skew-T diagram: a tool used by meteorologists to calculate the moisture content of the atmosphere.



STEP BY STEP EXPLANATION FOR EPAT

Step 2 – Seasonal Adjustment Step

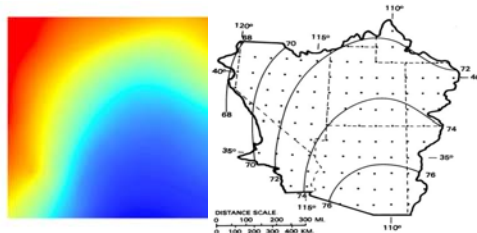
- The seasonal adjustment process is a way of maximizing the historical storm's potential.
- Adding 15 days towards the time of year when more moisture exists.
 - A 15-day push towards the maximum PWI
- For the EPAT-West, the peak seasonal maximum date for the year is August 15th.
- Example: a historical storm developed on May 5th. This storm would be moved forward 15 days, making the seasonal adjustment date May 20th.

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STEP BY STEP EXPLANATION FOR EPAT

Step 2 – Seasonal Adjustment Step

- HMR-49 has maps of the predefined climatological surface dewpoints for each of the summer months over southwestern United States as seen below.
- This map is then digitized and geo-referenced into GIS.
- A Raster Interpolation of the digitized lines are then created using TopoGrid since it is designed for contours. Similar to IDW but maintains surface continuity.

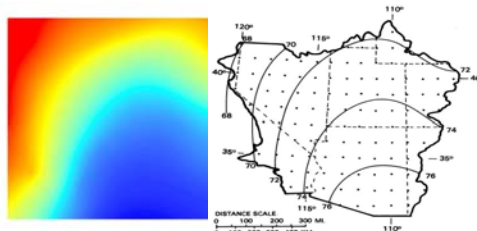


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STEP BY STEP EXPLANATION FOR EPAT

Step 3 -Transposition adjustment

- Occurs when the storm is moved from its original location to the new location in the dam's basin.
- Changes the climatology of the Surface Temperature Dewpoint.
- Amount of precipitable water in the atmosphere will be different in the new location, altering the amount of rainfall occurring with the storm.

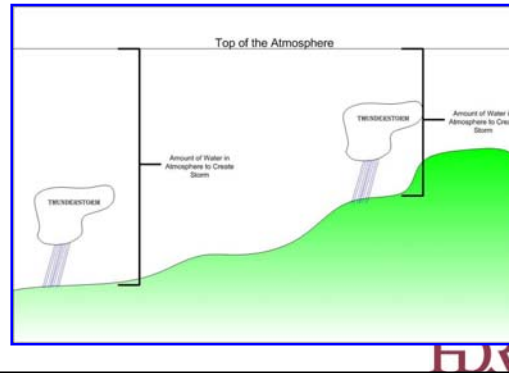


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STEP BY STEP EXPLANATION FOR SSPMP

Step 4 - Elevation-Adjusted Maximized Precipitation

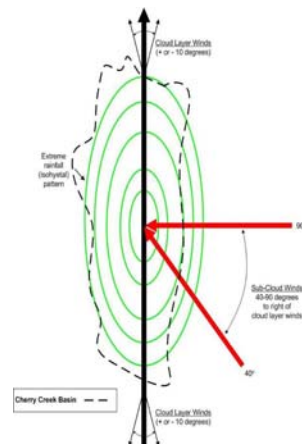
- The process of evaluating the change of elevation from the historical storms original location to its new location.
- If the storm increases in elevation, then the amount of water in the atmosphere decreases.
- If it decreases in elevation, the water in the atmosphere increases.
- The resulting increase/decrease of atmospheric moisture results in a pro-rated increase/decrease in the historical storm rainfall.



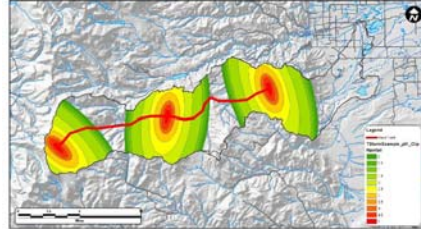
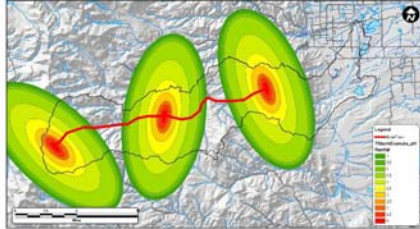
STEP BY STEP EXPLANATION FOR SSPMP

Step 5 –Storm Placement

- Research at HDR Engineering has shown that the length and the width of the storms are unique to the low-level wind flow into it and cloud layer steering winds.
- The storm can be placed to a best “physically possible” fit to determine the greatest amount of volume in the basin.
- Low-level winds can only move through a basin along its lowest point, typically along the stream bed.



