RFP - No. PWG123-FLOOD-4707

Scope of Work

Task 1 Background Research

Task 1.A Collect/Research Current Manual information:

The Consultant shall gather and review all relevant Hydrology Manual information, including the current Hydrology Manual, Addendum, Detention Basin Design Criteria, and related data. This will include obtaining, reviewing, compiling comments and proposed resolutions, and identifying any additional work from the previous Hydrology Manual, which will need to be reviewed and confirmed in coordination with the District Committee.

Task 1.B Additional items to be included in the updated Hydrology Manual:

The Consultant shall perform research, review the existing Hydrology Manual, Addendum, and Detention Basin Design Criteria, and determine all revisions and additional analyses necessary to issue a new Hydrology Manual by **<u>updating the current Hydrology Manual, including but not limited to the following objectives:</u>**

1) Using the NOAA Atlas 14 data in the hydrology methods.
2) Using the Natural Resources Conservation Service (NRCS) website to determine the soil groups and suggest a different method to be used in cases of missing data on the NRCS website.
3) Provide a method to analyze the Sediment Bulking factor and the recommendation for where and when this factor should be used.
4) Provide a post-fire hydrology method to calculate the runoff after a fire.
5) Provide the different methods that can be used to calculate the lag time for the unit hydrograph method and the recommendations for using each method.
6) The recommendation of when using (1) day or (5) days unit hydrograph calculations and provide the details procedure for both.
7) The process and calculations for the maximum loss rate, and the low loss fraction for five (5) days unit hydrograph.
8) The recommendation of when using reduction factors for rainfall data with the unit hydrograph and the way to determine this.
9) The ability to use the technique of Precipitation Zone Numbers (PZN), Arc Hydro application (GIS for water resources), HEC-HMS Software and/or develop new software with details procedure for how to implement in the updated Hydrology Manual.
10) Provide relation curves and/or equations between different return frequencies.
11) All the hydrology analyses shall be simple (i.e., the ability to do hand Calculations) and provide detailed examples for each method showing the hydrology map, and detailed hand calculations.
12) Provide a list of the approved computer software that matches the New Updated Hydrology Manual procedure and can be used in any hydrology analyses.

13) Provide an update on the Detention Basin Design Criteria memo and to be included in the New Updated Hydrology Manual.

14) Other suggestions are based on current industry standards and experience.

15) The impacts of revised methodology on existing studies/projects.

16) Any additional work required and/or recommended by The District Committee.

This work will include a meeting with the District Committee to discuss these findings and the results of the work associated with Tasks 1.A & 1.B. The final results of this effort shall be submitted to The District. The final list of revisions will be shared with The District Committee during meeting number 1 (below) and the recommendations will then be considered for inclusion by The District. The approved revisions will be incorporated into appropriate sections of the Hydrology Manual. The number of chapters (sections) of the New Updated Hydrology Manual will be per the discussion between the Consultant and the District Committee to include all the work described here in the scope of the work.

Task 2 TAC Meetings

The Consultant shall facilitate meetings with The District Committee to gather input on the Manual and discuss proposed revisions, chapter by chapter, throughout the Manual revisions process. The process will require the Consultant to plan each meeting and: distribute the agenda and request comments on the applicable sections to all the District Committee at least 3 weeks prior to each meeting with the deadline to return comments in one week's time; assemble all of the comments into the comments spreadsheet and redistribute to all the District Committee at least 1 week prior to each meeting; facilitate each meeting and take meeting minutes including names and details of what was said and clearly record the recommendation or resolution of all comments and any additional items or work required; prepare written minutes and update comments spreadsheet with a recommendation or resolution information including justification or supporting information for each comment and document any correspondence that has any bearing on the recommendations; distribute finalized spreadsheet and minutes to The District Committee the week prior to the next meeting.

In order to gather input from the District Committee in an expeditious manner, the following meeting schedule, by Hydrology Manual Chapter, is proposed:

Meeting	Hydrology Manual Chapters
1	Kick-off meeting, Overview Previous Studies, Submit schedule
2	1, 2, 3, 4
3	5, 6, 7
4	8, 9, 10, 11
5	Any New Chapters, Appendices, and Workbook
6	Final Meeting

Task 3 Manual Revisions

Task 3.A Compile County Committee:

Following Task 1 and each of the proposed Task 2 meetings, the Consultant shall provide the District with meeting minutes and a spreadsheet of The District Committee's comments on potential revisions to the Manual as outlined in Task 2. The consultant will also coordinate with The District Committee as necessary and identify, detail, summarize, and document any additional work, research, or studies required.

Task 3.B Hydrology Manual Revisions

The Consultant shall revise the Hydrology Manual text, formatting, exhibits, figures, and tables chapter by chapter, following the meetings outlined under Task 2. The revisions will also include the work necessary to address the comments from The District Committee, with any work requiring any additional studies.

Task 4 Draft and Final Manual Submittals

Following the District approval, the Consultant shall submit a draft and final updated Hydrology Manual for The District's review and approval. Deliverables are outlined in more detail under Section 6 below.

Task 5 Presentations to The District Committee:

Following final approval of the updated final Hydrology Manual, the Consultant shall provide a presentation on the updated Hydrology Manual to The District Committee. The consultant shall prepare a PowerPoint presentation and a handout summarizing the changes for distribution. The PowerPoint and handout will be submitted to The District for review and comment 2 weeks prior to the initial presentation.

C. MATERIAL AND DATA TO BE FURNISHED BY THE DISTRICT

The Consultant shall attend a kick-off meeting, in addition to the meeting outlined in Task 2 above, with The District project manager within 30 days after the initial Notice to Proceed. The District shall furnish the following material, in digital format when possible, at this meeting:

- A current copy of the Hydrology Manual in PDF format.
- A current copy of the Hydrology Manual Addendum in PDF format.
- A current copy of the Detention Basin Design Criteria in PDF format.

D. SERVICES TO BE PERFORMED BY THE DISTRICT

The District shall provide project management and administration. All questions about project definition and scope will be answered in a timely manner when requested by the Consultant. All correspondence with respect to the contract and submittals required will be directed to the Project Manager.

E. DELIVERABLES

The following table summarizes the deliverable work products for Tasks 1 through 5 of the San Bernardino County Hydrology Manual Update.

Task	Number of Copies	Description
Task 1	1 Digital Copy, via email	*Details of suggestions updated and the additional required items.*
Task 2 and 3.B	2 Paper Copies; 1 Digital Copy of each document in track changes and 1 clean copy	*Meeting agendas, Hydrology Manual update comments spreadsheets and meeting minutes, chapter-by-chapter*
Task 4	2 Paper Copies of Draft and Final Manuals; 1 Digital Copy (of both Draft and Final Manuals) of the document in track changes and 1 cleaner digital file of the Hydrology Manual with navigable/linkable table of contents, list of figures, and list of tables.	*Draft and final Hydrology Manual*
Task 5	1 digital copy via email	*PowerPoint presentation and revision summary handout*

F. SCHEDULE

The County Hydrology Manual Updates shall be completed in approximately 24 months, The consultant is required to submit a project schedule. This schedule assumes that all required data provided by The District is complete at the start of work and that the Notice to Proceed for this task order is received by November 2022. Additionally, it is assumed that the District Committee will review delivered items (Manual chapters, presentations, and Draft and Final Manuals) and submit comments within 2 weeks of receiving them. Changes in project scope may result in modifications to the project schedule. The District reserves the right to delay or postpone dates as necessary.

G. ADDITIONAL REQUIREMENTS

The Consultant must be registered as a Civil Engineer with the California Board for Professional Engineers, Land Surveyors, and Geologists. The Consultant should have similar work experience in updating or preparing Hydrology Manual with any Federal, State, or Local agent. The Consultant should have experience in preparing hydrology and hydraulic reports for different types of projects. A list of experiences and a copy of the professional license must be submitted with the proposal.

