LOWER BOIS D'ARC CREEK RESERVOIR

PROBABLE MAXIMUM FLOOD ANALYSIS

AUGUST 2007

Prepared for:

North Texas Municipal Water District

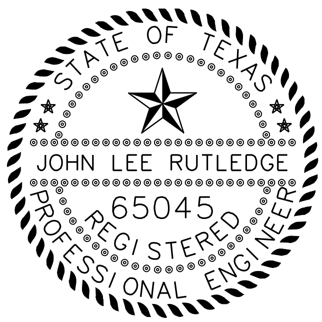

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

In the spring of 2004, Freese and Nichols, Inc. completed the conceptual assessment of the proposed reservoir site on Lower Bois d'Arc Creek in Fannin County, TX. This assessment developed a calibrated hydrologic model for design storm runoff and a hydraulic model for routing these flows through the proposed reservoir. In 2006, further study, including limited geotechnical field exploration, was performed. This information, combined with updated hydrologic and hydraulic models, was used to develop a preliminary design of the dam and reservoir for the water rights permit application submitted to the Texas Commission on Environmental Quality (TCEQ), which was submitted in December of 2006.

In the spring of 2007, updated mapping of the basin with one foot ground elevation contours was developed and Freese and Nichols was authorized to update the previous hydraulic model and the estimate of the Probable Maximum Flood (PMF), which is the design flood required for the Lower Bois d'Arc Creek Reservoir, according to TCEQ regulations. The updated model is to be used to:

- Update the PMF design storm levels,
- Confirm the appropriateness of the spillway configuration,
- Develop more accurate estimates of the impact of the lake on flood levels, and
- Update maps showing estimated flood levels around the reservoir.

1.1 2006 Preliminary Design for TCEQ

Based on the preliminary design phase, as submitted to the TCEQ for the water right permit in December 2006, Lower Bois d'Arc Creek Reservoir Dam is planned to be constructed as a zoned earthen embankment with a 150 foot wide service spillway and a 1,400 foot wide emergency spillway. In accordance with the criteria set forth in Section 299 of the Texas Water Code, Section 299.12 (Size Classification) and Section 299.13 (Hazard Classification Criteria), the proposed Lower Bois d'Arc Creek Reservoir Dam will be classified as a large, high-hazard dam. Section 299.14 of the Water Code indicates that the appropriate design storm for a large high-hazard dam is 100 percent of the PMF.

Appendix B includes a copy of the application drawings for the proposed reservoir as submitted to TCEQ for the water rights application in December 2006. Data for the design storm analysis developed for the application drawings are summarized on sheet 7 of those drawings. As proposed in 2006, the dam will be about 10,400 feet in length and will have a maximum height of about 90 feet. The design top elevation of the embankment will be 553.0 msl, with varying amounts of overbuild to allow for settlement after construction. The planned embankment will provide 19 feet of freeboard above the conservation pool of Lower Bois d'Arc Creek Reservoir, at elevation 534.0 msl and 3.2 feet of freeboard above the Probable Maximum Flood (PMF) developed for that study of elevation 549.8 msl

The 2006 preliminary design for the service spillway calls for a service spillway to be located near the right (east) abutment of the dam. The spillway will consist of an approach channel, an uncontrolled concrete weir, chute, hydraulic jump stilling basin and outlet channel. The weir will consist of a concrete gravity, ogee-type section with a crest length of 150 feet. The crest of the weir will be at elevation 534.0 msl and the weir will have a discharge capacity of about 37,300 cfs at the maximum design water surface, elevation 549.8 msl. The spillway structure will extend 958 feet downstream from the centerline of the dam to the downstream edge of the end sill. A hydraulic jump stilling basin, with baffle blocks and an end sill, will be provided. The stilling basin will be at elevation 456.0 msl and it will be 128 feet long. Spillway discharges will be conveyed to Bois d'Arc Creek by a discharge channel approximately 2,300 feet long with a 150-foot bottom width.

The emergency spillway will be 1,400 feet long and will also be located in the right (east) abutment, beyond the service spillway. It will have a crest elevation of 541 and is not planned to be operated in any flood less than the 100-year flood. Due to its infrequent operation, it will not be lined, but will only have a grassed surface.

Lower Bois d'Arc Creek Reservoir will have a surface area of 16,526 acres and storage of 367,609 acre-feet at the top of conservation storage, elevation 534.0 msl. It will have a surface area of 26,715 acres and storage of 757,446 acre-feet at the top of the dam, elevation 553.0 msl.

All of the data provided are from the preliminary design, as submitted to the TCEQ for the water rights application in 2006. Since that analysis was based on the earlier hydraulic model, there are slight discrepancies between those results and the results of this report for the updated PMF, as will be described later. However, the configuration described above was used as a starting point with the intention of confirming its suitability. Changes would only be made if significant differences in the results dictated.

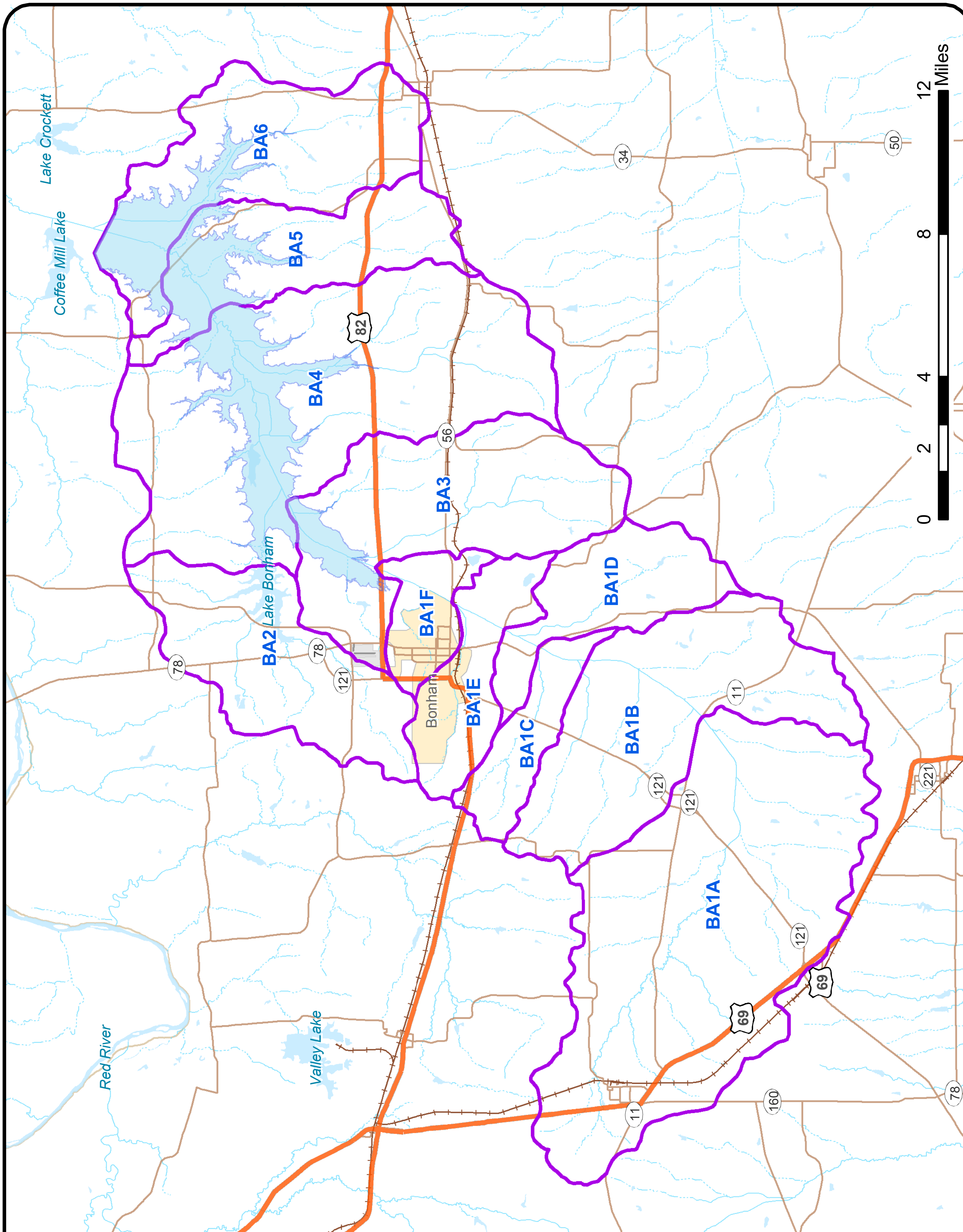
2.0 UPDATE OF PROBABLE MAXIMUM FLOOD

The Probable Maximum Flood (PMF) was estimated using the procedures outlined in *Hydrologic and Hydraulic Guidelines for Dams in Texas*[1], published by TCEQ in August of 2006. This process included identification of the design storm rainfall amounts, estimates of runoff amounts that the rainfall would produce, and the development of a flood routing model that would route the estimated runoff through the Lower Bois d'Arc Creek Reservoir. Each of these steps are described below.

2.1 Probable Maximum Precipitation

The 327 square mile drainage area of the Lower Bois d'Arc Creek Reservoir was subdivided into 11 subbasins in addition to the reservoir surface, as shown in Figure 1. Rainfall amounts for the various storms studied were estimated using available standard resources. The Probable Maximum Precipitation (PMP) was found using the standard guidelines from the *Hydrometeorological Report No. 51*[2] and *Hydrometeorological Report No. 52*[3], published by NOAA, or referred to as HMR-51 and HMR-52. The values were input into the *HMR-52 Probable Maximum Storm Generalized Computer Program*[4] issued by the US Army Corps of Engineers. HMR-52 was used to distribute the rainfall spatially over the various subbasins and to optimize the storm area and orientation for maximum rainfall. The new TCEQ Design Storm Guidelines, described in the next section was used to temporarily distribute the rainfall.

The PMP depths for a particular storm size and range of storm durations were used to determine the critical storm duration for a dam. The intention of the process is to review multiple potential durations of storm events in order to determine a critical event, namely, that which produces the maximum reservoir level. Possible durations would include 1, 2, 3, 6, 12, 24, 48, and 72 hours. For this analysis, the minimum design storm duration is 6 hours based on the total contributing drainage area for the dam, as shown in Table 1.



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Subbasins

Lower Bois d'Arc Creek Reservoir

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FIGURE
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Table 1 – Minimum PMP Duration

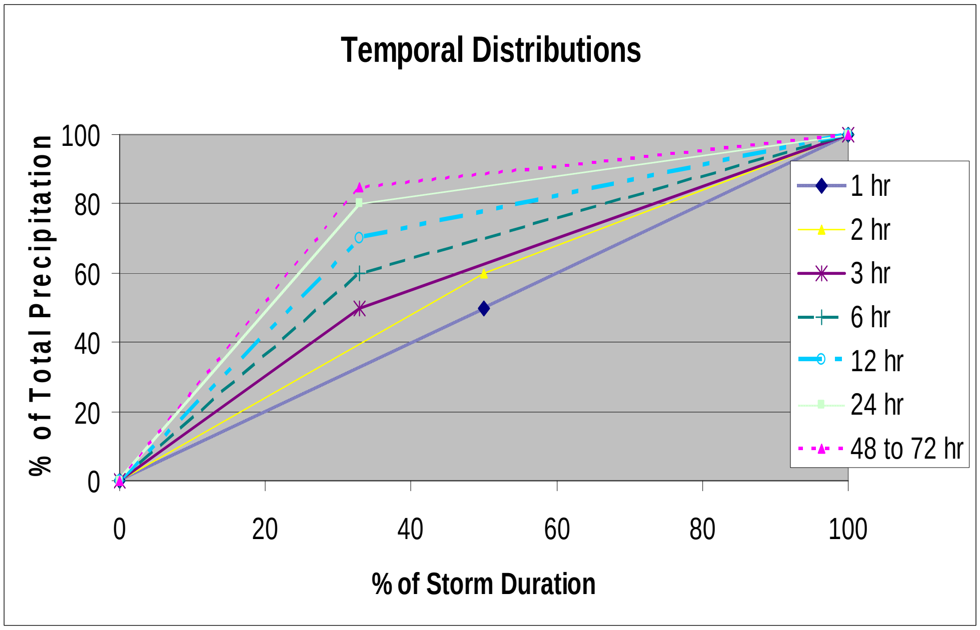
Contributing Drainage Area (DA) (square miles)	Minimum Storm Duration (hours)
DA < 25	1
25 ≤ DA < 100	3
100 ≤ DA < 1,000	6
1,000 ≤ DA < 10,000	24
DA ≥ 10,000	72

The PMP depths should first be determined for the minimum storm duration listed in Table 1. Then, each possible duration up to the 72-hour storm duration should be reviewed in order to determine the critical duration. First, the peak reservoir level from a 6-hour PMP is determined, then that of a 12-hour and a 24-hour PMP event. This continues until the peak reservoir level from a longer duration event is lower than the previous one, thus bounding the critical duration. The duration which produces the maximum reservoir level then becomes the critical duration and that duration event is used for the PMF. If the 72-hour PMP produces the maximum reservoir level, then a 72-hour PMF is utilized. No durations longer than 72 hours need to be reviewed.

The total depth of the PMP for each of the sub basins was temporally distributed in accordance with the dimensionless parameters of Figure 2. This temporal distribution criteria applies to all PMP durations as described above.

The temporal distributions provided for by these guidelines attempt to provide a reasonable estimate of a likely distribution for an extreme event of the given duration.

Figure 2 – Temporal Distribution of Total Depth of PMP for All Durations of PMP



The breakpoint for each distribution will vary depending on the duration storm being analyzed and is shown below in Table 2 For a 1-hour event, a breakpoint of 50% and 50% is listed for consistency, though this represents a linear distribution of rainfall over the hour.

