BUREAU OF RECLAMATION

Technical Report No. ENV-2020-011

Thunderbird Reservoir 2015 Sedimentation Survey

Norman Project, Oklahoma
Great Plains Region

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Sedimentation and River Hydraulics Group
Denver, Colorado

February 2020
Rev 1 January 2021

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Acknowledgements

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Cover: Norman Dam, Oklahoma (Reclamation)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
Rev 1 January 2021	Final report	May to June 2015

4. TITLE AND SUBTITLE
Technical Report No. ENV-2019-011
Thunderbird Reservoir 2015 Sedimentation Survey
Norman Project, Oklahoma
Great Plains Region

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Technical Service Center
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Building 67, Mail Code: 86-68240
Denver, Colorado

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
https://www.usbr.gov/tsc/techreferences/reservoir.html

13. SUPPLEMENTARY NOTES

14. SHORT ABSTRACT

The 2015 multibeam bathymetric survey of Thunderbird Reservoir was combined with 2007 Aerial LiDAR to produce a combined digital surface of the reservoir bottom. Analysis of this data indicates that at the top of flood control pool elevation (1049.4 feet, Reclamation Project Vertical Datum), the reservoir would have a surface area of 7,959 acres and a storage capacity of 172,718 acre-feet. Since the original filling in 1966, the reservoir is estimated to have lost 23,500 acre-feet of storage capacity (12%) due to sedimentation.

15. SUBJECT TERMS
Thunderbird Reservoir survey, sedimentation, capacity,

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	THIS PAGE			Blair Greimann
U	U	U		67	19b. TELEPHONE NUMBER *(Include area code)* 303-445-2563

BUREAU OF RECLAMATION
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Acronyms and Abbreviations

AF	acre-feet
cfs	cubic feet per second
DOI	Department of the Interior
DEM	Digital Elevation Model
°F	degrees Fahrenheit
ft	foot (feet)
GIS	Geographic Information System
GPS	Global Positioning System
HARN	High Accuracy Reference Network
HUC	Hydrologic Unit Code
in	inches
LiDAR	Light Detection and Ranging
mi^2	Square miles
m	Meters
NAD 1983	North American Datum, established 1983
NAVD 1988	North American Vertical Datum, established 1988
NGS	National Geodetic Survey
NGVD 1929	National Geodetic Vertical Datum, established 1929
NID	National Inventory of Dam
NRCS	Natural Resources Conservation Service
OK	Oklahoma
OPUS	Online Positioning User Service
%	Percent
Reclamation	Bureau of Reclamation
RPVD	Reclamation Project Vertical Datum
RSI	Reservoir Sedimentation Information
RTK	Real-Time Kinematic
SGMC	State Geologic Map Compilation
TSC	Technical Service Center
USGS	U.S. Geological Survey
yr	Year

Executive Summary

Norman Dam was constructed by Bureau of Reclamation from 1962 to 1965 and is located at the confluence of Hog Creek and Little River about 13 miles east of Norman, Oklahoma and about 30 miles southeast of Oklahoma City, Oklahoma. The zoned earthfill dam impounds water, creating Thunderbird Reservoir. A bathymetric survey of Thunderbird Reservoir was conducted in 2015 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1966 and since the last survey in 2001 and

2. Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations.

A complete bathymetric survey was conducted from May 30 to June 6, 2015 from a boat using a Teledyne® MB1 multibeam depth sounder to continuously measure water depths. The horizontal position of the moving boat was continually tracked using Real-Time Kinematic Global Positioning System (RTK GPS).

These bathymetric data were combined with Light Detection and Ranging (LiDAR) data collected by the City of Norman on February 7, 2007. They provided 2-foot contours developed from that LiDAR and this data was used for elevations above the pool elevation to produce a digital surface of the reservoir bottom surface.

Analysis of the combined data sets indicates the following results:

- At the top of the conservation pool of 1039 feet (Reclamation Project Vertical Datum) the reservoir surface area was 5,505 acres with a total (gross) storage capacity of 103,840 acre-feet.
- At the top of flood control pool elevation (1049.4 feet, Reclamation Project Vertical Datum), the reservoir would have a surface area of 7,959 acres and a storage capacity of 172,718 acre-feet (AF).
- Approximately 23,500 AF of sedimentation below the spillway crest has occurred since construction in 1965, which is approximately 12 percent of the original storage below spillway crest. The average sedimentation rate over this 50-year period is 470 AF/year (yr) below the spillway crest. This equates to a sediment yield of 1.93 AF/mi^2/yr which is considered high as defined in Reclamation (2006).
- The current measured design dead storage is approximately 73 percent of the original design and is accumulating sediment at rate of 0.2 ft/yr near the intake. The current minimum sediment elevation is at 983 feet, which is 14 feet below the elevation of the low-level intake.

A summary description of the dam, reservoir, and survey results is presented in Table ES-1.

Table ES-1. Reservoir Survey Summary Information

Reservoir Information

Reservoir Name	Lake Thunderbird	**Region**	Great Plains
Owner	Bureau of Reclamation	**Area Office**	Ok-Tx
Stream	Little River	**Vertical Datum**	RPVD
County	Cleveland	**Top of Dam (ft)**	1,071.0
State	Oklahoma	**Spillway Crest (ft)**	1,049.4
Lat (deg min sec)	35 12 24	**Power Penstock Elevation (ft)**	NA
Long (deg min sec)	97 13 02	**Low Level outlet (ft)**	1,010
HUC4	1109	**Hydraulic Height (ft)**	94.7
HUC8	11090203	**Total Drainage Area (mi^2)**	257
NID	OK02504	**Year storage began**	1966
Dam Purpose	Irrigation, Municipal Water, Recreation, Flood	**Year for normal operations**	1966

Original Design

Storage Allocation	Elevation (ft)	Surface area (acres)	Capacity (AF)	Gross Capacity (AF)
SURCHARGE	1,064.7	-	171,300	367,500
FLOOD CONTROL	1,049.4	8,788	76,600	196,200
CONSERVATION	1,039	-	105,900	119,600
INACTIVE	1,010	-	12,500	13,700
DEAD	997	-	1,200	1,200

Survey Summary

Survey Date	Type of Survey	No. of Range lines or Contour Intervals	Contributing Sediment Drainage Area (mi^2)	Period Sedimen-tation Volume (AF)	Cumula-tive Sedimen-tation (AF)	Lowest Reservoir Elevation (ft)	Remaining Portion of Dead Storage (%)
1965	Photogram-metry	5-ft	244	-	-	974	
2001	Single beam	Unknown	244	19,000	19,000	983	93
2015	Multibeam/LiDAR	1-ft/2-ft	244	4,500	23,500	983	73

Notes

Survey Summary volumes are the volumes below the spillway crest elevation of 1,049.4 feet

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1. Introduction

Norman Dam is located at the confluence of Hog Creek and Little River about 13 miles east of Norman, Oklahoma and about 30 miles southeast of Oklahoma City, Oklahoma. The zoned earthfill dam impounds water, creating Thunderbird Reservoir, which is more commonly called Lake Thunderbird (Figure 1). The dam and reservoir are operated by Central Oklahoma Master Conservancy District as part of the Norman Project that provides a supplemental municipal water supply for the cities of Norman, Del City, and Midwest City, Oklahoma; flood protection to lands south and east of the project area; and recreation benefits to the surrounding area. Principal features are Norman Dam on Little River about 13 miles east of Norman, Oklahoma; two pumping plants, and pressure pipelines serving the three municipalities. No irrigation features or power development are included in the project.

Because all rivers transport sediment particles (e.g., clay, silt, sand, gravel, and cobble) and reservoirs tend to trap sediment, the reservoir storage capacity diminishes over time. Reservoir sedimentation affects all elevations of the reservoir, even above and upstream of the full pool elevations. Cobble, gravel, and sand particles tend to deposit first forming deltas at the upstream ends of the reservoir while silt and clay particles tend to deposit along the reservoir bottom between the delta and dam.

Periodic reservoir surveys measure the changing reservoir surface area and storage capacity and provide information for forecasting when important dam and reservoir facilities will be impacted by sedimentation.

As part of ongoing operations and sediment monitoring activities, the Great Plains Regional office requested the Technical Service Center's (TSC) Sedimentation and River Hydraulics Group (86-68240) to conduct a bathymetric survey of the underwater portions of the reservoir that were accessible by boat. A complete bathymetric survey was conducted from May 30 to June 6, 2015 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1966 and since the last survey in 2001 and

2. Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations.

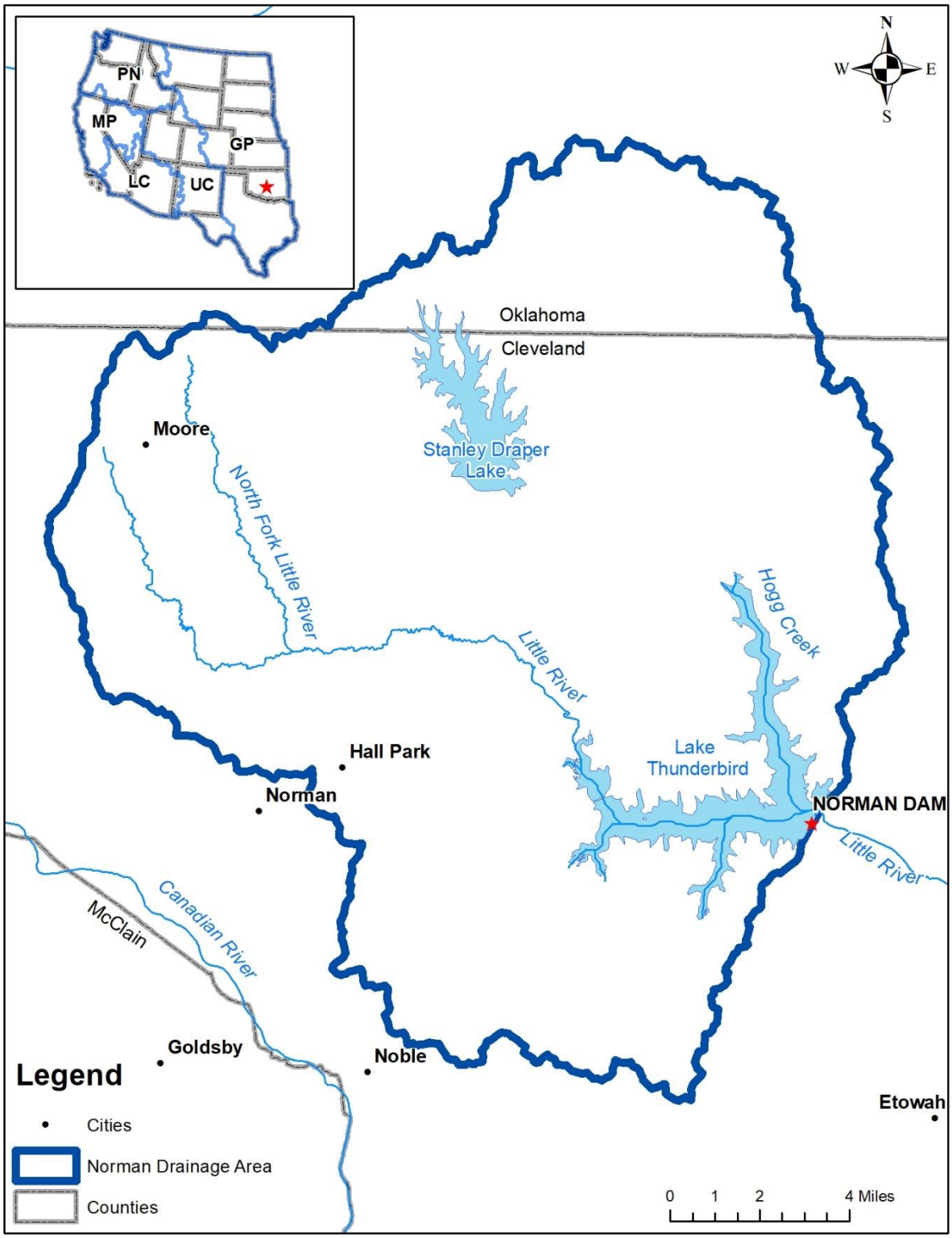

Figure 1. Location map of Norman Dam and Thunderbird Reservoir (also called Lake Thunderbird), 13 miles east of Norman, Oklahoma.

2. Watershed Description

The watershed upstream from Norman Dam has a total contributing drainage area of 257 mi^2 and there is one significant upstream dam named Stanley Draper Dam, built in 1962, which reduces the sediment contributing drainage area above Norman Dam to 244 mi^2. The city limits of Oklahoma City, Moore, and Norman, Oklahoma encompass both Thunderbird Reservoir and almost the entire watershed contributing to the reservoir. The dam was built just downstream of the confluence of the Little River and Hog Creek. The Little River watershed is approximately 175 mi^2 of the total watershed area, while Hog Creek watershed is 82 mi^2.

2.1. Geology, Soils and Land Use

The watershed area, average precipitation, elevations, and hydrologic characteristics derived from USGS StreamStats (USGS, 2019) online tool and a 30-Meter Digital Elevation Model (DEM) are given in Table 1. The watershed has low relief with only about 380 feet of elevation change.

A description of the basin is given in the Reclamation Project Data online (Reclamation, 2019b): Little River has eroded its shallow valley in thick clastic sedimentary rocks. The strata dip gently in an upstream direction. A widespread mantle of sandy soil obscures the bedrock, but isolated outcrops and numerous exposures in road cuts in the area reveal the nature and structure of the rocks. Alluvial terrace deposits on the valley sides are poorly developed to absent. The river has deposited 35 to 50 feet of fine-grained alluvium in building up the present floodplain, and it is in these deposits that the river was channelized several decades before the construction of Norman Dam as a flood control measure. Sedimentary rocks comprising in descending order the Gerber, the Wellington and the Stillwater formations of the Enid group of the lower Permian age underlie the vicinity of the Norman dam site and reservoir basin.

The surface geological units from Horton (2017) are given in Figure 2 and the area of each unit is given in Table 2. Sandstones are present in the majority of the basin and are dominant in the eastern portion of the watershed. Shales, siltstones and older terrace deposits are present in the western portion of the watershed. The soil coverage from the Digital General Soil Map of U.S. by National Resources Conservation Service (NRCS) is shown in Figure 3. Table 3 contains the percentages within each soil type and average soil characteristics as determined from the Soil Data Viewer which accesses the Digital General Soil Map of the U.S. (Soil Survey Staff, NRCS, 2019). Fine sandy loams dominate the eastern portion of the watershed while silt loams are dominant in the western portion of the watershed. The fine sandy loams are generally present where the sandstone is present whereas the silty loams are present where the shales, siltstones and older deposits are present.

The land use percentages were obtained from Oklahoma Water Resources Board (2018) and are given in Table 4. Approximately 16 percent of the watershed is developed at some level of intensity, while the remaining is primarily deciduous forests and grasslands. It is expected that the level of development will increase over time as the cities grow in population and size.

Table 1. Watershed characteristics from USGS StreamStats (USGS, 2019).

Watershed Characteristic	Value
Drainage Area	257 mi^2
Unregulated Drainage Area	244 mi^2
Mean Annual Precipitation	38.1 in
Mean Basin Elevation	1160 ft
Maximum Elevation*	1332 ft
Minimum Elevation*	983 ft
Percent of Impervious Area determined from NLCD 2001 Impervious dataset	3.7 %
Percent of drainage area covered by canopy as described in OK SIR 2009_5267	27.7
Average Soil Permeability	1.32 in/hr

*estimated from existing topographic maps

Table 2. Surface geology of Thunderbird Reservoir (from Horton, 2017).

Watershed Characteristic	Area (mi^2)	Percentage (%)
Fairmont Shale	28.9	11.2
Garber Sandstone	135.7	52.7
Kingman Formation or Kingman Siltstone	13.4	5.2
Salt Plains Formation	9.7	3.8
Alluvium	37.8	14.7
Terrace Deposits	19.5	7.6
Water	12.6	4.9

Table 3. Soil types within Watershed. Surface soil properties as computed from NRCS Soil Data Viewer 6.2 (Soil Survey Staff, NRCS, 2019).

Soil Name	Area (mi^2)	Area (%)	USDA Classification	Plasticity	Clay (%)	Silt (%)	Sand (%)
Stephenville-Darnell	162	63	Fine Sandy Loam	5.4	16	19	65
Zaneis-Renfrow-Grainola-Coyle	68	26	Silt Loam	10.5	21	41	38
Renfrow-Krikland	15	6	Silt Loam	9	21	50	29

Table 4. Land use acreage for watershed above Norman Dam (from Oklahoma Water Resources Board, 2018).

