Technical Memorandum
Hydrology Review

Buckhorn-Mesa Structures

Prepared for:

Flood Control District of Maricopa County
(FCD No. 2003C062) and
LTM Engineering, Inc.

KHA Project No. 091725005

Kimley-Horn
and Associates, Inc.

TECHNICAL MEMORANDUM
HYDROLOGY REVIEW
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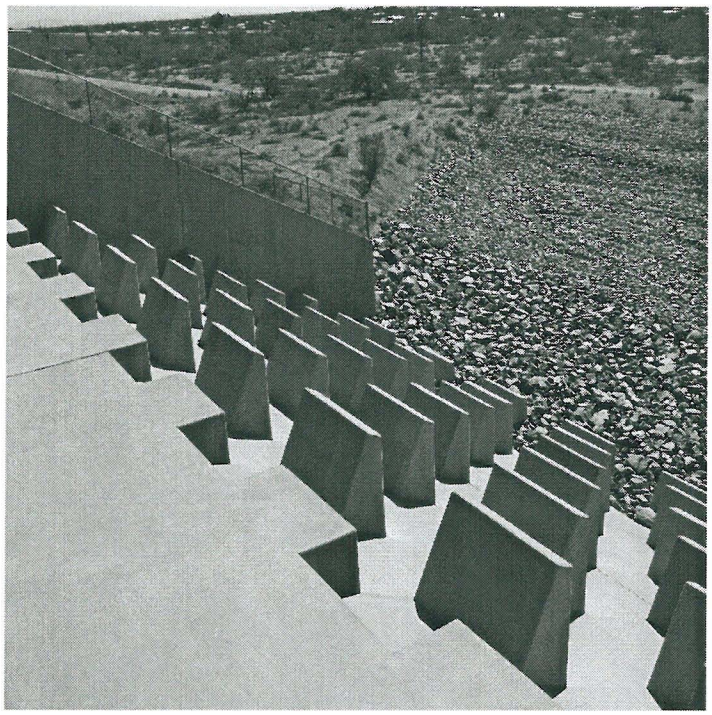

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FCD 2003C062

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BUCKHORN-MESA FLOOD RETARDING STRUCTURES

TECHNICAL MEMORANDUM
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A. Introduction

The Buckhorn-Mesa Watershed, comprising nearly 70,000 acres, is located in eastern Maricopa County and northwestern Pinal County. The watershed originates in the rough Usery Mountains, Goldfield Mountains, and the western flank of the Superstition Mountains. Rainfall on the watershed drains onto a wide alluvial piedmont upon which improvements such as subdivisions and commercial-industrial developments have been constructed (KHA 2001).

The Buckhorn-Mesa Watershed Work Plan was prepared by the Natural Resources Conservation Service (NRCS) in January 1963 to provide flood and erosion control benefits for developments (agriculture, commercial and urban areas) in the watershed. The workplan was also prepared to minimize flooding impacts to the Cities of Mesa and Apache Junction, Arizona.

The projects developed under the Watershed Work Plan were conceived in the early 1960's after 33 floods were recorded in the area between 1910 and 1960. These floods varied in magnitude and damaged land, homes, businesses, and roads. The project was analyzed and designed by the NRCS and constructed from 1978-1988. The projects consist of a series of earthen dams with interconnecting floodways and a diversion structure that detains floodwater and then routes floodwaters to an outlet into the Salt River. The specific features of the Buckhorn-Mesa Watershed Project (from east to west) include:

1. **Apache Junction Flood Retarding Structure and Floodway.** This project includes a 1.6 mile long low head earthen dam and a 1,500 foot floodway that collects flood water from a wash above the dam. The project drains six square miles north of the City of Apache Junction. Flows from the principal spillway are discharged to the Bulldog Floodway.

2. **Bulldog Floodway.** The Bulldog Floodway is a 1.7 mile long floodway that conveys stormwater released from the principal spillway at Apache Junction FRS to the Signal Butte FRS. The Bulldog Floodway also intercepts stormwater runoff from the contributing watershed upstream of the floodway and conveys that collected stormwater to the Signal Butte FRS.

3. **Pass Mountain Diversion Structure and Outlet.** This structure is a 1.2 mile-long earth diversion embankment with a 2,800 foot outlet that drains floodwaters from a four square mile area to the Signal Butte FRS.

4. **Signal Butte Flood Retarding Structure and Floodway.** This project consists of a 1.3 mile long low head earthen dam and a 2.7 mile floodway. The Signal Butte FRS principal spillway discharges stored floodwater to the Signal Butte Floodway. The floodway then conveys stormwater to the Spook Hill FRS. The Signal Butte Floodway also intercepts and collects stormwater from its upstream contributing watershed and conveys those flows to the Spook Hill FRS.

5. **Spook Hill Flood Retarding Structure and Floodway.** This project consists of a 5 mile earthen dam and a 2 mile floodway. The floodway outfalls into the Salt River. The Spook Hill FRS impounds flows from a 14 square mile watershed plus flows delivered by the Signal Butte Floodway. The Spook Hill FRS principal spillway discharges impounded flows to the Spook Hill Floodway.