Table 2 – Break Points for PMP Temporal Distributions

Duration (Hr)	X (%)	Y(%)
1	50	50
2	50	60
3	33	50
6	33	60
12	33	70
24	33	80
48 to 72	33	85

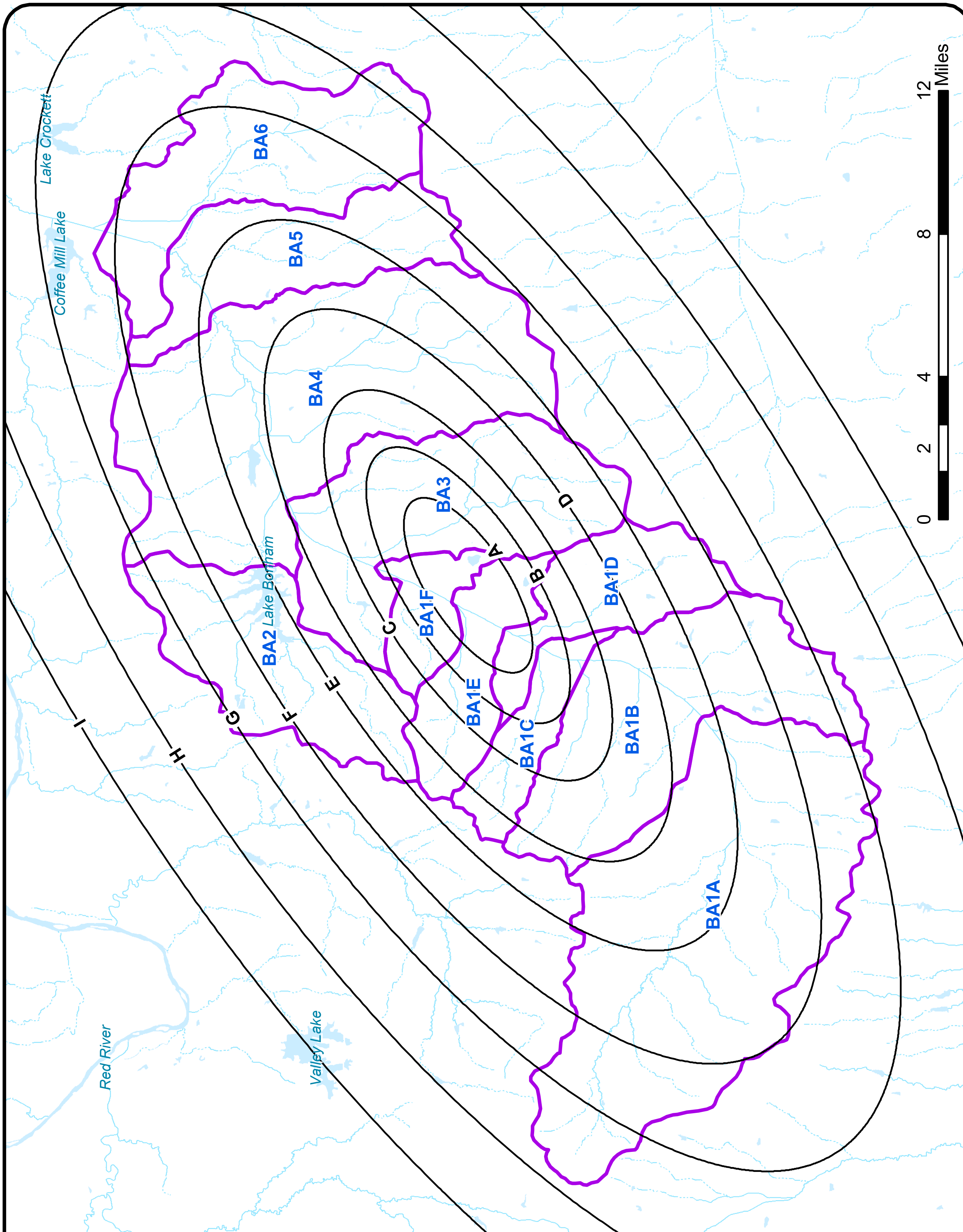
The precipitation was input into the HEC-HMS model to find the greatest runoff for the various durations. The 72 hour duration gave the largest inflow volume, inflow runoff into the Lower Bois d'Arc Creek Reservoir and the largest water height over the spillway. The HMR-52 program was used to optimize the storm's critical storm size, location, and orientation for the given storm center location in order to produce the maximum rainfall. Figure 3 shows the isohyetal pattern location for the critical storm center. For the 327 square mile drainage area of the Bois d'Arc Creek watershed, an average total rainfall of 36.3 inches was estimated for the watershed for the 72-hour event.

2.2 Loss Method

The loss method used established an initial loss amount and a uniform loss rate. The initial assumption was that all rainfall is lost to infiltration up to the initial loss amount. After that, the uniform rate is adjusted to the calculation time step and then subtracted from the rainfall amount for each time step. The remaining precipitation is the excess rainfall. According to the new guidelines used by the TCEQ, the initial loss amount should be zero, equivalent to saturated conditions, when calculating the PMF. The uniform rate is estimated based on soil types. The values will typically range from 0.05 in/hr for clays to as high as 0.4 in/hr for sandy soils. Values derived from the calibration process, as described earlier, were not utilized, as these generally reflect rainfall data error correction in the calibration process more than actual field values. Uniform infiltration losses of 0.06 inch per hour were adopted based on a review of the area soils. An initial loss of one inch was used for various frequency events and no initial loss was used for the PMF. After adjusting the PMP for the infiltration losses, the total rainfall-excess for the 72-hour PMP was 32.1 inches.

2.3 Unit Hydrographs for Bois d'Arc Creek Watershed

The 327 square mile drainage area of the Lower Bois d'Arc Creek Reservoir was subdivided into 11 subbasins in addition to the reservoir surface. The watershed, as shown in Figure 1, was modeled using Arc-GIS with Arc-Hydro and HEC-GeoHMS[5] and a digital elevation model (DEM) developed from the updated topographic mapping. This mapping was based on an aerial LiDAR survey of the watershed, which was flown in late January 2007. Arc-Hydro was used to process the DEM and to recreate the general boundaries of each drainage area based on elevations from the DEM and the streams.



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Isohyetal Pattern for Design Storm

Lower Bois d'Arc Creek Reservoir

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FIGURE

The GIS map created for the watershed was used to generate the input parameters for HEC-HMS[6], the computer model used to generate runoff hydrographs from input rainfall amounts.

A separate unit hydrograph was developed for each subbasin using the Snyder method of developing synthetic unit hydrographs based on measured basin characteristics. Two parameters are needed to develop a Snyder Unit Hydrograph:

- T_L, lag time
- C_p, shape factor, also commonly expressed as C_p640.

The following equation was used to develop the lag time:

$$T_L = C_T(L*L_{CA}/S^{0.5})^{0.38}$$

C_T = coefficient representing variations in watershed slope and storage

L = hydraulic length of watershed along the longest flow path (mi)

L_{CA} = hydraulic length along the longest water course from the point under consideration to a point adjacent to the centroid of the drainage basin (mi)

S = weighted slope of the basin (ft/mi), measured from the 85% to the 10% points along the longest stream path in the basin..

The shape factor C_p640 is usually obtained from calibration and reflects the sharpness of the hydrograph. High values, up to about 500, reflect a rapidly responding basin with a sharply peaked hydrograph. Low values, such as 250, generally reflect a flatter, more slowly responding basin with a longer, flatter hydrograph. Values for the two primary Snyder's coefficients (C_p640 and C_T) values were calibrated using observed data at the Randolph gauge in the upper portions of the basin. The resulting values were:

C_p 640	=	499
C_T	=	1.72

These values were then used along with the appropriate measured basin parameters to each of the other subbasins. Table 3 lists the calculated Snyder's Lag times for each of the basins using the calibrated C_T value.

Table 3 – Subbasin Characteristics

Subbasin	Area (sq mi)	Length (mi)	Centroid Length (mi)	Lag Time (Hr)
BA1A	71.86	20.03	8.48	8.27
BA1B	35.90	9.55	3.00	3.61
BA1C	8.74	6.70	2.62	2.90
BA1D	15.31	7.93	3.66	3.43
BA1E	12.51	6.89	2.26	2.82
BA1F	7.35	3.99	1.29	1.80
BA2	25.43	9.27	2.83	3.63
BA3	34.60	9.84	3.29	3.98
BA4	63.22	11.38	2.58	3.75
BA5	21.57	10.02	4.11	4.17
BA6	30.22	11.01	5.02	4.79

The unit hydrographs developed for the sub-basins were then applied to the rainfall-excess values to obtain the estimated runoff for PMF runoff hydrographs from each subbasin. An unsteady HEC-RAS hydraulic model was created to account for hydraulic flood routing along Bois d'Arc Creek and to finalize the PMF elevation of the Lower Bois d'Arc Creek Reservoir.

2.4 Hydraulic Model

The final component of the computer model consisted of the river channel floodwave routing, performed with the unsteady flow routine of HEC-RAS[7]. HEC-RAS was originally developed by the Corps of Engineers as a one-dimensional backwater model. The backwater analysis is a water surface profile approximation based on the geometric and friction loss characteristics of the channel. An unsteady version was added by the Corps to route hydrographs through the same river model. This unsteady flow model was used to route the PMF event through Lower Bois d'Arc Creek Reservoir. An unsteady flow model is better suited to the flatter terrain, multiple tributaries, and the significant storage effects of bridges and other features of Bois d'Arc Creek. This is because the finite difference solution better accounts for energy losses due to these factors. Therefore, this routine provides a more accurate water surface profile and flow hydrograph because of the modeled effects of storage attenuation

As shown in Figure 4, the model used cross sections at frequent intervals to describe the channel along Bois d'Arc Creek from approximately 2 miles upstream of state highway 78 to the confluence with the Red River. The cross sections were defined based on the updated one-foot contour map recently developed using LiDAR aerial mapping. All cross sections were extracted using HEC-GeoRAS[8], developed by the Corps of Engineers, which allowed having a georeferenced model.

For Bois d'Arc Creek, 137 cross sections were used to describe 22 miles of the creek channel. This included eight bridges, located where SH 78, FM 271, unknown railroad, SH 56, US 82, FM 1396, FM 409, and FM 100 cross the Bois d'Arc Creek.

The downstream boundary for all models corresponded to the dam, defined with a fixed discharge rating curve for the proposed 150 foot wide service spillway, and 1,400 foot wide emergency spillway. This rating curve was developed based on standard hydraulic design criteria, as published by the Bureau of Reclamation in *Design of Small Dams*[9].

Manning's coefficients were defined for each cross section as a variable of the land use. A land use coverage based on 2006 aerial photographs was created in HEC-GeoRAS, defining 4 different land use types: water, clear areas, wooded areas and intermediate areas. This allowed identifying different land use types along each reach between cross sections. For each reach, a constant roughness coefficient was used to describe the channel roughness, the clear, wooded, and partially wooded overbank areas in the overbank. A roughness coefficient was also defined for the main channel, based on field observations. These four variables were estimated from a site visit to the area. Then appropriate composite roughness factors were developed for each reach based on these values.

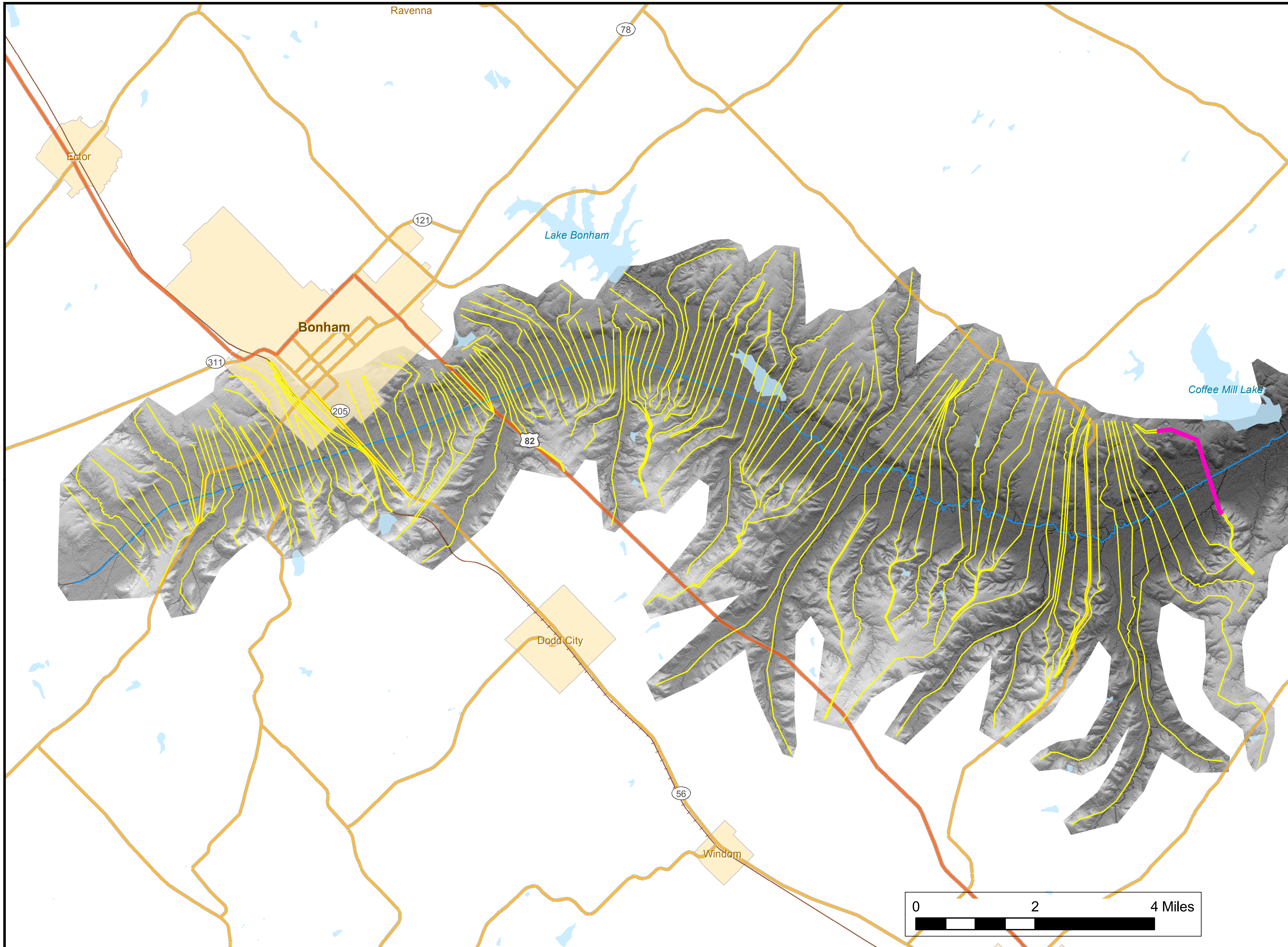

Figure 4

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HEC-RAS model, Cross Sections

Lower Bois d'Arc Creek Reservoir

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2.5 Final Results

The final PMF configuration produced a peak lake level of 550.53 feet at Lower Bois d'Arc Creek Reservoir, a rise of 16.53 feet above normal pool of 534.0. Figure 5 shows the stage and discharge hydrographs for the design storm event. The peak inflow and discharge were estimated to be 250,100 cfs and 143,100 cfs, respectively.