Land category	Percent of Watershed (%)
Open Water	4.3
Developed, open space	9.4
Developed, low intensity	4.3
Developed, medium intensity	2.0
Developed, high intensity	0.4
Barren Land	0.02
Deciduous Forest	35.3
Evergreen Forest	0.2
Grassland/Herbaceous	38.4
Pasture/Hay	3.5
Cultivated Crops	2.1
Emergent Herbaceous Wetlands	0.005

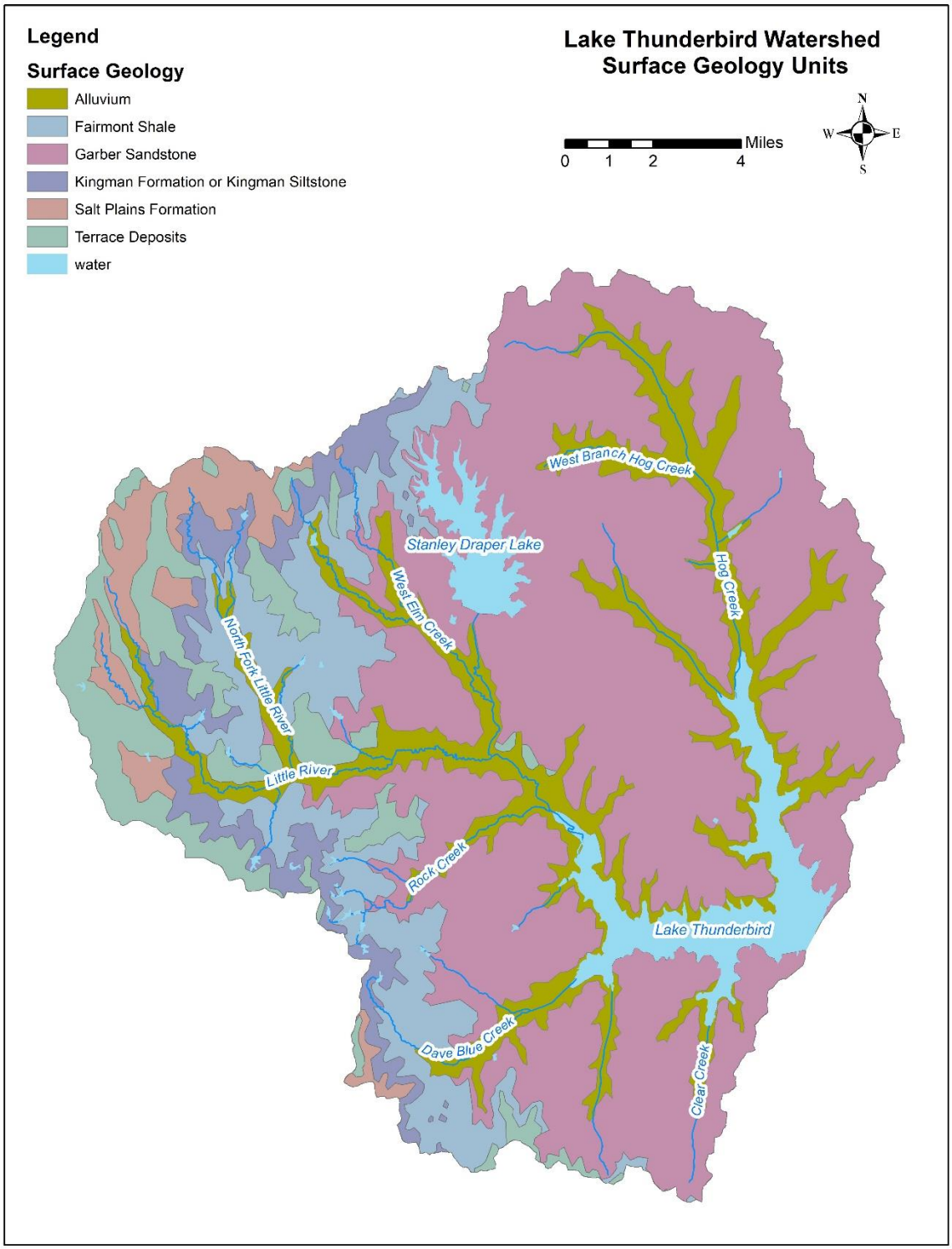

Figure 2. Surface geology in the watershed of Thunderbird Reservoir.

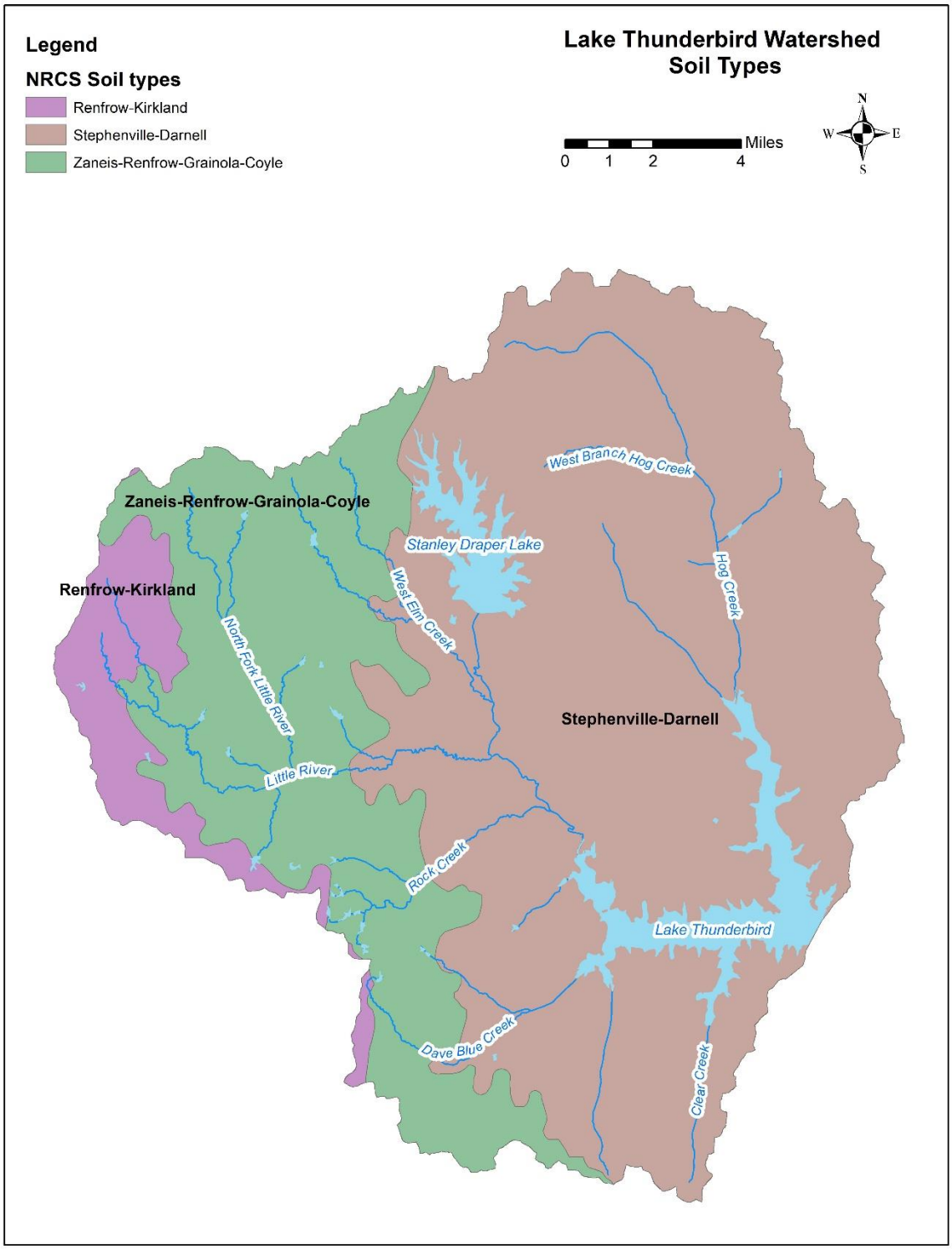

Figure 3. Soil Types in the watershed of Thunderbird Reservoir.

2.2. Climate and Runoff

The monthly average temperatures and precipitation totals are given in Figure 4. The average temperature is approximately 60 degrees Fahrenheit (°F), with summer highs averaging 92 °F in July and August and winter lows averaging below freezing in December through February. Precipitation can occur throughout the year with the highest totals in May and June.

Reservoir inflows are primarily from Hog Creek and Little River. The Little River watershed is significantly larger covering approximately 175 mi^2 of the total watershed area above Norman Dam of 257 mi^2. There were no USGS stream gage records available upstream of the dam, but there is a USGS gage downstream of the dam (number 07230000). The mean annual flow downstream of Norman Dam is 56 cubic feet per second (cfs) or 40,570 AF per year. This streamflow is primarily from rainfall. The Reclamation Project Data (Reclamation, 1981) states the average annual inflow is 57,300 AF, which gives a Capacity versus Inflow ratio of approximately 1.8. The relatively large reservoir volume in comparison to the inflow suggests that almost all the sediment entering the reservoir will be trapped within the reservoir.

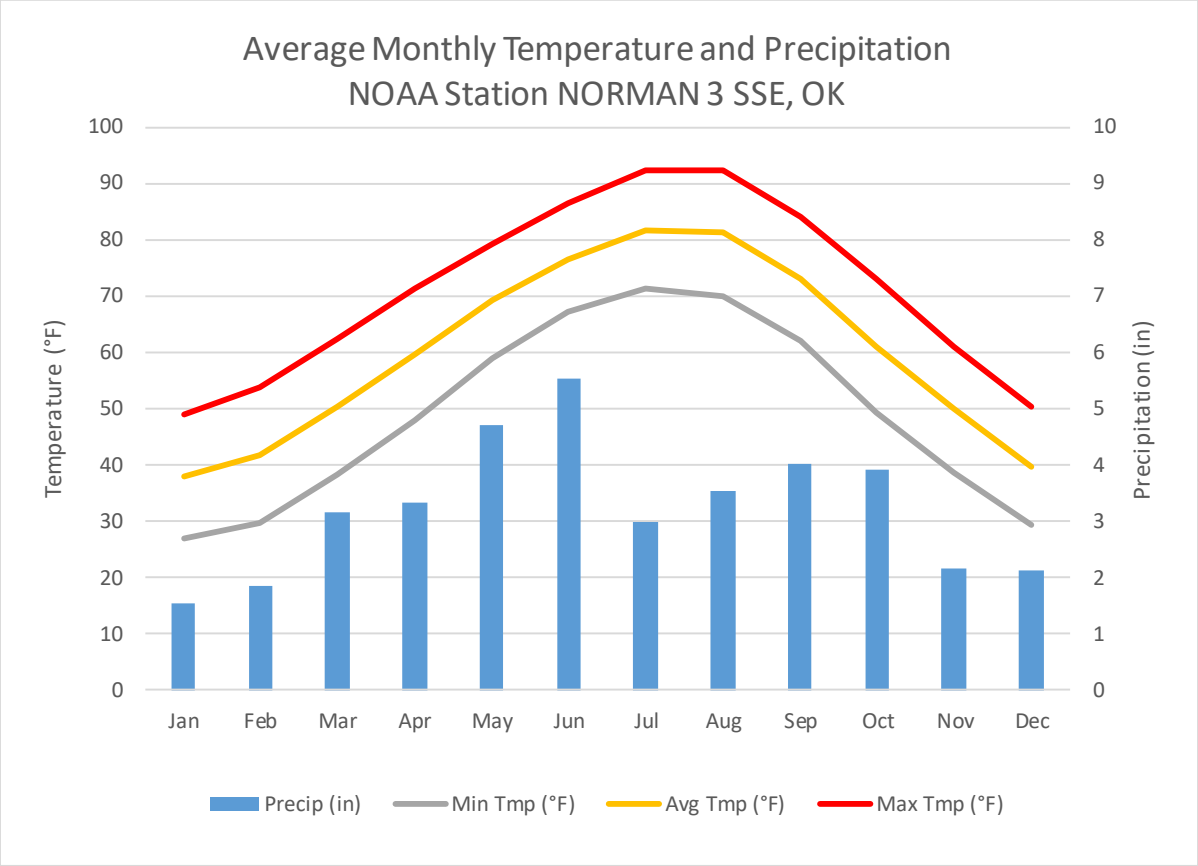

Figure 4. Average Monthly temperature and precipitation at the NORMAN 3 SSE NOAA weather station in Norman, Oklahoma (NOAA, 2019).

Table 5. Nearby Streams with USGS gages.

USGS Stream Gage		Drainage Area (mi^2)	Mean Annual Flow (cfs)	Period of Record
Name	**Number**			
Little River blw Lk Thunderbird nr Norman, OK	07230000	257	56	1952-10-01 to 2019-08-20

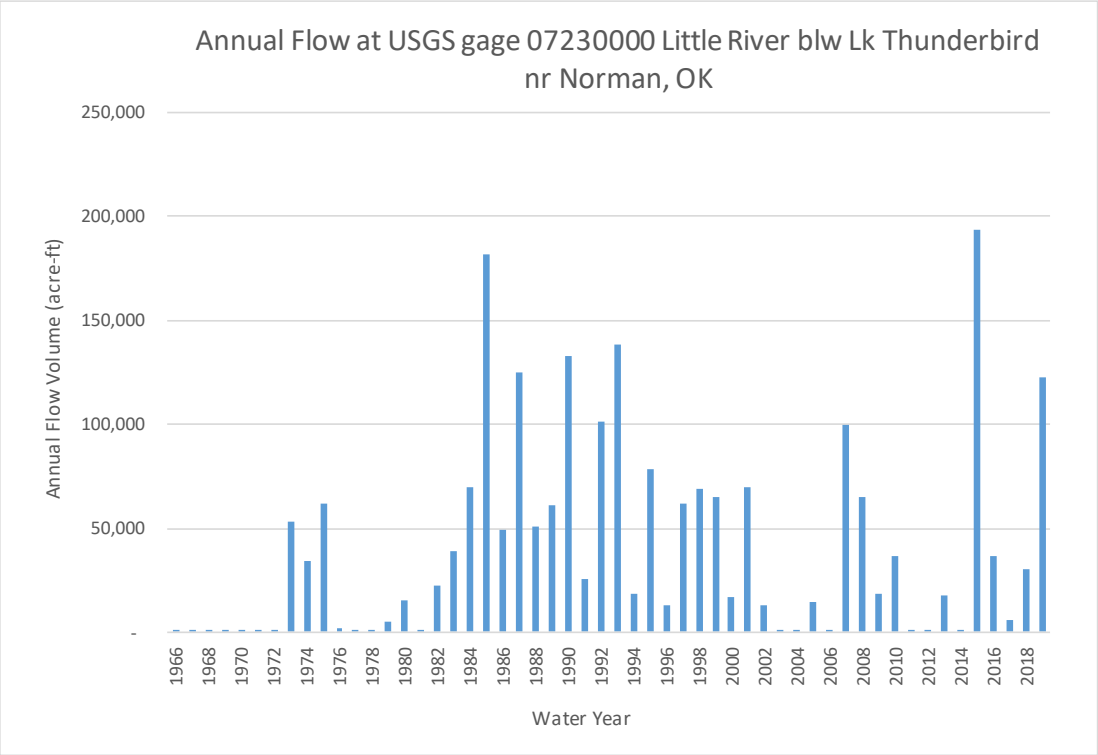

Figure 5. Historic Annual Outflow Volume from Thunderbird Reservoir as recorded by USGS gage below Thunderbird Reservoir (USGS gage #07230000).

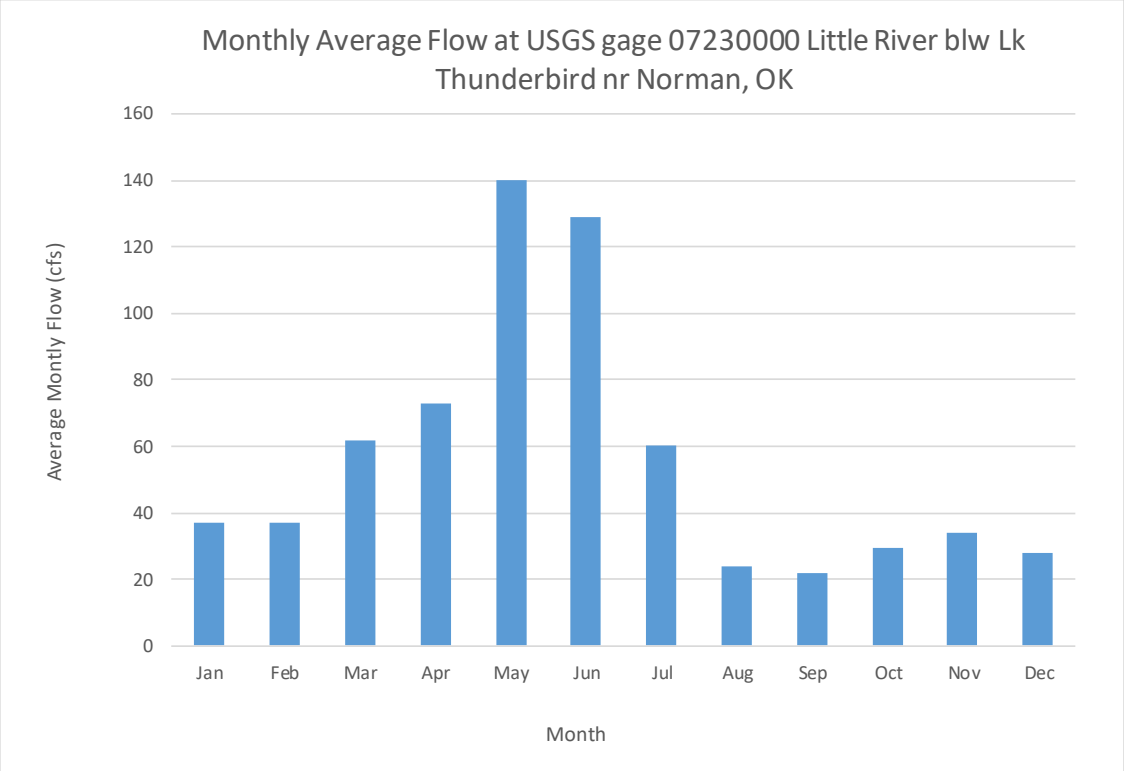

Figure 6. Historic Monthly Average Outflows from Thunderbird Reservoir as recorded by USGS gage below Thunderbird Reservoir (USGS gage #07230000).

2.3. Dam Operations and Reservoir Characteristics

Norman Dam is an earthen dam constructed between 1962 and 1965 and began storing water in 1966. The dam has a hydraulic height of 94.7 feet, with an uncontrolled spillway elevation of 1049.4 feet, and a low level outlet elevation of 997 feet, which is considered the top of the dead storage pool. The top of the conservation pool is at 1039 feet and the top of the ineffective storage pool is at 1010 feet.

The historic reservoir water surface elevations[1] (project datum) are presented in Figure 6 as given in the Hydromet Data System of Reclamation (Reclamation, 2019a). The reservoir water surface typically fluctuates less than 5 feet in most years. However, in dry years, the drawdown can be almost 10 feet below top of the conservation pool. Data are only electronically available since 1989, and the only time the spillway was active since 1989 was in 2015.

[1] The gage used to record water surface elevations at Norman Dam (USGS 07229900 Lake Thunderbird near Norman, Oklahoma) was calibrated to lake levels well below flood stage and matches Reclamation Project Vertical Datum (RPVD) closely in that range. When the lake is at flood levels, the USGS gage does not match RPVD as closely. During the 2015 survey Lake Thunderbird was at flood stage and GPS measurements indicated a difference of approximately 0.26 feet between RPVD and gage elevation.