The Final Hydrology Manual must be sealed and signed by the consultant.

WEST Consultants, Inc
Proposal Description

PROPOSAL DESCRIPTION

This section describes WEST's approach to update the San Bernardino County Hydrology Manual (Hydrology Manual). The WEST team will leverage both our engineering experience and our experience preparing hydrology manuals to meet the San Bernardino County Flood Control District's (District) goals and objectives as identified in the scope of work: collecting/researching current manual information; adding items to the updated Hydrology Manual; facilitating TAC meetings; preparing Hydrology Manual revisions with draft and final submittals; and presenting results to the District Committee. In general, many of the methods in the current Hydrology Manual are considered very sound and still appropriate. The requested improvements/changes in the scope of work are also considered relevant and provide the framework for this proposal. WEST is also recommending addressing the climate change topic in the updated Hydrology Manual as an additional improvement. A few items deserve special mention regarding the unique approach and methods the WEST team intends to implement:

- Sediment bulking factor (Item 3)
- Post-fire hydrology (Item 4)
- Infiltration rates and low loss / max loss (Items 2 and 7)
- Reduction factors for rainfall and depth-duration-frequency curves (Items 1, 8, and 10)
- Climate change considerations (Item 14)

The specific approaches for the scope of work tasks are discussed in detail below.

TASK 1A. BACKGROUND RESEARCH – COLLECT/RESEARCH CURRENT MANUAL INFORMATION

This task will be completed as described in the scope of work. Note that the WEST team is thoroughly familiar with most existing manuals in Southern California, Arizona, and Nevada through our hydrologic work with clients in those states including work updating hydrology manuals.

TASK 1B. BACKGROUND RESEARCH – ADDITIONAL ITEMS TO BE INCLUDED IN THE UPDATED HYDROLOGY MANUAL

The scope of work identified 16 specific objectives/topics to be included in the updated Hydrology Manual. WEST's approach to each topic is discussed below.

ITEM 1. USE OF NOAA ATLAS 14

Based on WEST's experience updating the Sacramento County Hydrology Manual, WEST will first review the NOAA 14 rainfall frequencies, including spatial variability and the background data used by NOAA before committing to include NOAA 14 methodologies in an updated San Bernardino County Hydrology Manual. In Sacramento, WEST found that the spatial distribution of NOAA 14 rainfall frequencies did not match known local rainfall climatology.

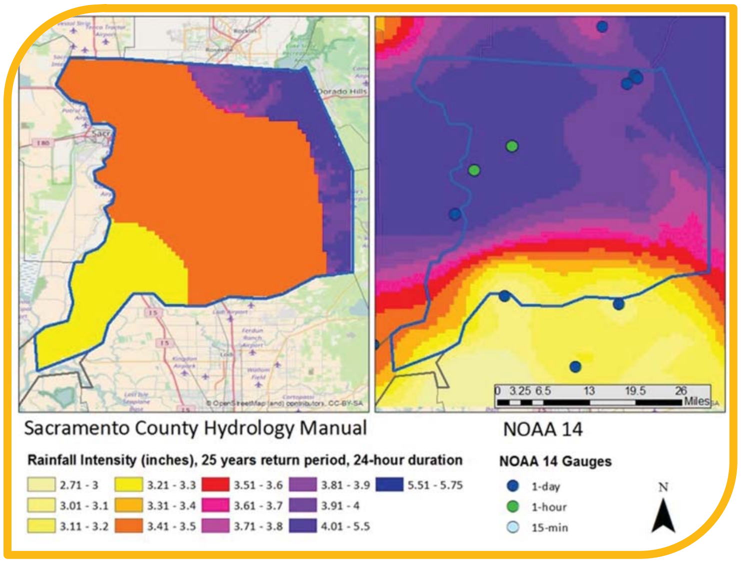

Figure 1: Comparison of previous 2- year, 24-hour duration rainfall in Sacramento County Hydrology Manual with NOAA 14.

In Sacramento County, it is well understood that rainfall generally increases from west to east, primarily due to orographic influences of the western slopes of the Sierra Nevada Mountains. In contrast, NOAA 14 showed the opposite. WEST found that only a handful of recording gage data records were used in the NOAA 14 analysis: two hourly gages and two daily rain gages located in Sacramento County. Additionally, data from Sacramento County's extensive ALERT rain gage network were ignored in the NOAA analysis.

As shown in **Figure 1**, known local behavior as indicated in the previous Sacramento County Hydrology Manual is quite different from NOAA 14.

To remedy the situation, Sacramento County tasked WEST to incorporate approximately 40-years of ALERT rainfall data and prepare a new precipitation frequency analysis.

The updated results for the 100-year, 24-hour precipitation values compared to the values in the existing hydrology manual are presented in **Figure 2**. The result is a significant improvement in the spatial variability of precipitation return periods across the county.

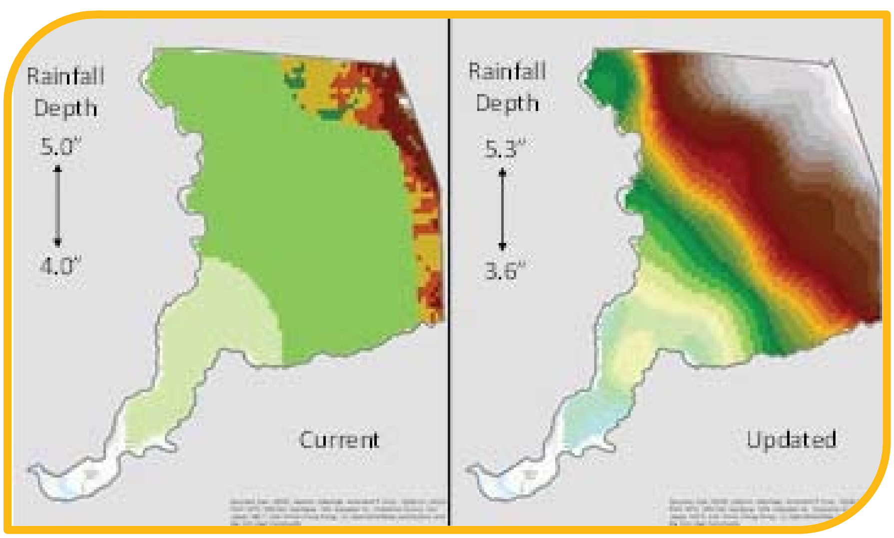

Figure 2: Comparison of previous Sacramento County 100-year, 24-hour with updated values.

For San Bernardino County, WEST will evaluate the rainfall records used in the NOAA 14 development across the County and verify that NOAA 14 values appropriately represent precipitation return periods over the County. The WEST team will make recommendations as to the viability of committing to NOAA 14 in the Hydrology Manual Update.

ITEM 2. USE OF THE NRCS WEBSITE TO DETERMINE THE SOIL GROUPS AND SUGGEST A DIFFERENT METHOD TO BE USED IN CASES OF MISSING DATA ON THE NRCS WEBSITE

In the current hydrology manual, unit hydrograph infiltration is incorporated through the use of low loss rates and maximum loss rates. In the calculation procedures, the low loss and maximum loss rates are compared at each computational time step. At time steps where the low loss exceeds the maximum loss rate, the maximum loss rate governs. The effective hyetograph is then developed by subtracting the governing loss rate from gross rainfall rate at each time step.