In the years between project conception and construction, the area from Mesa east to Apache Junction underwent expansive growth, increasing the need for flood protection.

B. Authority and Purpose

The Flood Control District of Maricopa County (District) operates and maintains the Buckhorn-Mesa projects (structures and floodways) and is updating its emergency action plans (EAP) for the structures as a part of their dam safety program. The District has retained LTM Engineering to develop an EAP for the Buckhorn-Mesa flood retarding structures (Spook Hill, Signal Butte, and Apache Junction Flood Retarding Structures). Kimley-Horn and Associates, Inc. (KHA) is assisting LTM Engineering in the review of previous hydrologic, dambreak, and spillway inundation studies for the structures as part of the development of the EAP.

EAPs for high hazard dams are required by the Arizona Department of Water Resources (ADWR). Minimum requirements for EAPs are provided in the Departments rules and regulations for dam safety and in the Federal Emergency Management Agency (FEMA) 64 guidelines titled "Emergency Action Planning for Dam Owners" (FEMA 1995).

This technical memorandum documents Kimley-Horn's review of the project watershed hydrologic analysis originally conducted by the NRCS during watershed plan formulation and documents KHA's review of revisions and modifications to the project hydrology made post-construction of the project. This memorandum also documents the review of upstream hydrology and hydraulics to evaluate whether or not the existing hydrology models adequately represents the operations of the structures from a system perspective and to examine if the existing hydraulic analyses investigated the effect of floodways on dam hydraulics.

The hydrologic review examined if there were changes to watershed hydrologic characteristics (particularly land use, contributing watershed areas, flow paths, and reservoir storage changes) that may impact the design or as-built hydrologic and

hydraulic performance of the structures. The hydrologic review also reviewed the current approved hydrology for the inflow design flood (IDF) for each structure. The hydrograph of the IDF is required for the development of dambreak models for Signal Butte FRS and Apache Junction FRS. The dambreak analysis for these two structures is being prepared under separate cover.

C. Methodology

The approach conducted for the hydrologic review was to collect and review previous hydrologic studies of the Watershed Work Plan and subsequent hydrologic and hydraulic evaluations for the structures. Data collection included obtaining studies and reports from the NRCS (Phoenix office), the District main and watershed libraries, and ADWR office files. The collected data, reports, studies, and hydrologic models along with the Individual Structures Assessments (ISA) reports were then reviewed to understand the hydrologic characteristics of the system.

Several field reconnaissance visits were conducted to the Buckhorn-Mesa watershed and structures to observe the field conditions of the structure, principal and emergency spillways, reservoir area, and the upstream contributing watershed. The first site visit was conducted on October 14, 2004 with the District, LTM Engineering, and KHA in attendance. This site visit was documented by LTM Engineering. A second site visit was conducted by KHA on November 24, 2004. This site visit consisted of a drive-through reconnaissance of the watershed of the Buckhorn-Mesa project area.

D. Hydrologic Design Criteria

The Spook Hill, Signal Butte, and Apache Junction Flood Retarding Structures were designed to intercept flood flows and impound the flows long enough to reduce the flood peaks and safely convey those flows downstream to protect irrigated cropland and urban development downstream of the structures.

The NRCS designated the three flood retarding structures as Class C structures. The Class C designation is based on the potential downstream damage and loss of life due to a failure of the dam. The structures were analyzed, initially, using the NRCS Engineering Manual 27 "Earth Dams" (EM-27) dated March 19, 1965. EM-27 is the precursor manual to NRCS Technical Release 60 (TR-60) "Earth Dams and Reservoirs" dated October 1985. EM-27 and TR-60 both specify that NRCS Class C structures with earth-lined emergency spillways will impound runoff from the 100-year, 6-hour return frequency events with no emergency spillway discharge and will convey the Probable Maximum Flood (PMF) through the emergency spillway without overtopping the structure. The structures will impound the water from the design storm and release slowly downstream over a period of less than 10 days as required by TR-60.

The structures, at the time, were analyzed and designed based on the following inflow hydrograph definitions:

1. **Principal Spillway Hydrograph (PSH)** is the hydrograph used to determine the minimum crest elevation of the emergency spillway. It is used to establish the principal spillway capacity and determine the associated minimum floodwater retarding storage. For Class C structures, the PSH is based on the 100-year event storm with 1-day and 10-day duration. A storm duration of not less than 10 days is to be used for sizing the principal spillway.

2. **Emergency Spillway Hydrograph (ESH)** is the hydrograph used to establish the dimensions of the emergency spillway. For Class C structures, the ESH is based on the following formula: $P_{ESH} = P_{100} + 0.26(PMP - P_{100})$, where P_{100} is the rainfall depth from the 100-year, 6-hour duration precipitation event and the PMP is the Probable Maximum Precipitation depth for the watershed.

3. **Freeboard Hydrograph (FBH)** is the hydrograph used to establish the minimum settled elevation of the top of dam. It is also used to evaluate the structural integrity of the spillway system. For Class C structures, the FBH is based on the PMP. The PMP storm for the Buckhorn-Mesa watershed has a duration of 6 hours based on NRCS guidelines.