The reservoir has two major arms, each about 6 miles long formed by its two major tributaries. The width of each of the two arms varies between approximately 0.5 miles to 1 mile. The sedimentation pattern in the Little River tributary arm is a "bird's foot" delta, so-called simply because it looks like a bird's foot. These deltas have multiple channels entering the reservoir with the sedimentation focused along the banks creating natural levees along the channel. The delta at Hog Creek is fan shaped and may have less sediment entering the reservoir as this watershed is approximately half the size of Little River watershed.

There is no record of past reservoir sediment management activities.

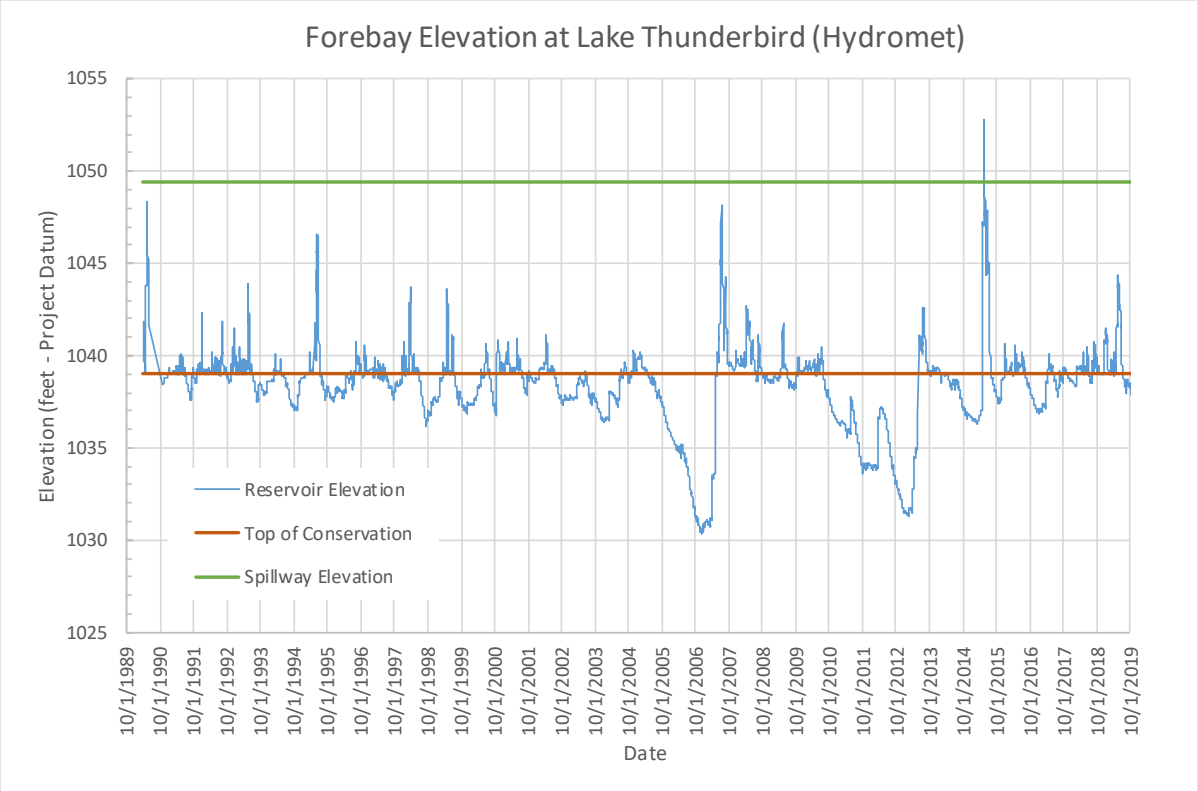

Figure 7. Historic Thunderbird Reservoir water surface elevations (project datum). Data web source: https://www.usbr.gov/gp/hydromet/archive.html.

3. Previous Reservoir Surveys

Prior to dam closure and initial reservoir filling, a survey was conducted in 1965 to measure the original surface areas and corresponding storage capacities. Although the documentation summarizing the original survey methods has not been located for this analysis, the Denver, Moore, Little Ax, and Franklin USGS 1:24,000 quadrangle maps were likely used to develop the original surface areas and capacities. A 10-foot contour interval map was produced from this original survey.

Another survey was conducted in June 2001 (Oklahoma Water Resources Board, 2001) using a differential global satellite positioning system, an acoustic depth sounder, and oceanographic mapping software. Transects were run across the reservoir at 300-foot intervals slightly modified to follow the shoreline when possible. The reservoir elevation was 1039 feet at the time of the survey, which is approximately the top of the conservation pool. There was no reference to updating the topography above elevation 1039 feet. The original and subsequent reservoir survey are described in Table 6. Reclamation used the survey and existing contour data to develop an area and capacity versus elevation relationship published in 2009 (Reclamation, 2010).

Table 6. Previous Bathymetric Reservoir Surveys

Survey Year	Extent of Survey	Survey Method	Depth Sounder	Above water survey
1965	Full	Photogrammetry	NA	Photogrammetry
2001	Full	300-ft Range Lines	Single Beam	NA

4. Methods Summary

For the 2015 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (2011) State Plane (horizontal) coordinates, Oklahoma South Zone, Federal Information Processing Standard (FIPS) 3502, US survey feet, and North American Vertical Datum 1988 (NAVD 1988, Geoid 12A, US survey feet elevations). During processing, all bathymetry and GPS measurements were converted to Reclamation Project Vertical Datum (RPVD) for Thunderbird Reservoir. The RPVD was determined to be 0.08 feet lower than lower than NAVD 1988 (Geoid 18[2]). RPVD was assumed to be approximately equal to National Geodetic Vertical Datum of 1929 (NGVD 1929) at Lake Thunderbird and Norman Dam. The RPVD at Thunderbird Reservoir was determined from comparison of RTK GPS measurements of water surface and morning glory spillway crest

[2] NAVD88, Geoid 18 was used during the most recent analysis of 2015 data as it is the most recent and accurate vertical datum available at the time revisions were made to this report.

elevations to USGS gage water stage records at the dam and published elevations from original design drawings respectively.

The GPS base station receiver was set up over a temporary monument located between the two reservoir arms (Figure 7). State plane and elevation coordinates for the GPS base station were computed using the Online Positioning User Service (OPUS) developed by the NGS (www.ngs.noaa.gov/OPUS/).

A complete bathymetric survey was conducted from May 30 to June 6, 2015 from a boat using a Teledyne® MB1 multibeam depth sounder to continuously measure water depths. The horizontal position of the moving boat was continually tracked using RTK GPS. A map of the data points collected is presented in Figure 7. The water surface elevation varied between 1046 feet and 1048 feet (RPVD) at the time of collection.

The bathymetric data were combined with LiDAR data collected by the City of Norman on February 7, 2007. The vertical accuracy is stated as 0.3 meters, with a point spacing of 0.5 meters. It was collected in the NAD83 High Accuracy Reference Network (HARN) horizontal datum and WGS84 vertical datum. The data were available at the following website: http://maps.normanok.gov/maps/InteractiveBaseMap.html. The title of the dataset is "2007 Norman Rural Contour Lidar Project, OK".

The 2-foot contours developed from that LiDAR are publicly available and this data was combined with the elevation data from the bathymetric collection to produce a digital surface of the reservoir bottom surface. Surface areas at 1-foot contour intervals were computed using GIS software and Reclamation's Area-Capacity (ACAP) Program, 2003 Version (Reclamation, 1985) was used to produce the reservoir surface area and capacity tables at 0.01-foot increments. Appendix A provides more details of the hydrographic survey methods. Appendix B provides more details about the methods used to generate surface area and storage capacity tables. Appendix C contains elevation contour maps of the entire reservoir.

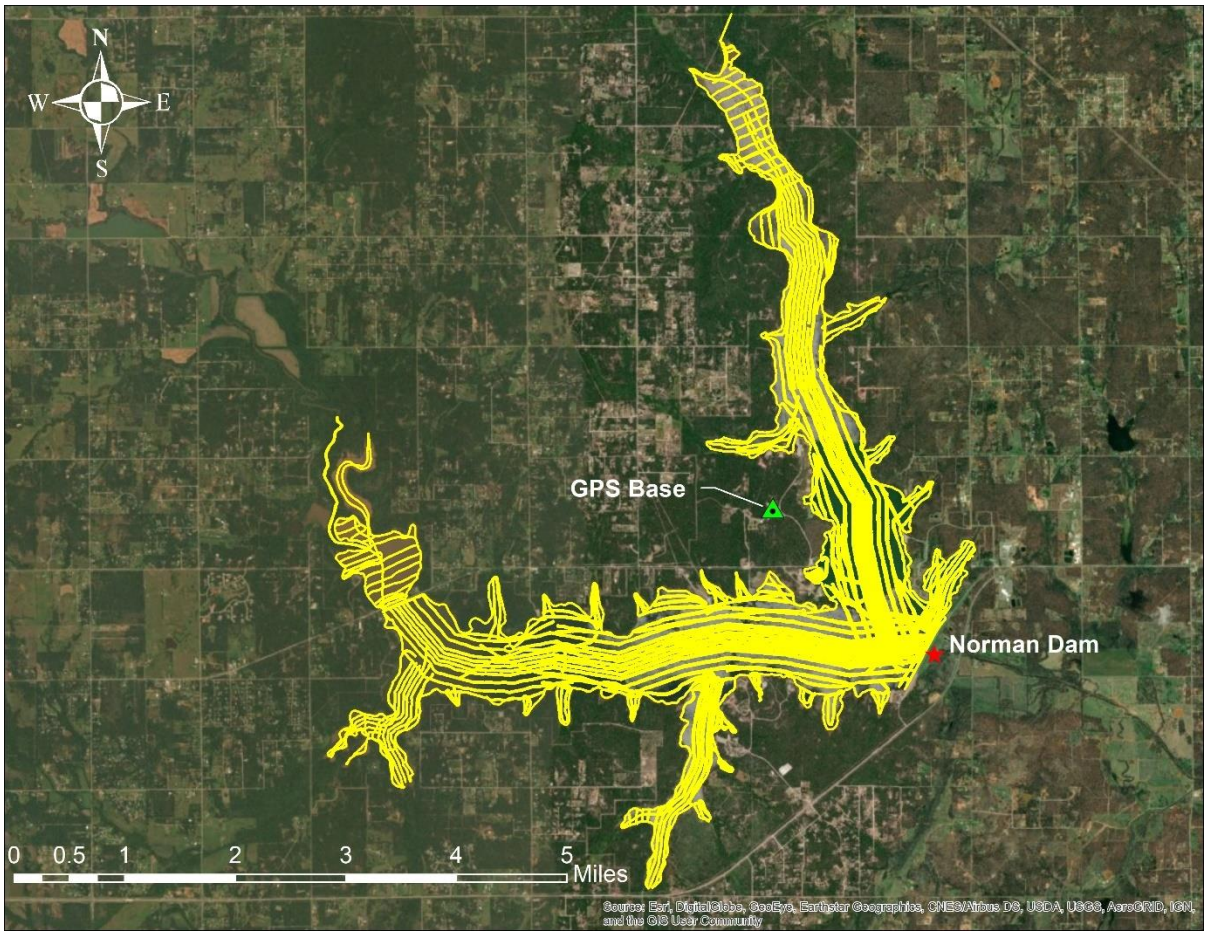

Figure 8. Map of bathymetric survey data coverage and survey control.

All bathymetric data was referenced to water surface elevations recorded by the dam gage at the time of the survey. Measured water depths were subtracted from recorded water levels to produce reservoir bottom elevations. The gage used to record water surface elevations at Norman Dam (USGS 07229900 Lake Thunderbird near Norman, Oklahoma) was originally calibrated to lake levels well below flood stage and matches Reclamation Project Vertical Datum (RPVD) closely in that range. When the lake is at flood levels, the USGS gage does not match RPVD as closely. During the 2015 survey Lake Thunderbird was at flood stage and GPS measurements indicated a difference of approximately 0.26 feet between RPVD and gage elevations.

Due to the discrepancy between the USGS gage and Reclamation Project Vertical Datum at high water levels, the decision was made to reference the 2015 bathymetry to RPVD instead of the water surface elevation gage records. On August 4, 2020, survey crews from Reclamation's Oklahoma Texas Area Office collected GPS measurements on the morning glory spillway crest and multiple other permanent control points to confirm RPVD. Results of this survey were used to determine RPVD is 0.08 feet below NAVD88 (Geoid 18) and 0.26 feet above the USGS gage records at flood stage. Bathymetric elevations originally referenced to USGS gage records were raised 0.26 feet to match RPVD. The survey report from August 2020 is included in Appendix D.

5. Reservoir Surface Area and Storage Capacity

Detailed tables of reservoir surface area and storage capacity for every 0.01 foot of elevation change were produced for the full range of reservoir elevations (Reclamation, 2020). Plots of the 2015 area and capacity curves are presented in Figure 8 along with curves from 1965 and 2001 surveys. For the 2015 survey, area and capacity are based on the bathymetric (below-water) survey up to the 1043-foot elevation contour (RPVD), while area and capacity above this elevation are based on 2007 aerial LiDAR survey. A comparison of the 2001 and 2015 data shows that the largest reduction in surface area and storage capacity between occurs above elevation 1040 feet. This is likely because the 2001 survey did not update the above water topography and the water surface elevation was 1039 feet at the time of that survey. The expected storage loss between the 2001 and 2015 is less than that reported because the 2001 survey likely did not account for sedimentation between 1965 and 2001 above elevation 1039 feet. Therefore, the 1965 areas above elevation 1039 feet were assumed to be the same as the 2001 area.

A summary of the elevation versus surface area tables is given in Table 7 and a summary of the elevation versus capacity tables is given in Table 8. The sedimentation volumes and rates since dam construction in 1965 are given in Table 9 and the sedimentation volumes and rates since 2001 are given in Table 10.

A comparison of the 2015 and 1965 data indicates that the sedimentation volume was 23,500 AF below the spillway crest and 15,800 AF below the top of the conservation pool since construction in 1965. The average sedimentation rate over this 50-year period is 470 AF/yr below the spillway crest and 316 AF/yr below the top of the conservation pool. The total percent capacity lost below the spillway crest is 12 percent.

The predicted rate of deposition based upon the original design was 350 AF/yr (Reclamation, 1954) and the previous estimate using a 2001 survey was 393 AF/yr below the conservation pool (Oklahoma Water Resources Board, 2001). Using the surface area of 5556 acres for the conservation pool, gives an average depth of sediment of 2.6 feet within the conservation pool for an average rate of 0.5 in/yr.

The rates of sedimentation below the top of conservation pool elevation 1039 feet since 2001 are relatively low compared to those above 1039 feet. The most likely explanation for the low sedimentation rates is that the 2015 survey was a multi-beam survey and the 2001 survey was a single beam survey with much less resolution. The use of two different methods can result in different reservoir capacities. Another likely source of inaccuracy in the 2001 survey is the assumption of no change in surface area or storage above elevation 1039 feet since 1965. Therefore, use of the sedimentation rates between 2001 and 2015 above elevation 1039 feet is not recommended. The sedimentation rates between 1965 and 2015 are considered more reliable because the sedimentation volumes are larger than the error introduced by using different survey methods.

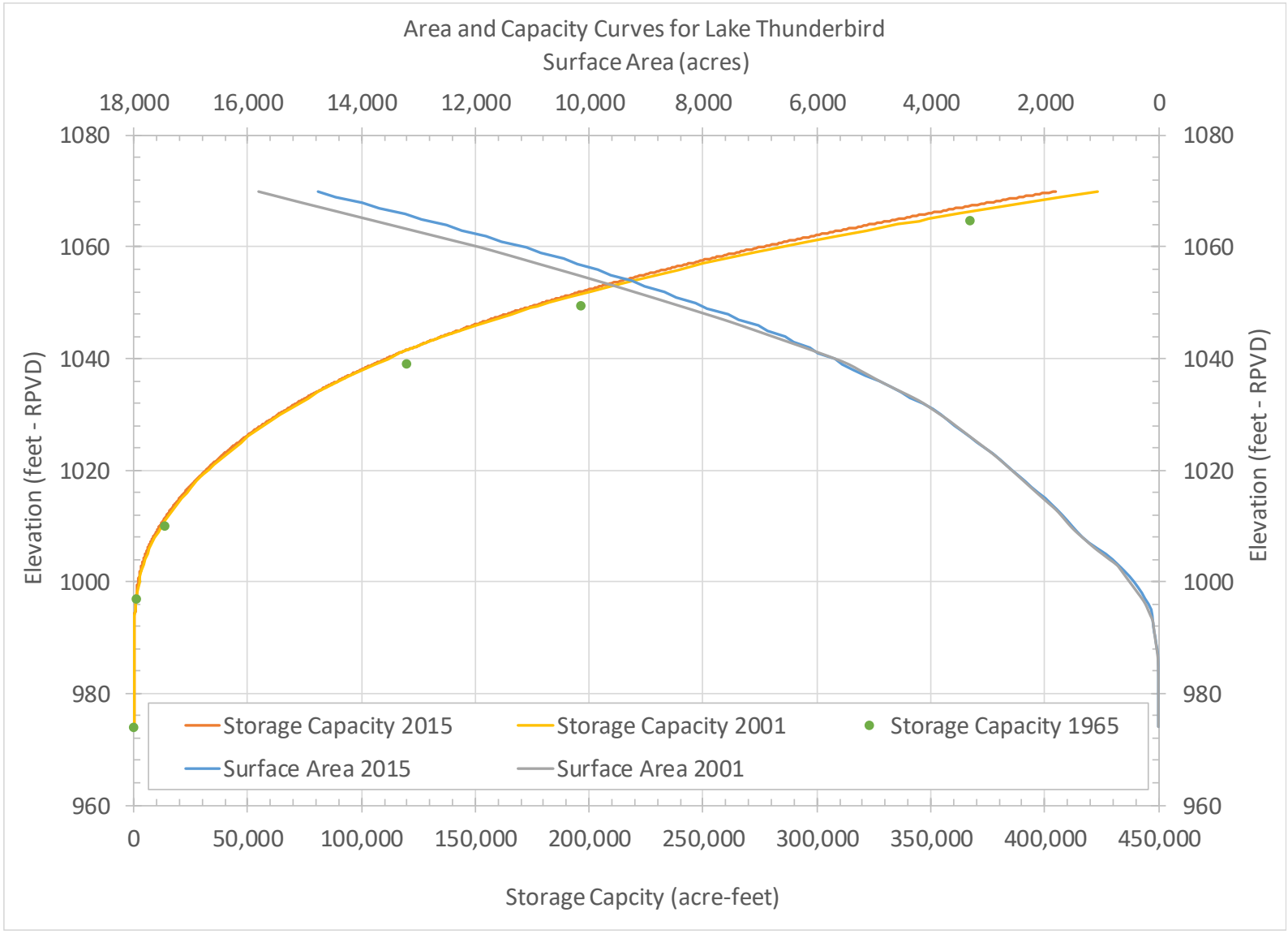

Figure 9. Plot of Thunderbird Reservoir surface area and storage capacity versus elevation (Project Datum).

