Technical Report No. ENV-2021-052

Lovewell Reservoir 2020 Sedimentation Survey

Pick-Sloan Missouri Basin Program
Missouri Basin and Arkansas-Rio-Grande-Texas Gulf Regions

U.S. Department of the Interior **March 2021**

Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acknowledgements

Several people from the Technical Service Center, Water, Environmental, and Ecosystems Division were involved in the success of this project. Mr. Kent Collins planned the 2020 hydrographic survey of Lovewell Reservoir and he led efforts to process the bathymetric data. Mr. Collins was assisted in the field by Mr. Robert Hilldale and Mr. Wesley Burkert of the Nebraska-Kansas Area Office. The bathymetric data were processed by Ms. Caroline Ubing. Mr. Brian Connolly developed the final topobathymetric surface and implemented the Area Capacity Calculations Tool. Finally, Mr. Jack Truax developed all maps published in this report. This study was funded by the Missouri Basin and Arkansas-Rio Grande – Texas Gulf Regional Office.

Disclaimer

Cover: Lovewell Reservoir (Kent Collins)

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14. SHORT ABSTRACT

The 2020 multibeam bathymetric survey of Lovewell Reservoir was combined with 2010 aerial LiDAR to produce a combined digital surface of the reservoir bottom. Analysis of this data indicates that, as of June, 2020, at the top of surcharge pool elevation (1610.3 feet, Reclamation Project Vertical Datum [RPVD]), the reservoir has a surface area of 7,663 acres and a storage capacity of 179,778 acre-feet. At the top of the active conservation pool elevation, 1582.6 feet (RPVD), the 2020 computed surface elevation was 2,980 acres with a storage capacity of 34,888 acre feet. Since the original filling in 1957, the reservoir is estimated to have lost 6,798 acre-feet of storage capacity (16 percent) due to sedimentation below the top of the active pool. The dead storage pool volume has reduced to 17 percent of the original dead storage volume, an estimated 83 percent storage loss in that area of the reservoir. The sedimentation level at the dam is at elevation of 1554 feet (RPVD), which is 70 percent of the height between the original reservoir bottom and the top elevation of the dead storage pool.

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Lovewell Reservoir 2020 Sedimentation Survey

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Date: 2021.03.24 12:40:23 -06'00'

Prepared by: Caroline Ubing P.E., Hydraulic Engineer
Sedimentation & River Hydraulics, 86-68240

TRAVIS HARDEE Digitally signed by TRAVIS HARDEE
Date: 2021.03.24 12:46:19 -06'00'

Prepared by: Travis Hardee, Hydraulic Engineer
Sedimentation & River Hydraulics, 86-68240

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Peer Reviewed by: Kent Collins P.E., Hydraulic Engineer
Sedimentation & River Hydraulics, 86-68240

Acronyms and Abbreviations

cfs	cubic feet per second (cfs)
DOI	Department of the Interior
feet	foot or feet
GIS	Geographic Information System
GPS	Global Positioning System
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
mi^2	square miles
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 Dams
NRCS	Natural Resources Conservation Service
OPUS	Online Positioning User Service
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

Executive Summary

Lovewell Dam and Reservoir are on White Rock Creek approximately 19 miles upstream from the confluence of White Rock Creek and the Republican River, about 3 miles northwest of Lovewell, Kansas.

A bathymetric survey of Lovewell Reservoir was conducted in 2020 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1957 and since the last survey in 1995; and

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

The bathymetric survey was conducted from a boat using a multi-beam depth sounder that was interfaced with real-time kinematic (RTK) global positioning system (GPS) instruments (for horizontal positioning) to map the reservoir bottom. The 2020 multibeam bathymetric survey of Lovewell Reservoir was combined with 2010 LiDAR data and one contour line digitized from 2017 aerial imagery to produce a combined digital surface of the reservoir bottom.

This survey was conducted between June 2 and June 5, 2020 when the reservoir water surface elevation ranged between 1582.91 and 1582.95 feet (Reclamation Project Vertical Datum [RPVD]), 0.33 feet above the normal operations elevation of 1582.6 feet. The above-water topographic data were measured in 2010.

Analysis of the combined data sets indicates the following results:

- At the top of active pool elevation (1582.6 feet, RPVD), the reservoir would have a surface area of 2,980 acres and a storage capacity of 34,888 acre-feet.

- At the top of the surcharge pool elevation (1610.3 feet, RPVD), the reservoir would have a surface area of 7,663 acres and a storage capacity of 179,778 acre-feet.

- Since the original filling of the reservoir in 1957, the reservoir is estimated to have lost 6,798 acre-feet of storage capacity (16 percent) due to sedimentation below the active pool (elevation 1582.6 feet, RPVD). Since the last reservoir survey in 1995, the reservoir is estimated to have lost 777 acre-feet of storage capacity below the top of the active pool. These volumes indicate an average sediment yield rate of 108 acre-feet per year (acre-feet/year) or 0.3 acre feet per square mile per year (acre-feet/mi^2/year) since 1957, which is considered low as defined in Reclamation (2006).

- By 2020, the dead storage pool volume had reduced to 17 percent of the original dead storage volume. The sedimentation level at the dam is at 1554 feet (RPVD), meaning that sediment has filled 70 percent of the height between the original reservoir bottom and the top elevation of the dead storage pool.

- Historic rates of reservoir sedimentation indicate a decreasing trend in since the original survey. However, only two surveys have been conducted since the original filling using very different technology. It is possible some of the large change in sedimentation rate between the original and 1995 survey is due to differences in survey techniques.

- Another survey should be conducted within the next ten years, by 2030, assuming no changes in dam and reservoir operations or no natural disasters.

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	**Lovewell Reservoir**	Region	Great Plains
Owner	Reclamation	Area Office	Nebraska-Kansas
Stream	White Rock Creek	Vertical Datum	RPVD
County	Jewell County	Top of Dam (feet)	1616.0 feet
State	Kansas	Spillway Crest (feet)	1575.3 feet
Lat (deg min sec)	39°53.1′ N	Power Penstock Elevation (feet)	*NA*
Long (deg min sec)	98°1.7′ W	Low Level outlet (feet)	1562.07
HUC4	1025	Hydraulic Height (feet)	75.3 feet
HUC8	10250016	Total Drainage Area (mi^2)	351 sq. miles
NID ID	KS00023	Date storage began (mm/dd/yyyy)	05/29/1957
Dam Purpose	Irrigation, Flood Control, Recreation	Date for normal operations	May 1958

HUC = Hydrologic Unit Code; NID = National Inventory of Dams

Original Design

Storage Allocation	**Elevation (feet)**	**Surface area (acres)**	**Capacity (acre-feet)**	**Gross Capacity (acre-feet)**
SURCHARGE	1610.3	7,635	94,146	186,296
FLOOD CONTROL	1595.3	5,025	50,463	92,150
JOINT USE / ACTIVE	1582.6	2,986	24,927	41,687
INACTIVE	1571.7	1,704	11,686	16,760
DEAD	1562.07	710	5,074	5,074

Survey Summary

Survey Date	**Type of Survey**	**No. of Range lines or Contour Intervals**	**Contributing Sediment Drainage Area (mi^2)**	**Period Sedimen-tation Volume (acre-feet)**	**Cumulative Sedimentation (acre-feet) at 1610.3 feet**	**Lowest Reservoir Elevation (feet)**	**Remaining Portion of Dead Storage (percent)**
May 1957	**Photo-grammetry**	**5-feet**	**351**	**0**	**0**	**1535**	**100**
June 1995	**Single Beam/ USGS Quad**	**5-feet**	**351**	**6,020**	**6,020**	**1550.3**	**33**
June 2020	**Multi-beam/ LiDAR**	**1-feet**	**351**	**498**	**6,518**	**1554.0**	**17**

Notes

- **Original survey date was assumed to correspond with dam closure on May 29, 1957**
- **Photogrammetry was the assumed method of the original (1957) survey**

Contents

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1. Introduction

Lovewell Dam and Reservoir are on White Rock Creek approximately 19 miles upstream from the confluence of White Rock Creek and the Republican River, about 3 miles northwest of Lovewell, Kansas (Figure 1). The dam and reservoir are operated by Reclamation as part of the Bostwick Division of the Pick-Sloan Missouri Program as part of the Lower Republican River Basin.