2.6 Wave Runup Conditions

Maximum wave runup for the Lower Bois d'Arc Creek Reservoir dam was determined using standard Corps of Engineers criteria[10]. As described in the new TCEQ guidelines, different wind speeds were used at different reservoir levels. This ranged from maximum historical winds at the conservation pool level to 33% of maximum winds at the PMF level.

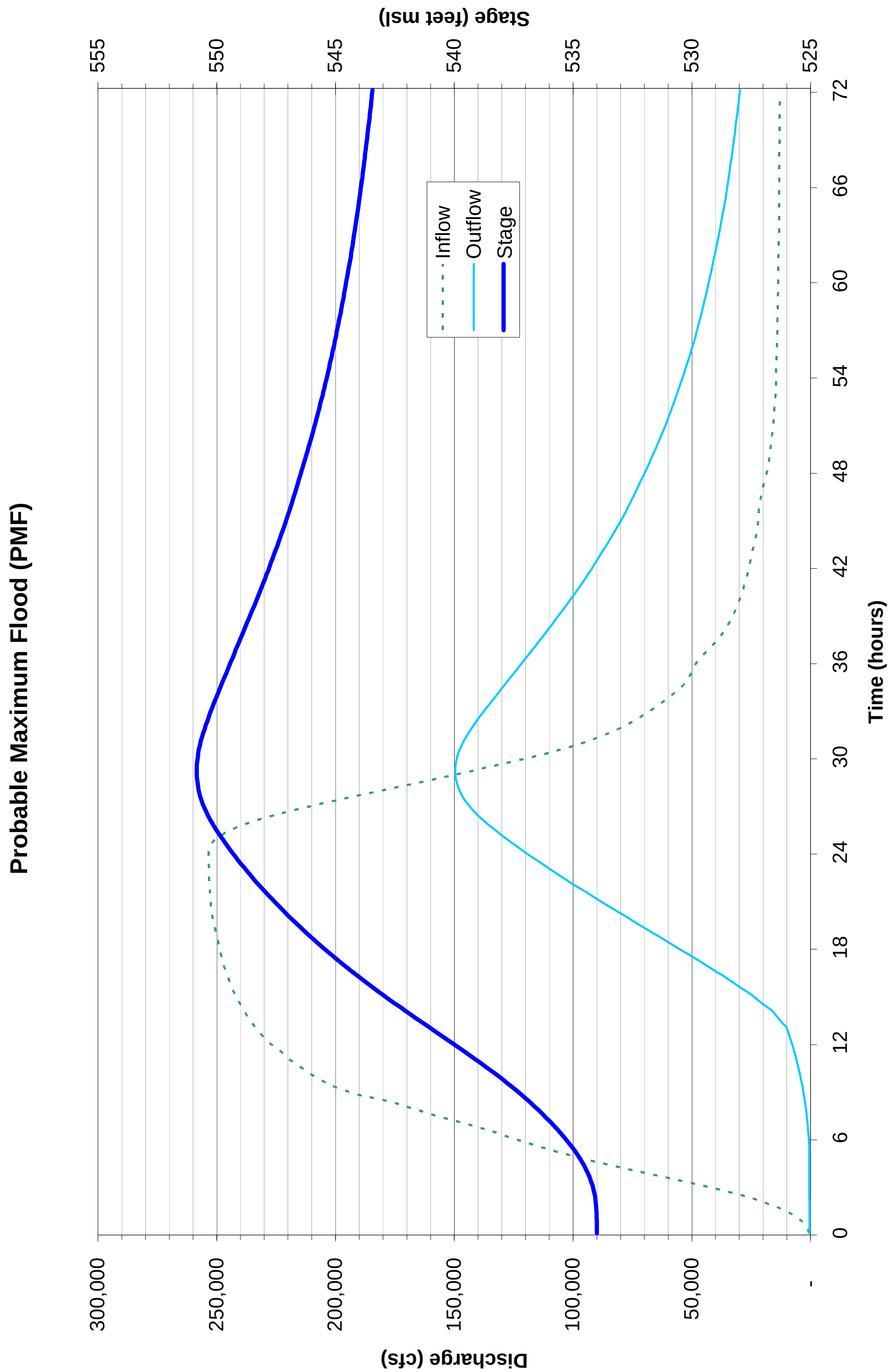
*Table 4 – Wave Runup and Freeboard Calculations**

	Conservation Pool	Emergency Spillway Crest	PMF Elevation
Water Surface Elevation (msl)	534	541	550.53
Effective Fetch (mi)	3.51	4.12	4.42
Wind Velocity (mph)	63	30.5	21.1
Wave Height (ft)	5.00	2.50	1.75
Wave Period (s)	4.30	3.30	2.85
Wave Runup** (ft)	7.50	3.88	2.80
Wind Setup* (ft)	0.70	0.27	0.09
Total Wave Runup* (ft)	8.20	4.14	2.90
Minimum Top of Dam (msl)	542.2	545.1	553.43

* Based on preliminary embankment design, as submitted to TCEQ for water rights application in 2006.
** (assuming a smooth, soil cement surface on the upstream face of the dam)

The above information indicates that the top of dam elevation theoretically required to prevent overtopping from wave runup is 2.9 feet above the PMF elevation. This controlled the top of the dam, and the spillway was sized to allow for the PMF to be passed slightly below the proposed top of dam elevation of 553.5 msl. With the updated model producing a PMF increase of approximately 0.5 feet, the final configuration of the dam may change slightly. This will be determined in the final design phase of the project.

Figure 5 – Probable Maximum Flood Hydrographs at the Dam



3.0 FREQUENCY ANALYSIS

Using the same hydrologic and hydraulic computer modeling system as described for the PMF calculations, an estimate was also made of various frequency floods, including the 10-, 50-, 100-, and 500-year floods. Rainfall values were determined for the full 327 square mile drainage area and distributed over the 11 subbasins and the reservoir surface, itself. Rainfall from standard frequency events, such as the 10-, 50-, 100-, and 500-year rainfall events, were derived from *TP-40* [11], and *HYDRO-35* [12] for durations ranging from 5 minutes to 24 hours. The values were adjusted for the full drainage area based on the depth–area–duration relationships in TP-40. These adjusted rainfall values were assigned evenly to all of the subbasins. Runoff and hydraulic routing for each frequency event were then performed in the same manner as for the PMF. The resulting reservoir elevations are listed in Table 5.

Table 5 – Frequency Analysis of Lower Bois d'Arc Creek Reservoir Elevations

	Return Period (years)			
	10	**50**	**100**	**500**
Total 24Hr Point Rainfall (in)	6.49	8.56	9.59	12.75
Total 24 Hr Adjusted Rainfall (in)	5.91	7.79	8.73	11.61
Peak Inflow (cfs)	68,300	98,000	113,000	168,200
Peak Discharge (cfs)	3,400	5,900	7,100	13,700
Peak Reservoir Elev.	537.57	539.05	539.71	541.63

3.1 Flood Levels in Bonham

The City of Bonham has historically experienced serious and frequent flooding on Bois d'Arc Creek, particularly adjacent to the Highway 56 bridge. Concerns have been raised that the construction of the reservoir could exacerbate this flooding. In the conceptual design of the reservoir project with the preliminary versions of the flood routing models, the normal reservoir pool level was chosen as the highest level that could be used without causing any incremental flooding upstream from Highway 82. The new model with the updated detailed mapping was used to check with greater precision and accuracy whether this design criterion that had been used still applied.

To do this, water surface profiles for each of the four frequency events analyzed were developed from the HEC-RAS model in order to define any potential impact on flood levels in the City of Bonham. These are plotted in Figures 6 through 9, for the 10-, 50-, 100-, and 500-year floods. These profiles are only for the upper end of the reservoir in order to provide greater definition and detail. In each profile, a plot of the current flood levels for these same events is also plotted, providing a comparison of the flood levels along the creek both with and without the reservoir. As can be seen in the profile plots, none of these floods cause higher water levels upstream of Highway 82 than would have occurred without the reservoir. In addition, no incremental impact would exist upstream of the portions shown in the profiles.

In each case, as can be seen in the profiles, there is a significant jump in the profile at the two bridges shown, Highways 82 and 56. This is because both bridges create a significant restriction in the otherwise wide floodplain. For example, at flood levels that almost overtop the Highway 56 bridge, which occurs relatively frequently, flows across the approximately 1 mile wide floodplain are restricted to only a few hundred feet of opening at the bridge. This effectively stores a tremendous amount of water upstream of the bridge and is responsible for the frequent overtopping. Once flow passes the bridge, the flows are then able to again utilize the full width of the floodplain without a restriction, effecting the drop in level. After the bridge is overtopped, more water can pass the bridge more freely, but there is still a significant drop in water surface elevation. The circumstances are similar at the Highway 82 bridge, though that bridge has not historically overtopped. For the 100-year flood, the calculated water surface upstream of Highway 56 is 2.5 feet higher than the water level downstream. At Highway 82, the difference between upstream and downstream levels is 2.3 feet. These bridges effectively serve as hydraulic control structures, forcing water levels to be at a certain level upstream in order have the hydraulic force needed to drive the flow past the constriction that the bridge provides. The water level downstream has little impact on this level, particularly when the bridge is overtopped. This is why the slight difference in water surface profiles with and without the reservoir that exists downstream of the Highway 82 bridge does not exist upstream of the bridge.

From the above information it is evident that:

1. The proposed Lower Bois d'Arc Creek Reservoir will not increase flood levels upstream of Highway 82, including at Highway 56.
2. Current flooding upstream of Highway 82 and Highway 56 bridges is partially due to constriction of the channel capacity at these two bridges. Flooding in this area could be reduced by increasing the channel capacity and the bridge opening size to allow water that now backs up at these bridges to be conveyed downstream under high flow events.