The development of Buckhorn-Mesa Watershed project hydrology was based on NRCS procedures and guidelines based on the above rainfall frequencies and durations. Aside from EM-27 and TR-60, other pertinent NRCS guidelines include the NRCS National Engineering Handbook (NEH-4), Section 4, Hydrology (for development of principal, emergency, and design freeboard hydrographs), Technical Release 20 (TR-20) for preparation of hydrologic computer models and alternative plans, and the National Weather Service Hydrometerological Report 49 (HMR-49) for PMP development of the Apache Junction FRS.

E. Data Review

A number of studies and investigations were previously conducted to estimate the rainfall and runoff characteristics for the Buckhorn-Mesa Watershed Project. These studies include:

1. Spook Hill FRS and Floodway Design (NRCS, 1976).
2. Signal Butte FRS, Floodway, and Pass Mountain Diversion Design Report (NRCS, 1985).
3. Signal Butte FRS, Floodway, and Pass Mountain Diversion Hydrologic Analysis-Emergency Action Plan Report (NRCS, 1984a).
4. Apache Junction FRS and Floodway and Bulldog Floodway Design (Ebasco, 1985).
5. Spook Hill Area Drainage Master Plan (WPA, 1999).
6. Spook Hill FRS Existing Conditions Analysis (DMJM, 2002).

The original hydrologic and hydraulic analyses and designs for the Spook Hill FRS and Floodway, Signal Butte FRS and Floodway and Pass Mountain Diversion studies were completed by the NRCS. The Apache Junction FRS and Floodway and Bulldog Floodway original hydrologic and hydraulic analyses were completed by Ebasco under contract to the NRCS.

Wood Patel and Associates (WPA) developed updated 100-year hydrology for the Spook Hill Area Drainage Master Plan (ADMP) which includes the Buckhorn-Mesa watershed. WPA re-delineated the watershed sub-basins in the Spook Hill FRS watershed and recomputed rainfall loss and basin/stream routing characteristics for current and future conditions for the entire Buckhorn-Mesa watershed area.

Daniel, Mann, Johnson, and Mendenhall (DMJM) completed a new existing hydrologic conditions analysis of the Spook Hill FRS and Floodway as part of the design of the Arizona Department of Transportation (ADOT) Loop 202-Red Mountain freeway design, which impacts the Spook Hill FRS and Floodway. In addition to a 100-year return frequency analysis, DMJM also estimated runoff for the PMP 6-hour and 72-hour event.

1. "Spook Hill FRS and Floodway Design". (NRCS, 1976). The Spook Hill FRS was designed to detain the 100-year storm event from the upstream contributing watershed. The Spook Hill hydrologic analysis for the 100-year and PMP used in the original design are based upon SCS NEH-4 criteria. The structure was designed according to NRCS criteria at that time. The recent DMJM PMP/PMF analysis has been accepted by the District and ADWR. The results of the DMJM analysis supersede the original NRCS analysis and were used by ADOT to develop a dam-break model for Spook Hill FRS as part of the Red Mountain Freeway project.

2. "Signal Butte FRS, Floodway, and Pass Mountain Diversion Design Report". (NRCS, 1984) The design report completed for the Signal Butte FRS, Signal Butte Floodway, and Pass Mountain Diversion is dated July and August 1984. The design report included information from all engineering design disciplines including hydrology and hydraulics. The NRCS designed the Signal Butte FRS to detain the 100-year storm event.

Output from several NRCS design DAMS2 program results and one TR-20 computer model results were included in the design report. Results from the design reports and construction documents are summarized in **Tables 1, 2, and 3**. One DAMS2 run for the PSH and a separate run for the ESH and FBH appear to be the model results that were used in the final design. The PSH DAMS2 run has a peak water surface elevation at 1712.4 ft (datum NGVD29 unless otherwise noted), which is the emergency spillway crest design elevation and principal spillway invert elevation. The starting water surface elevation for reservoir routing was 1700.75 ft, which is the top of the sediment pool. The total sediment volume was identified as 255.2 acre-feet. No floodwater storage was allowed below elevation 1700.75 ft and there was no discharge through the spillway.

What appears to be the DAMS2 FBH run that was used for the design of the FRS shows a maximum water surface elevation for the reservoir of 1720.95 ft, which is very similar to the actual design dam crest elevation of 1721.0 ft. This run also had a principal spillway elevation and emergency spillway crest elevation of 1700.75 ft and 1712.4 ft, respectively, so it is assumed that this FBH and associated ESH is the DAMS2 output that was used for the FRS final design. The maximum water surface elevation from this DAMS2 run were confirmed by the results from an alternatives analysis FBH run that was used to size the width of the emergency spillway that was with the design documents, which also showed that the maximum FBH water surface elevation was 1720.95 ft. No reference to the 100-year, 10-day duration storm was found in the design report.

The DAMS2 runs did not have any curve numbers or times of concentration for the various sub-basins. In the final DAMS2 run, the inflow hydrographs in the PSH and FBH/ESH DAMS2 runs were directly input into the program.