All rivers transport sediment particles (e.g., clay, silt, sand, gravel, and cobble) and reservoirs tend to trap sediment, diminishing the reservoir storage capacity 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, Missouri Basin and Arkansas-Rio Grande – Texas Gulf 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 June 2, 2020 to June 5, 2020 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1957 and since the last survey in 1995; and

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

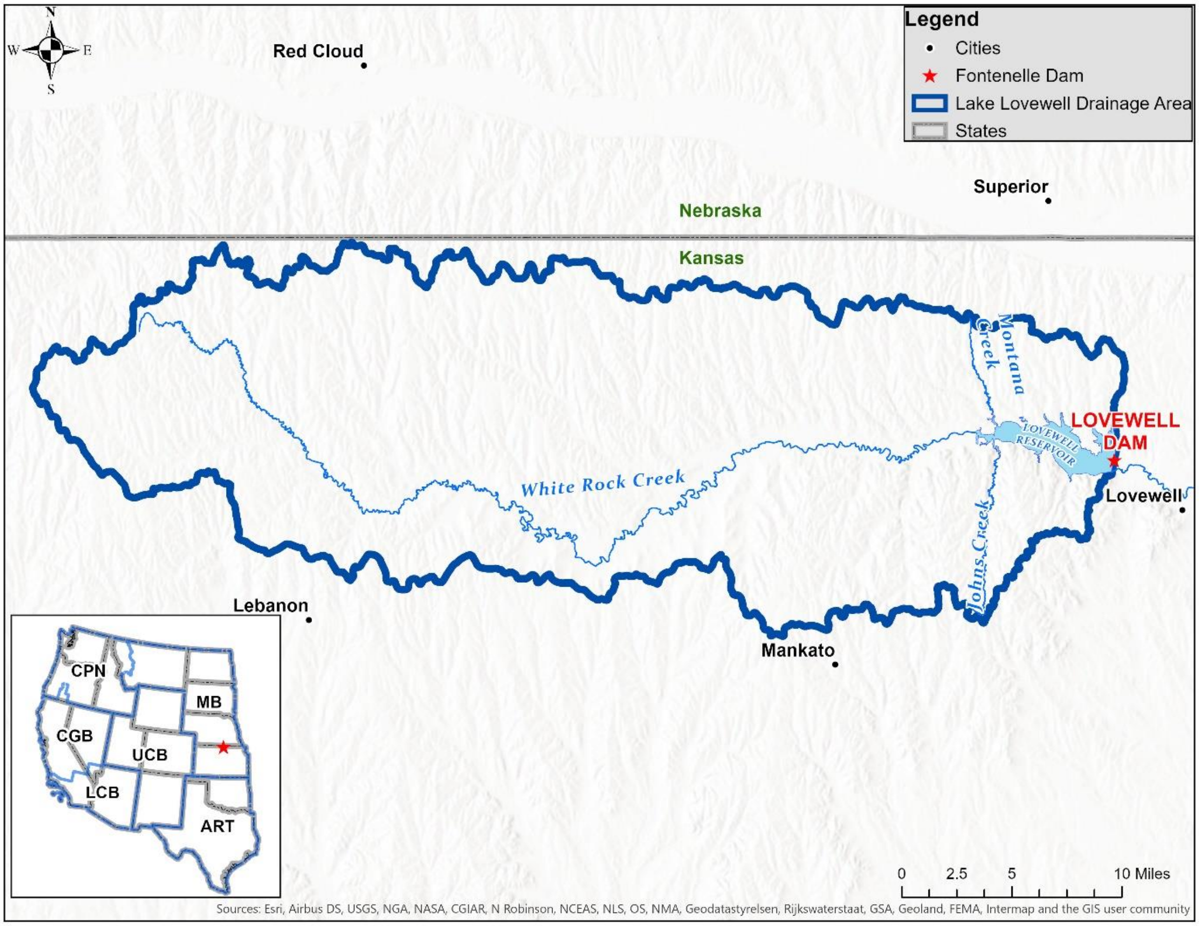

Figure 1. Location map of Lovewell Dam and Reservoir, 3 miles northwest from Lovewell, Kansas. The contributing drainage area for Lovewell reservoir is outlined in blue.

2. Watershed Description

2.1. Location and Drainage

The watershed upstream from Lovewell Dam as a total contributing drainage area of 345 square miles (mi^2; Figure 2). There are no major dams upstream of the reservoir that would trap considerable sediment, therefore the net sediment-contributing is estimated to be 345 mi^2. This watershed is relatively flat, low-relief agricultural land with elevations ranging from 1571.7 feet at the top of the inactive pool to 2080 feet along the western boundary of the drainage basin (Figure 2). The main contributing natural stream is White Rock Creek. The majority of flow comes from Courtland Canal from releases out of Harlan County Reservoir or natural flow from Republican River outside of irrigation season.

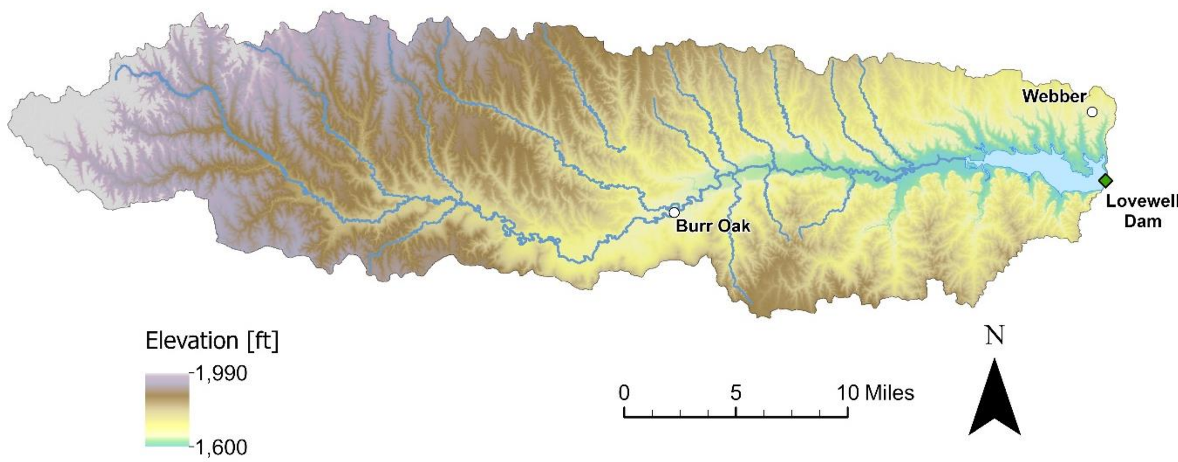

Figure 2. The watershed above Lovewell reservoir has a contributing area of 345 miles with a relief of approximately 500 feet.

2.2. Geology Vegetation, and Land Use

2.2.1. Geology, Soils, Vegetation, and Land Use

The geology of the watershed's drainage area consists primarily of loess (59 percent), shale sourced from the Niobrara Formation (Niobrara chalk, 22 percent), alluvium (15 percent), and Carlile Shale (2 percent) sourced from the Benton Formation (Figure 3). Loess typically comprises silt-sized material, which can easily be transported by both wind and water. Alluvium are deposits of clay, silt, sand, and gravel left by flowing streams, typically within a river valley. Shale is extremely erodible; rivers easily cut through this material, especially during large stochastic events. Therefore, the geology surrounding White Rock Creek consists mostly of fine non-cohesive material, which is easily transported.

Agricultural fields and grasslands make up most of the land cover. Agricultural activities including grazing typically increase the sediment yield of the basin above natural levels. However, the riparian zones along White Rock Creek and tributaries support thick stands of trees and shrubs. Dense vegetation along the riverbanks can help retain sediment from the adjacent farmlands, buffering the sediment yield into the river. Agricultural activities, including grazing, make up most of the land use in the watershed.