Table 7. Elevation versus Area Table. Reliable data for 1965 were not available.

Survey date	2001	2015
Vertical Datum	RPVD	RPVD
Elevation	Area (acre)	Area (acre)
1070	15,811	14,684
1064.7	13,757	12,698
1060	11,916	11,037
1050	8,573	8,080
1049.4	8,384	7,959
1040	5,677	5,649
1039	5,439	5,505
1030	3,834	3,790
1020	2,577	2,539
1010	1,547	1,495
1000	507	411
997	290	221
990	59	52
984	2	0
983	0	0
974	0	0

Table 8. Elevation versus Capacity Table. Reliable data for 1965 were only available for the specified elevations.

Survey date	1965	2001	2015
Vertical Datum	RPVD	RPVD	RPVD
Elevation	Volume (AF)	Volume (AF)	Volume (AF)
1070	-	423,158	401,171
1064.7	367,500	344,810	328,599
1060	-	284,438	272,778
1050	-	182,292	177,530
1049.4	196,200	177,205	172,718
1040	-	111,501	109,424
1039	119,600	105,943	103,840
1030	-	64,463	62,498
1020	-	32,651	30,974
1010	13,700	12,272	11,106
1000	-	2,305	1,803
997	1,200	1,110	870
990	-	130	99
984	-	1	0
983	-	0	0
974	0	0	0

Table 9. Sedimentation in Various Reservoir Storage Zones Since Construction in 1965.

Storage Allocation Zone	Elevation (ft)	Sedimentation Within Zone (AF)	Percent of Volume Lost Within Zone (%)	Cumulative Sedimentation (AF)	Cumulative Annual Rate (AF/yr)
SURCHARGE	1,064.7	15,400	9	38,900	778
FLOOD CONTROL	1,049.4	8,100	11	23,500	470
CONSERVATION	1,039	12,800	12	15,400	307
INACTIVE	1,010	2,300	18	2,600	52
DEAD	997	330	27	330	7

Table 10. Sedimentation in Various Reservoir Storage Zones Since Survey in 2001.

Storage Allocation Zone	Elevation (ft)	Sedimentation Within Zone (AF)	Percent of Volume Lost Within Zone (%)	Cumulative Sedimentation (AF)	Cumulative Annual Rate (AF/yr)
SURCHARGE*	1,064.7	NA	NA	NA	NA
FLOOD CONTROL*	1,049.4	NA	NA	NA	NA
CONSERVATION	1,039	940	1	2,100	150
INACTIVE	1,010	930	8	1,200	83
DEAD	997	240	22	240	17

*The 2001 survey did not update topography above elevation 1039 ft. Therefore, it is not recommended to use these values above 1039 ft.

NA: Not Applicable

6. Reservoir Sedimentation Volume Spatial Distribution

Longitudinal profiles and representative cross sections of the 2015 reservoir bottom surface were developed in GIS along the alignments presented in Figure 10. The profiles are given in Figure 11 and Figure 12 and show that the slope is relatively uniform through the reservoir deposit, but there is a noticeable increase in bed elevation due to the sediment delta formation at the top of the conservation pool elevation in the arm created by the Little River, which is approximately 175 mi^2 of the total watershed area above Norman Dam of 257 mi^2.

Reservoir cross section plots along the Little River arm (Figure 13 and Figure 14) show the original dredged channel of the Little River. This dredged channel is approximately 15 feet deep and was likely dredged before the dam was built. The pre-dam maps of the reservoir show the channel approximately 20 feet deep throughout the reservoir.

Sediment has most likely uniformly deposited over the cross section. The cross section 35,000 feet upstream of the dam has a channel that is slightly deeper due to the natural levees that have formed adjacent to the main channel. This cross section is located at approximately the top of the conservation pool and is where the “birds-feet” delta is located. The naturally formed levees along the channel banks are a characteristic of such deltas.

The cross section in the Hog Creek arm (Figure 15) has a dredged channel that is only approximately 3 to 4 feet deep because Hog Creek has a significantly smaller watershed and carries less water and sediment.

The minimum bed elevations within the dredged channel near the dam are approximately 983 feet, which is 14 feet below the bottom elevation of the low-level intake. There has been about 10 feet of sedimentation within the dredged channel in front of the low-level intake since 1965, which is a rate of 0.2 ft/yr. Therefore, there is little risk of the low-level outlet becoming obstructed by sediment within the next several decades.

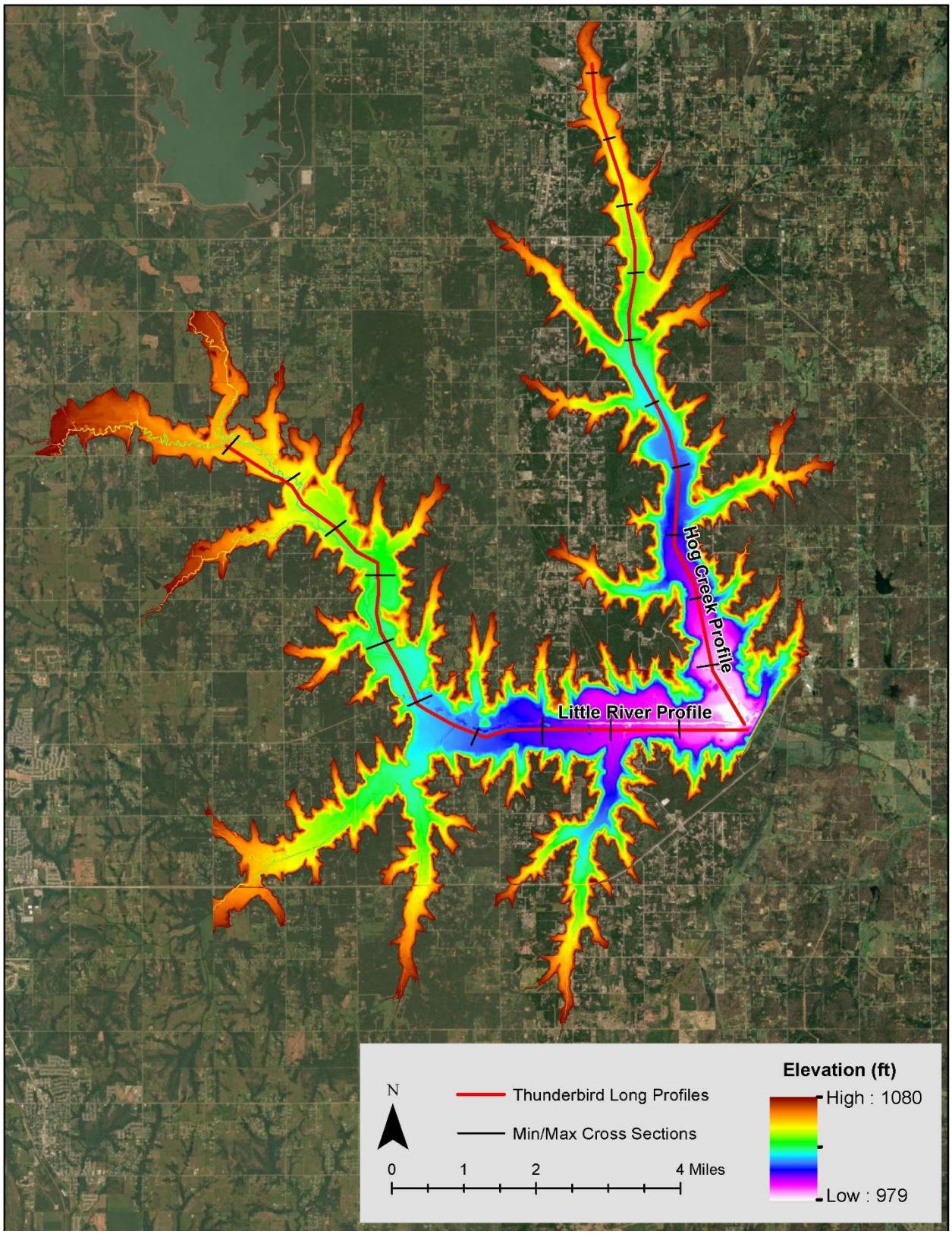

Figure 10. Reservoir surface elevation map and alignments of longitudinal profiles and representative cross sections.

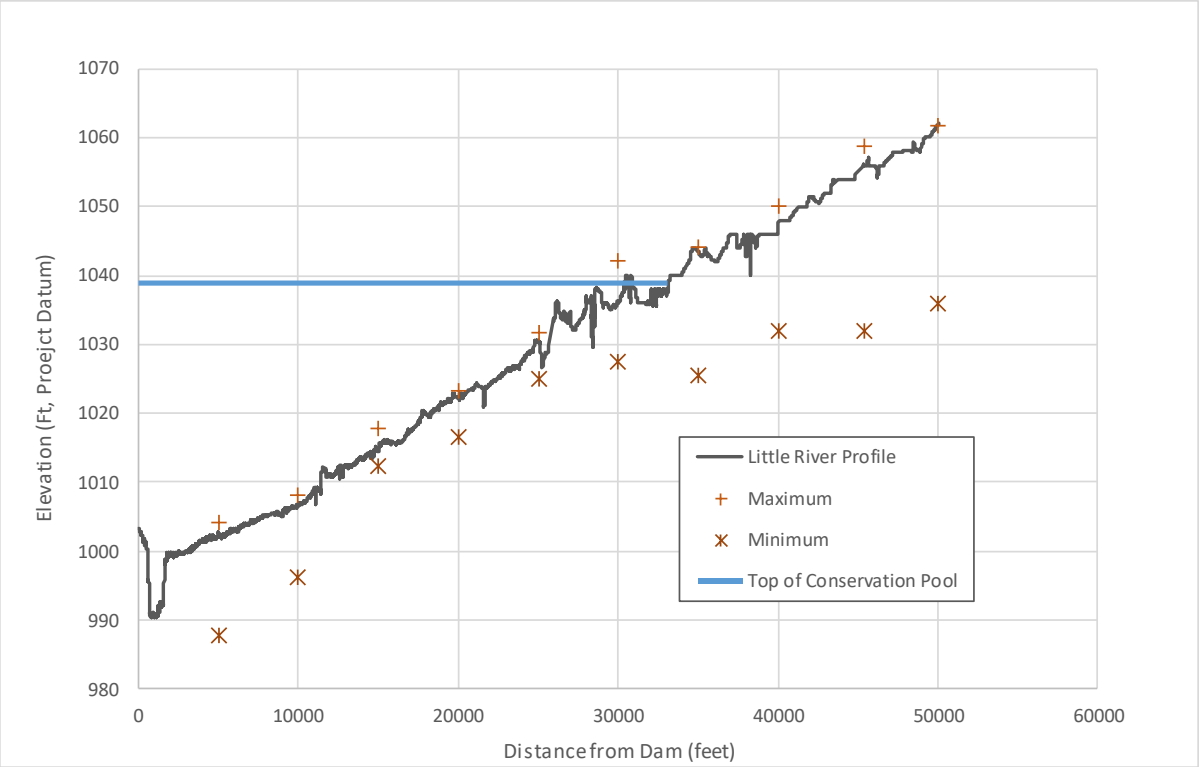

Figure 11. Longitudinal profile of Thunderbird Reservoir bottom as measured from the dam along the Little River arm.

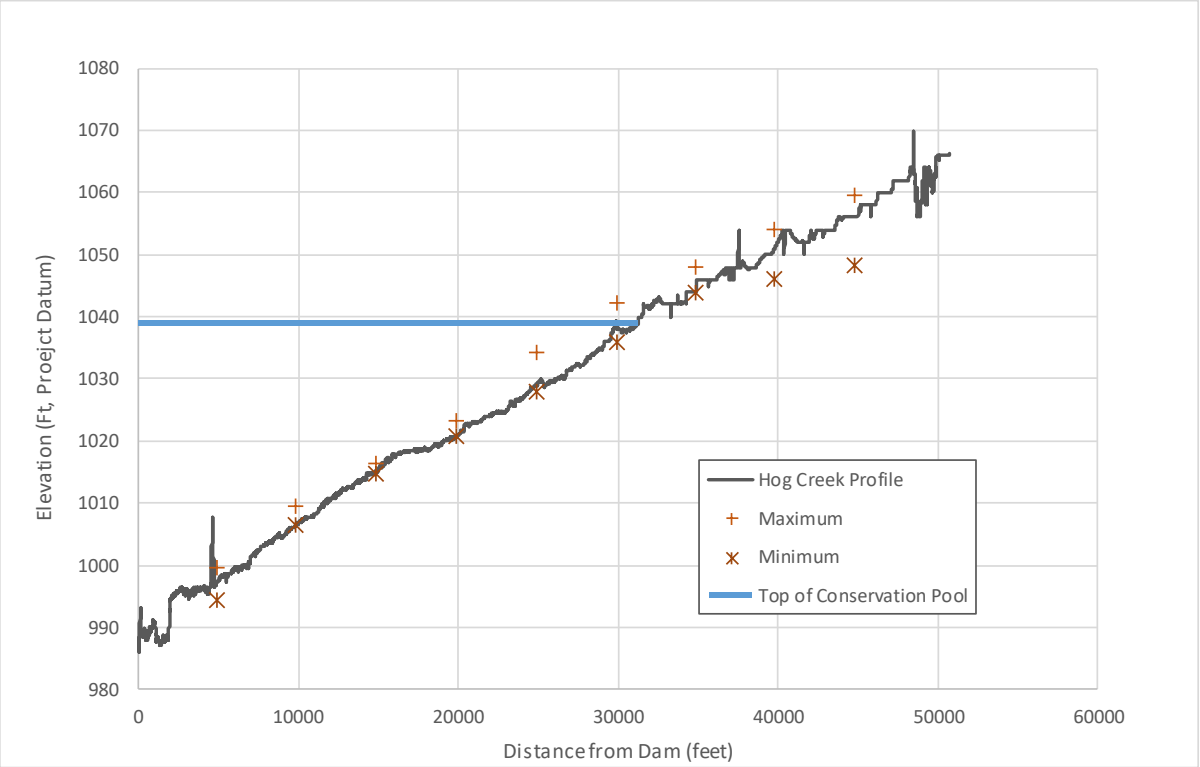

Figure 12. Longitudinal profile of Thunderbird Reservoir bottom as measured from the dam along the Hog's Creek arm.

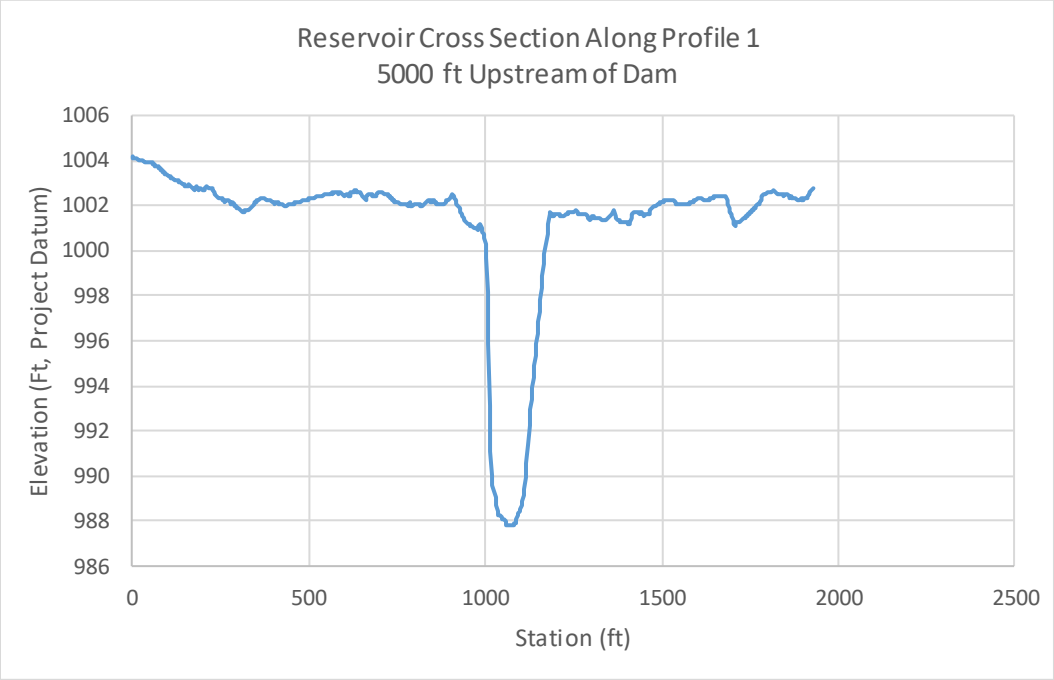

Figure 13. Cross Section 5000 ft upstream of Norman Dam along Profile 1.