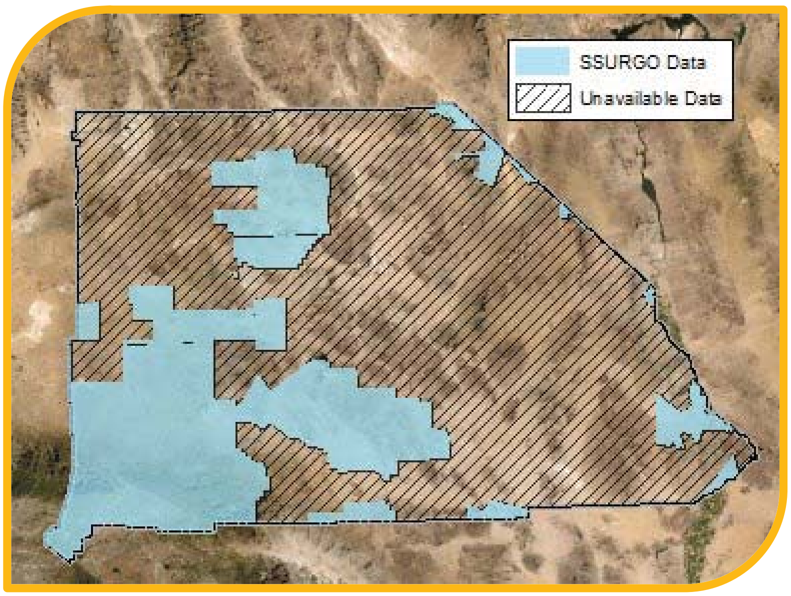

Figure 3: County Soil Data Availability

The subarea scale low loss rates are estimated using the Natural Resources Conservation Service (formerly SCS) Curve Number (CN) runoff equation. This equation is used widely throughout the engineering industry and is the basis of many past hydrology studies. Given its prevalence, the WEST team proposes to maintain its use in the updated manual. There are a variety of reasons for this decision, chief among them is maintaining a level of consistency with previous studies and any associated hydraulic structure design.

The maximum loss rates are typically calculated using Antecedent Moisture Condition (AMC) adjusted CN numbers in Figure C-6 of the current manual. Subsequent to the adopted date of the manual, publicly available soils data have been published on the NRCS website. In addition to the updated Hydrologic Soil Groups (HSG) A, B, C, and D classifications, infiltration rates are also available. Given the more extensive and updated soils and infiltration data, the WEST team proposes to update the maximum loss rate information. In general, this work will consist of the following tasks:

- Extract HSG and hydraulic conductivity data from the NRCS publicly available database for the entire county.
- In areas where data is missing (see **Figure 3**), characterize the soil texture and infiltration rates. This work will primarily consist of desktop analyses of existing HSG information, geology maps, and aerial imagery.
- Map existing countywide NRCS land use classifications to the proposed manual cover types and quality level. The proposed cover type information is assumed to remain consistent with the current manual.
- Create countywide spatial CN and infiltration files.

- Post-process the CN and infiltration files in order to update Figure C-6 in the current manual.

There is not an efficient way to automate the low loss and maximum loss calculation within most hydrologic software. Therefore, the WEST team will develop a script (*e.g.*, Python or Excel VBA) with a simple Graphical User Interface (GUI) that will allow a user to easily enter pre-processed data (*e.g.*, NOAA precipitation, time step, CN, etc.) for generation of the effective rainfall values needed for various hydrology software packages.

ITEM 3. PROVIDE A METHOD TO ANALYZE THE SEDIMENT BULKING FACTOR AND THE RECOMMENDATION FOR WHERE AND WHEN THIS FACTOR SHOULD BE USED

Flood control facilities are typically sized to convey or store flow from a hydrological event with a defined return interval. Because sediment/debris displaces water and contributes to an increase in the volumetric flow rate and flood depth, design flows are sometimes increased beyond the clear-water flow rate to account for the transported sediment/debris; this process is called sediment/debris bulking.

Gaged streamflow data represent the total (i.e., water plus sediment) flow, and therefore do not require additional bulking for sediment when used for flood-frequency analyses. However, when a hydrologic model is used to develop a clear-water design discharge for a given watershed, the peak clear-water flow rate may be multiplied by a factor greater than one (1) to compute a design flow that includes the volumetric contribution of the entrained sediment/debris. This multiplier is known as a bulking factor, and it is equal to the ratio of the bulked discharge to the clear-water discharge.

Portions of San Bernardino County lie within the eastern segment of the Transverse Mountain Ranges, which are known for their high erosion rates and extreme sedimentation events, especially following wildfires. Due to the history of these events, the County has constructed many sediment/debris basins to capture sediment/debris, effectively removing the material from the flow volume and thus reducing downstream impacts. The resulting use of debris basins has enabled basin cleanout data to be paired with storm precipitation and watershed burn data to develop regional regression equations (*e.g.*, Gartner *et al.*, 2014; Gatwood et al., 2000) useful for predicting design sediment/debris yields from undeveloped, mountainous watersheds. The predicted sediment volume can either be used to size sediment/debris basins (removing or reducing the need to bulk downstream flows) or distributed throughout a clear-water storm hydrograph to develop a peak bulked flow for conveyance infrastructure design.

The San Bernardino County Department of Public Works Water Resources Division currently applies a standard bulking factor of two (2) for recently burned watersheds, and the US Army Corps of Engineers Los Angeles District Debris Method is implemented using a spreadsheet tool and used to compute predicted post-fire sediment/debris volumes for sizing basins. Flows are also bulked pre-fire for other undeveloped land without an upstream sediment/debris basin, but bulking factors are selected on a case-by-case basis and there are no standard guidelines.

The WEST team will analyze available studies, geologic maps, and other resources to identify areas within San Bernardino County with elevated sediment/debris hazards, and for which sediment/debris must specifically be considered in the design hydrology. We anticipate these will include areas with a reasonable probability (*e.g.*, one percent) of post-fire minor and major debris flows, based on recent research by Kean & Staley (2021), and all desert alluvial fans. The result will be a map of the County that identifies high-sediment-hazard areas. We anticipate that any new projects located in the identified high-hazard areas will require planning for sediment in the design hydrology, regardless of the recent burn history.

Next, we will analyze available basin cleanout and watershed data within the County and perform a review of relevant literature to determine an appropriate method for computing a debris yield exceedance frequency relationship for a given watershed, using a coincident frequency analysis and available fire perimeter and National Oceanic and Atmospheric Administration (NOAA) Atlas 14 precipitation data. Using this method, users will be able to compute the *n*-year sediment/debris yield for a watershed that corresponds to the design hydrologic event. This will be an important contribution of the update: rather than solely plan for sediment hazards when a project is planned immediately following a fire, projects located in high-risk areas will be designed to accommodate a statistically-derived sediment yield event with a defined recurrence interval. We will develop a spreadsheet tool as a standard resource to accompany the Hydrology Manual.

Finally, the WEST Consultants team will develop clear guidance about when and how to plan for sediment in a hydrologic analysis. The following is an example approach:

- All projects located in or immediately downstream of high sediment/debris hazard areas will require planning for sediment hazard mitigation, whether this be design of a sediment/debris basin, design of flood control infrastructure with sufficient capacity to convey *n*-year peak bulked flows, or a combination of the two. Users will also have the option of adopting a reasonably conservative bulking factor in lieu of completing the analysis.

  Sediment hazards will always be considered for projects located in watersheds following a fire, regardless of whether the watershed is in an identified high-hazard area. We anticipate emergency projects designed in the period zero (0) to two (2) years following a fire will conform to a design procedure similar to that used by Federal Burned Area Emergency Response (BAER) teams and State Watershed Emergency Response Teams (WERT), if sediment hazards are not already identified by those groups.
- General design for projects located in an undeveloped watershed that burned two (2) to 10 years prior will also require planning for elevated sediment loading, but will use a similar approach as that for pre-fire, high-hazard areas.