Based on the watershed geology and land use, the sediment yield within the basin would be expected to be above natural levels.

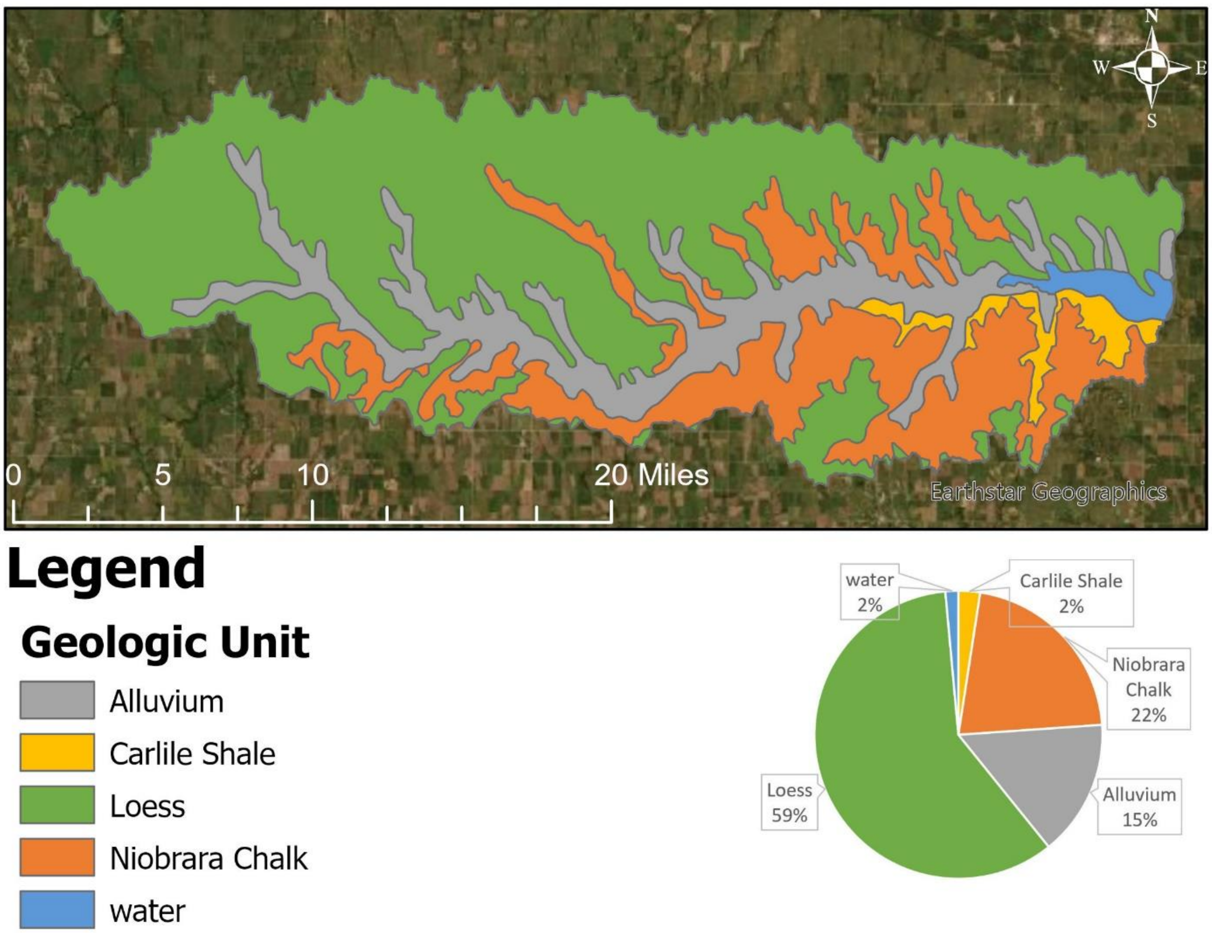

Figure 3. Geologic features of the Lovewell Reservoir watershed (Horton, J.D., 2017).

2.3. Climate and Runoff

Monthly average precipitation peaks in late-spring to early-summer (May, June, and July) whereas peak temperatures typically occur in mid- to late-summer (July and August; Figure 4). Winter low temperatures average below freezing for the months of December, January, and February.

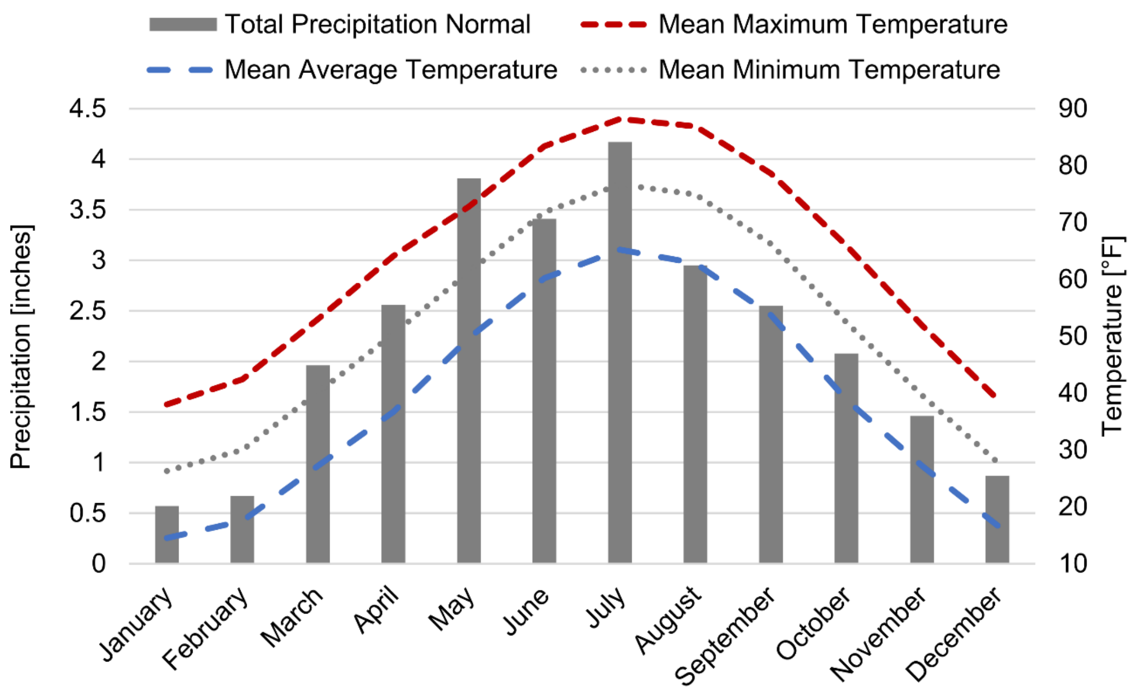

Figure 4. Mean monthly precipitation and temperature at the Burr Oak 1N, Kansas station (NOAA) Web Data source (https://w2.weather.gov/climate/xmacis.php?wfo=gid)

Inflows to the reservoir are from White Rock Creek and the Courtland Canal. USGS stream gage records are available for White Rock Creek near Burr Oak, Kansas (WHITE ROCK C NR BURR OAK, KS; USGS 06853800). The gage is located approximately 7.5 miles upstream of the reservoir delta and represents 66 percent of the total contributing drainage area. The annual instantons peak discharge was greatest in 1973 at 15,800 cubic feet per second (cfs) (Figure 5). Annual flow volume peaked in 1993 at 98,382 acre-feet and the average annual flow volume was 19,377 acre-feet (Figure 6). The mean annual flow volume from White Rock Creek, scaled to the total watershed area, is 29,066 acre-feet per year or 1.6 inches per year. Lovewell reservoir also receives inflows form the Republican River through the Courtland Canal. The scaled mean annual stream flow for White Rock Creek is approximately 40 cfs. The mean daily inflow from the Courtland Canal (station LVABKS; parameter "QJ") is approximately 68 cfs or 49,200 acre-feet/year. Inflow from Courtland Canal is seasonal, with higher inflows during summer months. The computed average daily inflow (station LVKS; parameter "IN") filtered for only positive inflow values is 94 cfs or a mean annual streamflow of 67,920 acre-feet per year (Figure 7). The percent inflow contributed by Courtland Creek versus White Rock Creek varies throughout the year and from year-to-year. Over the past 7 years, the average percent contribution by Courtland Canal is approximately 50 percent (personal communication, Dale Lentz).