EPAT STEP BY STEP

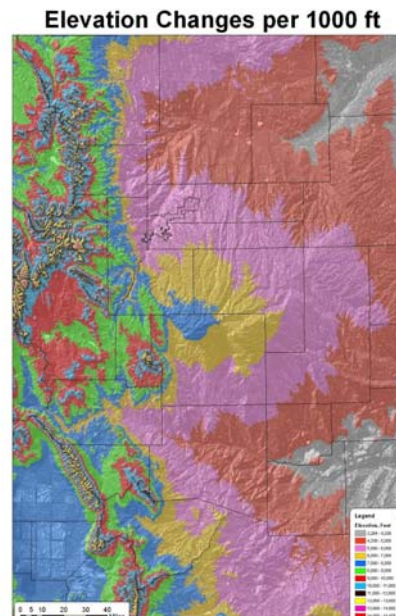
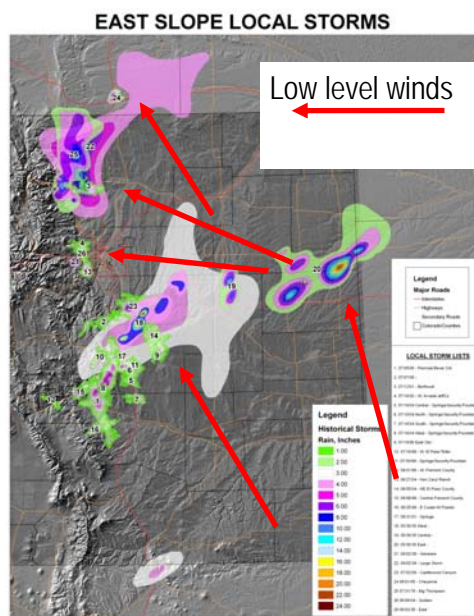


Step 5 – Storm Placement

- The storm is “clipped” to the basin at each point to determine the volume.



Location of extreme local storm events and topography



STEP BY STEP EXPLANATION FOR EPAT

Step 6 – Spatial Reduction

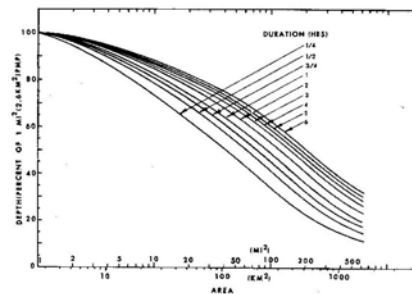
- Only applied to historical flooding events that only have one observation associated with them.
 - These observations are termed point rainfalls.
- Problem: these point rainfalls do not have spatial coverage associated with them.

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STEP BY STEP EXPLANATION FOR EPAT

Step 6 – Spatial Reduction

- The HMRs recognized this problem and created a spatial reduction graph.
- The graph determines a reduction factor based off the size of the basin being analyzed and the duration of the event.
- This graph was converted to a table that was input into the Storm Library.



Area (MI²)	Area (KM²)	Duration (HR)	Reduction Factor (%)
2	5	104	100
5	10	104	95
10	25	104	85
25	60	104	65
60	150	104	45
150	380	104	30
380	1000	104	20
2	5	4	100
5	10	4	90
10	25	4	75
25	60	4	55
60	150	4	40
150	380	4	28
380	1000	4	20

STEP BY STEP EXPLANATION FOR EPAT

STEP BY STEP CONCLUSION

- Each time the storm is placed in the dam's basin, calculations for steps 3, 4, 5, and 6 are performed.
- Ultimate goal of EPAT: To rank the storms that create the greatest total basin volume using an automated process.
- Each storm's temporal distribution is given as well

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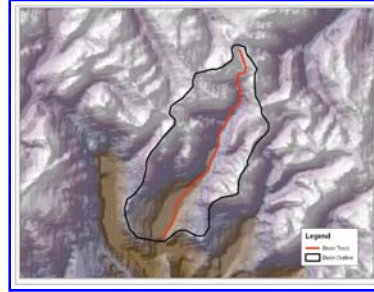
Extreme Precipitation Analysis Tool (EPAT)