Figure 6 – Water Surface Profiles for the 10-Year Event

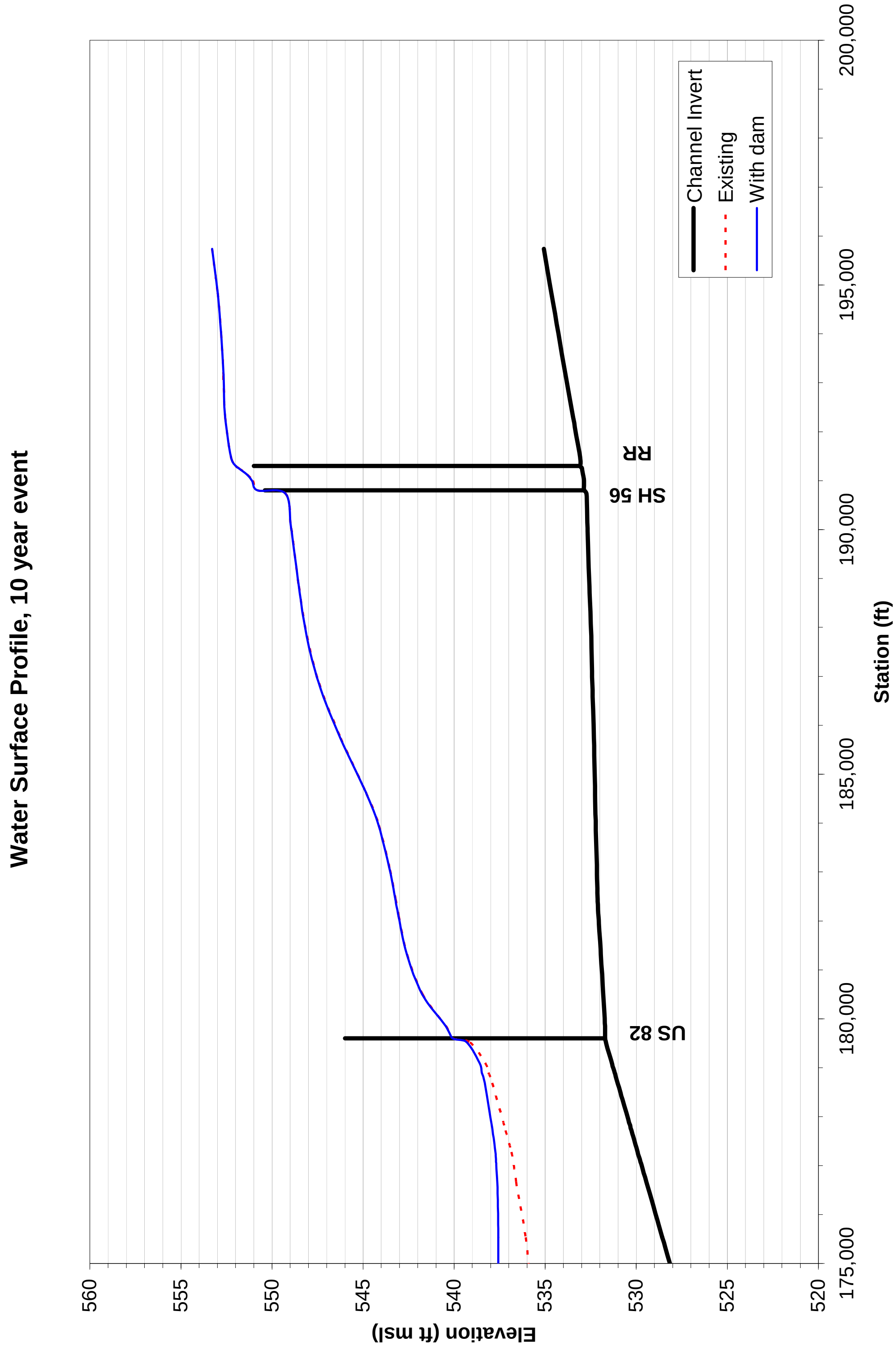


Figure 7 – Water Surface Profiles for the 50-Year Event

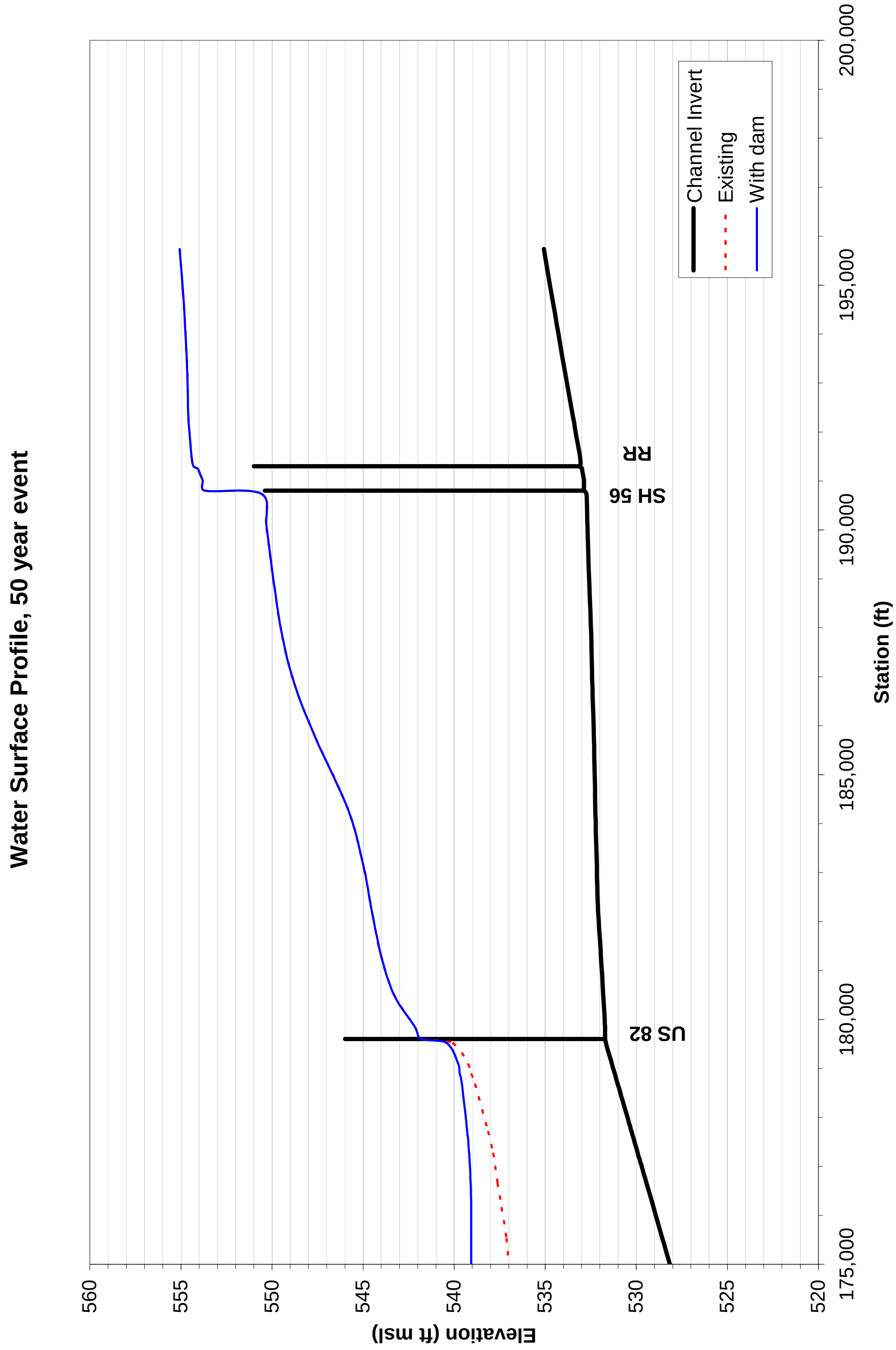


Figure 8 – Water Surface Profiles for the 100-Year Event

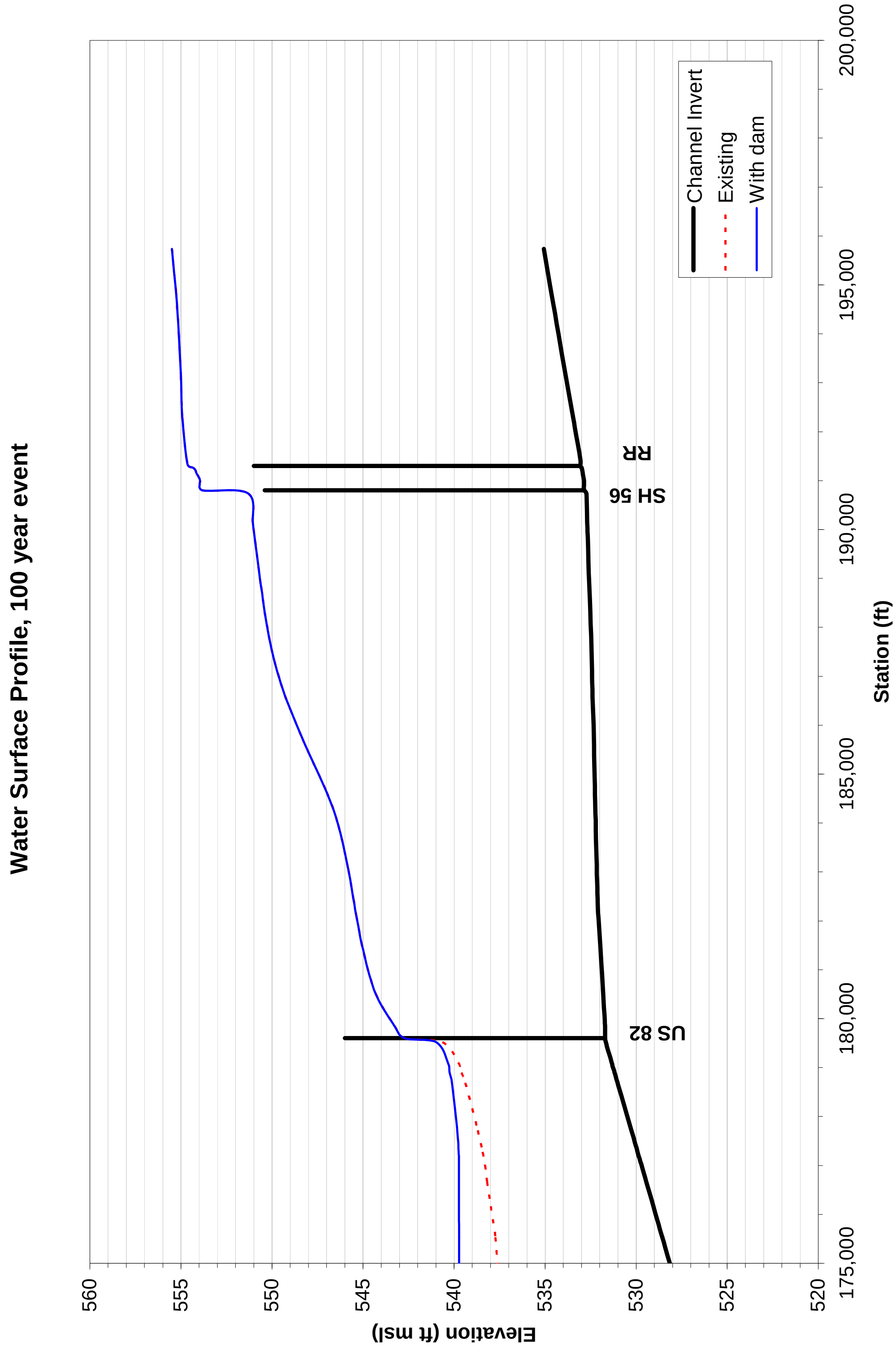
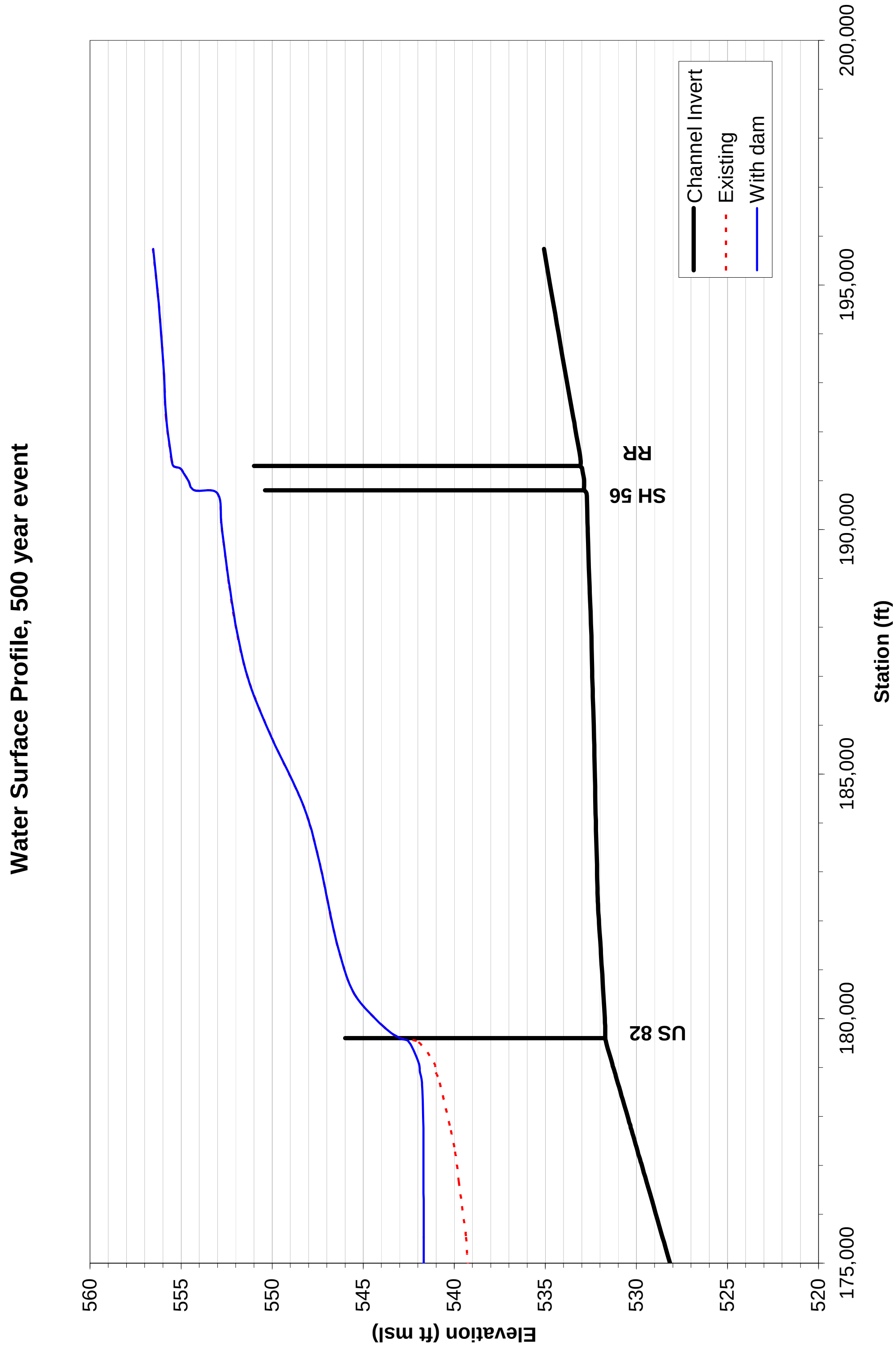


Figure 9 – Water Surface Profiles for the 500-Year Event



APPENDIX A
REFERENCES

1. Texas Commission on Environmental Quality (TCEQ): Hydrologic and Hydraulic Guidelines for Dams in Texas, August 2006.

2. U.S Department of Commerce, National Oceanic and Atmospheric Administration and U.S. Department of the Army, Corps of Engineers: Hydrometeorological Report No. 51, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, Washington, D.C., 1978.

3. U.S Department of Commerce, National Oceanic and Atmospheric Administration and U.S. Department of the Army, Corps of Engineers: Hydrometeorological Report No. 52, Application of Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, Washington, D.C., 1982.

4. National Oceanic and Atmospheric Administration. NOAA Technical Memorandum: NWS HYDRO-35, Five to 60-Minute Precipitation Frequency for the Eastern and Central United States. Silver Springs, Maryland: National Oceanic and Atmospheric Administration, 1977.

5. Us Army Corps of Engineers, Hydrologic Engineering Center: HEC GeoHMS – User's Manual, Davis, California, July 2000.

6. U.S. Army Corps of Engineers, Hydrologic Engineering Center: Hydrologic Modeling System HEC-HMS - User's Manual Version 3.1, Davis, California, November 2006.