The ratio of reservoir storage capacity at flood pool elevation to inflow (LVKS IN) is 2.6, indicating that, when full, the reservoir stores a water volume equivalent to 967 days (2.6 years) of mean annual computed inflow.

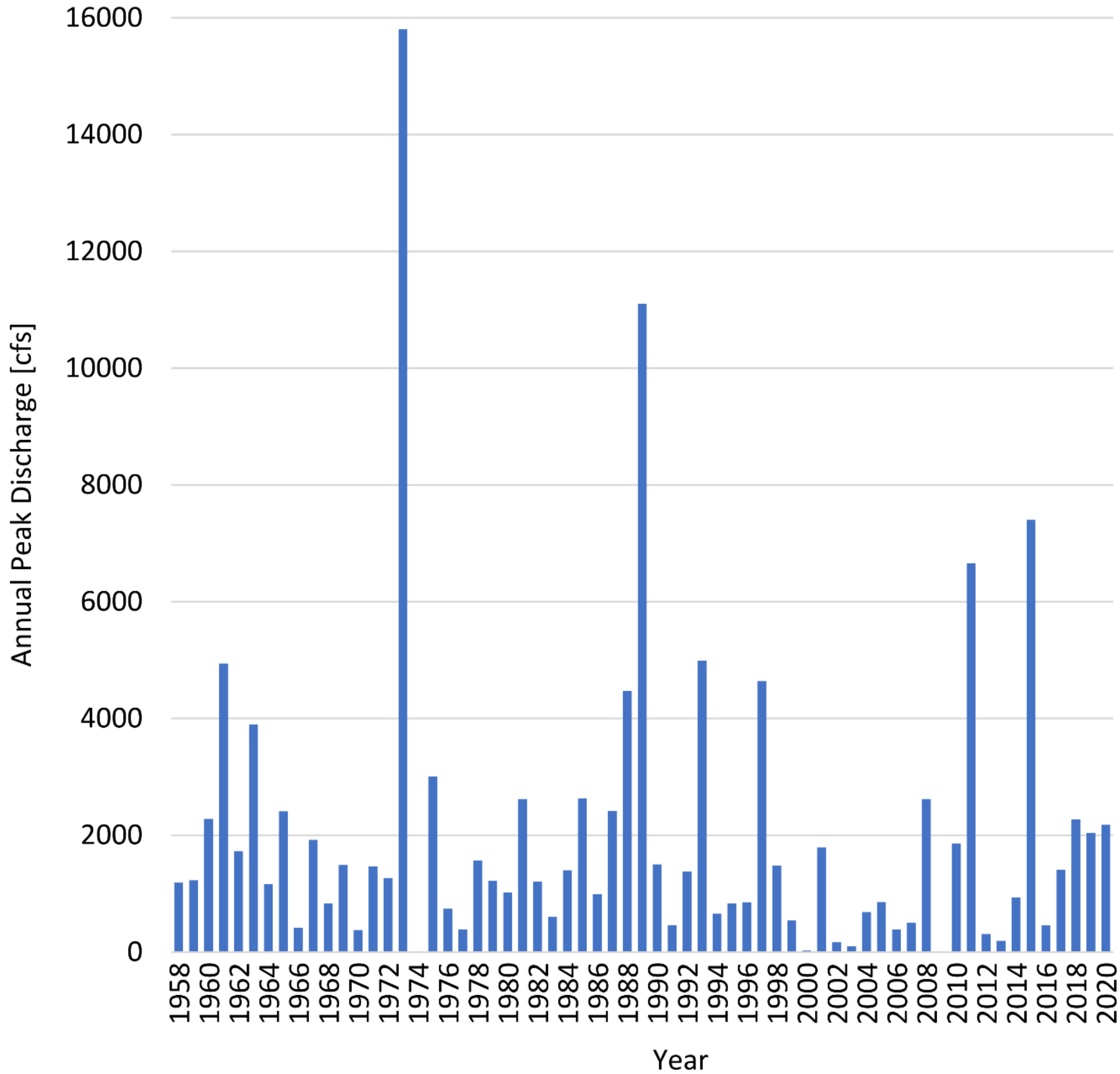

Figure 5. Annual peak discharge at Burr Oak, Kansas (USGS 0683500) from 1958 to 2020.

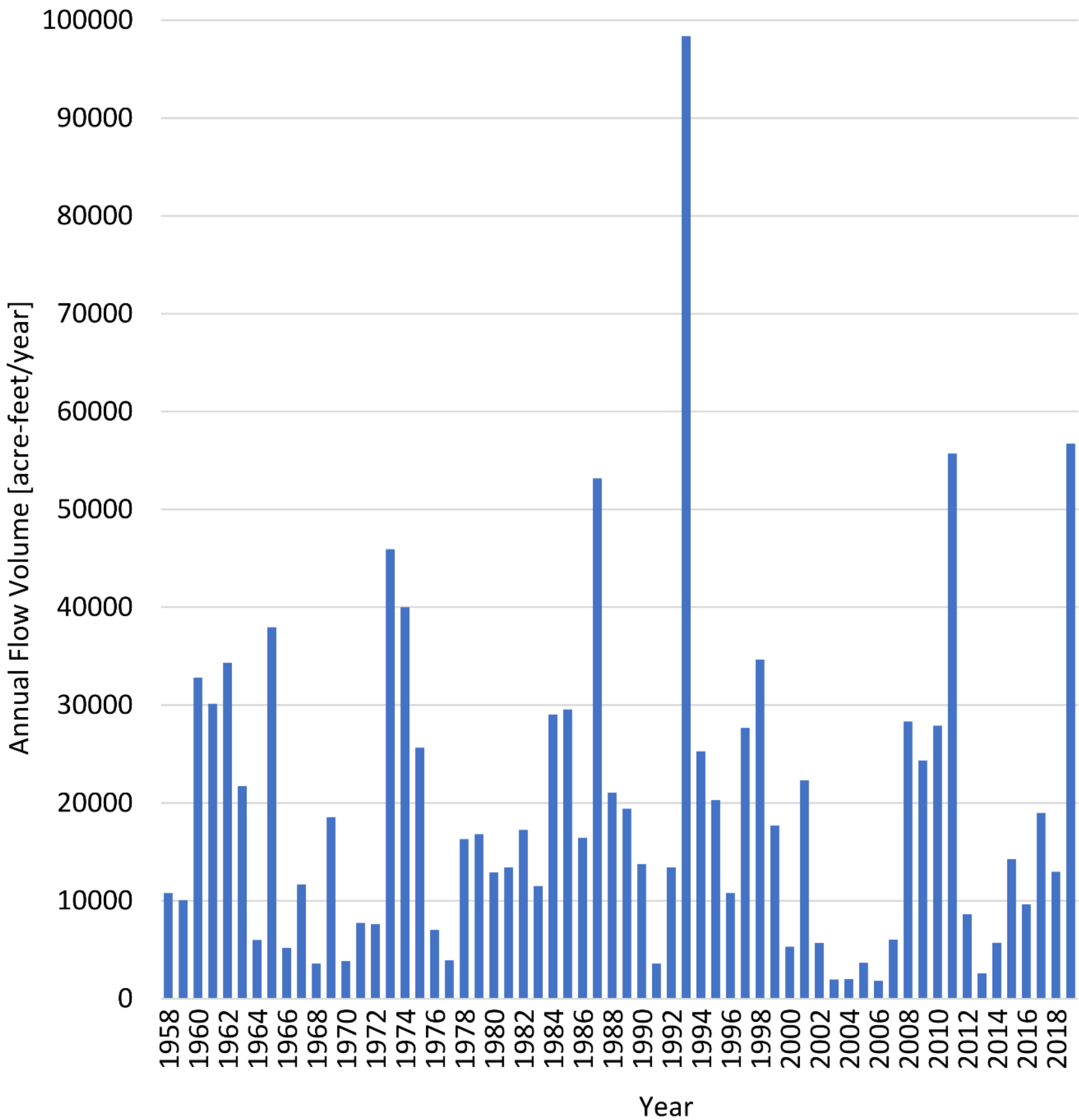

Figure 6. Average annual flow volume at Burr Oak, Kansas (USGS 06853800) from 1958 to 2019.