In both the 0 to 2 years and 2 to 10 years cases, an appropriately conservative bulking factor will also be permitted, with the highest bulking factor in the period 0 to 2 years post-fire and an intermediate bulking factor in the period 2 to10 years post-fire.

ITEM 4. PROVIDE A POST-FIRE HYDROLOGY METHOD

Wildfires can dramatically change the clear-water hydrological response of a watershed to even modest rainstorms. The loss of a vegetative canopy, leaf litter, and duff reduces interception, storage, and evaporative losses, while burned soils often become hydrophobic, limiting infiltration (DeBano 1981; Cannon et al., 2003; USDA, 2016). This produces increased runoff volumes (USDA, 2016), which arrive at basin outlets more quickly (reduced time of concentration) due to the removal of vegetative obstructions, resulting in larger peak flows. Post-fire runoff also increases proportionally with watershed size (Stoof et al., 2012).

When modeling a post-fire storm event, hydrologists must determine the extent to which clear-water runoff has increased/accelerated due to a loss of vegetation and/or the lack of infiltration due to soil hydrophobicity, then alter one or more runoff modeling components to reflect these changes. This can include adjustments to Curve Numbers (CN), times of concentration, flow travel times, Manning's roughness coefficients, soil infiltration characteristics, and unit hydrographs.

The San Bernardino County Department of Public Works Water Resources Division currently modifies basin hydrological analyses for post-fire watersheds by adjusting the maximum loss rate and low-loss fractions in the burned area, based on a change in the Antecedent Moisture Condition (AMC) from AMC II to AMC III and a corresponding increase in the CN. This is typically done based on knowledge of watersheds and engineering judgment, rather than using a standard process.

The WEST team will review available literature, including several recent studies, to identify appropriate methods for adjusting hydrologic parameters to reflect the impact of fires and subsequent watershed recovery on various physical processes in San Bernardino County watersheds. We anticipate this will mainly focus on adjustments to CN, reflecting a sudden loss of vegetation and increase in soil hydrophobicity, though the research will also determine the appropriateness of adjustments to the shape of the unit hydrograph and other factors. Based on this research, we will develop a simple and standard method for adjusting a given watershed's hydrologic parameters based on the time since the 100 percent coverage burn (with the latter computed using the method described by Gatwood et al. (2000)).

Next the WEST team will develop a process for determining the *n*-year adjusted clear-water flow value that incorporates the burn frequency of the watershed and rainfall recurrence interval. In general, this will involve the development of time-since-100 percent-watershed-burn frequency relationships and rainfall frequency curves. Based on watershed specific flow rate results from the aforementioned CN adjustments, a combined probability analyses will be performed to generate the *n*-year clear-water flow.

Finally, the WEST team will develop clear guidance about when and how to adjust clear-water hydrologic computations for watersheds subject to wildfire. We anticipate the following:

- All projects located in or downstream of undeveloped areas subject to wildfire and elevated runoff will require planning for elevated flows due to increased runoff following fire.
- For emergency mitigation projects designed in the period 0 to 2 years following a fire, clear-water design flows will be based on the greater of the following:
    - The modeled runoff for the current, burned condition, using a procedure like that used by Federal Burned Area Emergency Response (BAER) teams and State Watershed Emergency Response Teams (WERT), if runoff is not already estimated by those groups for the burned area

  - Runoff modeled using the *n*-year excess precipitation (computed using a coincident fire/precipitation frequency analysis) and any appropriate adjustments to the unit hydrograph reflecting the *n*-year fire condition

- For general (non-emergency) projects located in or downstream of undeveloped areas subject to wildfire, clear-water design flows will be based on the coincident n-year excess precipitation and any appropriate adjustments to the unit hydrograph reflecting the n-year fire condition.

When applicable, users will be required to multiply the design clear-water flow by a sediment bulking factor or add the anticipated post-fire sediment design discharge to the clear-water discharge, to identify the total (bulked) design discharge.

ITEM 5. PROVIDE DIFFERENT METHODS THAT CAN BE USED TO CALCULATE THE LAG TIME FOR THE UNIT HYDROGRAPH METHOD AND THE RECOMMENDATIONS FOR USING EACH METHOD

The current Hydrology Manual Unit Hydrograph (UH) lag time is referred to by some as “Corps lag.” The WEST team has used this lag formula successfully on many projects involving calibration and it is considered one of the best due to the physically based parameters and good results. The estimation of the $\bar{n}$ value is probably the most difficult parameter to estimate accurately; however, the current manual provides adequate guidance on this parameter. In addition to the Corps lag, WEST will provide recommendations for one or two other lag methods and guidance on when (if ever) an alternative to Corps lag is appropriate or recommended.

ITEM 6. THE RECOMMENDATION OF WHEN USING (1) DAY OR (5) DAYS UNIT HYDROGRAPH CALCULATIONS AND PROVIDE DETAILED PROCEDURES FOR BOTH

A one (1)-day hydrograph is often used to represent a high intensity event that is a common cause of flooding and scour damage in urban areas, where the time of concentration is relatively small. In larger watersheds, in can take quite a bit longer to reach the peak flow. Under those circumstances, not only is the peak flow of concern, but the sheer volume of water conveyed by the storm can overflow reservoirs and dams, which can drastically increase the potential for failure. For any jurisdiction responsible for flood safety in a large area, the five (5)-day hydrograph can be an essential computation.

Detailed computational procedures for development of a 5-day hydrograph is not entirely obvious; extrapolation of the 24-hour hydrograph may not be appropriate or computationally simple (at least by hand). Research conducted as part of this task will consider the 5-day hydrograph’s applicability to various conditions, best assumed antecedent conditions, and how that may change the magnitude and shape of the hydrograph.

ITEM 7. THE PROCESS AND CALCULATIONS FOR THE MAXIMUM LOSS RATE, AND THE LOW LOSS FRACTION FOR (5) DAYS UNIT HYDROGRAPH.

In the approach for Item 2, a procedure is discussed to calculate (and automate) the low loss and maximum loss. The low-loss procedure will be applicable to the 5-day unit hydrograph calculations, but with two important considerations:

1. Antecedent moisture condition (AMC) as applied to the 5-day hydrograph will need to be revised. Currently, the AMC is based solely upon the return storm event (e.g. AMC I for the 2-year and 5-year storm, etc.). It is also understood that soil will become saturated given a long rainfall event. Hence there is a disconnect: A 2-year storm, 5-day hydrograph is to use an AMC I value for computation, but by the end of the storm the ground will potentially be saturated at the AMC III value. It also cannot simply be assumed that the 5-year storm always has an AMC III condition throughout the event, as this may grossly overestimate the volume of water, and hence lead to poor decisions regarding flooding potential, dam operation, evacuation requirements, among other ramifications. This factor will be evaluated, and recommendations made as part of the project.

2. As part of this task, the loss rates will be analyzed and then potentially adjusted to consider the 5-hour storm parameters.

ITEM 8. THE RECOMMENDATION OF WHEN TO USE REDUCTION FACTORS FOR RAINFALL DATA WITH THE UNIT HYDROGRAPH

Rainfall reduction factors or, as they are commonly called, Depth Area Reduction Factors (DARF), are routinely used to convert a point estimate of rainfall depth for a given duration and frequency to an aerial estimate of rainfall depth of the same duration and frequency. The intent of DARF is to provide an appropriate uniform distribution of rain over the target watershed area for hydrologic design.