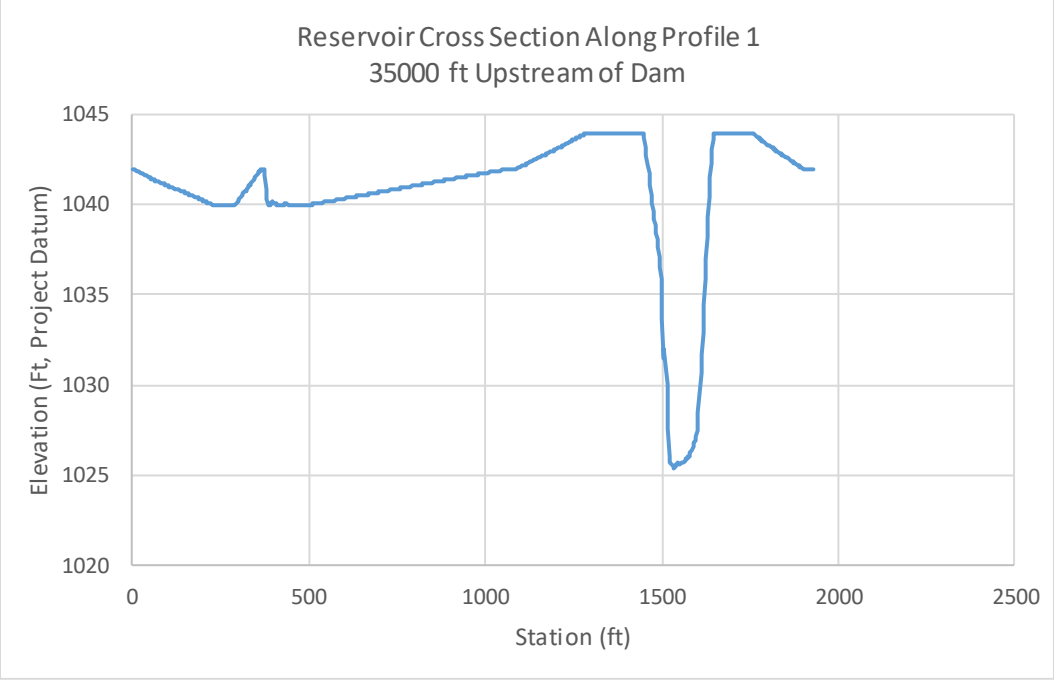

Figure 1. Cross Section 35000 ft upstream of Norman Dam along Profile 1.

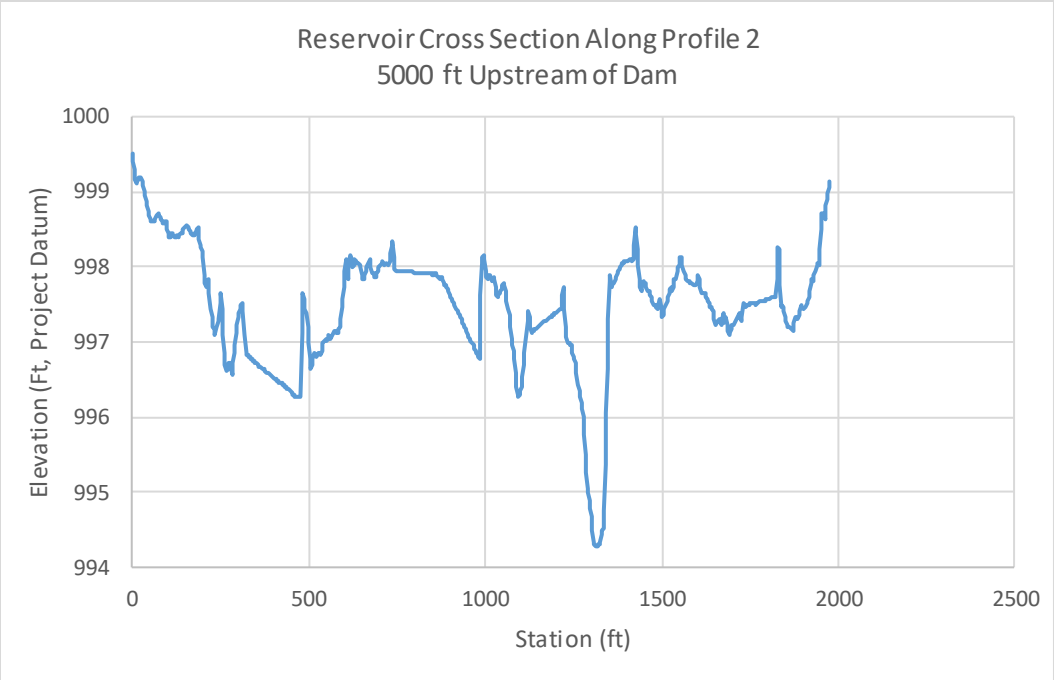

Figure 15. Cross Section 5000 ft upstream of Norman Dam along Profile 2.

7. Conclusions and Recommendations

7.1. Survey Methods and Data Analysis

The 2015 bathymetric survey, combined with 2007 LiDAR data of the above-water topography, has been used to produce a digital surface of the reservoir bottom. Reservoir surface areas were computed from this digital surface to determine the 2015 storage capacity. Surface area and storage capacity were then interpolated at 0.01-foot intervals. The difference in reservoir surfaces over time can be attributed to sedimentation, but also to the differences in survey methods. Because the 2001 survey was conducted with a single beam depth sounder and did not obtain new information above the reservoir pool, it is difficult to determine the sedimentation rates since 2001. The comparison with 1965 data is likely more reliable because the sedimentation volumes are much greater and therefore the relative errors between different survey methods are less important.

7.2. Sedimentation Progression and Location

Comparing the 2015 survey to the original design capacity in 1965, indicates that approximately 23,500 AF of sedimentation below the spillway crest has occurred since construction in 1965, which is approximately 12 percent of the original storage below spillway crest. The average sedimentation rate over this 50-year period is 470 AF/yr below the spillway crest. This equates to a sediment yield of 1.93 AF/mi^2/yr.

7.3. Recommendation for Next Survey

The frequency of survey is partially dependent upon the risks imposed by loss of capacity and loss of operational flexibility. Based upon the relatively small annual loss of reservoir capacity and the lack of sediment near the dam, another survey is recommended approximately 20 years after the last one, by which time another 5 percent of capacity is expected to be lost. If, however, operations change at the dam and the reservoir is drawn down significantly below an elevation of 1030 feet, then another survey is recommended soon after this operational change.

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Appendix A — Hydrographic Survey Equipment and Methods

A complete bathymetric survey was conducted from May 30 to June 6, 2015 from a boat using a Teledyne® MB1 multibeam depth sounder to continuously measure water depths. The horizontal position of the moving boat was continually tracked using RTK GPS. A map of the data points collected is presented in Figure 7. The water surface elevation varied between 1048 feet to 1046 feet (RPVD) at the time of collection.

The survey lines were spaced closely enough so there would overlapping coverage from the multibeam depth sounder or close enough that liner interpolation of multibeam depth data between survey lines would be adequate.

The survey employed an 18-foot, flat-bottom aluminum Wooldridge boat powered by outboard jet and kicker motors (Figure 16). Reservoir depths were measured using a multibeam echo sounder which consisted of the following equipment:

- variable-frequency transducer with integrated motion reference unit,
- near-surface sound velocity probe,
- two GPS receivers to measure the boat position and heading,
- an external GSP radio, and
- processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data.

Figure 16. Wooldridge boat with RTK-GPS and multibeam depth sounder system.

The multibeam transducer emits up to 512 beams (user selectable) capable of projecting a swath width up to 120 °F in 390 feet (120 meters) of water. Sound velocity profiles were collected over the full water depth at various locations throughout the reservoir. These sound velocity profiles measure the speed of sound through the water column, which can be affected by multiple characteristics such as water temperature and salinity. These sound velocity profiles were used to calibrate the depth sounder.

RTK GPS survey instruments were used to continuously measure the survey boat and measure other ground control points. The GPS base station and receiver was set up on a tripod over a point overlooking the reservoir (Figure 7). The coordinates of this point were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/). During the survey, position corrections were transmitted to the GPS rover receiver using an external GPS radio and UHF antenna (Figure 16). The base station was powered by a 12-volt battery.

Figure 17. The RTK-GPS base station set-up used during the survey.

The GPS rover receivers include an internal radio and external antenna mounted on a range pole (ground survey) or survey vessel (bathymetric survey). The rover GPS units receive the same satellite positioning data as the base station receiver, and at the same time. The rover units also receive real-time position correction information from the base station via radio transmission. This allows rover GPS units to measure accurate positions with precisions of

±2 cm horizontally and ±3 cm vertically for stationary points. When placed on a moving boat, the uncertainty will increase.

During the survey, a laptop computer was connected to the GPS rover receivers and echo sounder system. Corrected positions from one GPS rover receiver and measured depths from the multibeam transducer were transmitted to the laptop computer through cable connections to the processor box. Using real-time GPS coordinates, the Hypack software provided navigational guidance to the boat operator to steer along the predetermined survey lines.

The Hypack hydrographic survey software was used to combine horizontal positions and depths to measure the reservoir bathymetry in the North American Datum 1983 (2011) State Plane (horizontal) coordinates, Oklahoma South Zone FIPS 3502, US survey feet and North American Vertical Datum 1988 (NAVD 1988, Geoid 12A, US survey feet elevations). Water surface elevations from dam gage records and RTK GPS measurements were used to convert the sonar depth measurements to reservoir-bottom elevations in the RPVD. The multibeam depth sounder generates millions of data points. Sometimes fish, underwater vegetation, or anomalies mean that a small portion of depth measurements do not represent the reservoir bottom and these data are deleted during the post processing. Filtering of this large data file is necessary, so only one point within each 5-feet square was retained, which corresponded to the median elevation point within the 5-feet square.

Appendix B — Computation of Reservoir Surface Area, Storage Capacity, and Sedimentation Volume

A digital surface of the reservoir bottom was generated in GIS using the processed bathymetric data points (easting, northing, and elevation) combined with available above-water data. Horizontal surface areas were then computed at 1-foot increments, using functions within ArcGIS Pro, for the complete range of remaining reservoir elevations (974 to 1070 feet, RPVD). These reservoir surface areas were then used in Reclamation's Area-Capacity (ACAP) Program, 2003 Version (Reclamation, 1985), to compute the storage capacity at these increments and then interpolate surface areas and storage capacities at 0.01-foot increments between each 1-foot interval.

The program uses the least squares method to predict the reservoir storage capacity between 1-foot intervals using the following equation over a certain elevation interval:

$$V = A_1 + A_2(y - y_b) + A_3(y - y_b)^2$$

where: V = storage capacity (acre-feet)
y = reservoir elevation
y_b = reservoir elevation at bottom of elevation increment
A_1 = intercept and storage capacity at elevation y_b (acre-feet)
A_2 = surface area at elevation y_b (acres) and coefficient for linear rate of increase in storage capacity
A_3 = coefficient (feet) for nonlinear rate of increase in storage capacity

The reservoir surface area is computed from the derivative of the volume equation:

$$S = A_2 + 2A_3(y - y_b)$$

where: S = surface area (acres)

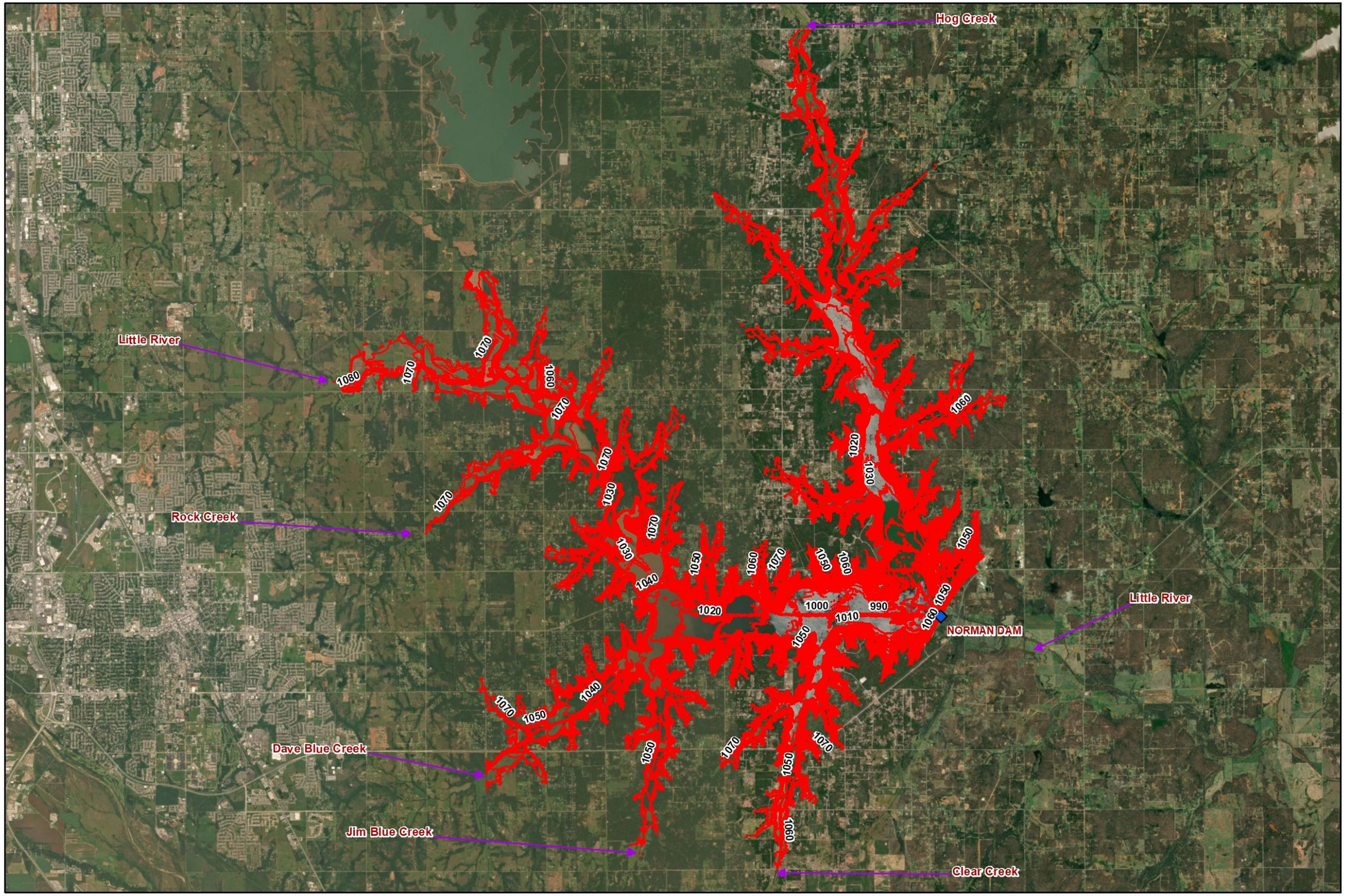
This method ensures that the given surface areas, and corresponding storage capacities, at the 1-foot intervals are not changed and there is a smooth transition in the interpolated values at the 0.01-foot intervals. The ACAP program produces the area and capacity tables for the full range of reservoir elevations. These data are documented in the report (Reclamation, 2019).

The sedimentation volume could be computed by subtracting digital surfaces of the predam reservoir surface from the 2015 digital reservoir surface. However, a predam topographic map and surface digital was not available at high enough resolution. The next option is to subtract the storage volume curve produced from the predam surface from the storage

volume curve of the 2015 surface. This method works well when the topographic map of the predam surface has good accuracy and precision. In some cases, the original topographic map significantly underestimated the actual storage capacity and subsequent surveys show an increased storage capacity even though reservoir sedimentation had reduced the actual storage capacity. In other cases the predam topographic map significantly overestimated the actual storage capacity and comparison with subsequent surveys show too large a sedimentation volume. Comparison of predam and post dam digital surface maps can help reveal these problems and provide ideas for correcting the original surface maps.

Sedimentation volumes can be computed for the range of elevations surveyed. In some cases, the sedimentation volumes can only be computed for the bathymetric survey because there was no new above water survey.