The NRCS design documents did contain a TR-20 model run, but the resultant hydrographs do not match the hydrographs input into the DAMS2 final design model. The results from this TR-20 run also showed a maximum PSH water surface elevation of 1712.61 ft and a maximum FBH water surface elevation of 1722.51 ft, which would overtop the emergency spillway crest and dam crest, respectively. So, it is assumed that the TR-20 run found in the design documents was not the same as the hydrology results used in the final DAMS2 preparation. KHA suspects that there was a later iteration of the TR-20 model that reflects final design parameters. However, this "final" design model could not be located in the design documents. The TR-20 run included in the design documents included the watershed for the Apache Junction FRS and Floodway along with the Signal Butte FRS, Floodway, and Pass Mountain Diversion watersheds.

Curve numbers in the TR-20 model ranged from 75 to 84 and times of concentration ranged from 0.23 to 0.89 hours for the sub-basins and are summarized **Tables 1 and 2** for general reference. These curve numbers and times of concentration are similar to what would be expected in the Buckhorn-Mesa watershed today and are similar to the values estimated for the other structures. It appears that the same curve numbers and times of concentration were used for PSH, ESH, and FBH.

The duration of the PSH, ESH, and FBH storms was 24-hours. The NRCS criteria, however, is to use a 6-hour duration. It could not be ascertained from the design documents the reason for using the 24-hour duration. The depth of rainfall for the PSH, ESH, and FBH storms was the same for all DAMS2 and the TR-20 runs, which was 3.94-inches, 7.06-inches, and 15.8-inches, respectively.

In **Table 2**, the peak inflow for the FBH was extracted from the hydrograph input sections of the DAMS2 model and the peak outflow was confirmed in FBH summary data. Runoff for the ESH and FBH are the only variables reported in **Table 2** that could

not be confirmed by the design reports and documents. These were found in the EAP documents (NRCS, 1984a).

3. "Signal Butte FRS, Floodway, and Pass Mountain Diversion Hydrologic Analysis-Emergency Action Plan Report". (NRCS, 1984a) The Emergency Action Plan (EAP) report completed in 1984 by the NRCS has the same DAMS2 output for PSH, ESH, and FBH as the NRCS design report above (NRCS, 1984). The same TR-20 output found in the design documents that shows the emergency spillway and dam crest being overtopped by the PSH and FBH, respectively, as described above, was found in the EAP design report.

An additional TR-20 model for the dam break hydrograph was noted in the EAP documents. The curve numbers and times of concentration for this EAP were similar to those in the TR-20 analysis from the design documents above, with minor variations. The FBH runoff depth reported for Signal Butte in **Table 2** is from the dam break hydrograph TR-20 output.

4. "Apache Junction FRS and Floodway and Bulldog Floodway Design". (Ebasco, 1985) Ebasco Services Incorporated (Ebasco) completed the analysis and design for the Apache Junction FRS and Floodway and the Bulldog Floodway in October 1986. Ebasco completed the design under contract from the NRCS. Ebasco completed all areas of design including contract drawings and specifications. The hydrology and hydraulic sections of the design documents were reviewed in for this study. Results extracted from the Ebasco design reports and construction is provided in **Tables 1 through 3**.

Ebasco used DAMS2 for the final analysis and design of the structure to develop the PSH, ESH, and FB. The 100-year return frequency rainfall depths for a 1-day and 10-day duration storms was taken from the NOAA Atlas 2. Ebasco used the rainfall-runoff modeling functionality in DAMS2 computer program to calculate the inflow hydrographs. DAMS2 uses the SCS dimensionless unit hydrograph to develop the runoff hydrographs and uses the 24-hour SCS Type II distribution to route the rainfall. Curve numbers were used to estimate the runoff characteristics of the watershed.

The PMP depth and distribution was determined using HMR-49 and was based upon a local thunderstorm with a duration of 6-hours. The PMP depth for 6-hour duration storm was 13.7 inches. The maximum 6-hour depth during a 24-hour duration storm was 10.1 inches based upon the Type II distribution. A PMP depth for the general thunderstorm with a duration of 24-hours was also estimated (15.7 inches), but the 6-hour duration thunderstorm produced the maximum reservoir stage so it was considered the critical storm. Ebasco also used the rainfall-runoff modeling capability in DAMS2 to develop the inflow as well as the outflow hydrographs for the ESH and FBH.

The anticipated sediment supply in the watershed that will be transported to the reservoir is 95 acre-feet, which was based upon the 'Sedimentation-1974 Supplement, Buckhorn-

Mesa Watershed' study completed by the NRCS. An additional 13.7 acre-feet of sediment storage was specified in the design calculations.

The curve numbers shown in **Table 1** for the PSH is an average of the curve numbers used in each of the individual sub-basins that were input into DAMS2. The curve numbers in **Table 2** for the ESH and FBH are the actual values input into DAMS2. The stage-storage curve found on the construction as-builts appears to be based upon the final results of the Ebasco hydrologic analysis.

There appears to be a slight discrepancy between calculated ESH rainfall depth and the depth used by Ebasco in the DAMS2 program. The rainfall depth calculated by the ESH standard is 6.6 inches based upon a P_{100} and PMP depth of 4.1 and 13.7 inches, respectively. The ESH rainfall depth used in the DAMS2 analysis is 6 inches.

The original hydrologic analysis results are found in **Tables 1 through 3** as follows:

Table 1. Principal Spillway Hydrograph.