7. U.S. Army Corps of Engineers, Hydrologic Engineering Center: River Analysis System - User's Manual, Davis, California, November 2006.

8. U.S. Army Corps of Engineers, Hydrologic Engineering Center: HEC-GeoRAS, An Extension for Support of HEC-RAS Using ArcView, User's Manual, Davis, California, September 2005.

9. US Bureau of Reclamation, Design of Small Dams, third edition, Washington, DC, 1987.

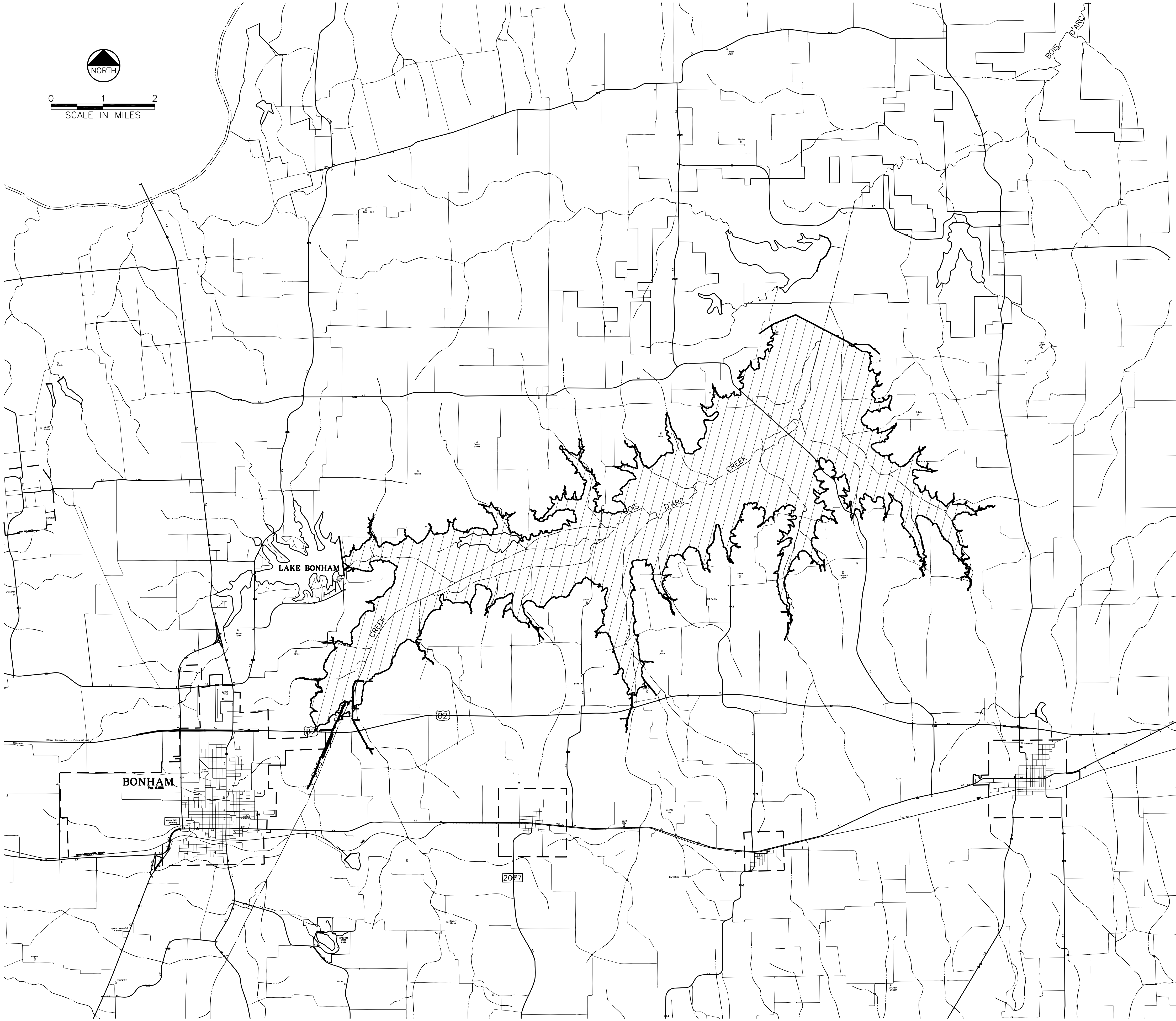
10. McCartney, B.L. 1976. Wave Runup and Wind Setup on Reservoir Embankments, prepared for U.S. Department of the Army, Corps of Engineers.

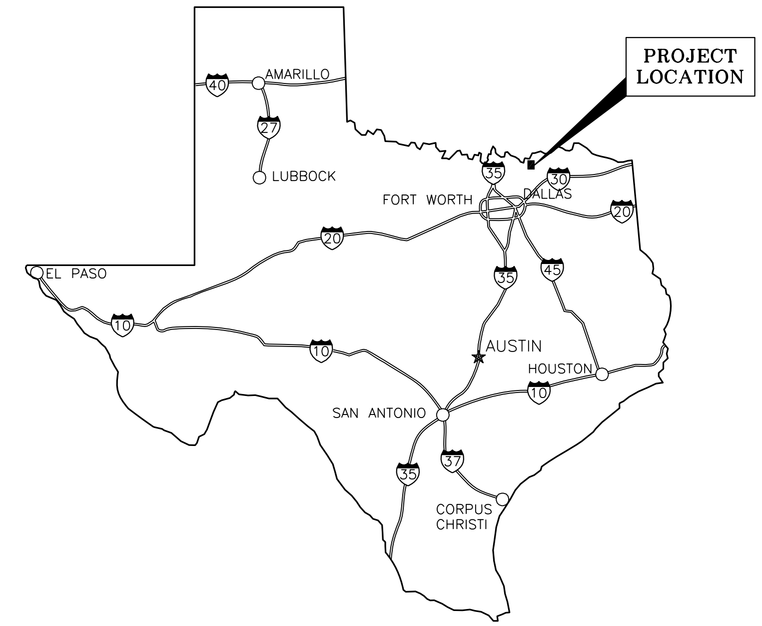
11. U.S. Army Corps of Engineers, Hydrologic Engineering Center: HMR52, Probable Maximum Storm (Eastern United States) User's Manual, March 1984.

12. Hershfield, D.M., 1961. Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. U.S. Weather Bureau, Technical Publication 40.

APPENDIX B

2006 WATER RIGHTS APPLICATION DRAWINGS





LOCATION MAP

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INDEX OF DRAWINGS

1. VICINITY AND LOCATION MAP
2. RESERVOIR AND DIVERSION MAP
3. DAM & SPILLWAYS PLAN AND PROFILE
4. DAM & SPILLWAYS PLAN AND PROFILE
5. TYPICAL EMBANKMENT SECTION AND MISCELLANEOUS SECTIONS
6. SERVICE SPILLWAY PLAN & SECTIONS
7. HYDRAULIC AND HYDROLOGIC DATA

I CERTIFY THAT THE APPLICATION DRAWINGS FOR LOWER BOIS D'ARC RESERVOIR PROJECT, SHEETS 1 THROUGH 7 DATED JULY 2006, OF NORTH TEXAS MUNICIPAL WATER DISTRICT, WERE PREPARED BY ME OR UNDER MY SUPERVISION.

REGISTERED PROFESSIONAL ENGINEER
4055 INTERNATIONAL PLAZA, SUITE 200
FORT WORTH, TEXAS 76109

NORTH TEXAS MUNICIPAL WATER DISTRICT
505 EAST BROWN STREET
WYLIE, TEXAS 75098

LOWER BOIS D'ARC CREEK RESERVOIR

FANNIN COUNTY, TEXAS

VICINITY AND LOCATION MAPS

DESIGNED: GGJ DRAWN: CAM TRACED: CHECKED: JLR	FREESE AND NICHOLS, INC. CONSULTING ENGINEERS FORT WORTH, TEXAS	DATE: JULY 17, 2006 SCALE: AS SHOWN SHEET 1 OF 7

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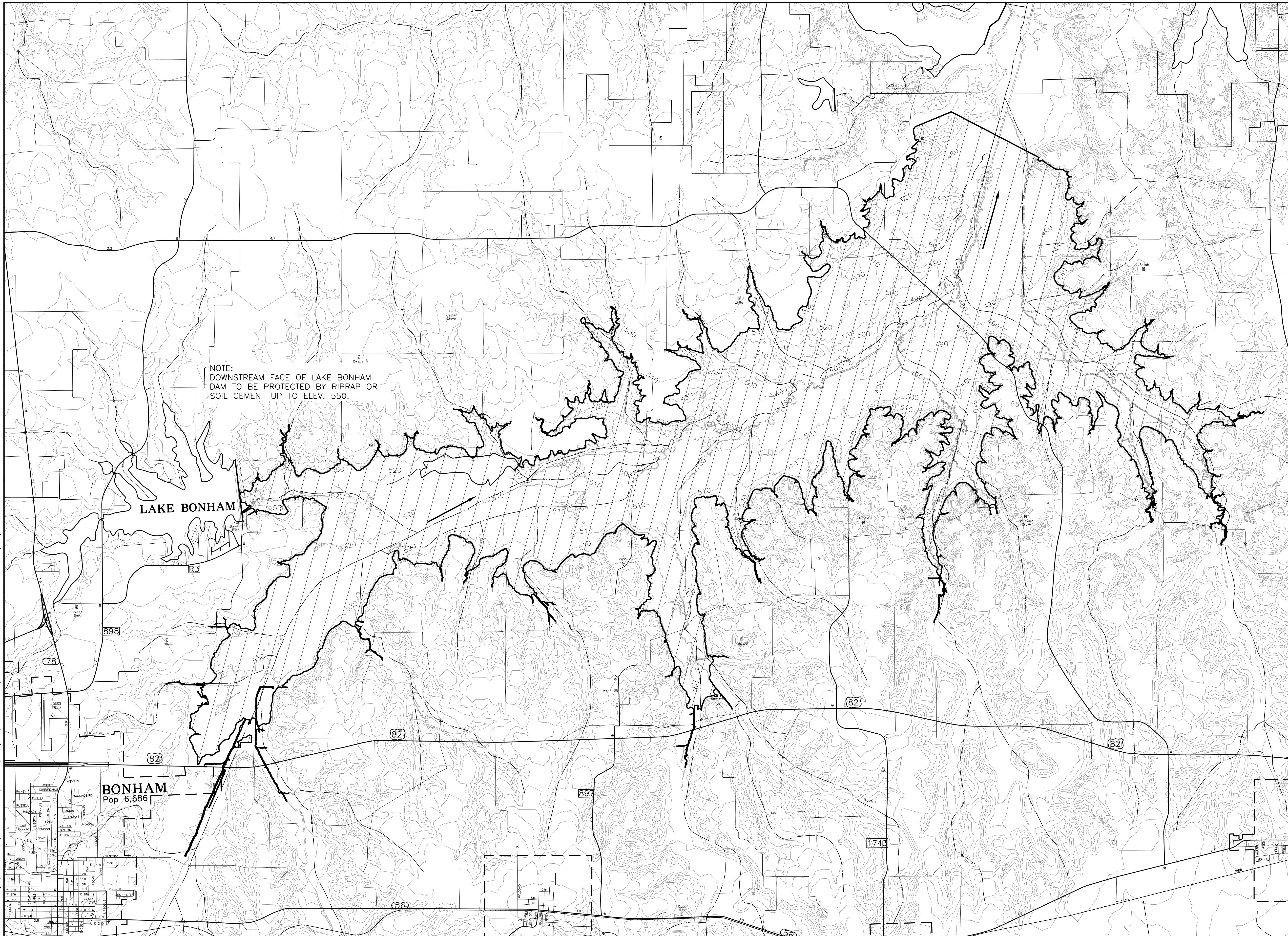

NORTH

0 3000' 6000'
SCALE IN FEET

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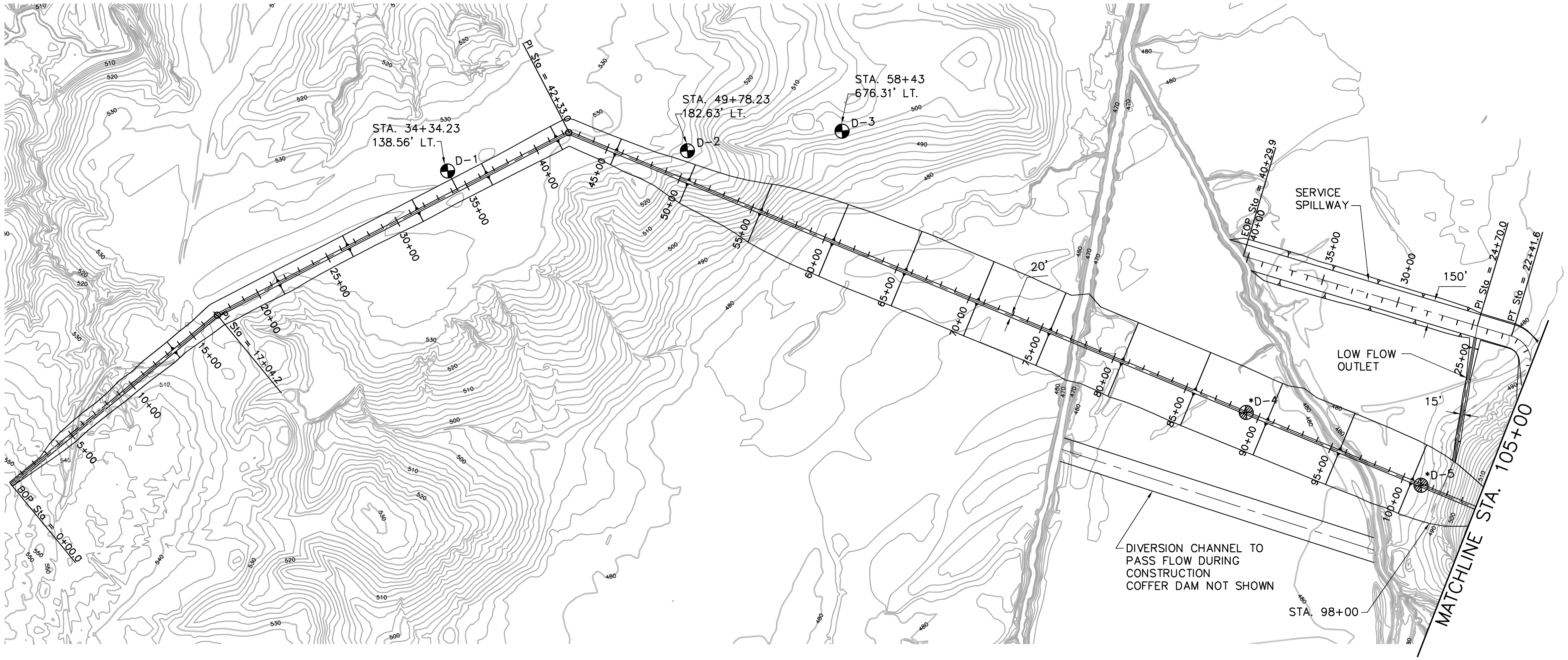
LOWER BOIS D'ARC CREEK RESERVOIR