Appendix C – Thunderbird Reservoir Elevation Contour Map



Thunderbird Reservoir Oklahoma Elevation Contour Map

Overview Map

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Morning Glory Spillway Crest Elevation Referenced to Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

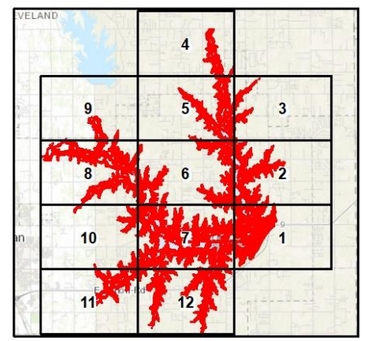
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:100,000

0 7,000 14,000 Feet



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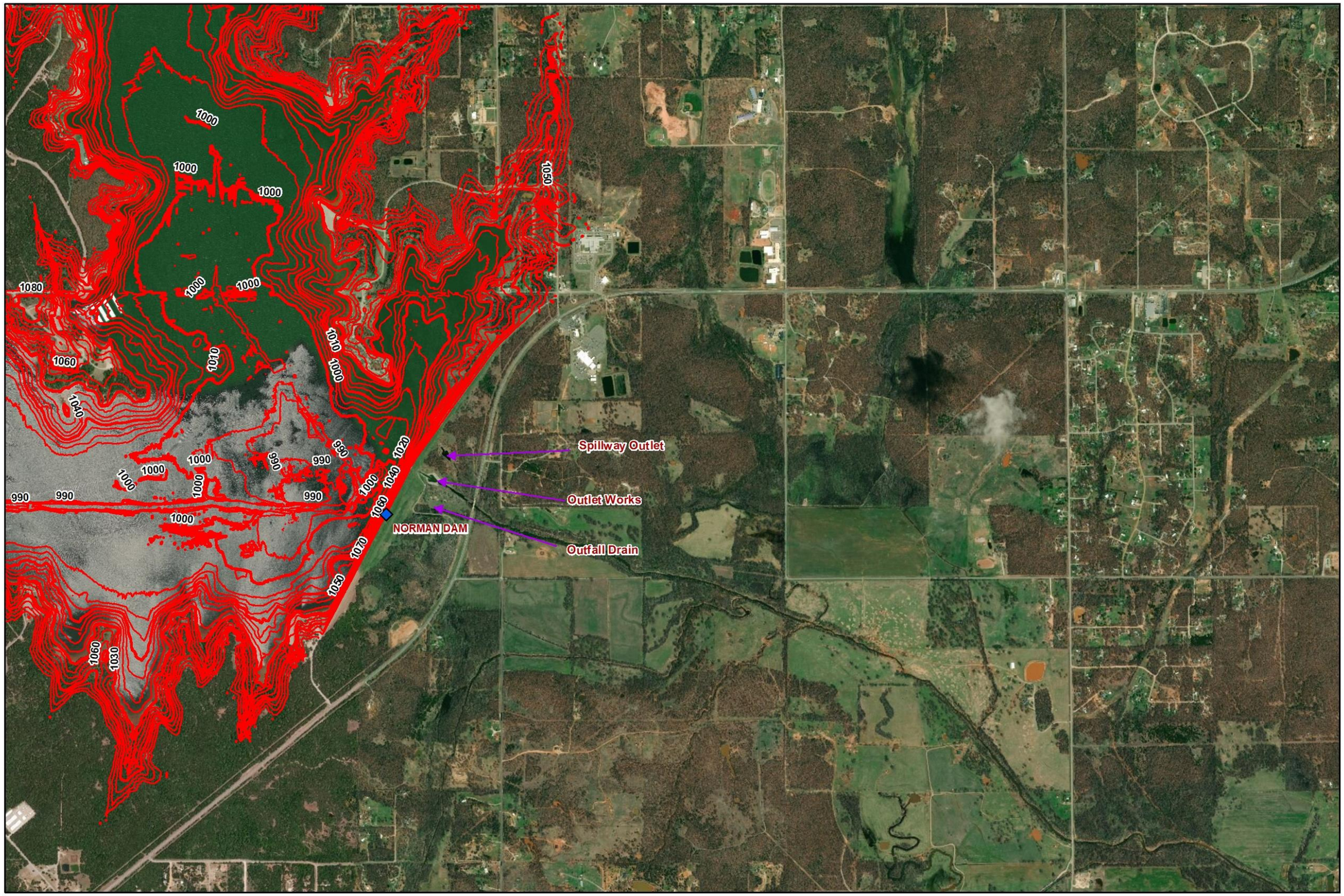


Thunderbird Reservoir Oklahoma Elevation Contour Map

Sheet 1

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Morning Glory Spillway
Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

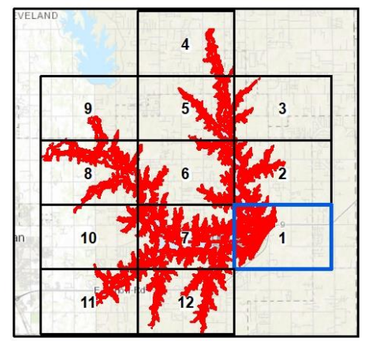
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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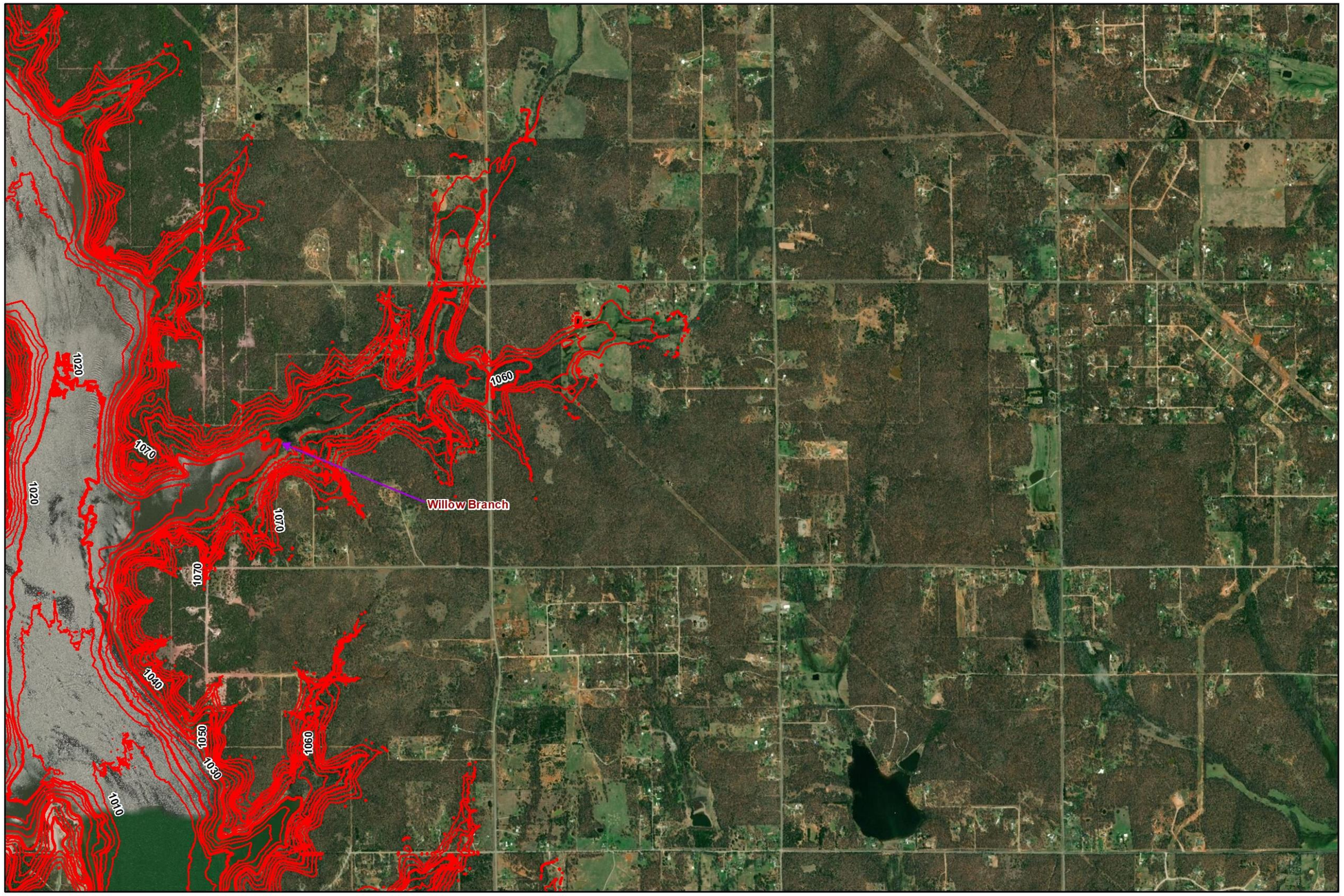


Thunderbird Reservoir Oklahoma Elevation Contour Map

Sheet 2

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Morning Glory Spillway Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

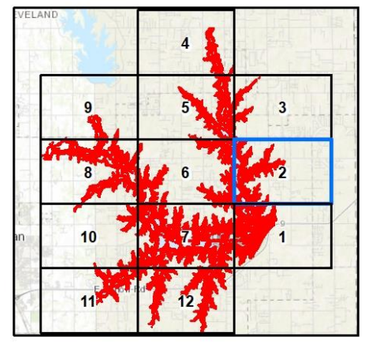
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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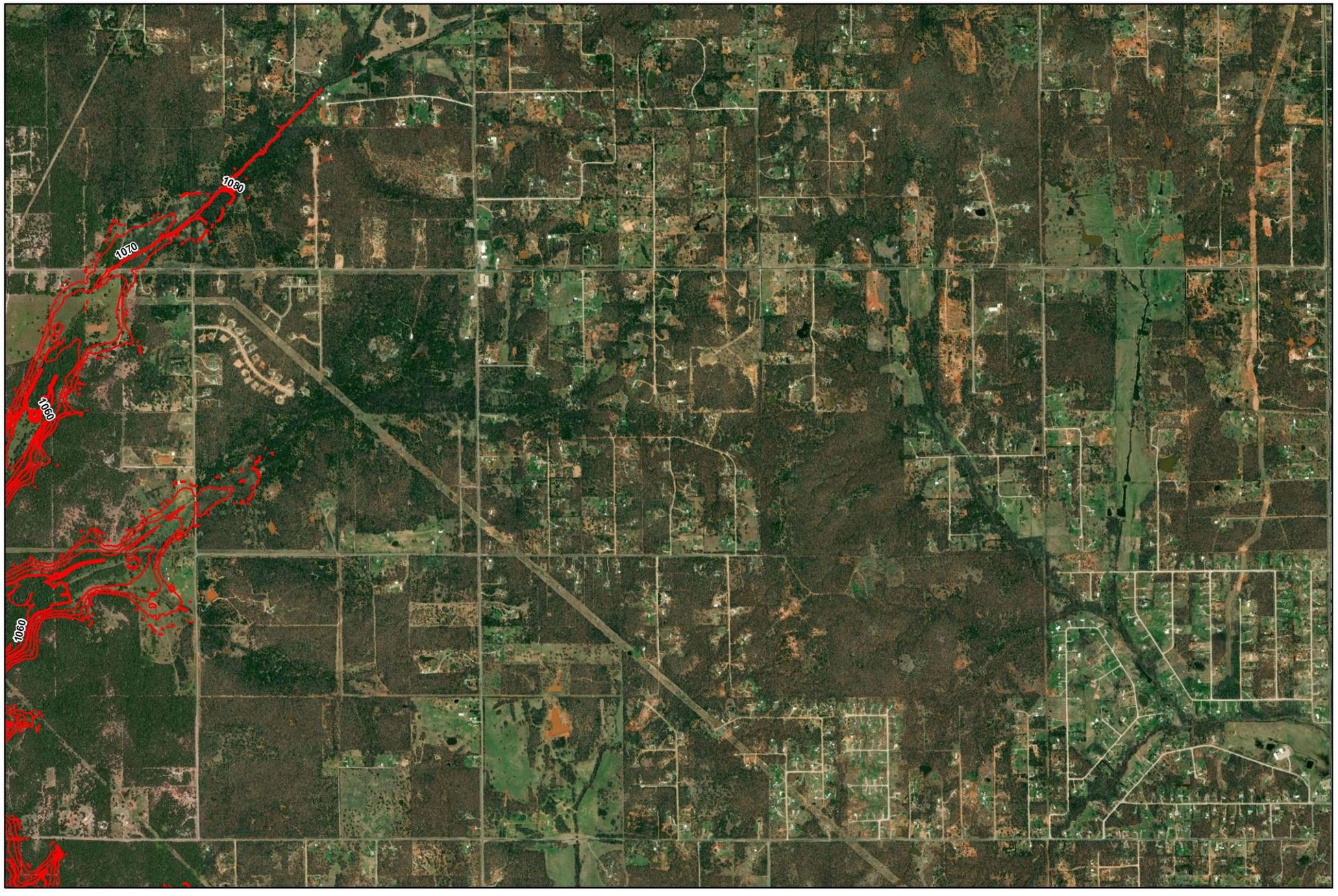


Thunderbird Reservoir
Oklahoma
Elevation
Contour Map

Sheet 3

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Morning Glory Spillway
Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

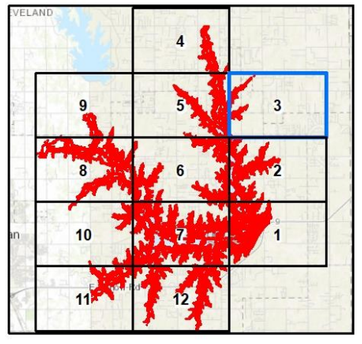
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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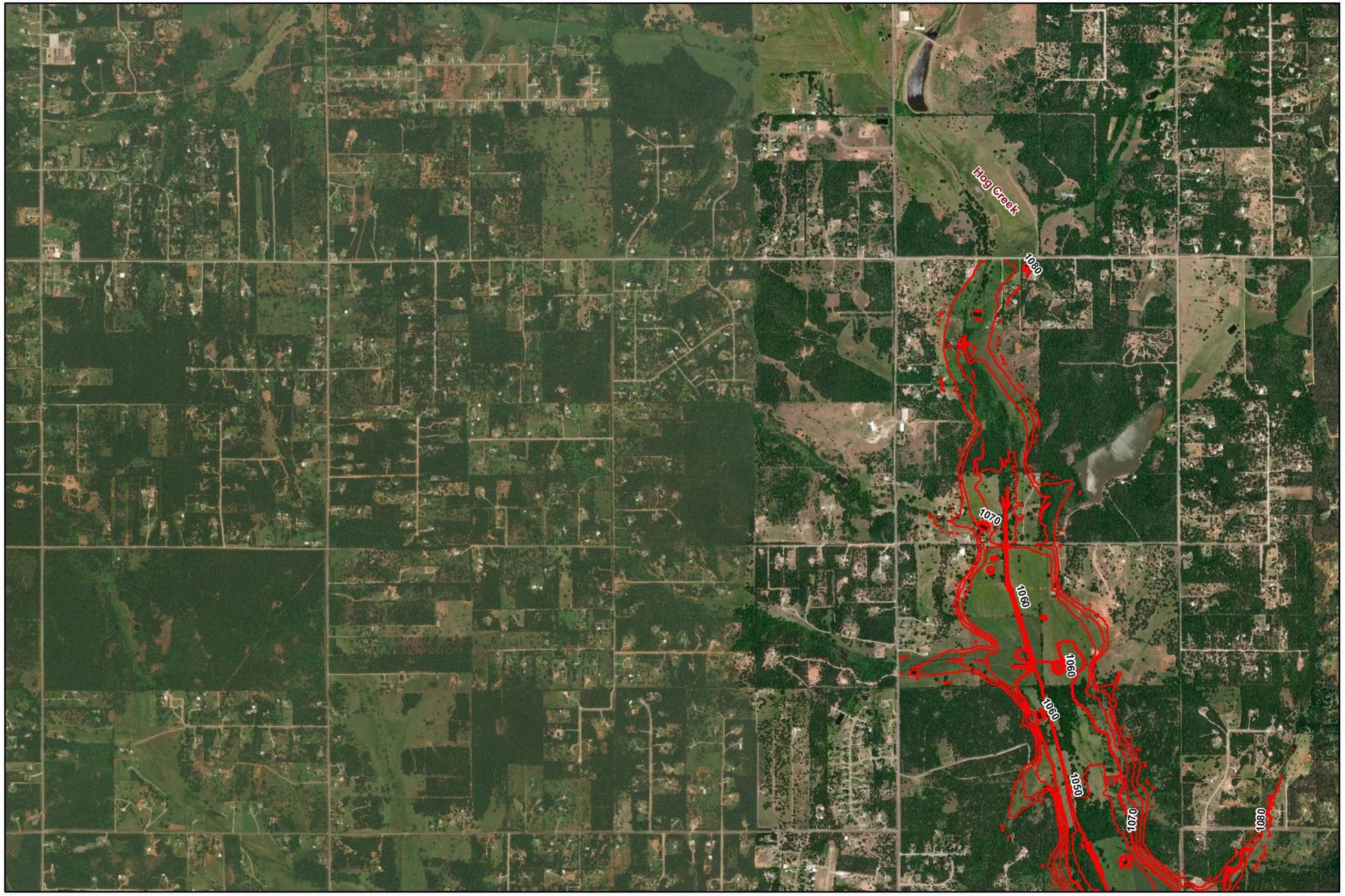


Thunderbird Reservoir Oklahoma Elevation Contour Map

Sheet 4

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Morning Glory Spillway
Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

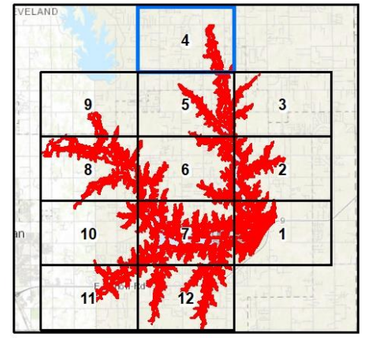
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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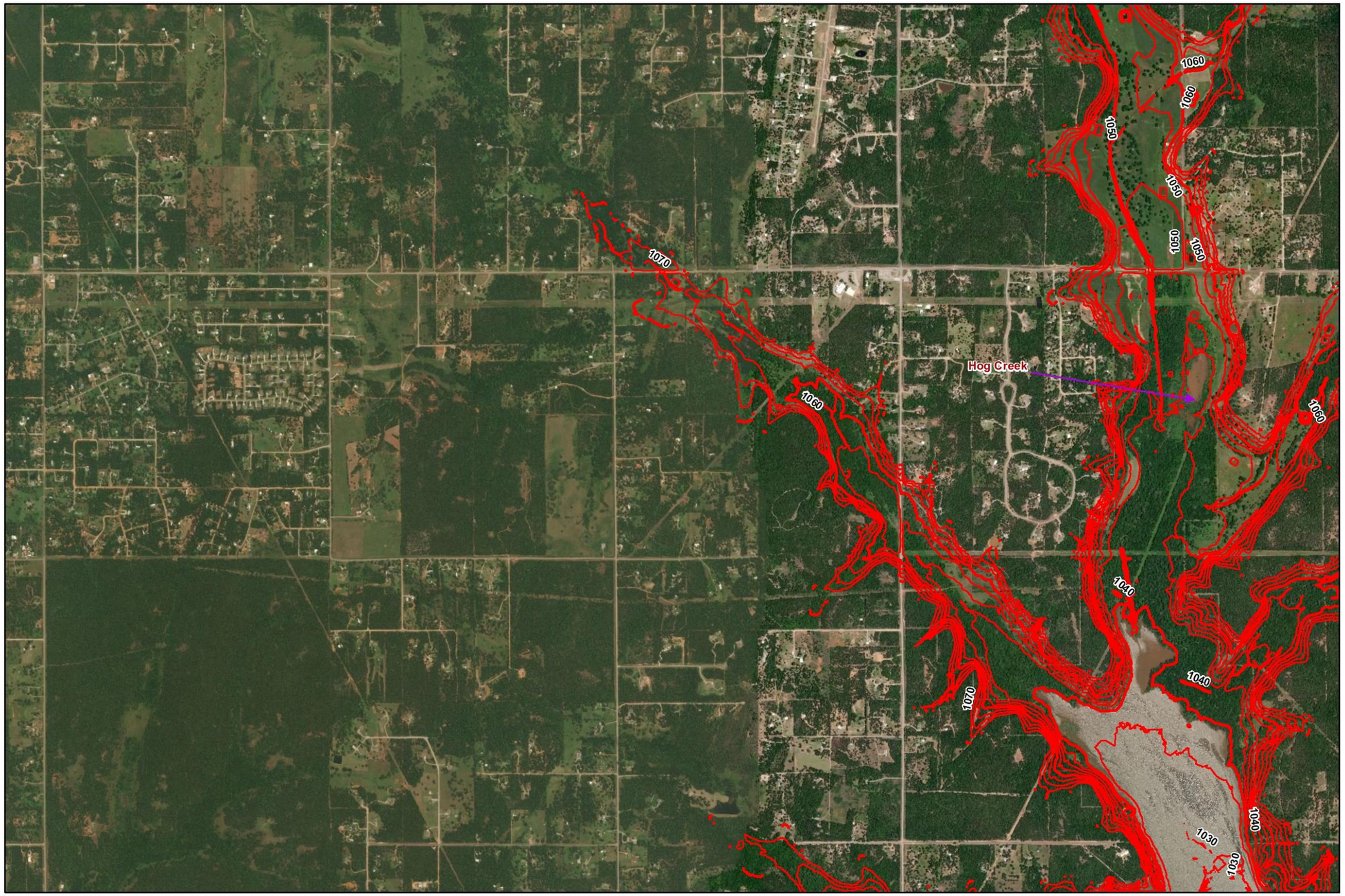