WEST personnel have developed a rigorous approach to DARF development through multiple recent large-scale studies of the geometric properties of storms in the United States. Curtis et. al., (2011) developed DARFs for eastern Colorado. The results were subsequently incorporated into design manuals for the City of Colorado Springs and for the Mile High Flood Control District in Denver. WEST Consultants and Applied Weather Associates (2021) developed DARFs across a spectrum of basin sizes and durations for the entire state of Arizona. Similarly, WEST Consultants led a research team that included the University of Texas, Arlington, Texas A&M University, and Rice University to develop DARFs across the state of Texas. (Curtis et. al., 2022). These studies collectively evaluated the geometric properties of approximately 500,000 individual storm cells to form the foundation for probabilistically defining DARFs. The DARF studies led by WEST personnel represent three of the most pre-eminent DARF studies in the southwestern US.

Figure 4 on the following page illustrates the procedure used in the referenced studies. First, gridded radar-rainfall images were analyzed, and areas of rainfall were identified as storm cells. Next, an ellipse was fit to each identified storm cell area of significant rainfall. For each ellipse, several properties were identified including shape (ratio of long axis to short axis), area of each ellipse, peak intensity within each ellipse, the distribution of intensities, and the ellipse orientation (angle of long axis from north). Speed and direction were also studied. The collection of storm cell properties was used to create an idealized typical storm cell shape as shown in the lower right corner of **Figure 4**.

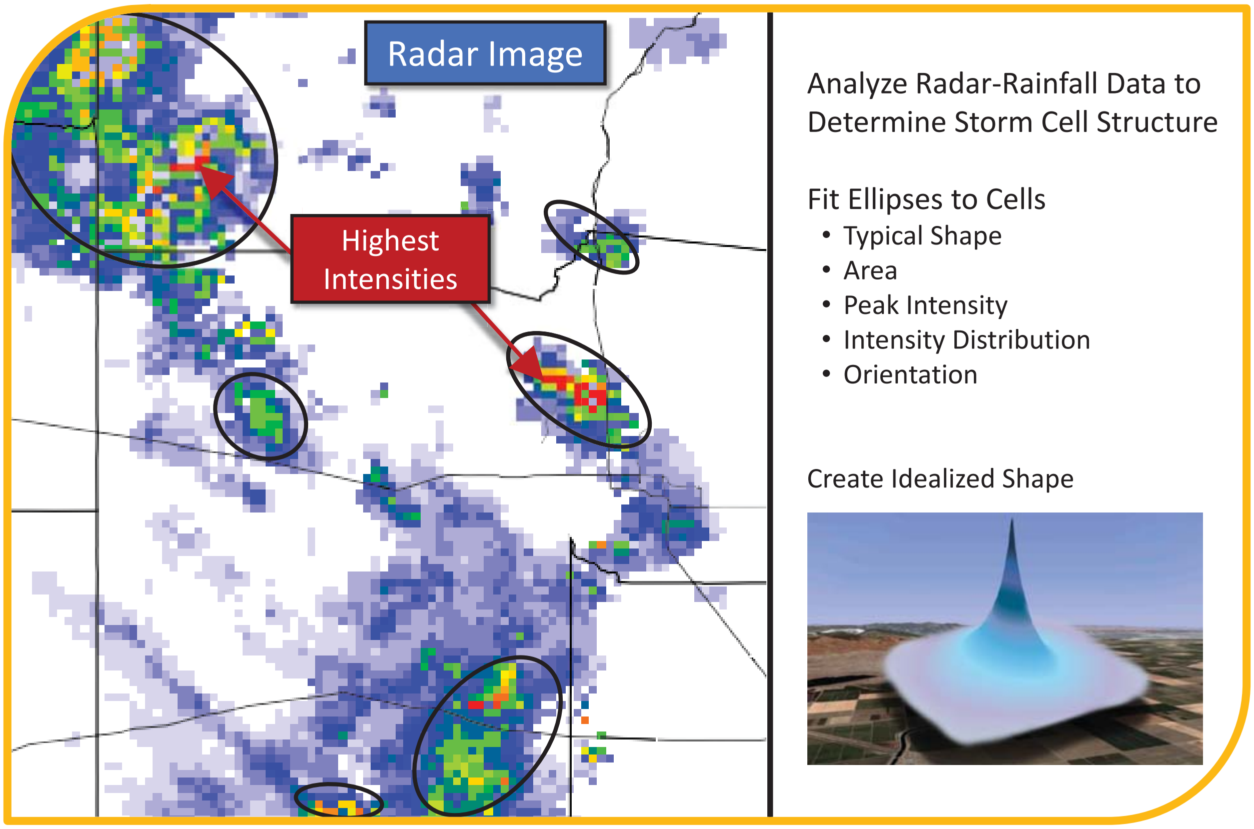

Figure 4: Analysis of Geometric Properties of Storms

WEST understands the challenges of complex terrain for radar coverage in the region to develop DARFs, especially over an area as large as San Bernardino County. WEST overcame similar challenges in the complex terrain of Colorado, the rugged arid Arizona environment, and the wide variety of conditions faced across the state of Texas.

The WEST team will develop DARFs for San Bernardino County leveraging methods, tools, and expertise developed for the referenced studies in Colorado, Arizona, and Texas. WEST will evaluate DARFs using multiple methods (i.e., geographically fixed, and storm-centered). Duration, return period, and watershed scale will be considered. WEST will also consider regionalization or zones if DARFs are found to significantly vary across the County or as a function of storm type.

WEST's approach will provide San Bernardino County with realistic DARFs that appropriately reflect the region's hydroclimatology in the County's hydrologic design procedures. WEST will provide the necessary charts, curves, tables, and/or tools needed to effectively use DARF in the County's design procedures and make recommendations for their application.

ITEM 9. THE ABILITY TO USE THE TECHNIQUE OF PRECIPITATION ZONE NUMBERS (PZN), ARC HYDRO APPLICATION (GIS FOR WATER RESOURCES), HEC-HMS SOFTWARE AND/OR DEVELOP NEW SOFTWARE WITH DETAILED PROCEDURE FOR HOW TO IMPLEMENT IN THE UPDATED HYDROLOGY MANUAL

The WEST team does not recommend adopting Precipitation Zone Numbers (PZN) as part of this project. Developing this procedure in a meaningful way would involve the analyses of a significant amount of data, which would be best as a separate project. If developing PZN zones is a District goal for this project, procedures will be described to implement this strategy and zones will be developed using available data, but our assumption is that new data would not be gathered by the WEST team for this purpose. The WEST team fully supports the concept for the updated Hydrology Manual to encourage the use of the Arc Hydro application and HEC-HMS software. As discussed in Item 2, WEST recommends developing a simple script (*e.g.*, Python or Excel VBA) to accomplish the low loss and maximum loss calculation. The WEST team will provide the complete procedure for calculating the loss and entering the effective rainfall (after losses) into HEC-HMS.

ITEM 10. PROVIDE RELATION CURVES AND/OR EQUATIONS BETWEEN DIFFERENT RETURN FREQUENCIES

Provided NOAA 14 proves to be a viable tool for San Bernardino County hydrology (see Item 1), the NOAA 14 easily accessible “point and click” website automatically provides tables and curves relating precipitation depths, duration, and return frequencies (DDF). **Figure 5** below shows a portion of a DDF table for a location in San Bernardino County. DDFs are provided for 1-1,000-year frequencies and 5-minute to 60-day durations. A corresponding set of DDF curves are show in **Figure 6** on the following page.