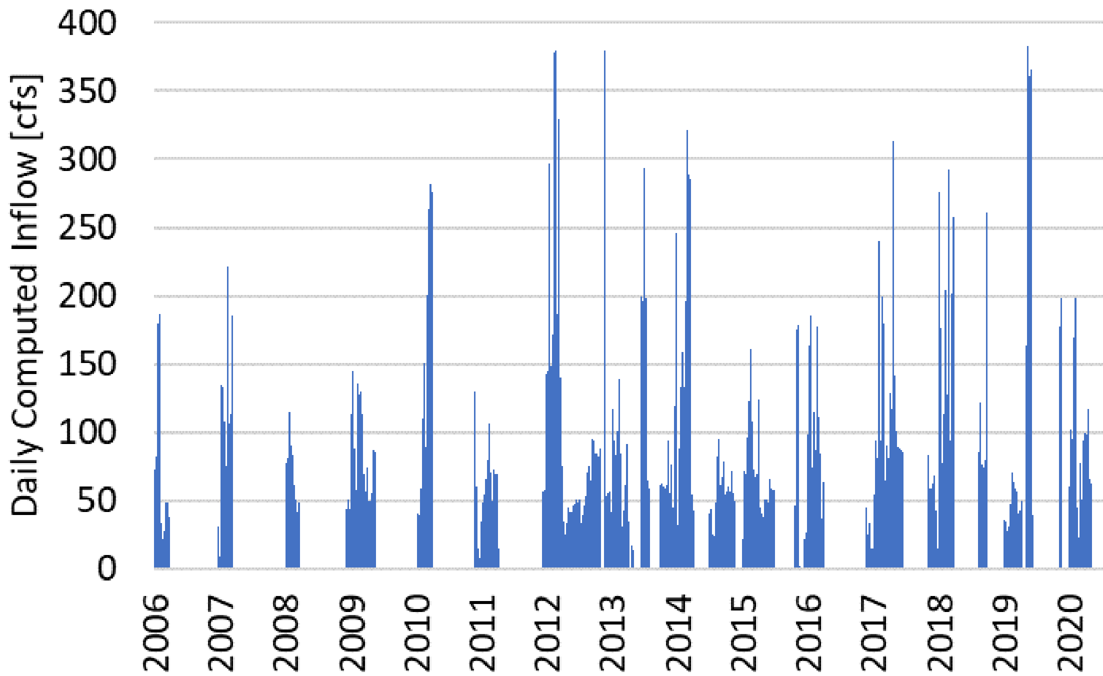

Figure 7. Daily computed inflow (LVKS IN) for the period of record. (https://www.usbr.gov/gp/hydromet/archive_form.html)

2.4. Dam Operations and Reservoir Characteristics

Lovewell Dam is an earth-fill embankment dam. Construction began in 1955 and water storage began in 1957. The historic reservoir water surface elevations (RPVD) are presented in Figure 8. Reservoir operations can impact sedimentation trends. For example, prolonged high reservoir levels can lead to increased deposition along the upstream portion of the reservoir. Alternatively, extended periods of reservoir drawdown can allow stream inflow to incise the reservoir delta, moving sediments further into the reservoir. There is no record of reservoir sediment management activities at Lovewell such as sluicing, flushing, or periodic drawdowns.

In Lovewell reservoir annual water surface elevation typically fluctuates an average of 10 feet, with minimum and maximum annual fluctuations ranging from 4 feet to 20 feet respectively. Since filling in 1957, the forebay water surface elevation fluctuates surrounding the top of active conservation pool (1582.6 feet) well within top of the dead storage (1562.07 feet) and top of flood control pool/top of spillway radial gate (1595.3 feet) elevations. In fact, automated float operations for the radial gates dictate that they open when water level reaches 1594.8 feet, which has only occurred once within recorded history on July 22, 1993. Due to the relatively steady water surface elevation, we do not expect that operations had a significant impact on sedimentation trends in Lovewell reservoir.

The dam has a structural height of 93 feet and a hydraulic height of 73 feet. The reservoir had an original length of about 7.6 miles long at full pool with one major tributary: White Rock Creek. Two minor tributaries contribute to the reservoir on the west end: Montana Creek contributes from the north and Johns Creek contributes from the south (Figure 1).

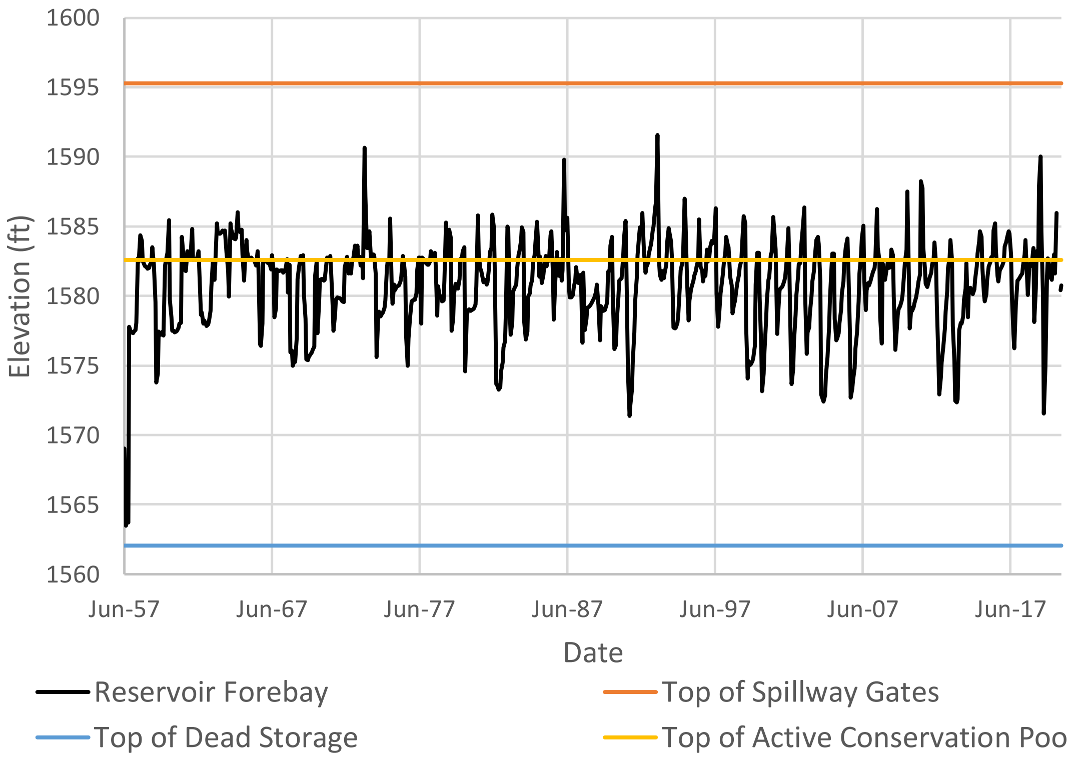

Figure 8. Historic end-of-month water surface elevations (RPVD). Data web source: https://www.usbr.gov/gp/hydromet/res070.html.

The reservoir is widest just upstream of the dam (6,600 feet), where a cove opens on river left and narrowest within the river delta (550 feet; Figure 2). A delta has formed approximately halfway through the reservoir, continuing upstream through White Rock Creek, west of the Highway 14 Bridge. Figure 9 is a plot of the reservoir bottom along the reservoir centerline. The path of the longitudinal profile follows the historical low flow channel at some locations, but is outside of the channel in the higher elevation overbanks at other locations. The deviation of the plotted profile path from the main channel (lowest point of the reservoir bottom) makes it difficult to discern the location of the downstream end of the delta face which begins around station 24,000 feet and extends upstream.