Flood Retarding Structure	Spook Hill	Signal Butte	Apache Junction
P_{100} 1-day Curve Number	75-79	75-84	78
P_{100} 10-Day Curve Number	58-64	NA	63
P_{100} 24-hour Precipitation (in)	3.9	3.94	4.1
P_{100} 10-Day Precipitation (in)	6.1	NA	7.3
P_{100} 24-hour Runoff (in)	*	2.41	1.94
P_{100} 10-Day Runoff (in)	*	NA	3.07
PSH Peak Stage (ft)	1578.2	1712.4	1799.77

* Could not be confirmed by data review

Table 2. Emergency Spillway and Freeboard Hydrograph.

Flood Retarding Structure	Spook Hill*		Signal Butte		Apache Junction	
Hydrograph	**ESH**	**FBH**	**ESH**	**FBH**	**ESH**	**FBH**
CN	75-79	75-79	75-84	75-84	82	82
Rainfall (in)	5.7	13.0	7.06	15.8	6.0	13.7
Storm Duration (hr)	6	6	24	24	6	6
Time of Concentration (hr)	--	--	0.23-0.89	0.23-0.89	0.69	0.69
Peak Inflow/Outflow (cfs)	--	47,315/ 21,286	5,460/2,449	14,352/ 11,309	12,285/ 1,875	37,362/ 10,566
Time to Peak (hr)	--	--	9.6	9.2	2.7	2.6
Runoff (in)	--	--	3.27	11.5	3.99	11.38
Peak Stage (ft) NGVD29	--	1539.38	1715.7	1720.95	1802.9	1809.4

*Spook Hill Data Extracted from DMJM Report

Table 3. Flood Retarding Structure Physical Design Characteristics.

Flood Retarding Structure	Spook Hill*	Signal Butte	Apache Junction
Dam Crest Elevation –ft	1591.0	1721.0	1810.0
Emergency Spillway Crest Elevation – ft	1582.0	1712.4	1799.77
Sediment Pool Elevation – ft	1577.5	1700.75	1793.5
Principal Spillway Crest Elevation - ft	1577.5	1701.0	1793.5
Principal Spillway Outlet Pipe	7 ft by 7.5 ft box	36-in dia	30-in dia
Storage to Emergency Spillway Crest (af)	849	1365.3	503.4
Storage to Top of Dam Crest (af)	4,070	2822.1	2019.3
100-year Sediment Pool Storage (af)	271	255.2	108.7

*Spook Hill Data Extracted from DMJM Report

5. "Spook Hill Area Drainage Master Plan" (ADMP) (WPA, 1999). WPA developed new 100-year hydrology for the Spook Hill ADMP. WPA created the100-year hydrology for the entire Buckhorn-Mesa watershed. In the Spook Hill FRS watershed, WPA re-delineated many smaller basins from the original NRCS design. New subbasin boundaries for the Spook Hill FRS were primarily needed because of upstream development, which also called for a change to the existing conditions hydrologic parameters to reflect the more urbanized watershed. Sub-basin boundaries for the Signal Butte and Apache Junction structures remained unchanged from the original design.

New two-foot contour topographic mapping was developed for the ADMP, which WPA used to develop updated stage-discharge and stage-storage curves for all of three structures. The ADMP report indicated that with the new topographic mapping the maximum storage capacity of the Spook Hill FRS reservoir is 5,100 acre-feet at the dam crest elevation compared to the 4,070 acre-feet indicated on the Spook Hill as-built plans. WPA developed updated hydrology for existing and future conditions land use conditions. Future land use information from the Cities of Mesa and Apache Junction were used in the analysis.

WPA used District hydrologic methods to develop the new hydrology. The methods for estimating precipitation for the 100-year return frequency event are similar to what was used in the design of the structures, based upon the NOAA Atlas and the rainfall distribution is based upon the same SCS Type II dimensionless unit hydrograph for the 100-year storm, 24-hour duration storm. WPA used the Green and Ampt infiltration equation, which is the method preferred by the District, to estimate rainfall loss and the Clark Unit Hydrograph method to transform the excess rainfall into runoff in the watershed. The WPA hydrologic approach coupled with the new topography resulted in

notable changes to the hydrologic results (lower values) that were reported as part of the original analysis, design, and as-built construction of the structures.

As part of the Spook Hill ADMP, WPA recreated the TR-20 analysis found in the Signal Butte design documents (NRCS, 1984). The purpose of recreating the TR-20 model was to develop a baseline for the evaluation of potential hydrologic changes that have occurred in the watershed. For the Apache Junction and Signal Butte structures, the TR-20 run found in the design documents were successfully recreated, but as stated previously, it appears that the TR-20 output in the design documents does not match the inflow hydrographs input into the NRCS DAMS2 program that was ultimately used to design the Signal Butte FRS, nor does it match the data from the Ebasco DAMS2 analysis. Since WPA used the TR-20 analysis from the design documents, the ESH and FBH data reported by WPA for both the Apache Junction and Signal Butte structures is based upon a 24-hour duration storms.