FANNIN COUNTY, TEXAS

RESERVOIR AND DIVERSION MAP

DESIGNED: GGJ DRAWN: CAM TRACED: CHECKED: JLR	FREESE AND NICHOLS, INC. CONSULTING ENGINEERS FORT WORTH, TEXAS	DATE: JULY 17, 2006 SCALE: AS SHOWN SHEET 2 OF 7	



N

0 400' 800'
SCALE IN FEET

LEGEND

- D-1 COMPLETED SOIL BORINGS
- *D-1 PROPOSED SOIL BORING

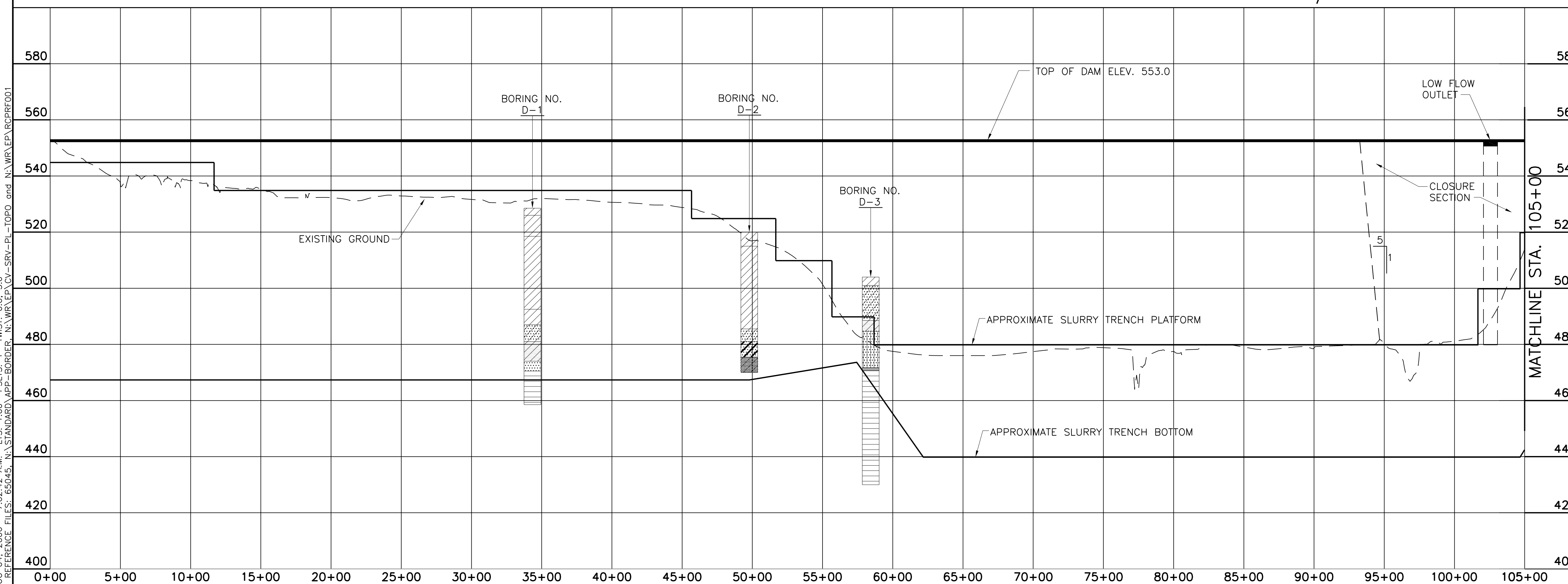
NOTE:

* ACCESS HAS NOT BEEN GRANTED TO THE PROPOSED SOIL BORING LOCATIONS AT THE TIME OF THIS REPORT.

KEY TO SYMBOLS

STRATA SYMBOLS

- SANDY CLAY (CL)
- CLAYEY SAND (SC)
- POORLY GRADED SAND
- SHALE
- SANDY CLAY (CH)
- LOW PLASTICITY CLAY (CL)
- SILTY SAND
- WEATHERED SHALE



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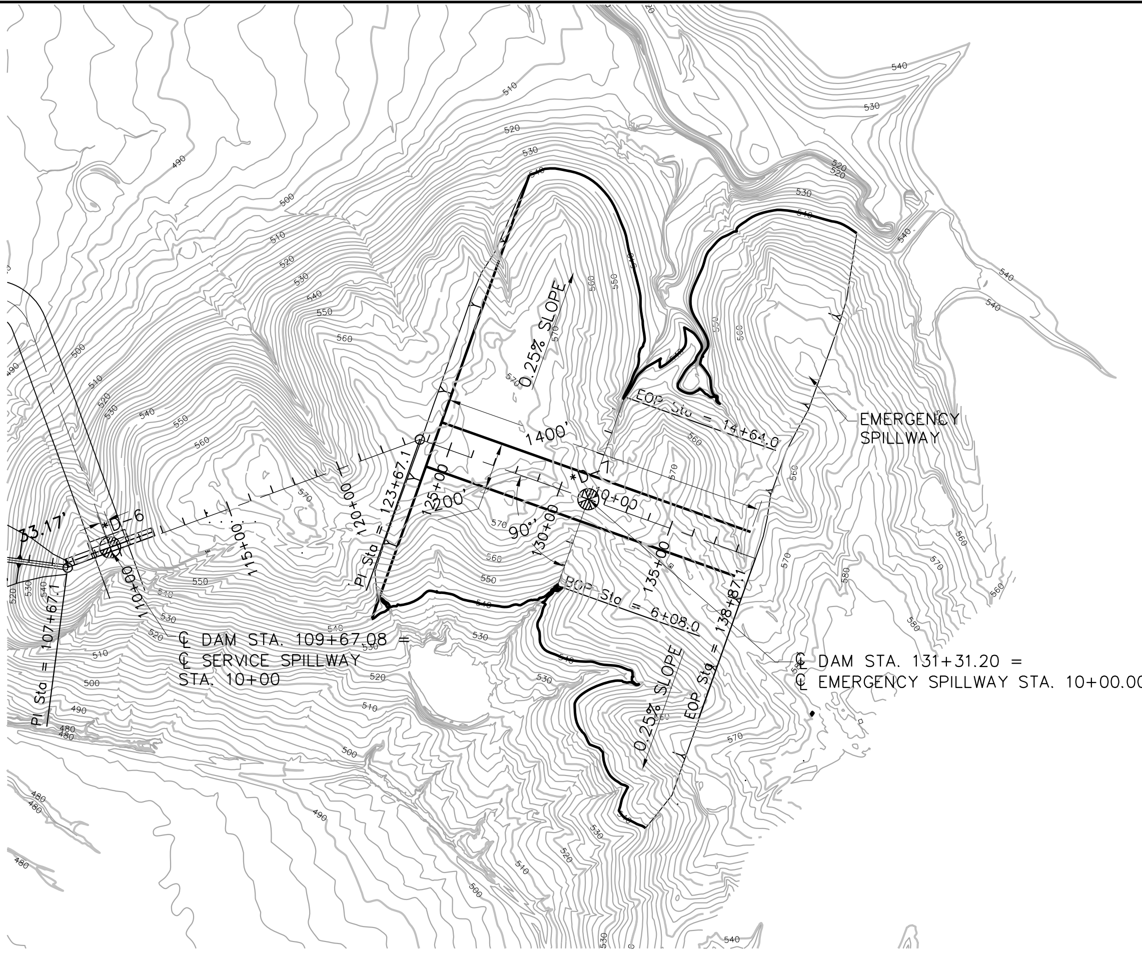
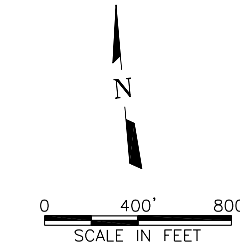
LOWER BOIS D'ARC CREEK RESERVOIR

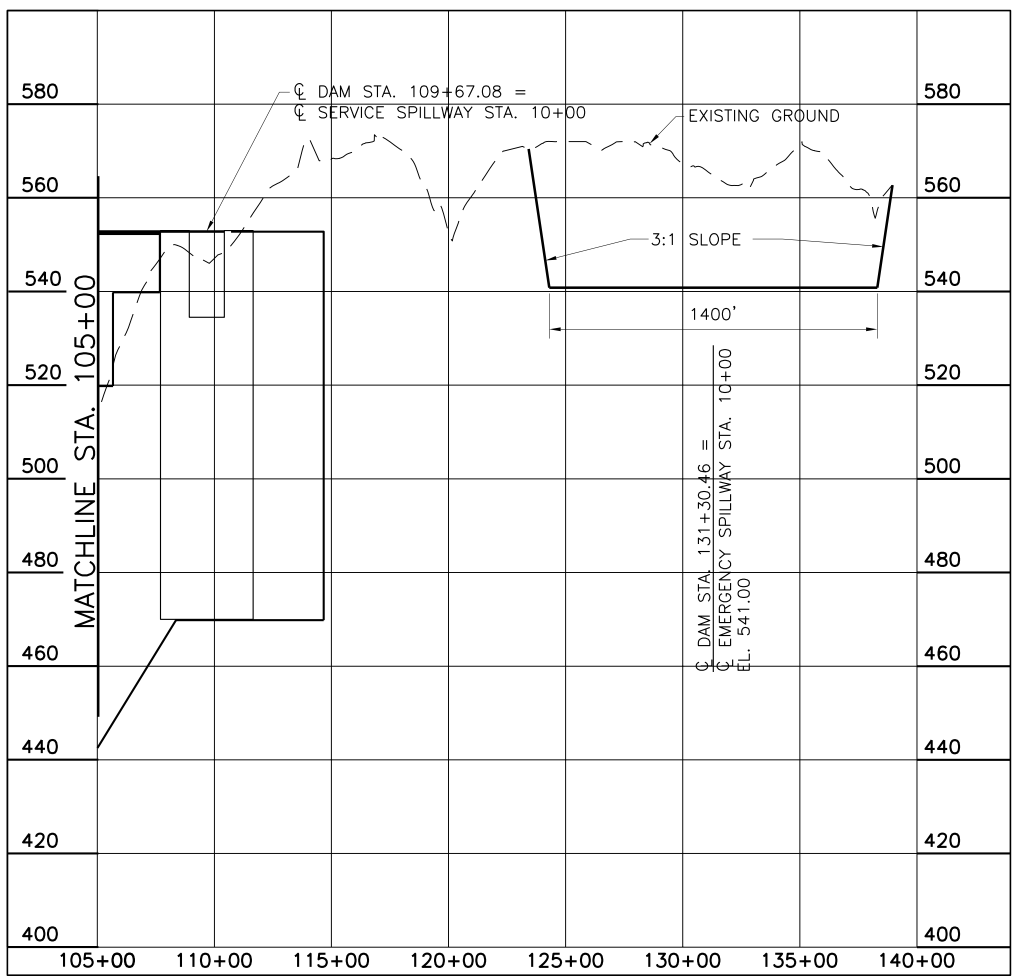
FANNIN COUNTY, TEXAS

DAM & SPILLWAYS PLAN AND PROFILE

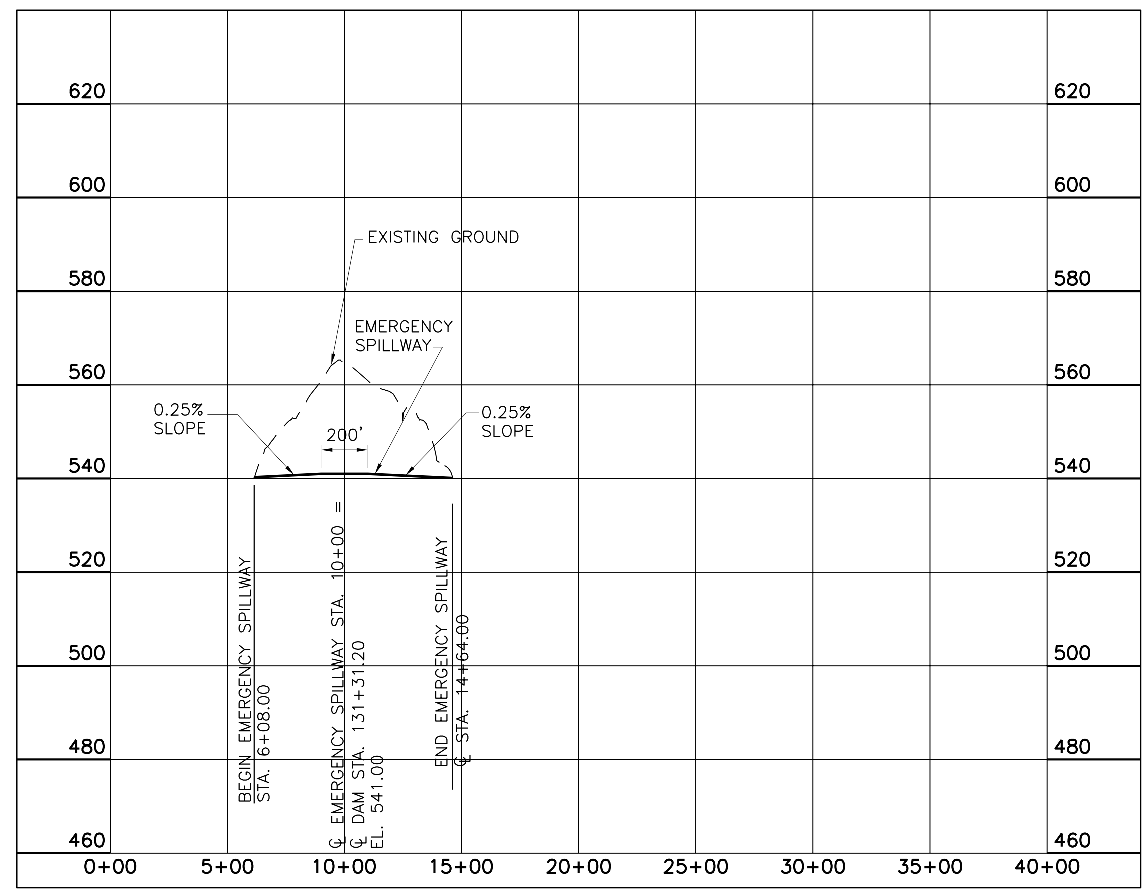
DESIGNED: GGJ DRAWN: NBB TRACED: CHECKED: JLR	FREESE AND NICHOLS, INC. CONSULTING ENGINEERS FORT WORTH, TEXAS	DATE: JULY 17, 2006 SCALE: AS SHOWN SHEET 3 OF 7	