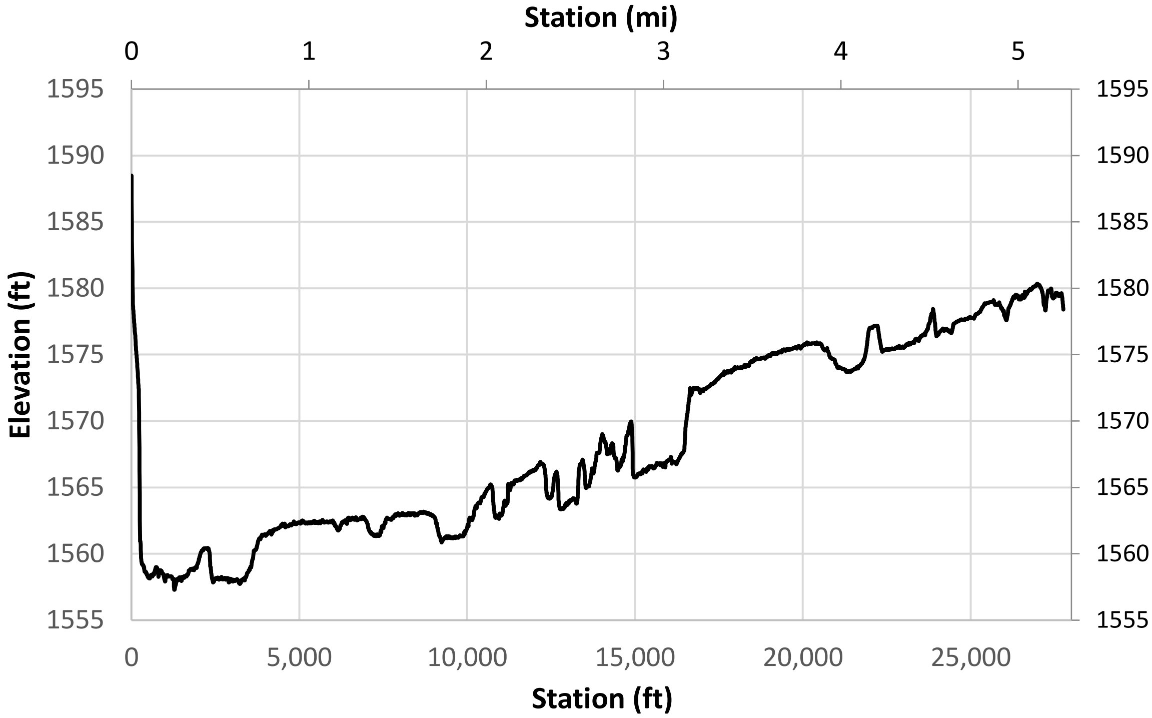

Figure 9. Topobathymetric profile through the reservoir center from Lovewell Dam to Hwy 14 Bridge. The profile line deviates from the historic channel between stations 17,000 and 21,000 feet. The downstream end of the sediment delta, although not evident in this figure, begins around station 24,000 feet.

3. Previous Reservoir Survey(s)

Prior to dam closure and initial reservoir filling beginning in May 1957, a survey was conducted to measure the original surface areas and corresponding storage capacities. The documentation summarizing the original survey methods has not been located for this analysis. Based on the time period, original areas were likely determined by digitizing United States Geologic Survey quadrangle (USGS quad) maps developed from aerial imagery, or the original areas may have been measured from the aerial imagery itself. Surface areas at 5-foot elevation increments were measured from the original survey and storage capacities were computed from those areas using the ACAP85 program (Reclamation, 1995). The original capacity of the reservoir at the top of active conservation pool (1582.6 feet) was recorded to be 41,687 acre-feet.

The survey conducted in 1995 combined single-beam sonar data with USGS quad maps. Below water topography, from elevation 1550.3 feet to 1580.0 feet, was measured with a sonic depth recording equipment interfaced with global positioning system (GPS). Above water topography included digitizing the 1583 and 1595 feet contour lines from USGS quad maps of the reservoir area. These maps were based on aerial photography obtained in 1967. No change in surface area was assumed above 1595.0 feet. The final product was the same: a 5-foot interval contour map of the reservoir and surrounding shoreline. The reservoir capacity measured at the top of the active conservation pool was 35,666 acre-feet.

The original and subsequent reservoir surveys are described in Table 1.

Table 1. Previous Bathymetric Reservoir Surveys

Survey Year	Extent of Survey	Survey Method	Depth Sounder	Above water survey
1957	Full	Likely photogrammetry	N/A	Likely photogrammetry
1995	Full	Sonic Depths	Single Beam	USGS quad maps (1967)

These previous surveys are described in more detail in the 1995 Lovewell Reservoir survey report (Reclamation, 1995).

4. Reservoir Survey Methods and Extent

4.1. Survey Methods

A complete bathymetric survey was conducted from June 2 to June 5, 2020 from a boat using a 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 10.

Appendix A provides more details of the hydrographic survey methods. These bathymetric data were combined with 2010 LiDAR data collected above water to produce a digital surface of the reservoir bottom. However, there is a spatial gap between the LiDAR data and the bathymetric data. This gap was addressed by adding a contour line by manually digitizing the water's edge from 2017 NAIP aerial imagery collected on a known date at a known water surface elevation. Within the data gap, the surface was built using linear interpolation of the surrounding data (Figure 11).

Appendix B provides more details above the-water survey data. Surface areas at 1-foot contour intervals were computed using GIS software and a computer program the was used to produce the reservoir surface area and capacity tables at 0.01-foot increments.

Appendix C provides more details about the methods used to generate surface area and storage capacity tables.

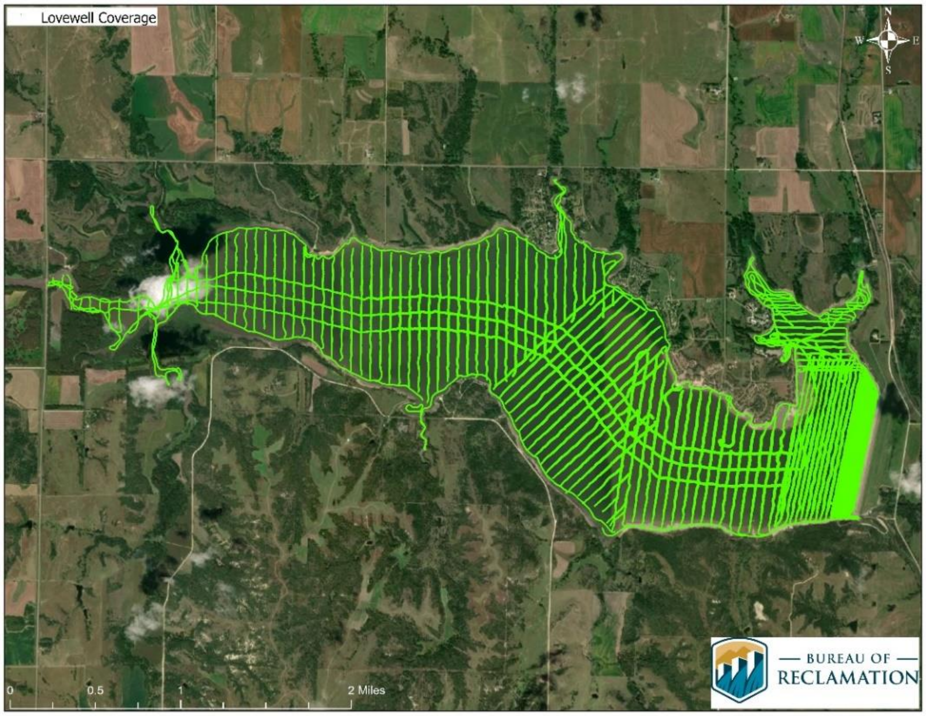

Figure 10. Map of bathymetric survey data coverage.