WPA completed hydrology for the PMP event for the Spook Hill FRS existing conditions as a part of developing a baseline for comparison and for the new hydrology under the future land use. WPA also revised the original TR-20 model to adjust to the 100-year, 10-day duration storm. Reservoir routing began at 1577.5 ft, the principal spillway elevation in all the ADMP models. WPA examined the 100-year hydrology, which had a 24-hour duration, so ultimately the PMP results based on future land use would be based upon a 24-hour duration storm.

6. "Spook Hill FRS Existing Conditions Analysis". (DMJM, 2002) DMJM reviewed the Spook Hill NRCS hydrology and completed new hydrologic analysis for the Spook Hill FRS, Floodway, and Signal Butte Floodway as part of the design of the Arizona Department of Transportation (ADOT) Loop 202-Red Mountain freeway design, which impacts the Spook Hill FRS and Floodway. DMJM created new hydrology for the 25, 50, and 100-year return frequency events and for the PMP event based on the existing watershed conditions of 2001.

For the new existing condition PMP runoff event, DMJM completed analysis for both a general 72-hour duration storm and for a local 6-hour thunderstorm. Rainfall depths and distribution were developed using HMR-49 for both storms. DMJM found that the critical storm was the local thunderstorm, so the 6-hour duration local thunderstorm results were used for comparison to the original NRCS documentation.

The total rainfall depth was 12.8 inches distributed over a 6-hour duration using HMR-49. The sub-basin boundaries were re-delineated from the original NRCS design to provide inflow hydrographs at required locations, where roadway infrastructure needs were to be analyzed by DMJM. DMJM used District rainfall loss and unit hydrograph procedures, Green and Ampt and Clark Unit Hydrograph, to determine the rainfall losses and to transform excess rainfall to runoff. The Green and Ampt and Clark Unit Hydrograph variables were developed using the District standards as found in District's hydrology methods except for the time of concentration variable. Channel routing was

accomplished using the normal depth routing approach in HEC-1 and reservoir routing was completed using the Modified Puls level pool routing method.

A customized method for determining the time of concentration was developed by DMJM for their analysis. The methodology comes from TR-55 with a computational algorithm developed by DMJM. The algorithm iteratively defines the average channel flow parameters using a unit width approach to determine the channel element travel time and subsequent time of concentration.

The starting water surface elevation for reservoir storage in the DMJM study was 1575.1 ft. DMJM notes in their HEC-1 analysis that the sediment storage volume below the principal spillway is 271 acre-feet. The rating curve indicates 287 acre-feet of stormwater storage is available between elevations 1575.1 ft and 1577.5 ft in their HEC-1 analysis. It appears that DMJM, using the stage-storage information developed by WPA based on the new topography, converted from NAVD 88 to NGVD 29 and used it for their HEC-1 modeling. WPA indicated the sediment volume would fill the reservoir to elevation 1577.2 ft, so DMJM converted that elevation to NVGD 29 (1575.1 ft) and allowed stormwater storage between 1575.1 ft and 1577.5 ft.

Table 4 shows the results of the DMJM PMP critical storm analysis.

Table 4. DMJM Spook Hill PMP Analysis Results.

Variable	Results
Rainfall Depth (in)	12.8
Storm Duration (hrs)	6
Peak Inflow/Outflow (cfs)	28,208/14,478
Time to Peak (hr)	9.4
Peak Stage (ft) NGVD 29 Datum	1,588.5
Dam Crest Elevation (ft)	1,591.0
Storage to Top of Dam (acre-feet)	3,139

F. Observations

The following are general observations for each flood retarding structure from the literature cited above:

1. Spook Hill FRS

a. The peak inflow/outflow and storage volume results of the DMJM analysis are approximately 50-70% of the original analysis values. The DMJM results are dependant on the times of concentration analysis that was completed for Loop 202-Red Mountain Freeway project.

b. The WPA PMP results from the ADMP were prepared based on a 24-hour duration storm for all storm frequencies evaluated.

c. The original NRCS analysis developed the PMP rainfall depths and distribution using SCS methods. DMJM developed the PMP using methods from HMR-49.

d. The District and ADWR have approved the PMP/PMF hydrologic analysis completed by DMJM. DMJM evaluated both the local 6-hour storm and 72-hour general storm PMPs.

2. Signal Butte FRS

a. Though the TR-20 output and DAMS2 input do not match, the times of concentration and curve numbers in the TR-20 data are generally similar with the other Buckhorn-Mesa sub-basins. The input hydrographs for the ESH and FBH DAMS2 are apparently the design hydrographs for Signal Butte FRS (Note: the FBH is the same as the PMF).

b. The duration of the PSH, ESH, and FBH storms was 24-hours in the NRCS hydrologic study. The original 1963 watershed work plan showed that the design storm duration would be 6-hours, so between the 1963 and the 1984 design, the duration of the design storm was altered. No documentation as to why this occurred could be located In contrast, the Spook Hill and Apache Junction FRS design documents show that the critical storm for those structures is the 6-hour duration PMP.