POINT PRECIPITATION FREQUENCY (PF) ESTIMATES
WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION
NOAA Atlas 14, Volume 6, Version 2

PF tabular | PF graphical | Supplementary information | Print page

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.101** (0.084-0.123)	**0.133** (0.111-0.162)	**0.176** (0.146-0.214)	**0.210** (0.173-0.259)	**0.258** (0.205-0.328)	**0.295** (0.229-0.383)	**0.332** (0.252-0.443)	**0.371** (0.273-0.509)	**0.425** (0.300-0.608)	**0.466** (0.318-0.691)
10-min	**0.145** (0.121-0.176)	**0.191** (0.159-0.232)	**0.252** (0.209-0.307)	**0.302** (0.248-0.371)	**0.370** (0.294-0.470)	**0.422** (0.328-0.549)	**0.476** (0.361-0.635)	**0.532** (0.392-0.730)	**0.609** (0.430-0.871)	**0.668** (0.455-0.991)
15-min	**0.176** (0.146-0.213)	**0.231** (0.192-0.281)	**0.305** (0.253-0.371)	**0.365** (0.300-0.448)	**0.447** (0.355-0.569)	**0.511** (0.397-0.664)	**0.576** (0.437-0.768)	**0.644** (0.474-0.883)	**0.736** (0.519-1.05)	**0.808** (0.551-1.20)
30-min	**0.260** (0.217-0.316)	**0.343** (0.285-0.417)	**0.452** (0.375-0.551)	**0.541** (0.445-0.665)	**0.663** (0.527-0.843)	**0.758** (0.589-0.985)	**0.854** (0.648-1.14)	**0.955** (0.703-1.31)	**1.09** (0.771-1.56)	**1.20** (0.817-1.78)

Figure 5: Example depth, duration, frequency table for a location in San Bernardino County from NOAA 14.

NOAA 14 also provides gridded rainfall maps for all frequencies and durations, for the median, low (5%) and high (95%) confidence intervals. These maps can be used within an automated tool to extract the precipitation value for the desired duration and return period. That information is preferable over relation curves or equations, since they reflect the exact estimates obtained by NOAA 14.

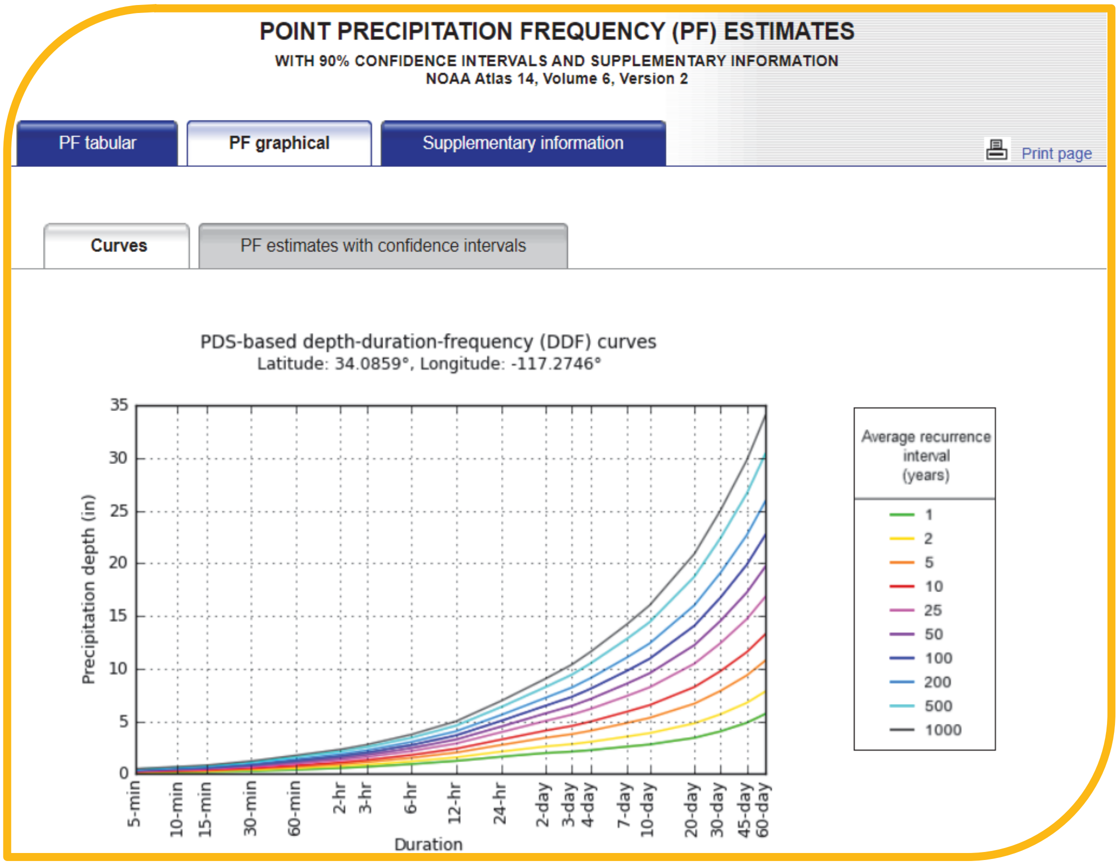

Figure 6: Example DDF curves from NOAA 14.

WEST developed a graphical user interface tool for the Flood Control District of Maricopa County, AZ, that extracts precipitation frequency for different return periods and durations based on information provided by the user (*e.g.*, a shapefile with a polygon for a specific basin, or coordinates). The tool also selects the most appropriate depth area reduction factor (DARF) based on the size of the project area. An example of one of the tool outputs is shown in **Figure 7** on the following page.

For the cases when automated systems cannot be used, WEST can develop relationships or tables used to manually calculate design rainfall. While uncertainties will always be added by that simplification, these relationships can be determined based on specific characteristics that control extreme precipitation, for example, topography, or distance to the coast. WEST's experienced hydrometeorologists have the expertise to fit these relationships, without adding undesired uncertainties.

Should NOAA 14 be found inappropriate for use in San Bernardino County, WEST will make recommendations for alternative methods to produce DDF tables and curves.

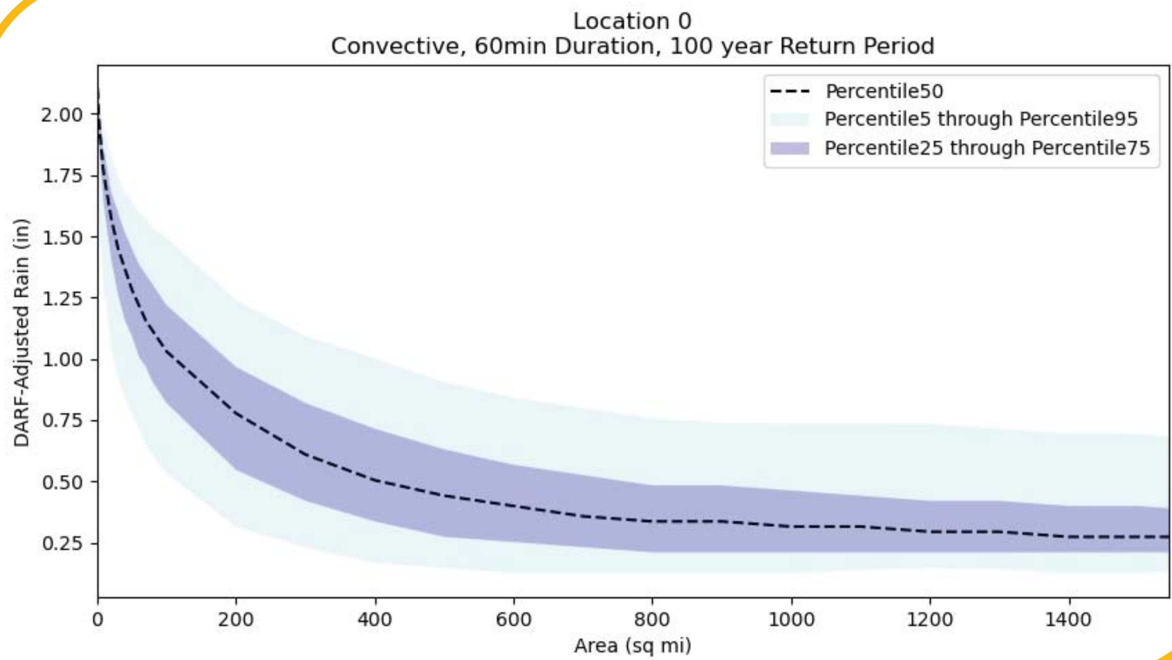

Figure 7: One of the outputs of the tool created for the Flood Control District of Maricopa County, AZ, showing the depth-area-reduction-factor (DARF) Adjusted 60-minute, 100-year rainfall values with uncertainty.