℄ LOWER BOIS D'ARC DAM



℄ EMERGENCY SPILLWAY

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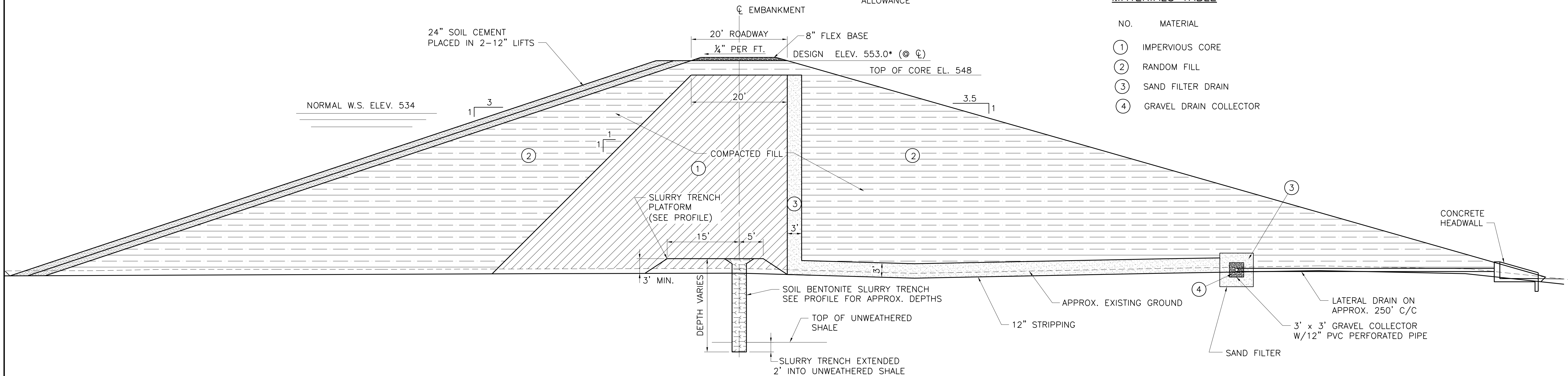
LOWER BOIS D'ARC CREEK RESERVOIR

FANNIN COUNTY, TEXAS

DAM & SPILLWAYS
PLAN AND PROFILE

DESIGNED:	GGJ	FREESE AND NICHOLS, INC.	DATE: JULY 17, 2006
DRAWN:	NBB	CONSULTING ENGINEERS	SCALE: AS SHOWN
TRACED:		FORT WORTH, TEXAS	SHEET 4 OF 7
CHECKED:	JLR		

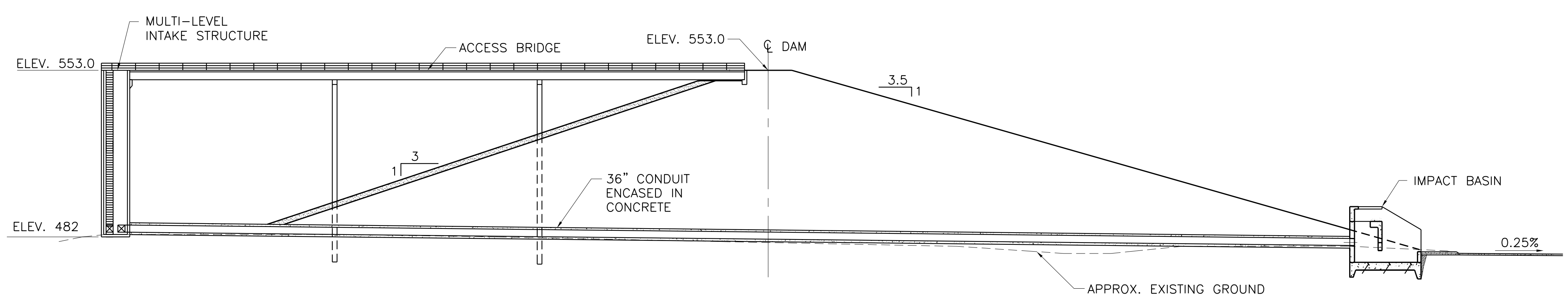


MATERIALS TABLE

NO.	MATERIAL
1	IMPERVIOUS CORE
2	RANDOM FILL
3	SAND FILTER DRAIN
4	GRAVEL DRAIN COLLECTOR

1 TYPICAL SECTION THROUGH EMBANKMENT

0 10' 20'
SCALE IN FEET



2 SECTION THROUGH LOW-FLOW OUTLET

0 10' 20' 30' 60'

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LOWER BOIS D'ARC CREEK RESERVOIR
FANNIN COUNTY, TEXAS

TYPICAL EMBANKMENT SECTION AND MISCELLANEOUS SECTION

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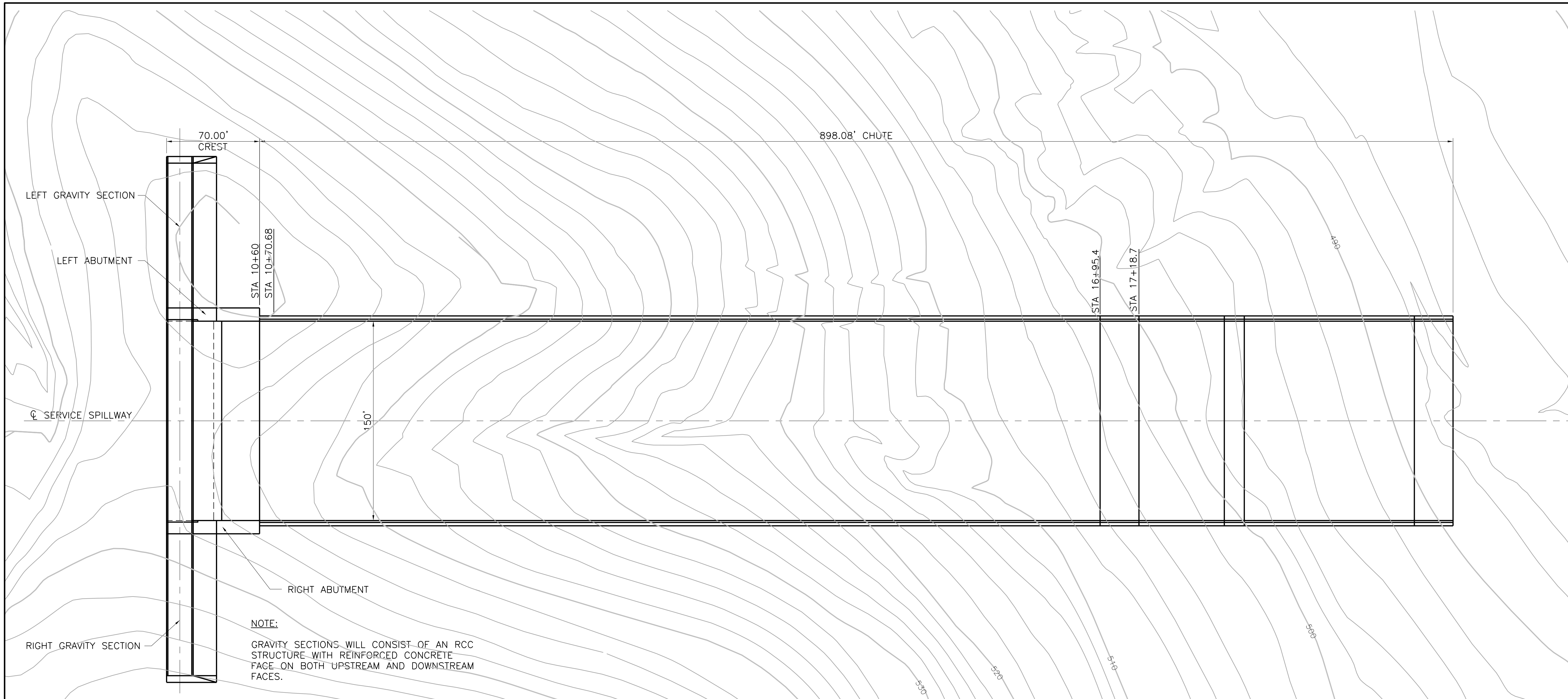
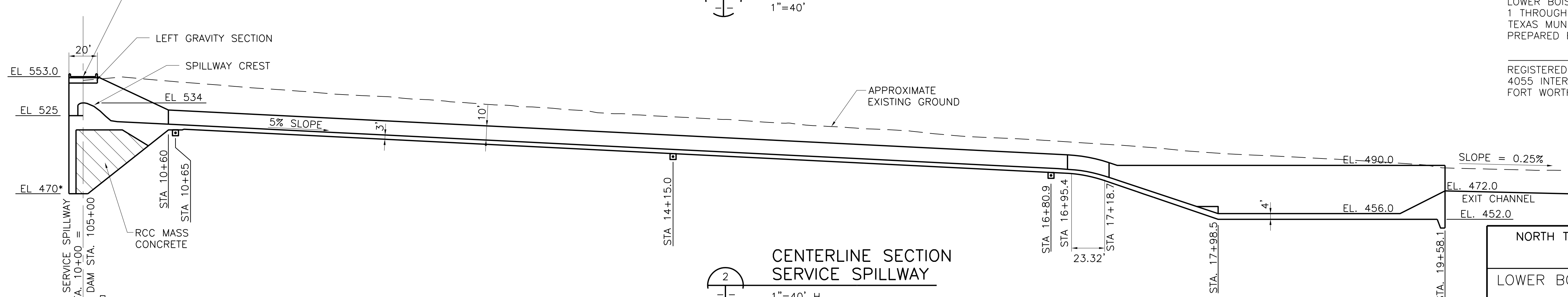


NOTE:

GRAVITY SECTIONS WILL CONSIST OF AN RCC STRUCTURE WITH REINFORCED CONCRETE FACE ON BOTH UPSTREAM AND DOWNSTREAM FACES.

1 PLAN
SERVICE SPILLWAY
1"=40'



2 CENTERLINE SECTION
SERVICE SPILLWAY
1"=40' H
1"=20' V

* TO BE FOUNDED ON UNWEATHERED SHALE. ELEVATION TO BE DETERMINED.