c. It appears that the NRCS used results from the DAMS2 models to set the design parameters for the Signal Butte FRS, including the emergency spillway and dam crest elevation. The TR-20 model recreated by WPA during the ADMP was the same TR-20 analysis that was found in the design documents, but that TR-20 analysis did not produce the same results as the DAMS2 models. As stated, the TR-20 analysis shows the emergency spillway and dam crest being overtopped by the PSH and FBH, respectively. It appears WPA recognized that as they developed several alternatives to lower the maximum PSH and FBH water surface elevation and extending the Pass Mountain Diversion structure (WPA, 1999-Appendix A, Volume 2). It should also be noted that, the NRCS design is based upon the NGVD 29 datum and the ADMP was based on NAVD 88 datum, so the structural elevations reported in the ADMP do not match the design documents or plans.

d. PMP rainfall distribution is assumed to be based upon SCS 24-hour standards, possibly the Type II distribution. HMR-49 is generally the current standard of practice in determining the PMP rainfall depth and distribution.

e. A PMP 6-hour and 72-hour duration hydrologic analysis could not be located in the design documents.

3. Apache Junction FRS

a. The TR-20 runs recreated by WPA included the Apache Junction FRS and Floodway. The TR-20 model recreated by WPA during the ADMP was the same TR-20 analysis that was found in the design documents, but that TR-20 analysis did not produce the same results as the DAMS2 models.

b. The Ebasco design documents show a clear connection between the DAMS2 results in design elevations of the structure, which include the principal spillway, emergency spillway, and dam crest elevation, as well as the sediment storage elevation. The DAMS2 results were used in the design of the structure.

c. The Ebasco analysis used SCS methods in determining rainfall loss, excess rainfall and channel routing parameters.

d. Increased urbanization has occurred in the watershed since the design of the structure in 1985, which may potentially modify the soil/loss parameters, sub-basin delineation boundaries, and routing characteristics of the watershed.

e. A PMP 72-hour duration hydrologic analysis could not be located.

G. Conclusions

A number of hydrologic analyses have been conducted that incorporate the Buckhorn-Mesa watershed and the three flood retarding structures. However, all of these studies had different purposes and goals. The original hydrologic analyses were conducted as part of the design of the structures. Subsequent hydrologic analyses were conducted to assist in the development drainage master planning alternatives for the Spook Hill FRS watershed and to evaluate the impact of the proposed ADOT Red Mountain Freeway (Loop 202) construction at the Spook Hill FRS.

From review of the Buckhorn-Mesa watershed documentation, there is only one hydrologic model study that was prepared to construct a system model of the watershed, structures, and floodways. The system approach for this model constructed a watershed-wide hydrologic model to evaluate the operational characteristics of the dams/floodways system. The objective of this systems approach was to understand the inter-relationship of the rainfall-runoff response of the watershed and storage and conveyance relationship of the dams and the floodways. In this fashion, the study results provided an indication of the operational behavior of system components with each other. For example, discharges from the principal spillway of the Apache Junction FRS are conveyed by the Bulldog Floodway to the Signal Butte FRS. Flows in the Bulldog Floodway contribute to the inflows into the Signal Butte FRS. The interaction of the Bulldog Floodway flows and the flows from the contributing watershed to Signal Butte FRS may be examined to detect the interaction of the operational response of the dam.

The documentation indicates that there was a partial system model prepared which was the TR-20 model developed by the NRCS as part of the hydrologic evaluation of the Signal Butte FRS. This TR-20 model included the Apache Junction FRS, Apache Junction floodway, Bulldog Floodway, Signal Butte FRS, and the Pass Mountain Diversion. This model study was prepared in 1983-1984, just over 20 years ago, and based on existing land use conditions in the upstream watershed at that time. The TR-20 was developed for the 100-year 24-hour storm event. The hydrologic model provided for the simulation of rainfall over the Buckhorn-Mesa watershed and resulted in inflow hydrographs into the dams and floodways and provided for routing of flows through the floodways. A review of the curve number and subbasin area hydrologic parameters provided in the TR-20 model appeared to be reasonable.

The second and third system model was prepared by WPA for the Spook Hill ADMP. The second model was a HEC-1 model developed for the Buckhorn-Mesa watershed using District hydrologic methods for the 100-year 24-hour storm as described in Section E.5 above. The HEC-1 model included all structures and floodways in the Buckhorn-Mesa watershed workplan. The results of the HEC-1 analysis provided lower peak flow discharges and flow volumes compared to the TR-20 model (third system model). The reason given by WPA for the lower results was due to the new topographic mapping (provided greater detention volume; stage-storage curves for the dams) and the change in hydrologic methods (District versus NRCS) for the time of concentration and rainfall loss parameters.

The third model was again, a partial system model, developed using the TR-20 model that was re-created by WPA from the NRCS TR-20 model. The discussion presented in Section E.5 indicates that the original TR-20 model prepared by the NRCS does not match as-built stage-storage or stage-discharge rating curves nor does the model match as-built elevations for key physical dam parameters (principal spillway elevation, emergency spillway elevation, and top of dam crest elevation).

Of the three models, the second system model, prepared using HEC-1, is, in our opinion the more reasonable representative system-wide hydrologic model of the Buckhorn-Mesa structures for the 100-year 24-hour storm event. This opinion is based on the use of updated stage-storage and stage-discharge rating curves developed as part of the Spook Hill ADMP, re-delineation of the Spook Hill FRS subbasins to reflect current drainage parameters in the FRS watershed, and on updated existing conditions and future conditions land use. The results of the model provide the operational characteristics of the three dams and floodways for the storm event modeled.