**The next few slides illustrate how
EPAT operates on an example basin.**

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THE GIS-BASED EXTREME PRECIPITATION ANALYSIS TOOL – (EPAT)

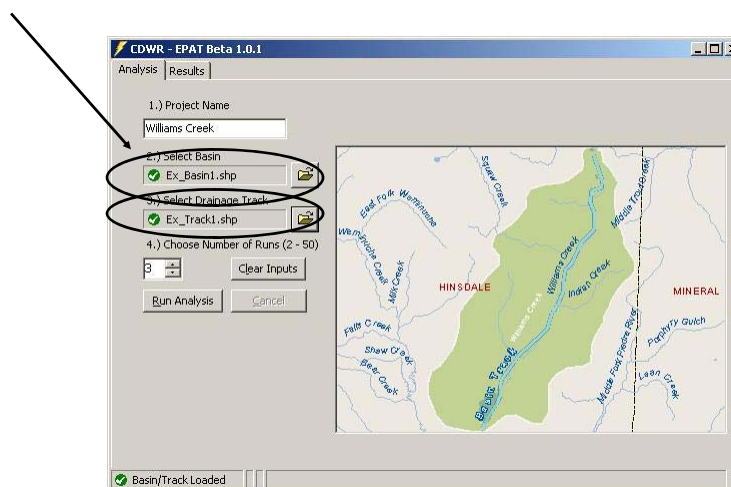
- The Extreme Precipitation Analysis Tool software takes into account the 6 steps mentioned above. The software is user friendly, and the following steps are used to operate it.
- The user only needs two shapefiles to run the EPAT: an outline of the basin, and a digitized line representing the stream in the basin, which is termed the Basin Track.



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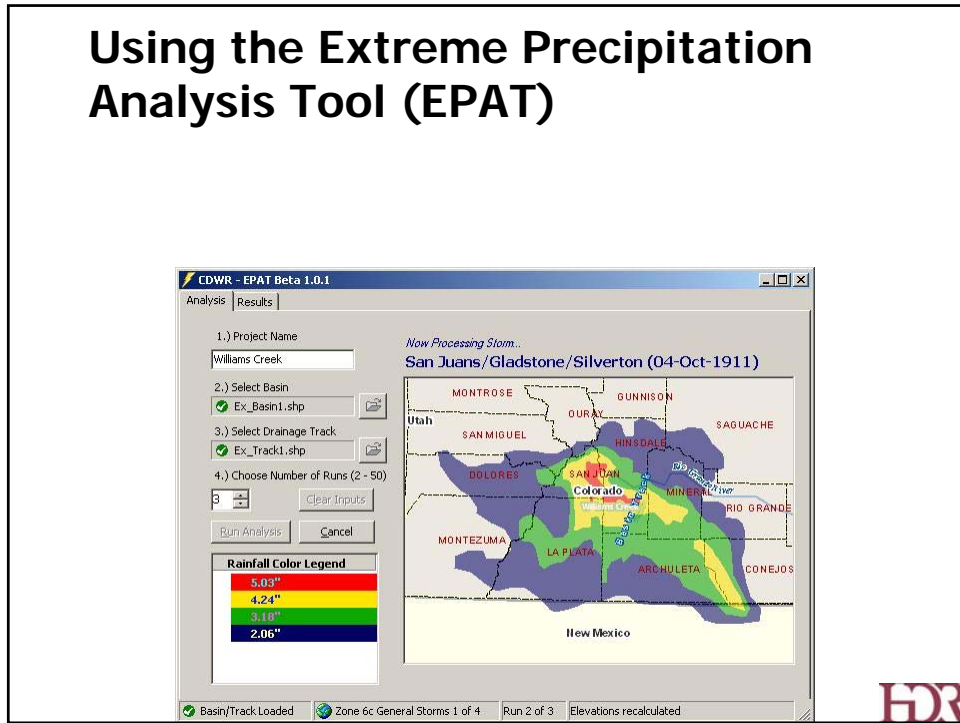
Using the Extreme Precipitation Analysis Tool (EPAT)