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LOWER BOIS D'ARC CREEK RESERVOIR

FANNIN COUNTY, TEXAS

SPILLWAY PLAN AND SECTION

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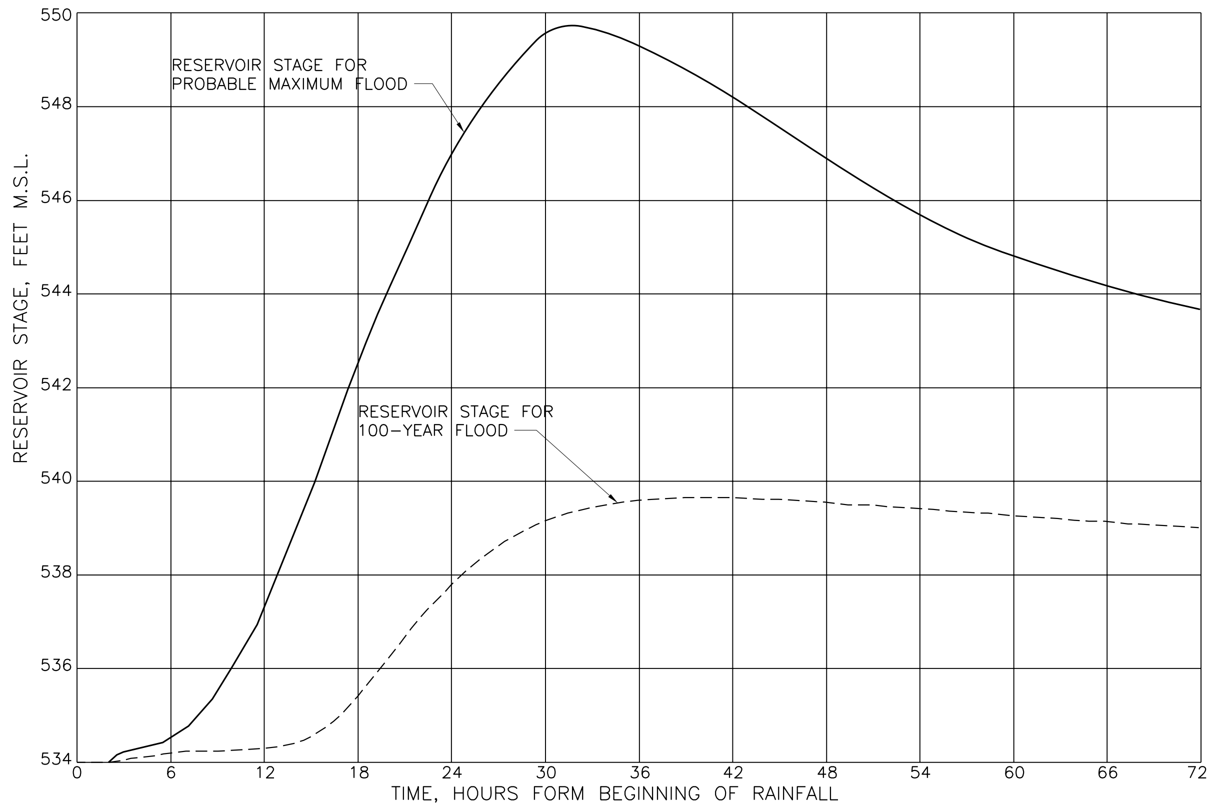
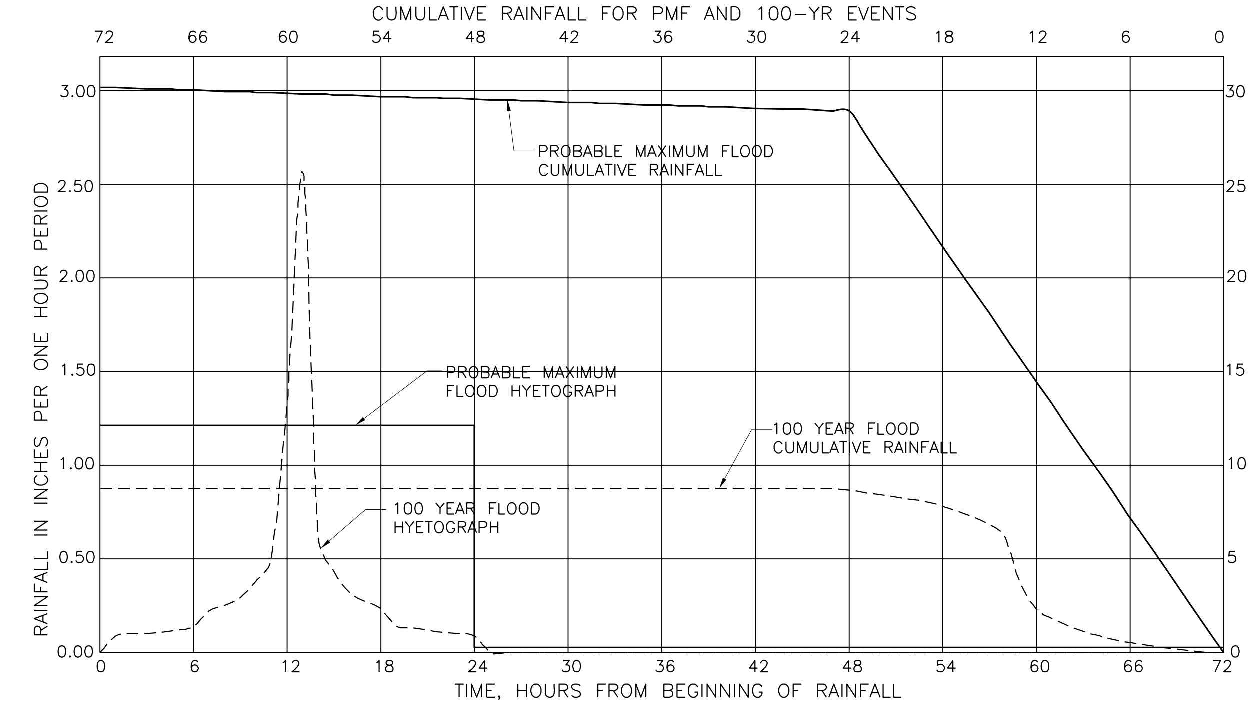
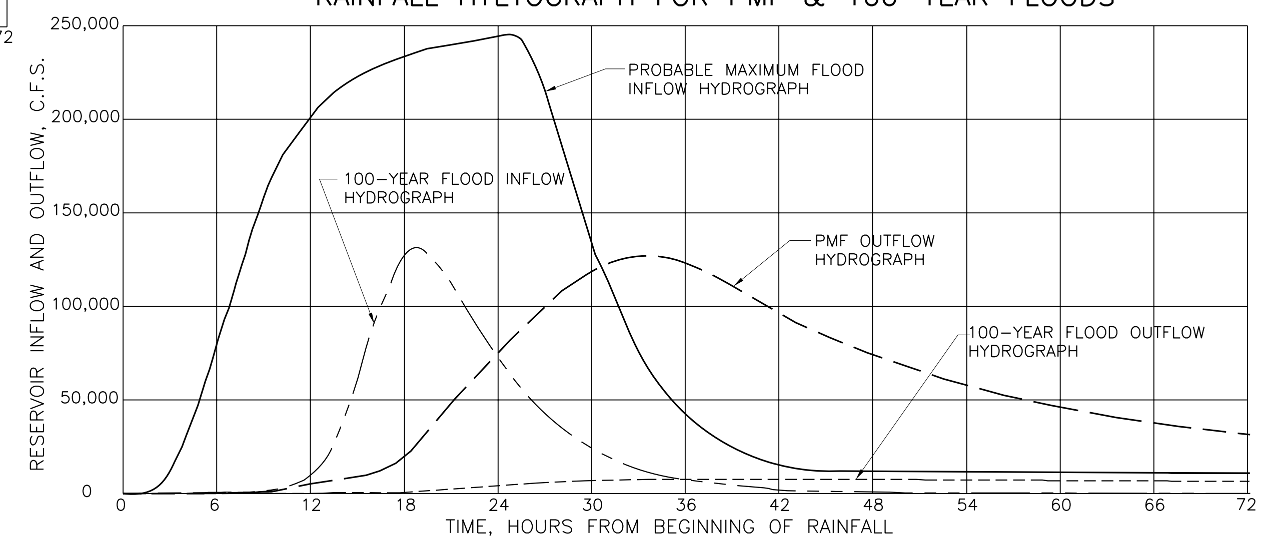


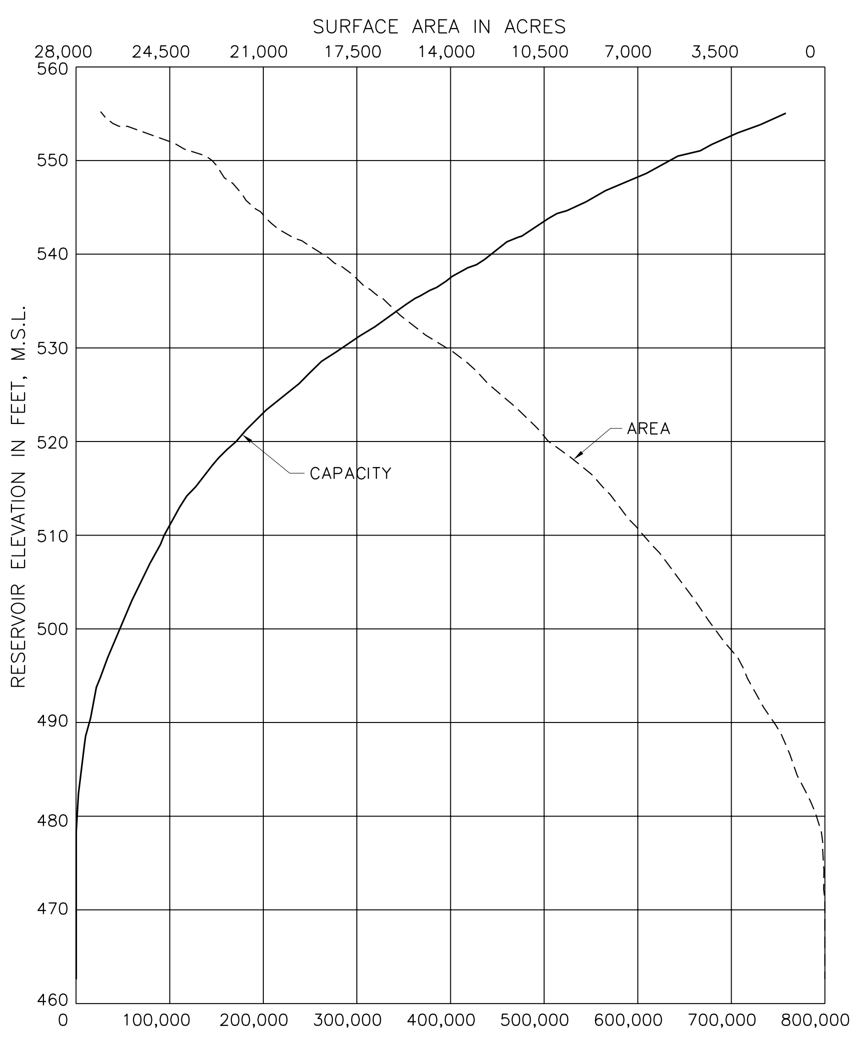
RESERVOIR STAGE FOR PMF AND 100-YEAR FLOOD



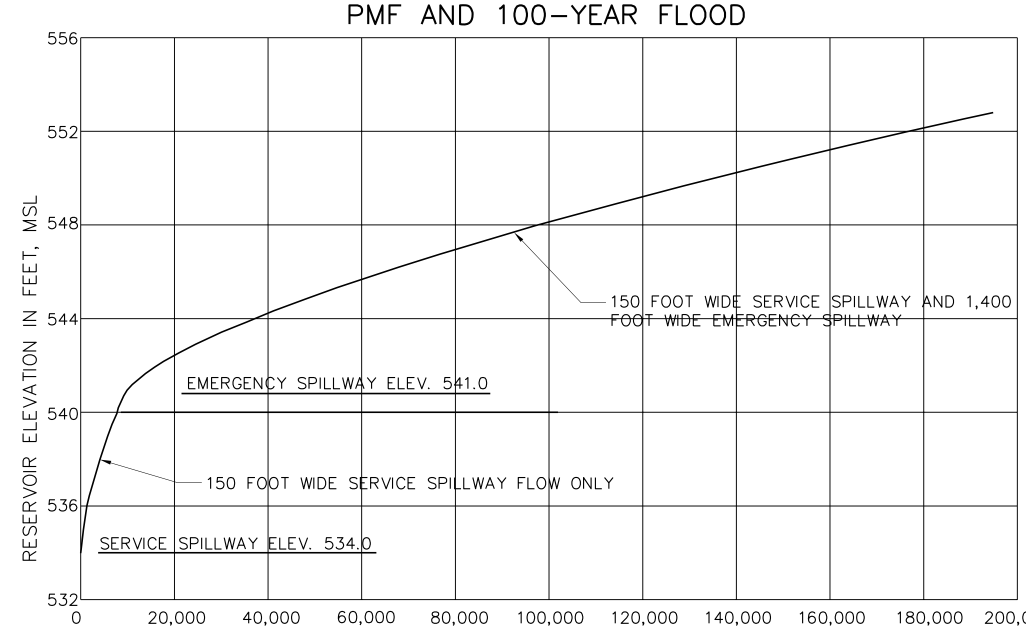
RAINFALL HYETOGRAPH FOR PMF & 100-YEAR FLOODS



PMF AND 100-YEAR FLOOD



AREA – CAPACITY CURVES



SPILLWAY RATING CURVE

PERTINENT DATA LOWER BOIS D'ARC CREEK RESERVOIR

MISCELLANEOUS	
DRAINAGE AREA ABOVE DAM, SQUARE MILES	326.7
IMPOUNDED AT NORMAL MAX. W.S. ELEV. 534.0	
SURFACE AREA , ACRES	16,526
STORAGE CAPACITY, ACRE-FEET	367,609
PROBABLE MAXIMUM FLOOD ON BOIS D'ARC CREEK WATERSHED	
PEAK INFLOW, C.F.S.	242,229
VOLUME OF RUNOFF, ACRE-FEET	520,987
VOLUME OF RUNOFF, INCHES	29.90
PEAK OUTFLOW, C.F.S.	128,189
100-YEAR FLOOD ON BOIS D'ARC CREEK WATERSHED	
PEAK INFLOW, C.F.S.	130,758
VOLUME OF RUNOFF, ACRE-FEET	119,086
VOLUME OF RUNOFF, INCHES	6.83
PEAK OUTFLOW, C.F.S.	7,693

RESERVOIR

FEATURE:	ELEVATION FEET, M.S.L.	AREA ACRES	CAPACITY ACRE-FEET
TOP OF DAM	553.0	26,715	757,446
PROBABLE MAX. FLOOD ON BOIS D'ARC CREEK	549.8	23,832	673,573
100-YEAR FLOOD ON BOIS D'ARC CREEK	540.0	19,616	467,767
NORMAL W.S.	534.0	16,526	367,609
STREAMBED	462.8	0	0

SERVICE SPILLWAY
TYPE: 150' WIDE UNCONTROLLED OGEE SPILLWAY WITH HYDRAULIC JUMP STILLING BASIN

EMERGENCY SPILLWAY
TYPE: 1400' WIDE UNCONTROLLED BROAD CRESTED SPILLWAY

DAM	
TYPE: EARTHFILL	
TOTAL LENGTH, FEET	10,400
HEIGHT ABOVE STREAMBED, FEET	90
CROWN WIDTH, FEET	20
SIDE SLOPES:	
UPSTEAM	3:1
DOWNSTREAM	3:1

NOTE:
TAILWATER RATING CURVE NOT SHOWN. SPILLWAY DISCHARGE NOT AFFECTED BY TAILWATER.

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HYDRAULIC AND HYDROLOGICAL DATA

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