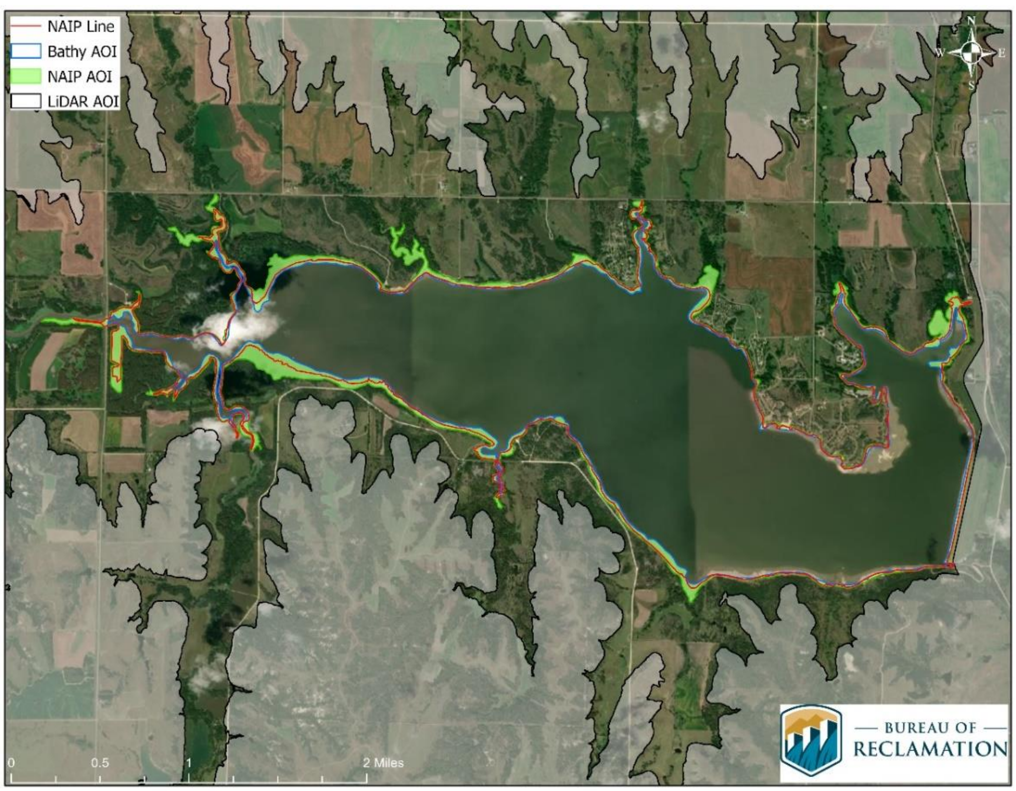

Figure 11. Bathymetric data were combined with an NAIP contour line of the water surface elevation (red) and LiDAR Data (outlined in black). There is a gap in topography data (green shaded area) where the surface was created through linear interpolation.

4.2. Survey Control, Datum, and Monuments

For the 2020 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (NAD 1983, 2011) State Plane (horizontal) coordinates, Kansas North Zone (FIPS 1501), 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 Lovewell Dam. The RPVD was determined to be 0.53 feet lower than NAVD88 (Geoid 18).

The GPS base station receiver was set up over a temporary monument located off a dirt road to the south of the reservoir (Figure 12 and Figure 13).

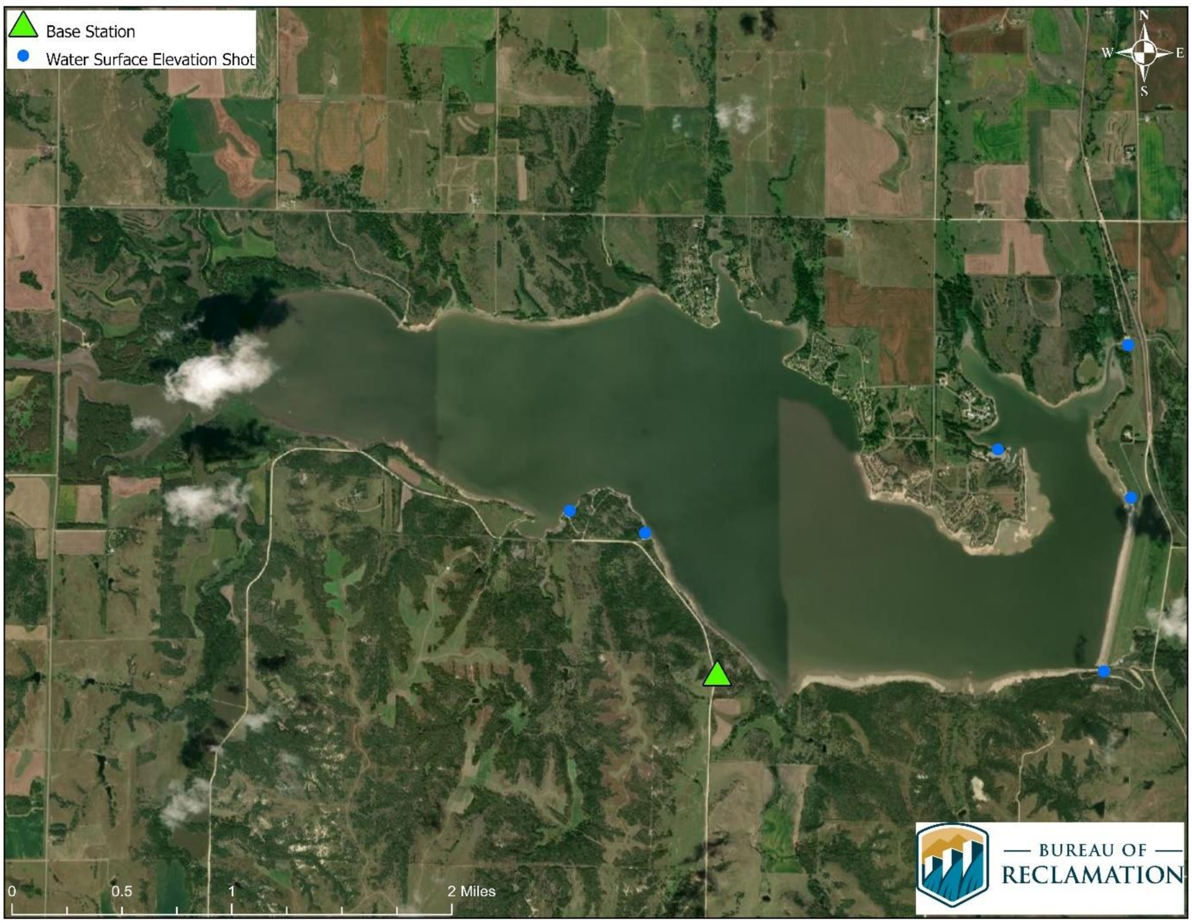

Figure 12. Location of GPS base station to the south of Lovewell Reservoir.

Figure 13. GPS base and temporary monument (inset photo) located in pull-out on dirt road along south side of reservoir.

State plane and elevation coordinates for the GPS base station were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/).

The RPVD at Lovewell Reservoir was determined from RTK GPS measurements on the dam crest and water surface elevations measured at various locations along the reservoir shoreline (Figure 12).

5. Reservoir Surface Area and Storage Capacity

Tables of reservoir surface area and storage capacity were produced for the full range of reservoir elevations (Lovewell Area and Capacity Tables 2020). Plots of the 2020 area and capacity curves are presented in

Figure 14 along with curves from the 1957 and 1995 surveys. For the 2020 survey, area and capacity curves are based on the bathymetric (below-water) survey up to elevation 1580 feet elevation (RPVD), while curves above this elevation are based on 2010 LiDAR and the digitized contour line from NAIP 2017 imagery. A comparison of these curves indicates that largest reduction in surface area occurs at the top of the dead storage, 1562.07 feet in elevation and the largest change in storage capacity occurs below 1575 feet elevation (RPVD). Contour maps of the surface generated from the 2020 survey are included in at the end of this document.