NEXT STEP – Add Basin and Basin Track



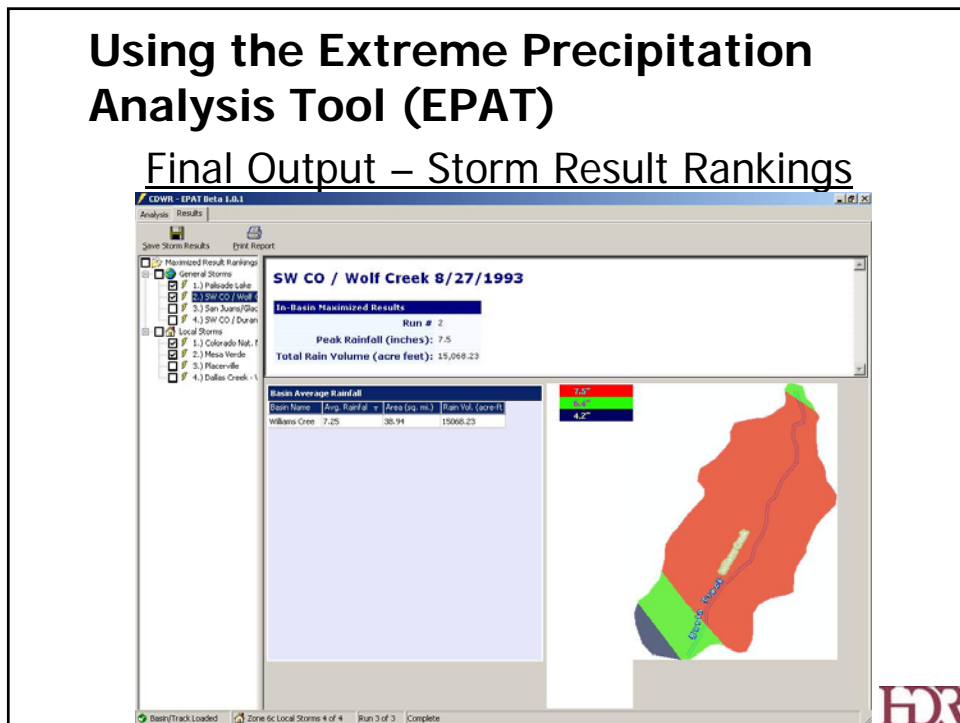
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Using the Extreme Precipitation Analysis Tool (EPAT)



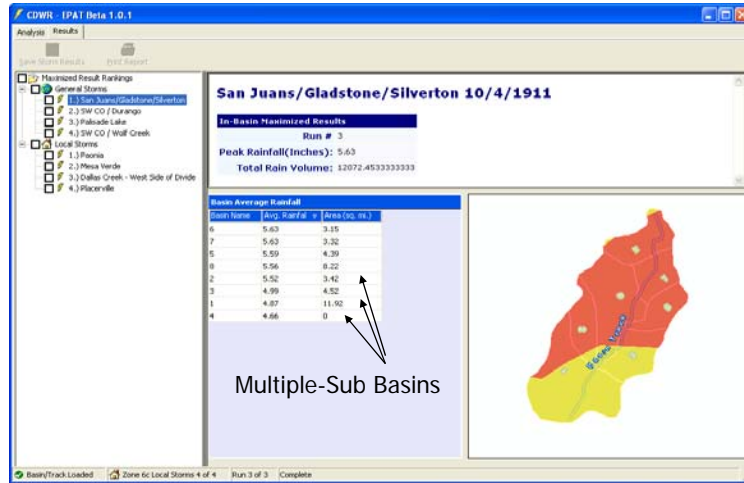
Using the Extreme Precipitation Analysis Tool (EPAT)

Final Output – Storm Result Rankings



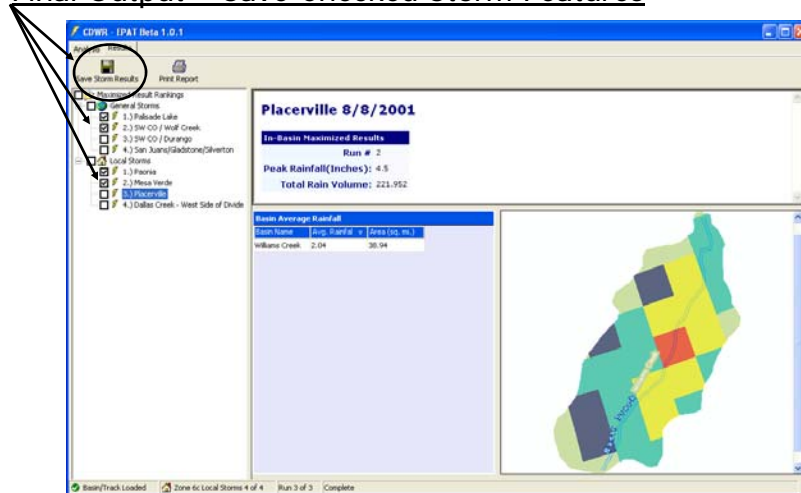
Using the Extreme Precipitation Analysis Tool (EPAT)