Thunderbird Reservoir Oklahoma Elevation Contour Map

Sheet 5

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Morning Glory Spillway
Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

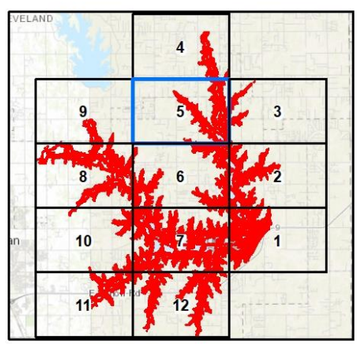
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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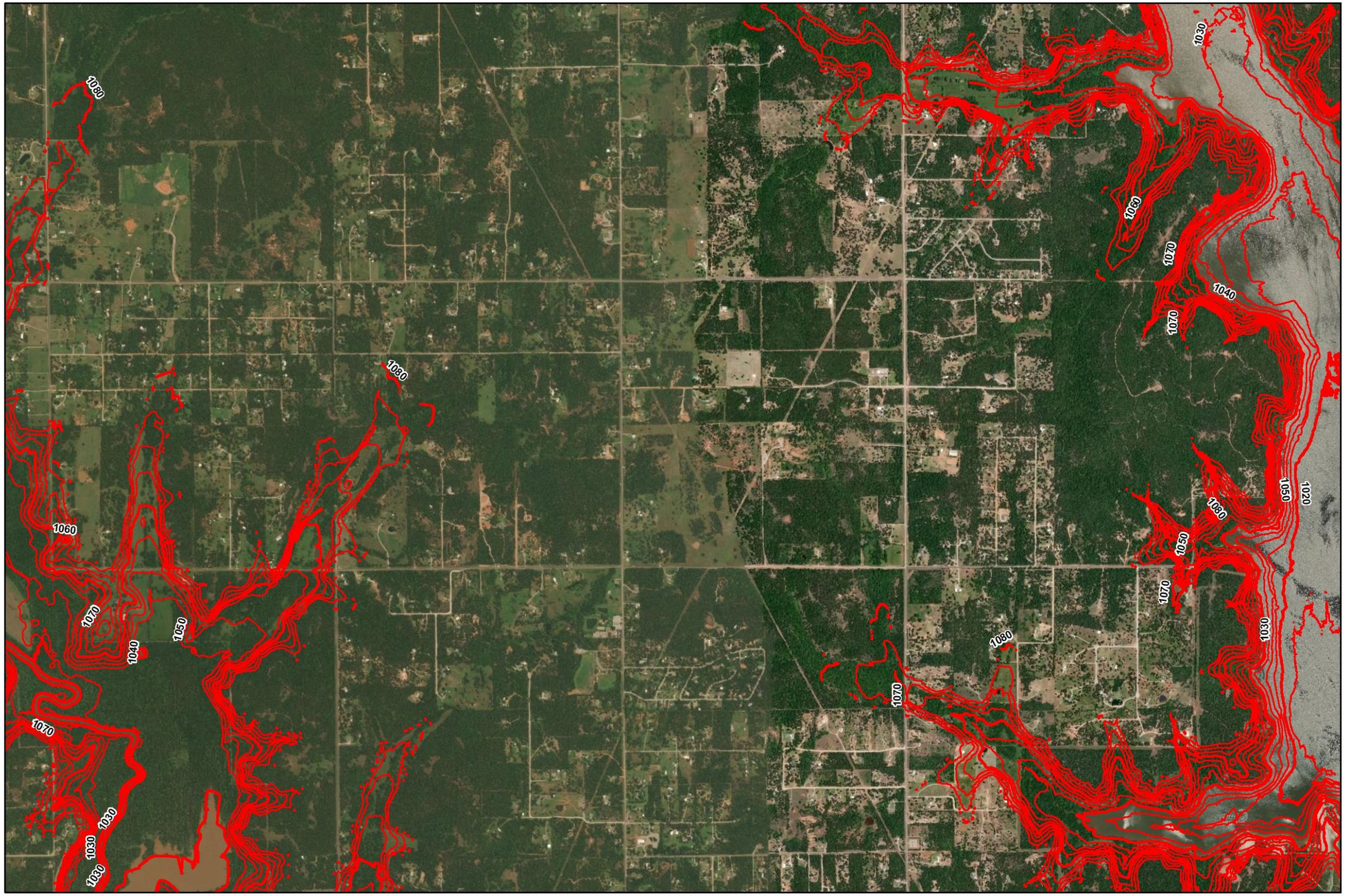


Thunderbird Reservoir
Oklahoma
Elevation
Contour Map

Sheet 6

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Morning Glory Spillway
Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

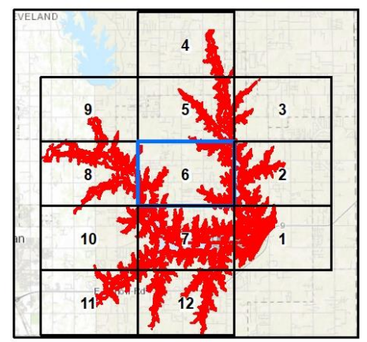
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Thunderbird Reservoir Oklahoma Elevation Contour Map

Sheet 7

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Morning Glory Spillway Crest Elevation Referenced to Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

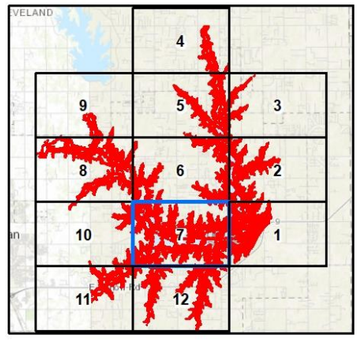
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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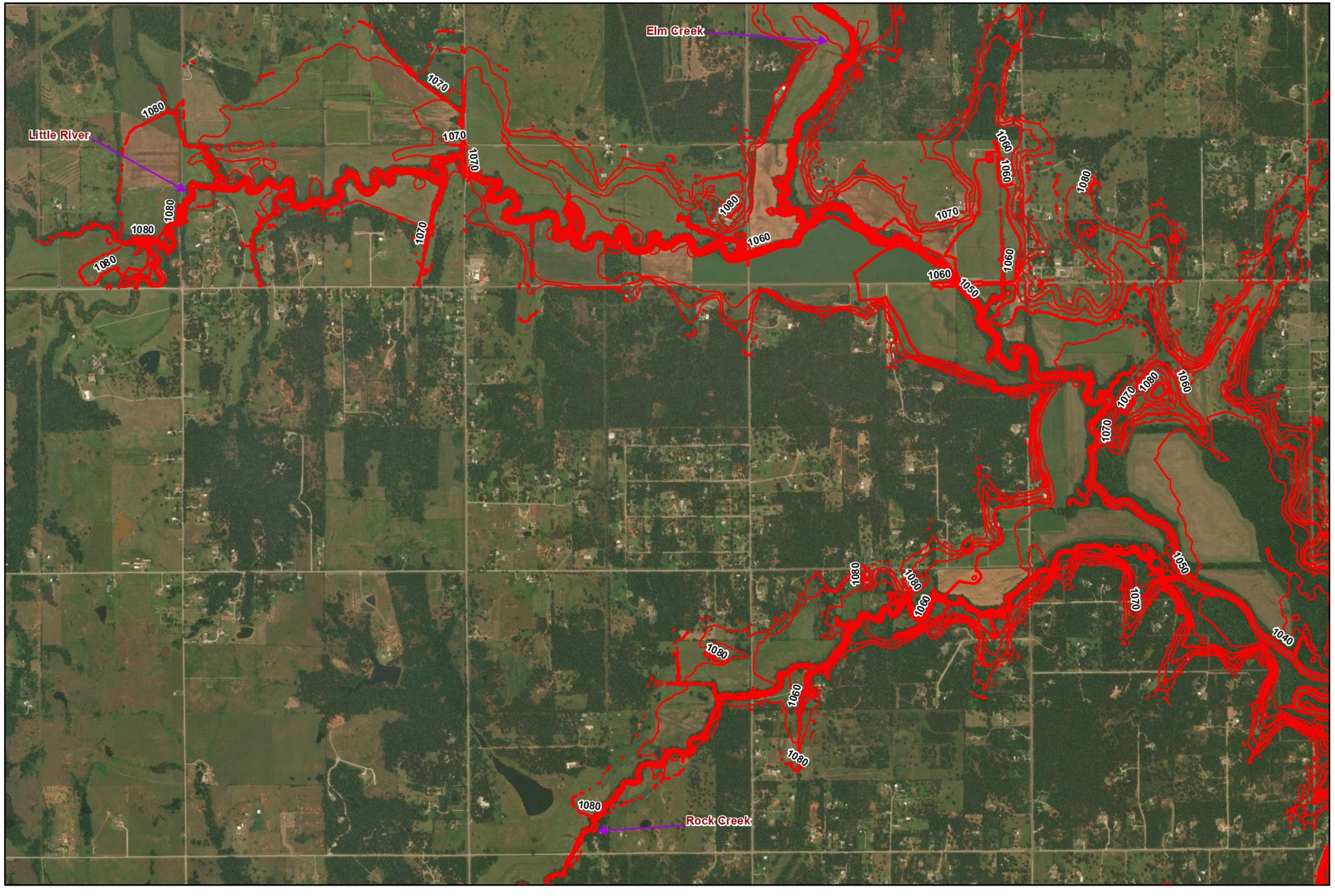


Thunderbird Reservoir Oklahoma Elevation Contour Map

Sheet 8

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Morning Glory Spillway
Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

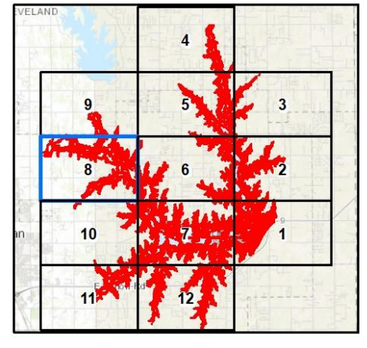
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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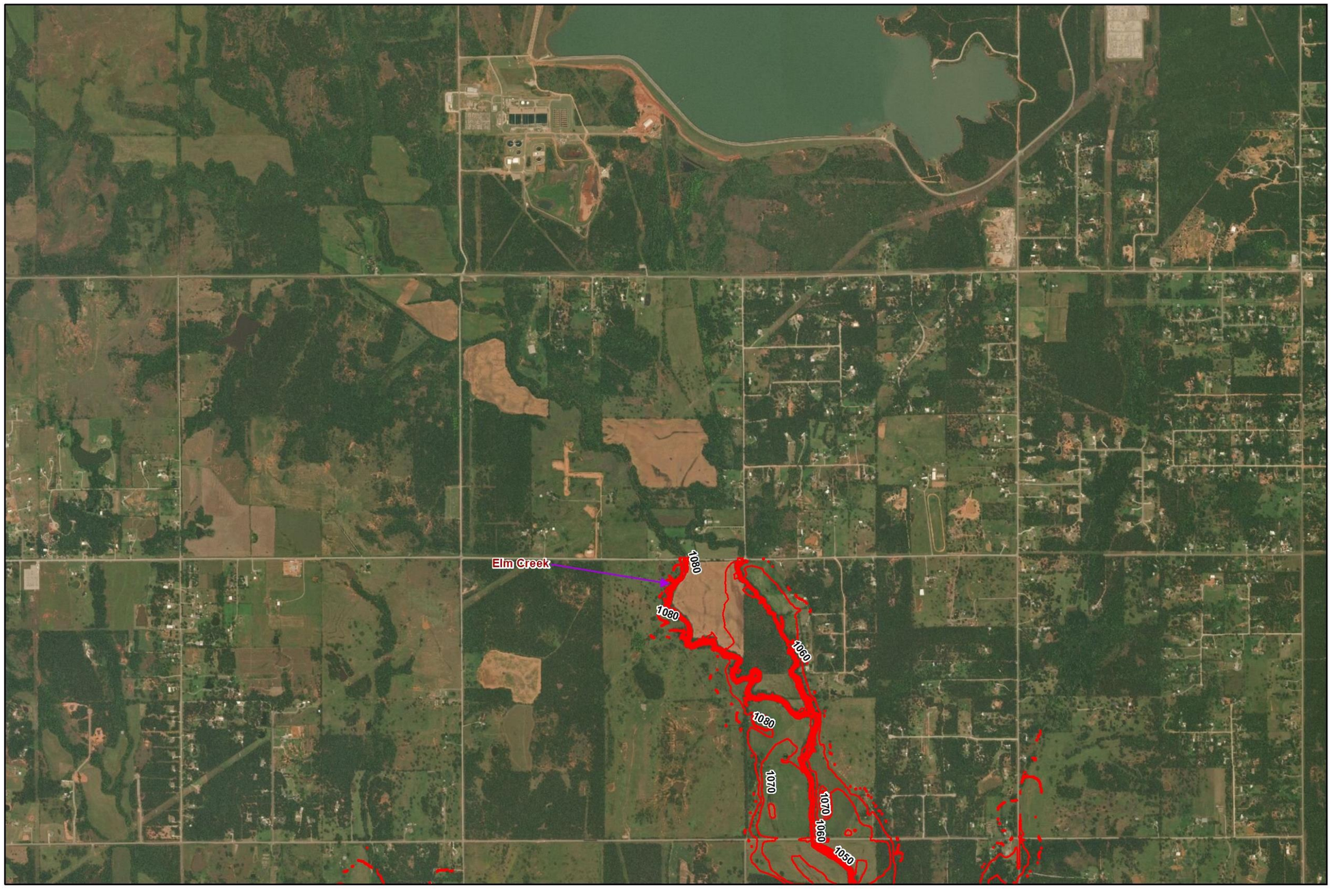


Thunderbird Reservoir Oklahoma Elevation Contour Map

Sheet 9

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Morning Glory Spillway Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

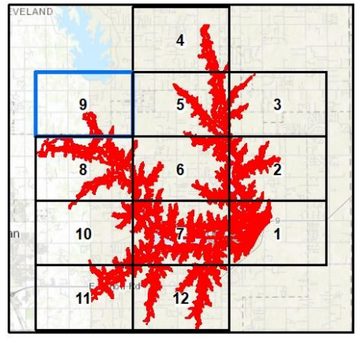
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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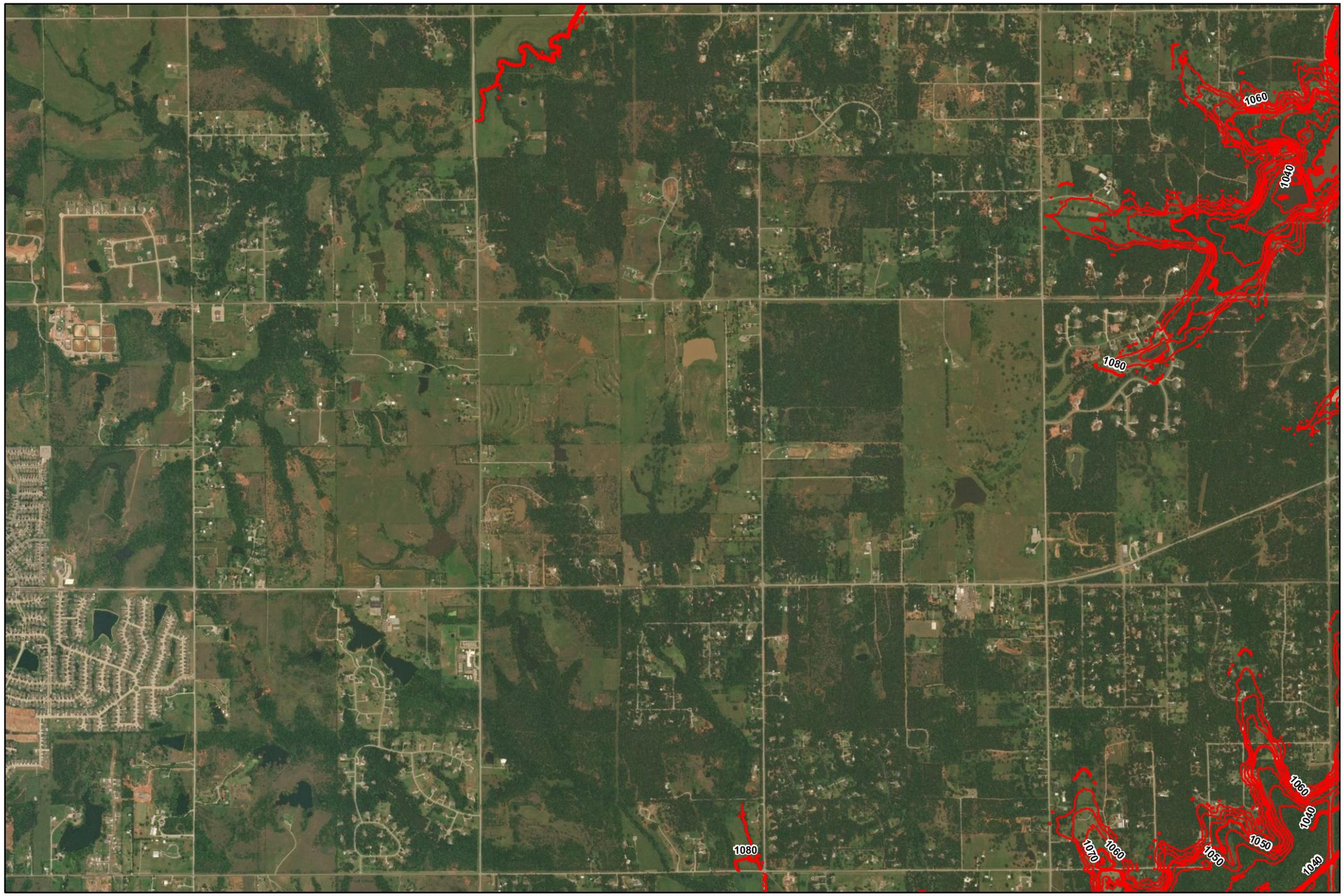