ITEM 11. ALL THE HYDROLOGY ANALYSES SHALL BE SIMPLE (I.E., THE ABILITY TO DO HAND CALCULATIONS) AND PROVIDE DETAILED EXAMPLES FOR EACH METHOD SHOWING THE HYDROLOGY MAP, AND DETAILED HAND CALCULATIONS

WEST understands there are many users of the Hydrology Manual within the District and some that are not familiar with hydrologic software. The ability for hand calculations will be preserved (especially for Rational Method calculations, where appropriate). One idea for the District to consider is adopting a “Hydrology Manual Spreadsheet” that provides needed hydrologic forms and calculations as clearly labeled Excel tabs. There is also a potential to incorporate the scripts discussed in other sections (*e.g.*, Item 2 and 3) potentially 4 into this spreadsheet. The benefit would be that any calculation needed for compliance with the Hydrology Manual would be completed in that single document with pre-formatted forms and the ability to expand as needed to accommodate both large and small projects. A single spreadsheet concept for calculations would also simplify District reviews.

ITEM 12. PROVIDE A LIST OF THE APPROVED COMPUTER SOFTWARE THAT MATCHES THE NEW UPDATED HYDROLOGY MANUAL PROCEDURE AND CAN BE USED IN ANY HYDROLOGY ANALYSIS

As discussed in Item 11, the WEST team recommends considering a single spreadsheet for all calculations needed for compliance with the updated Hydrology Manual. After those calculations are completed, model input data could be imported to HEC-HMS or other similar software packages. The WEST team can include a list of software packages we have seen and used in the past, however, our intent will be to create a process that will be widely applicable to hydrologic software, including less frequently used software packages that may be preferred by some users.

ITEM 13. PROVIDE AN UPDATE ON THE DETENTION BASIN DESIGN CRITERIA MEMO AND TO BE INCLUDED IN THE NEW UPDATED HYDROLOGY MANUAL

The current Hydrology Manual included an overview of detention design, but detailed aspects were published in a separate 1987 memorandum titled “Detention Basin Design Criteria for San Bernardino County” (SBCFCD & SBCLMD, 1986). The scope of work here includes both the Hydrology Manual and the Detention Basin Design Criteria for San Bernardino County (referred to hereafter as the ‘Criteria’), with the Criteria remaining a separate entity.

The separation of the Criteria from the Manual is somewhat misleading, since detention basin design requires nearly all hydrologic factors included in the Manual to be considered, including precipitation, infiltration, bulking, hydrograph development, flow routing and hydraulics, sediment transport, scour, environmental impacts, and others. Hence, it is critical that an update to the Criteria be consistent with related areas in the Hydrology Manual.

The Criteria must also recognize that detention basin design relies upon subject matter experts outside of hydraulics and hydrology. This expertise is required to effectively meet the detention related geotechnical investigations, bank stability design, and structural analysis of the numerous supporting appurtenances such as reinforced concrete spillways and retaining walls. The latter would require a specialized foundation design by geotechnical experts that takes into consideration both soil factors and flow dynamics (Travis, Kandaris, & Wahlin, 2018). Also, roadway design is often needed to ensure access to the basins to allow removal of debris, and so transportation engineers may also be required.

The WEST team will identify the aspects of the Criteria that remain accurate and relevant today. The current Criteria includes guidance in several areas that was sophisticated and forward thinking, and arguably remains the best approach even today. There are also areas that deserve a more complete treatment and implementation of updated information, improved procedures, and new or improved applicable software. These areas include:

- Requiring design to consider return storms that span from the 2-year to the 100-year. It is common for older manuals to fail to recognize the importance of more frequent events. As an example, the Pima County Hydrology Manual considered only the 100-year flow until recently, when it was updated to include proper consideration of the full spectrum of flows, which improved accuracy of the procedure (Travis, 2018). Of direct relevance for multiple storm returns are mixed-use basins that may attempt to improve water quality, water supply, flood protection, debris capture and other factors. Although multi-use basins were largely overlooked as a design focus until the late 1980's, there are now many items in the literature on these systems.
- The Criteria includes analysis of the timing of other detention basins within an overall system. In 1986 work regarding how to analyze and optimize this system had only just been published (Bennett & Mays, 1985), and it took another twenty years to extend this work to consider retention basin networks as well – a configuration that allowed consideration of detention basins with low outflow (Travis & Mays, 2008). This area of the Criteria can be expanded further given work on overflow systems that also work as flow measuring devices, and estimation of debris accumulation and how it propagates through a detention basin network.
- Vortex prevention devices, such as those required in the Criteria, can be critical components, since vortex formation remains difficult to predict, even utilizing the most advanced techniques. [Travis & Mays (2011) & (2012)]. For perspective, there are myriad research papers published on this subject since 1986 which will need to be considered as part of the update.
- The Criteria takes particular note of the impact of burned watersheds on debris magnitude, an overlooked aspect of detention basin design at the time of writing. However, since the Criteria was developed other adverse effects of runoff from burned watersheds have been determined and efforts made to update current manuals accordingly. These adverse effects include higher runoff, non-Newtonian flow characteristics, and even direct changes to the fundamental structure of the impacted soil (Travis, Teal, & Gusman, 2012). Research has also considered inherent increases in prediction risk following fires (Travis & Wahlin, 2012) and regression equations to predict stormflow have been developed based upon previously overlooked or minimized watershed characteristics (Wilder, et al., 2021). Coordination with effort conducted as part of Items 3 and 4 will be necessary here.
- Determining debris-storage requirements for detention basins is an essential aspect to the detention design requirements listed in the original Criteria. In particular, the Criteria states that the engineer is to use the information found in Tatum (1963) to guide design. Tatum's work was ground-breaking, but research has now moved significantly past this oft-cited work. Among other applicable and more recent research that will need to be considered includes work by Gartner, Cannon, and Helsel (2008). Their publication is relevant because it includes specific consideration of San Bernardino County and adjacent regions in southern California, even using a picture of debris deposition in San Bernardino County as the cover picture.

Figure 8. Debris deposited in San Bernardino County.

Another aspect of the Criteria update is to include new advances in modeling, whether it be by hand or by software. Indeed, since the original publication of the Criteria, computer modeling has advanced greatly. These improvements range from complex Computational Fluid Dynamics (CFD) to new simplified methods. In addition, entirely new modeling opportunities have become available, such as the ability to perform simplified risk analyses of relevant aspects such as bank collapse [Travis, Schmeeckle, & Sebert (2011a), (2011b)].