SUB-BASINS



Using the Extreme Precipitation Analysis Tool (EPAT)

Final Output – Save Checked Storm Features

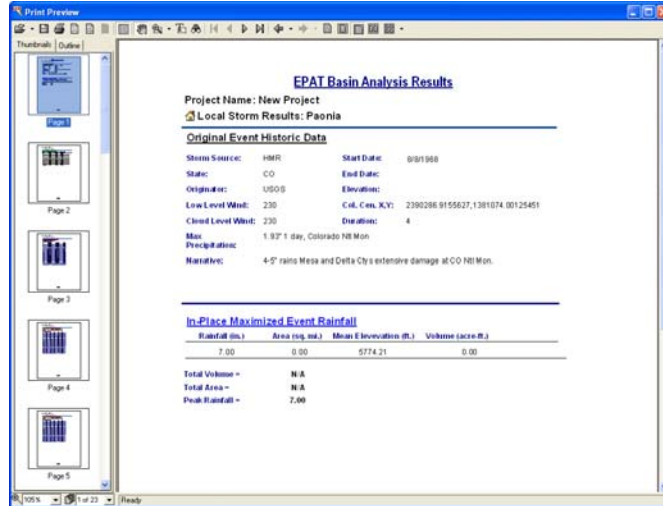


Using the Extreme Precipitation Analysis Tool (EPAT)

Final Output – Checked Storm Print/Export Window

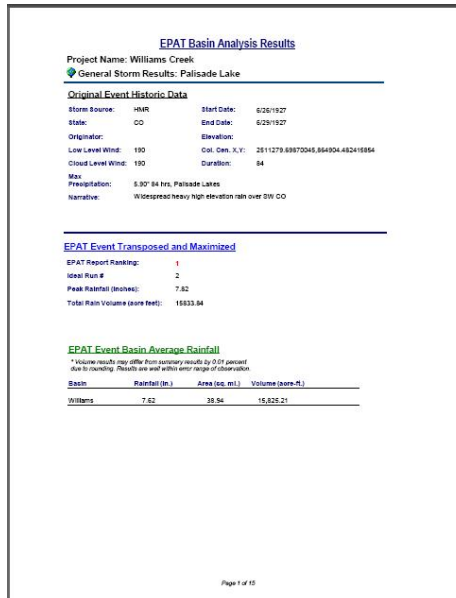
Results Report may be Printed or Exported to:

- [Adobe PDF](#)
- [Rich Text \(.rtf\)](#)
- [MS Excel](#)
- [Enhanced Metadata\(.emf\)](#)



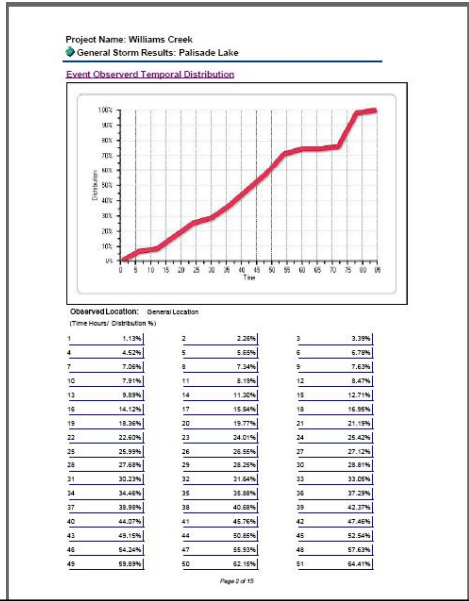
Using the Extreme Precipitation Analysis Tool (EPAT)

Storm Printed Report



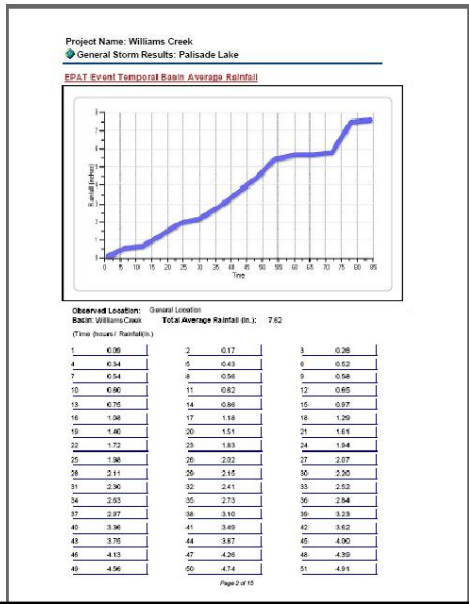
Using the Extreme Precipitation Analysis Tool (EPAT)