Thunderbird Reservoir
Oklahoma
Elevation
Contour Map

Sheet 10

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Morning Glory Spillway
Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

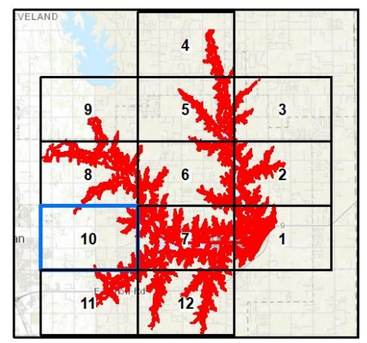
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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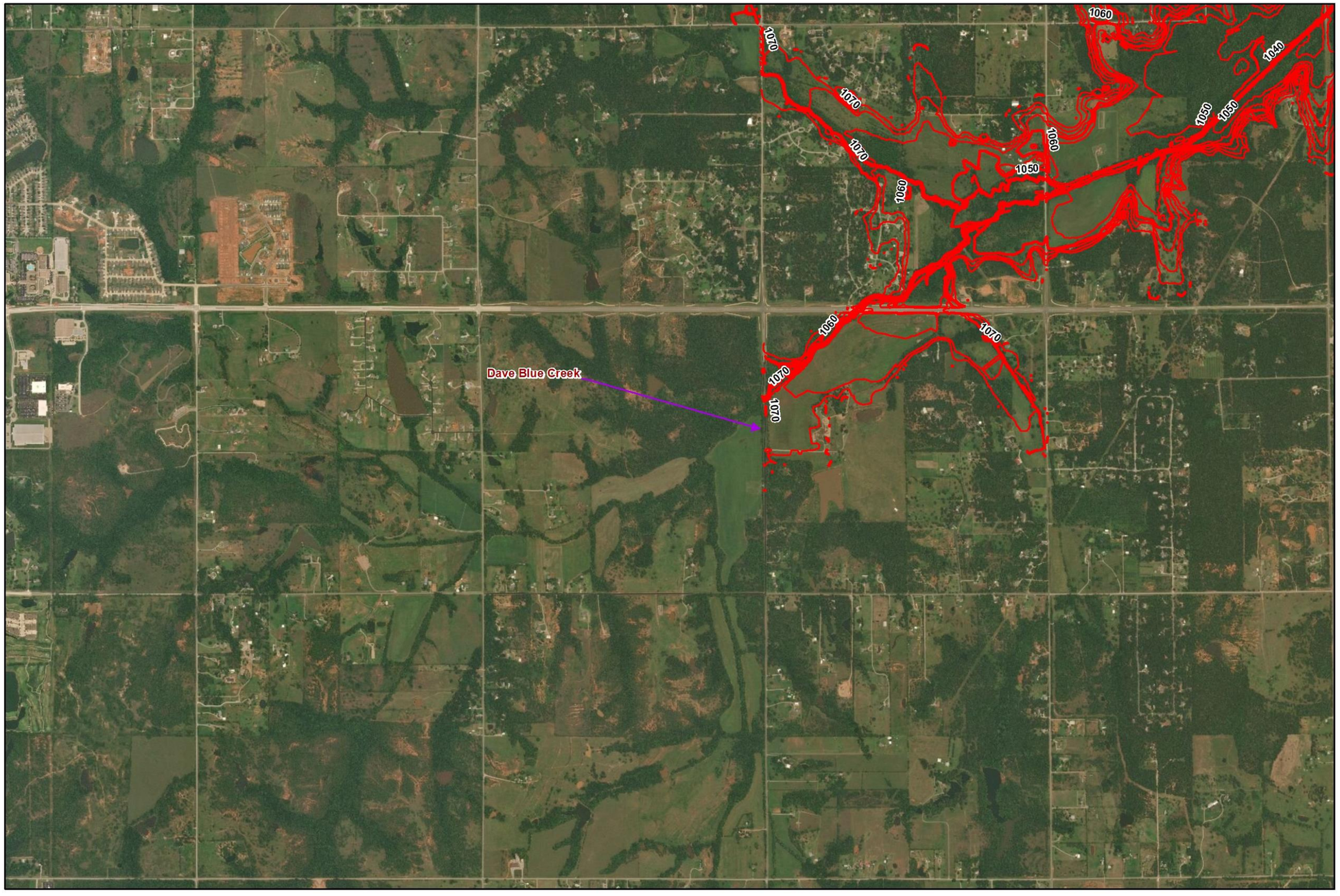
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Thunderbird Reservoir Oklahoma Elevation Contour Map

Sheet 11

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Morning Glory Spillway Crest Elevation Referenced to Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

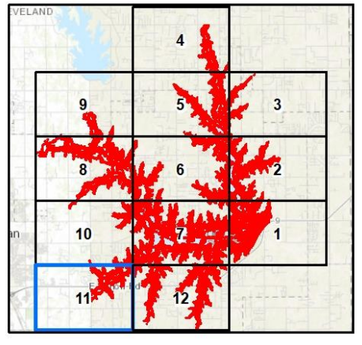
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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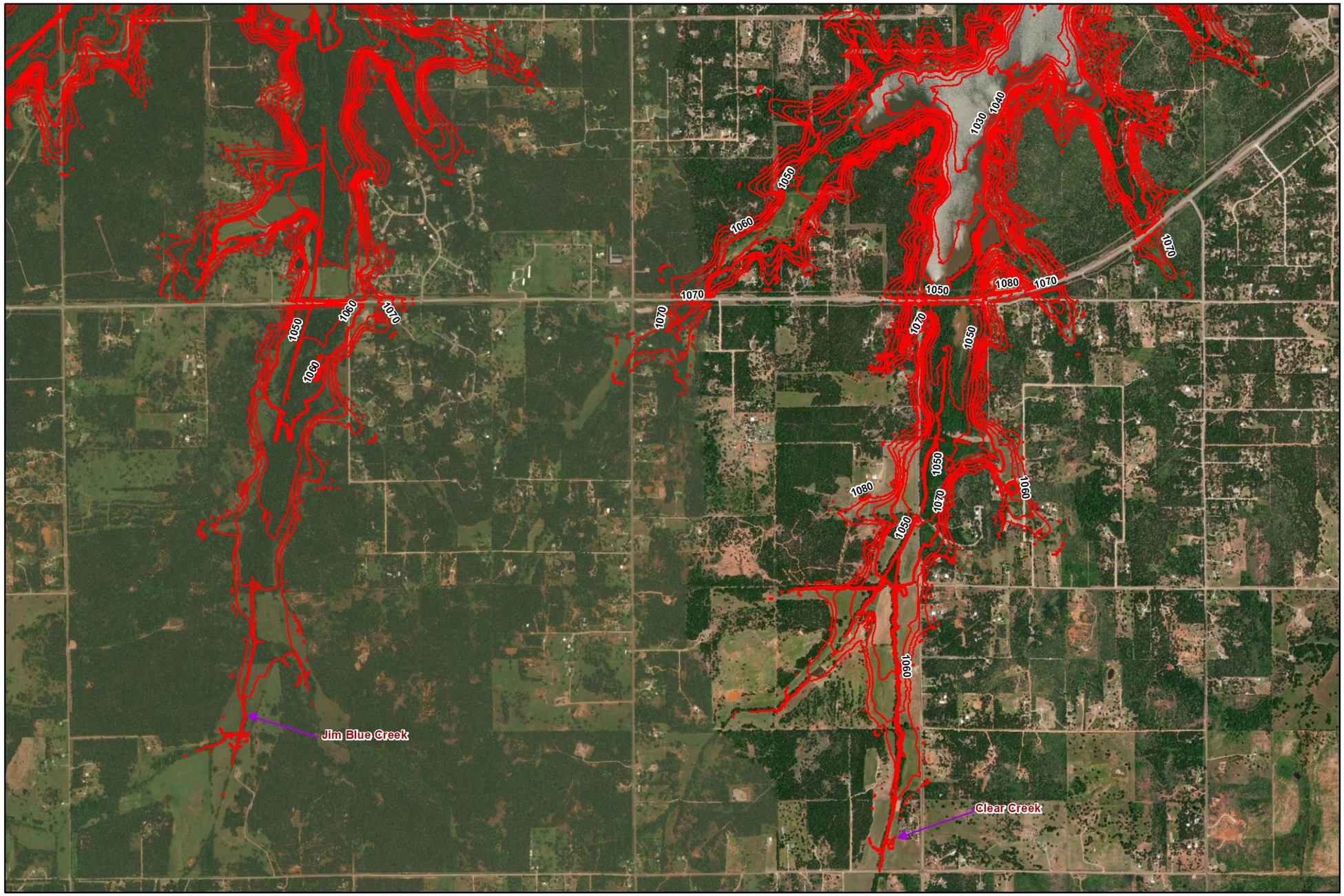


Thunderbird Reservoir
Oklahoma
Elevation
Contour Map

Sheet 12

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Oklahoma South Zone FIPS 3502
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Morning Glory Spillway
Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) - RPVD = 0.08 sft
RPVD ≈ NGVD29

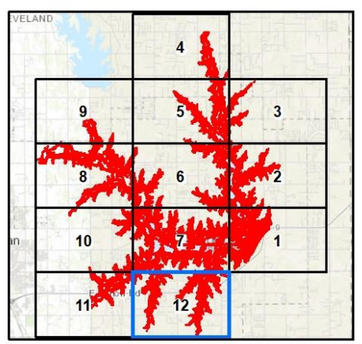
Five Foot Contour Interval

Primary Data Source:
2015 Thunderbird Reservoir Study

N

Scale 1:20,000

0 1,500 3,000 Feet



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Appendix D – Thunderbird Reservoir: August 4, 2020 OTAO Survey Report

2020 NORMAN DAM - SURVEY CONTROL COORDINATE TABLE						
POINT I.D.	**STATE PLANE (GRID NORTH) (U.S. SURVEY FOOT)**		**LOCAL (U.S. SURVEY FOOT)**		**ELEVATION (NAVD88)**	**ELEVATION (NGVD29)**
	NORTHING	**EASTING**	**NORTHING**	**EASTING**		
SURVEY CONTROL POINTS						
93-4AB	687,093.92	2,201,306.10	87,126.57	201,410.71	1,071.81	1,071.73
93-4ABCRT	687,093.91	2,201,306.11	87,126.56	201,410.72	1,073.15	1,073.07
93-5AB	688,174.34	2,201,879.47	88,207.04	201,984.10	1,073.09	1,073.01
BM1	685,206.75	2,200,312.50	85,239.31	200,417.06	1,095.29	1,095.21
EVAPPAN	690,520.93	2,191,192.60	90,553.75	191,296.73	1,062.17	1,062.10
M-1-R	687,926.36	2,202,088.32	87,959.05	202,192.96	1,005.55	1,005.47
M-2-R	686,948.15	2,201,406.52	86,980.80	201,511.13	1,024.55	1,024.48
M-3-L	688,131.67	2,202,203.44	88,164.37	202,308.09	1,004.01	1,003.93
M-4-L	688,572.81	2,202,322.21	88,605.53	202,426.86	1,012.70	1,012.63
OW-STILLBSN	688,606.60	2,202,435.48	88,639.32	202,540.15	987.07	986.99
P93-1	687,001.95	2,201,492.18	87,034.59	201,596.80	1,017.07	1,016.99
P93-2AB	687,302.88	2,201,557.10	87,335.54	201,661.72	1,027.79	1,027.71
P93-3	688,189.13	2,202,033.72	88,221.84	202,138.36	1,026.66	1,026.59
PTNO110	688,619.00	2,202,441.86	88,651.73	202,546.53	988.09	988.01
RP20L	691,287.94	2,203,497.34	91,320.80	203,602.05	1,053.94	1,053.86
RP20R	691,269.12	2,203,532.68	91,301.97	203,637.39	1,055.04	1,054.96
RP20R	691,269.12	2,203,532.68	91,301.97	203,637.39	1,055.04	1,054.96
RP20R.2	691,269.13	2,203,532.69	91,301.98	203,637.40	1,055.05	1,054.98
RP82.5L	691,317.04	2,203,443.03	91,349.90	203,547.75	1,051.43	1,051.36
RPCLDAM	691,766.89	2,204,584.32	91,799.77	204,689.08	1,075.22	1,075.15
SCMCREST	688,055.58	2,201,795.76	88,088.27	201,900.40	1,073.25	1,073.17
SMCDS	689,255.06	2,202,958.04	89,287.82	203,062.73	1,041.67	1,041.60
SMCTOE	687,885.91	2,202,107.84	87,918.60	202,212.49	999.50	999.42
SM-NORTH	688,131.68	2,202,203.42	88,164.38	202,308.07	1,004.00	1,003.93
SM-SOUTH	687,926.36	2,202,088.33	87,959.05	202,192.98	1,005.54	1,005.46
SP20	691,575.33	2,204,208.03	91,608.19	204,312.78	1,066.59	1,066.51
SP20L	691,598.74	2,204,175.78	91,631.60	204,280.53	1,065.76	1,065.68
SP151.5	691,207.41	2,203,648.77	91,240.26	203,753.49	1,057.59	1,057.51
TOPSPWY2	689,483.74	2,202,510.03	89,516.50	202,614.69	1,049.48	1,049.41
TOPSPWY3	689,483.27	2,202,510.50	89,516.03	202,615.16	1,049.49	1,049.42
TOPSPWY4	689,484.89	2,202,509.35	89,517.65	202,614.02	1,049.46	1,049.38
TOPSPWY5	690,520.94	2,191,192.54	90,553.76	191,296.67	1,062.16	1,062.08

2020 SURVEYOR'S REPORT

1. Bureau of Reclamation employee Mr. Meyer Jay of the Oklahoma-Texas Area Office (OTAO) conducted a field survey August 4, 2020. Mr. Jay established survey control and collected topographic survey data utilizing 2-Leica Viva GS15.R2 GNSS Receivers.

2. Mr. Jay referenced the project horizontal and vertical control reference frames to Norman Dam control point "SP151.5" utilizing Global Navigation Satellite System (GNSS) control quality measurements.

3. The project horizontal control is referenced to the Oklahoma South Zone, State Plane Coordinate System NAD 83 (2011)(EPOCH:2010.0000). Mr. Jay established horizontal coordinates on Norman Dam control point "SP151.5" using GNSS static observations collected on August 11-12, 2020. Mr. Jay set the base receiver to collect static observations at 5 second intervals. The base receiver collected 26 hours and 7 minutes of static observations. The base receiver's antenna reference point (ARP) was 2.000 meters. At Mr. Jay's request, Missouri Basin Regional Office employee Mr. Ron Robertson submitted a RINEX file to National Geodetic Society's Online Users Positioning Service (NGS OPUS) to obtain state plane coordinates and an orthometric height. OPUS results met National Geodetic Society standards for a high-quality position and utilized a Precise ephemeris. Mr. Robertson post-processed GNSS data with Leica Infinity software, ver. 3.3.2 Build 33504.

4. Horizontal Coordinates are Local Project Coordinates. Units are U.S. Survey Foot. Mr. Jay collected 4- to 11-real-time kinematic (RTK) observations on each point I.D. with the exception of point I.D. SP151.5.

5. Basis of Bearings: Grid North, Oklahoma South Zone, State Plane Coordinate System (3502 OK), NAD 83.

6. Horizontal Reference Frame: State Plane and Local Project Coordinates are based on August 11-12, 2020 GNSS static survey referenced to the Oklahoma South Zone, State Plane Coordinate System (3502 OK), NAD83 (2011)(EPOCH:2010.0000). These State Plane Coordinates are in U.S. Survey Feet (One U.S Survey Foot = 12/39.37 Meter). The site specific State Plane Grid to Ground Plane conversion factor is 1/0.999952480779, applied at a 0, 0 origin. Local coordinates are truncated by subtracting 600,000 from the northings, and subtracting 2,000,000 from the eastings.

7. Vertical Reference Frame: NAVD88 (Computed using GEOID18). Elevations are in U.S Survey Feet (One U.S Survey Foot = 12/39.37 Meter). The elevations are based on Norman Dam control point "SP151.5", elevation 1,057.59 feet. To generate elevations based on NGVD29 vertical datum, subtract 0.07719-ft. from NAVD88 elevations. Note: NGVD29 reference frame is the assumed project vertical datum. Conversion factor calculated by subtracting the NAVD88 measured values for the spillway crest height from the published crest height of 1049.40 feet.
For comparision, National Geodetic Survey (NGS) Height Conversion Methodology calculates a conversion value of 0.3379-ft: "This process is designed to provide datum shift between the NAVD 88 and NGVD 29 vertical datums at specified geographic position. Dennis G. Milbert, Ph.D. 05/12/1999. National Geodetic Survey program VERTCON was used to compute modeled difference in orthometric height between NAVD88 and NGVD29. Tests of the predictive capability of the physical model show a 2.0 cm RMS agreement at our 381,833 data points. For this reason, the VERTCON 2.0 model can be considered accurate at the 2 cm (one sigma) level. It should be emphasized that VERTCON 2.0 is a datum transformation model, and can not maintain the full vertical control accuracy of geodetic leveling. In some rare cases, these local NGVD 29 distortions could be 20 cm or more."