Given the need to provide solution algorithms that can be calculated by hand, it is recommended that the presented procedures be included in an accompanying Excel workbook (or equivalent) exactly as presented in the Criteria. This workbook could also facilitate County review of submitted material. Among other uses, this Excel file could provide the following algorithms, including:

- Anti-vortex design (limited)
- Compound weir computation
- Convex channel routing
- Debris-storage volume estimates
- Detention geometry (area-depth)
- Inflow hydrograph generation
- Modified Puls
- Seismic Seiche per UBC Chapter 70
- Simple routing systems
- Spillway hydraulics

The presentation of each of these key analytical procedures would be provided within Excel the same way one might proceed by hand. The table approach to computation, already prevalent in the Criteria, is well suited for direct implementation into an Excel worksheet; (Table F-1 on page F-4 is one example). This implementation can include nomographs, referenced figures, etc., without difficulty, as the WEST team has extensive experience incorporating these and other visual based analytical tools into Excel. This experience has been contributed to the engineering community at large - examples include Travis, (2011) Travis, Wahlin, & Piotrowski (2017); Travis, (2014); and Travis, Wahlin, & Miller (2018) – as well as deliverables to governmental entities and private clients. Examples of the latter include:

- 1-D flow irrigation routing prediction, Salt River Project (SRP), 2018
- Database Interface for Rapid Population Of Data For The VIPER Workbook, United States Bureau of Reclamation (USBR), 2013
- Detention flow routing, Mohave County Flood Control District (MCFCD), 2015

- Detention pond evaporation, Anonymous mining company, 2013
- Groundwater dynamics, New Mexico Interstate Stream Commission (NMISC), multiple years
- Sediment transport, Flood Control District of Maricopa County (FCDMC), multiple years

ITEM 14. OTHER SUGGESTIONS BASED ON CURRENT INDUSTRY STANDARDS AND EXPERIENCE

Although not specifically mentioned in the RFP, climate change is an issue that cannot be overlooked. Updated hydrology standards may be in place for the next 25 to 50 years and will likely be impacted by the changing climate. In California, climate change impacts on design accrue due to a very strong natural variability signal in California's climate which, at times, may amplify or mitigate anthropogenic climate forcings. With the rapidly accumulating evidence that DDFs are being influenced by a changing climate, San Bernardino County would be remiss if climate change impacts on precipitation were not given serious thought.

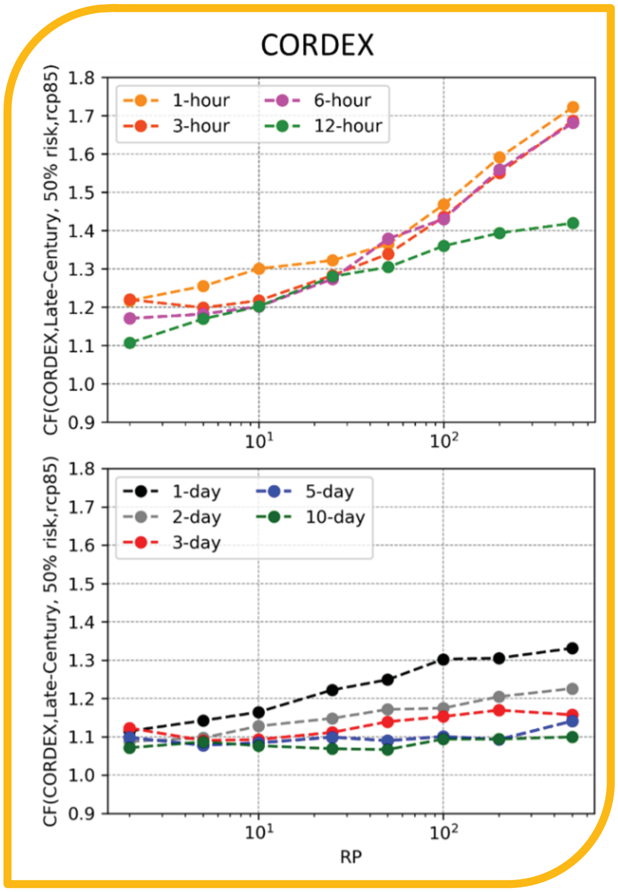

Figure 9: Ratio between projected and observed Depth Duration Frequency curves.

The WEST team has broad experience working with a wide range of issues regarding climate change including serving the California Department of Water Resources (DWR) Climate Change Technical Advisory Group, evaluating climate change impacts of drought contingency planning for reservoir operations with the Sacramento District of the US Army Corps of Engineers and the Middle Rio Grande Conservancy District, and conducting an expert peer review of a California DWR commissioned study of the changing flood risk in California's Central Valley.

WEST recently provided DDFs for the updated Sacramento County Hydrology Manual based on climate changes projected using downscaled data from global climate models (CMIP5). The results show up to a 70% increase in precipitation with short duration (hourly) and high return period (larger than 100-year), and an increase of approximately 10% for durations larger than a day for all return periods. The ratio between projected DDF and observed DDF for Sacramento for multiple durations and return periods are shown in **Figure 9** above. Similarly, WEST is accounting for the impact of projected climate changes on design storms in Texas and on the development DARFs in Arizona.

The next generation of downscaled climate model data (CMIP6) is becoming available. CMIP6 models reflect the most recent weather and climate modeling technology and offer much better resolution than prior generations. Higher resolution models are important for regions with complex terrain like San Bernardino County. Some CMIP6 data subsets are available now. Complete CMIP6 data sets for California should be available in early 2023.

DDFs provided by NOAA 14 do not account for a changing climate. Furthermore, NOAA 14 does not include the most recent data. This raises two key questions:

1. Are trends already present in the observed data set which hint at future trends?
2. Is climate change altering the depth, duration, frequency relationships that are so critical for hydrologic design?

A further complicating factor is the pending development of a successor to NOAA 14 which is tentatively titled NOAA 15. NOAA 15 will leverage the most recent data, newer statistical approaches, and consider the impact of climate change on DDFs. Work is in the very preliminary stages for this nationwide effort with no guarantee on the timing of functional deliverables, particularly for southern California. It may be at least three to five years before a finished NOAA 15 project is available.

What is clear is that eventually there will be a NOAA 15 with climate change informed DDFs. It would be prudent for San Bernardino County to consider how best to navigate the transition from a hydrology manual update that considers climate change to a NOAA 15 based manual. Preparing a thoughtful transition will minimize costs for the next manual update.

ITEM 15. THE IMPACTS OF REVISED METHODOLOGY ON EXISTING STUDIES/PROJECTS

This item is proposed to be addressed by selecting up to three (3) hydrology studies which implemented various components (*e.g.*, UH calculations) of the current Hydrology Manual. The WEST team will then selectively update the included calculations using the proposed revised methodology. A brief quantitative and qualitative analyses will be conducted to present potential impacts of the revised methodology. The WEST team will coordinate with the District regarding particular preferences and/or concerns prior to completing this task to ensure this item is adequately addressed.

ITEM 16. ANY ADDITIONAL WORK REQUIRED AND/OR RECOMMENDED BY THE DISTRICT COMMITTEE

WEST assumes a level of effort for this item comparable to updating a single average chapter. Significant additional work may need to be scoped separately if budgeted hours are inadequate to complete the task.

TASK 2. TAC MEETINGS

After completing the initial research for Task 1A, WEST recommends holding the first TAC meeting as soon as possible to obtain input from the engineering community for the updated Hydrology Manual. Subsequent

TAC meetings will occur as described in the scope of work. WEST has assumed the TAC meetings will occur in person, but significant savings may result if an online meeting venue is preferred by the District. An online venue may also result in more participation from the engineering community and controls can be implemented to limit microphone/video privileges in a manner to keep the meeting on schedule and on topic.

TASK 3A. MANUAL REVISIONS – COMPILE COUNTY COMMITTEE

This task will be completed as described in the scope of work.

TASK 3B. MANUAL REVISIONS – HYDROLOGY MANUAL REVISIONS

This task will be completed as described in the scope of work.

TASK 4. DRAFT AND FINAL MANUAL SUBMITTALS

This task will be completed as described in the scope of work.

TASK 5. PRESENTATIONS TO THE DISTRICT COMMITTEE

This task will be completed as described in the scope of work.