Storm Printed Report



Using the Extreme Precipitation Analysis Tool (EPAT)

Storm Printed Report



Current Evaluation of EPAT West

- The EPAT tool has become the new state standard of practice since January 2008 for elevations above 5500 feet.

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Potential in other locations

- The software can be developed and altered for other mountainous states in the western US.
- New Mexico has become the next state to utilize the EPAT tool and work is currently in progress.
- Wyoming and Arizona have shown interest as well.



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Future Extensions for EPAT

Extensions to EPAT are currently in research and development stages as well. Such as...

- Incorporating Hec-HMS and Geo-HMS in order to determine the approximate Probable Maximum Flood (PMF)
- Automation of the basin delineation and basin track to eliminate user errors.
- The EPAT tool currently runs on a ArcGIS 9.1 and 9.2 platform. However, it can be altered to run on ArcEngine and or ArcServer.
- Additional snowpack melt GIS layer to add in the potential for rain on snow and snowmelt for the PMP.
- Spatial and Temporal refinement based on WSR-88D Radar Observations.



OTHER OPTIONS

Can EPAT be used for Flood Retarding Structures?

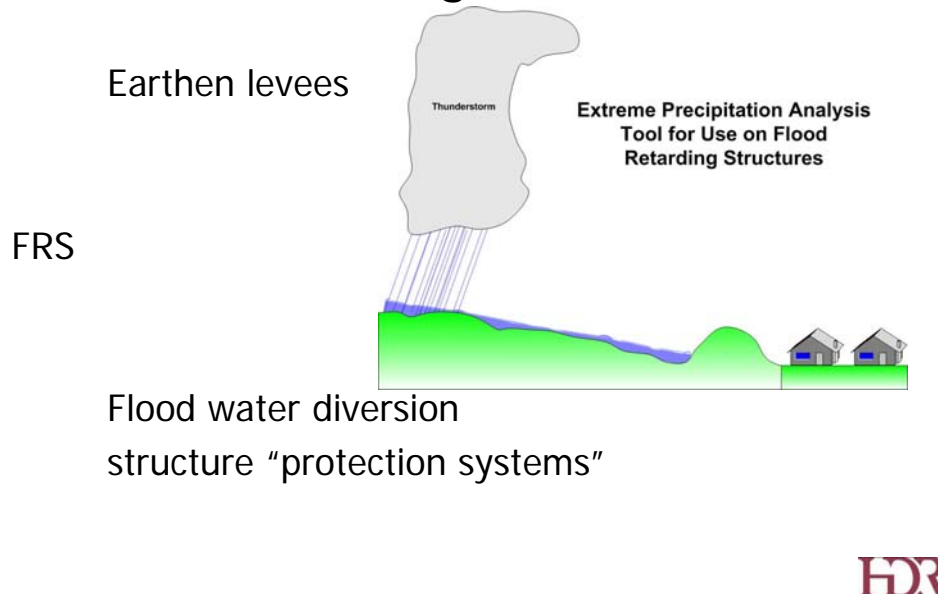


Flood Retarding Structure Disasters

1. Winslow, AZ Levee failure in 1993
2. Granite Reef (levee – dam) failure in Maricopa County due to Hurricane Nora in 1997
3. Fernly, NV levee failure in 2008 due to gophers weakening the structure.



Flood Retarding Structure Background

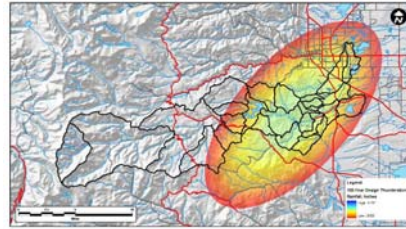


EPAT Usage for FRS

Conceptual Idea for EPAT would be to automate the Design Storm. Thus, using GIS to digitally create a design storm which is based off of observations.

The final product would give the user the design storm along with temporal distributions for the:

- 100yr
- 200yr
- 500yr
- PMP (absolute worst case)



QUESTIONS