However, the system-wide hydrologic models and data do not provide a single watershed wide hydrologic model for the inflow design flood (IDF) for Signal Butte FRS or Apache Junction FRS. Developing such a model using the HEC-1 100-year 24-hour model as a base would require modifying the rainfall distribution and rainfall depth.

H. Recommendations for Future Hydrologic/Hydraulic Updates for Buckhorn-Mesa Watershed.

As District resources become available, the following are recommendations for further study:

1. The system HEC-1 model prepared by WPA should be modified to develop a multi-frequency storm event model. A multi-frequency model that models the storm events for the 2, 5, 10, 25, 50, 100, and 500-year storm events will provide the District with the operational characteristics of the Buckhorn-Mesa structures for the more reasonably anticipated frequent storms (2, 5, and 10-year storms) and for the less frequent storms (25, 50, 100, and 500-year storms). The District actions and responses for the more frequent less intense storm events may not be identical to the less frequent more intense storm events. The system model should include upstream drainage facilities constructed in the watersheds for the Signal Butte FRS and Floodway, the Apache Junction FRS and Floodway, and the Bulldog Floodway since completion of construction of the dams and the floodways. This multi-frequency system model may be conducted at a time when District programming allows for such a study.
2. The current locations of inflow points into the floodways (Apache Junction Floodway, Bulldog Floodway, Signal Butte Floodway, and Spook Hill Floodway) should be identified. An updated hydrologic analysis should include the effects of subdivision block walls and upstream drainage improvements on the location of the inflow points, change in drainage patterns, and evaluate and compare (original design versus existing conditions) the impacts of such walls and improvements on peak discharges into the floodways. This study should be conducted as part of District dam safety Phase II investigations.
3. The Arizona Department of Water Resources current dam safety rules and regulations require that a PMP analysis be conducted for the 6-hour local storm and the 72-hour general storm. The more critical of the two storms will generally be the accepted PMP analysis for the dam. An updated PMP/PMF analysis should be conducted for Apache Junction and Signal Butte FRS based on ADWR criteria.
4. The updated PMP/PMF analysis should include routing the floods into the Signal Butte FRS and Apache Junction FRS based on the updated stage-storage and stage-discharge rating curves prepared by WPA using new topographic mapping.
5. Preparation of unsteady flow, dynamic flow routing models may be a feasible undertaking for the Buckhorn-Mesa structures. The hydraulic evaluation should be conducted for multiple storm frequencies to include more frequent and less frequent storms. The results of such hydraulic analyses will provide the District with hydraulic operational parameters for the structures for multiple frequency storms (floodways: flow

velocities, water surface elevations; dams: water surface elevations, time to fill and drain, potential for emergency spillway discharges, freeboard, etc.). A study of this nature may be undertaken by the District when future programming allows for such a study.

6. The results of the WPA HEC-1 results indicates lower flood peaks and flow volumes for the 100-year storm event. One may deduce that such a reduction may occur for other storm frequencies. As such, KHA recommends that an updated sediment yield analysis be conducted for both the Signal Butte and Apache Junction FRS based on the updated hydrologic analyses. The study may indicate a lower volume of sediment generated from the upstream contributing watershed. The implications of such a finding means that the two dams will require a smaller sediment pool volume and hence additional storage volume may be dedicated to flood control. If a lower sediment pool volume results in a lower sediment pool elevation, the ADWR routing requirements of the IDF may proceed with an initial lower pool elevation. This study should be conducted as part of District Phase II investigations.
7. An unsteady, dynamic flow routing model should be prepared for the Signal Butte FRS and Apache Junction FRS to evaluate emergency spillway hydraulics and downstream inundation limits for the PMF or IDF for each structure. The downstream limit of such a hydraulic analysis should extend beyond the Central Arizona Project (CAP) canal. The existing spillway inundation studies for both dams terminate at the CAP canal. The results of the existing studies indicate that the CAP canal could be overtopped for the peak discharges modeled in the spillway studies.

I. Recommendations for the Update of the Emergency Action Plan

The following are recommendations for the update for the Emergency Action Plan.

1. The PMP analyses for Signal Butte FRS and Apache Junction FRS should be updated prior to the preparation of the dambreak models. The PMP documentation for Signal Butte FRS indicates that the existing PMP is based on a 24-hour duration. For Apache Junction, the PMP analysis is based on a 6-hour duration. ADWR dam safety rules and regulations require the more critical of the 6-hour or 72-hour duration by used in a PMP analysis. The WPA HEC-1 model prepared as part of the Spook Hill ADMP may be used as the base hydrology model to update the PMP for both structures.
2. The existing spillway delineation studies for the Signal Butte and Apache Junction FRSs were developed based on District hydraulic methods and approach. The spillway delineations appear to be adequate for emergency action planning and response. The EAP should note that the downstream limit of the delineations terminate at the Central Arizona Project canal.

Both technical reports indicate that the CAP could potentially be overtopped during spillway flows.

J. References

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