Table 2 lists the surface areas and capacities computed for the 1957, 1995, and 2020 surveys. At maximum water surface/top of surcharge pool elevation, 1610.3 feet (Reclamation Project Vertical Datum), the reservoir has a surface elevation of 7,663 acres and a storage capacity of 179,778 acre-feet. The top of active conservation pool has a reservoir water surface elevation of 1582.6 feet (RPVD), which is 0.3 feet below water at the time of survey. As of June 2020, the reservoir surface area was 2,980 acres with a storage capacity of 34,888 acre-feet at the top of active pool elevation (1582.6 feet, RPVD).

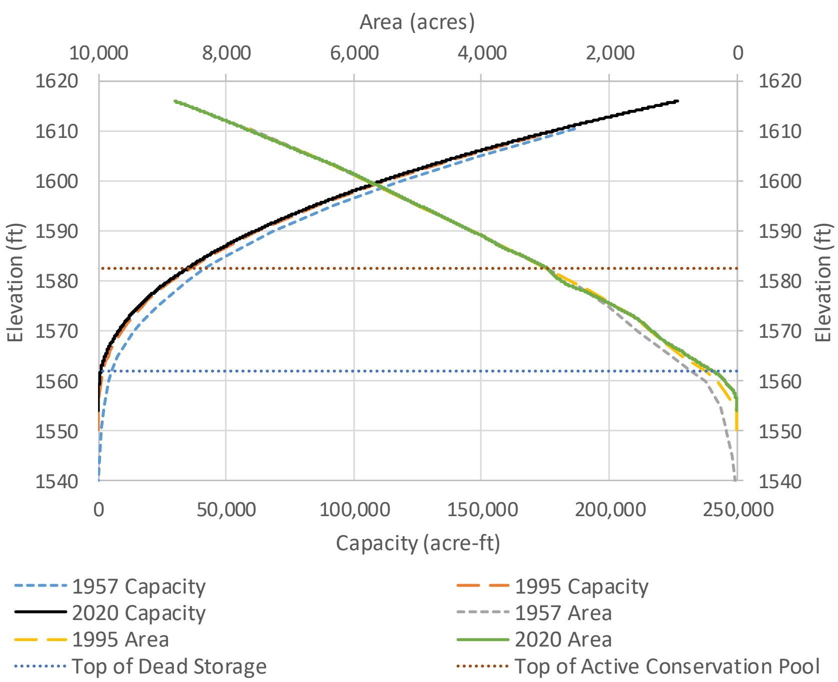

Figure 14. Plot of Lovewell Reservoir surface area and storage capacity versus elevation (RPVD).

Table 2. Historical summary of reservoir surface area and storage capacity data.

	Reservoir Surface Area (acres)			Reservoir Storage Capacity (acre-feet)			Sedimentation Volume (acre-feet)
Elevation (feet)	**1957**	**1995**	**2020**	**1957**	**1995**	**2020**	**1957 to 2020**
1610.3	7,635	7,635	7,663	186,296	180,276	179,778	6,518
1605	6,620	6,620	6,664	148,540	142,521	141,814	6,726
1600	5,780	5,780	5,770	117,540	111,521	110,833	6,707
1595.3	5,025	5,024	5,006	92,150	86,131	85,527	6,623
1590	4,109	4,109	4,148	67,938	61,918	61,269	6,669
1585	3,350	3,350	3,348	49,290	43,271	42,450	6,841
1582.6	2,986	2,987	2,980	41,687	35,666	34,888	6,798
1580	2,592	2,594	2,755	34,435	28,410	27,438	6,997
1575	2,020	1,892	1,922	22,905	17,194	15,813	7,092
1571.7	1,704	1,495	1,480	16,760	11,644	10,248	6,511
1570	1,542	1,342	1,327	14,000	9,232	7,867	6,133
1565	1,023	864	762	7,588	3,642	2,553	5,035
1562.07	710	498	384	5,074	1,674	861	4,214
1560	484	293	191	3,820	846	291	3,529
1555	266	34	1	1,945	46	0	1,945
1550.3	170	0	0	920	0	0	920
1550	164	0	0	870	0	0	870
1545	69	0	0	288	0	0	288
1540	23	0	0	58	0	0	58
1535	0	0	0	0	0	0	0

6. Reservoir Sedimentation Volume Spatial Distribution

A longitudinal profile and representative cross sections of the 2020 reservoir bottom surface were developed in GIS along the alignments presented in Figure 15. The longitudinal profile (Figure 16) show that the reservoir delta is not very pronounced in this reservoir, but likely begins near Cross Section 3 (near station 17,000) and continues upstream (near station 21,000) into White Rock Creek. Reservoir cross section plots (Figure 17 through Figure 20) show the lateral distribution of sedimentation. While the reservoir is relatively flat across the dam face, a clear historic channel can be seen further upstream (Cross section 2) as we approach the reservoir delta, that historic channel has become buried by sediment re-distribution.

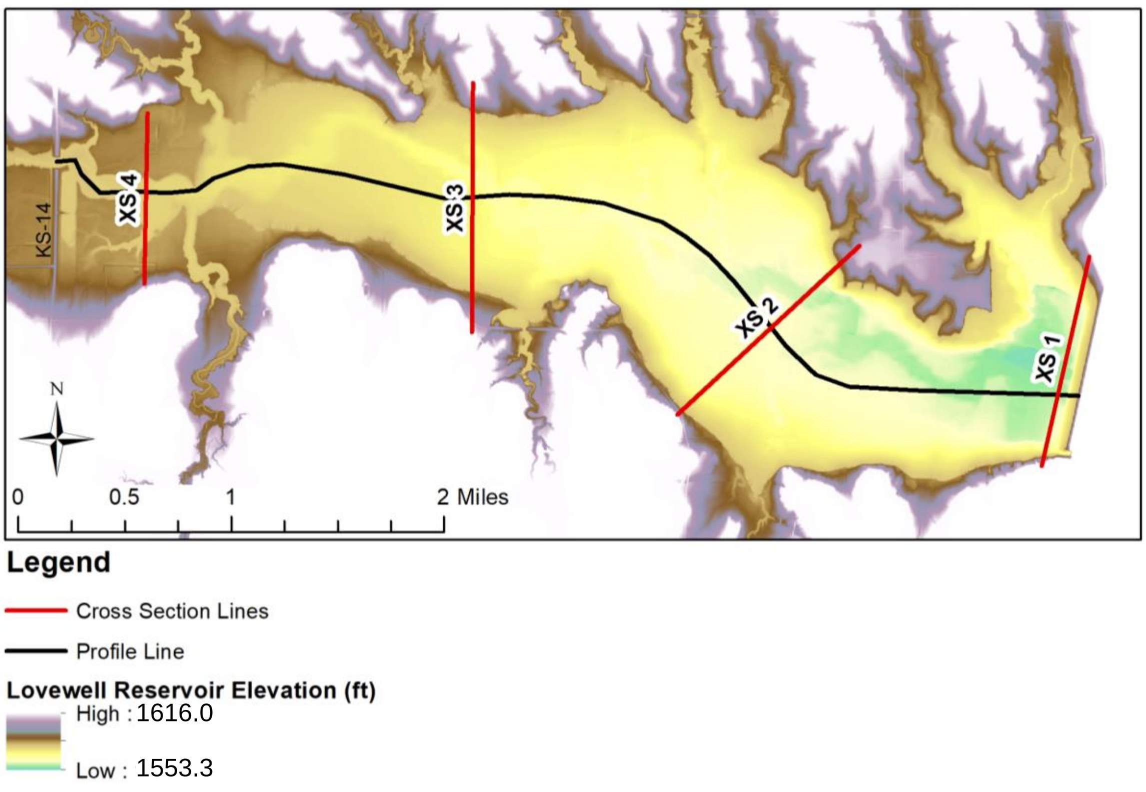

Figure 15. Reservoir surface elevation map and alignments of longitudinal profile and four representative cross sections.

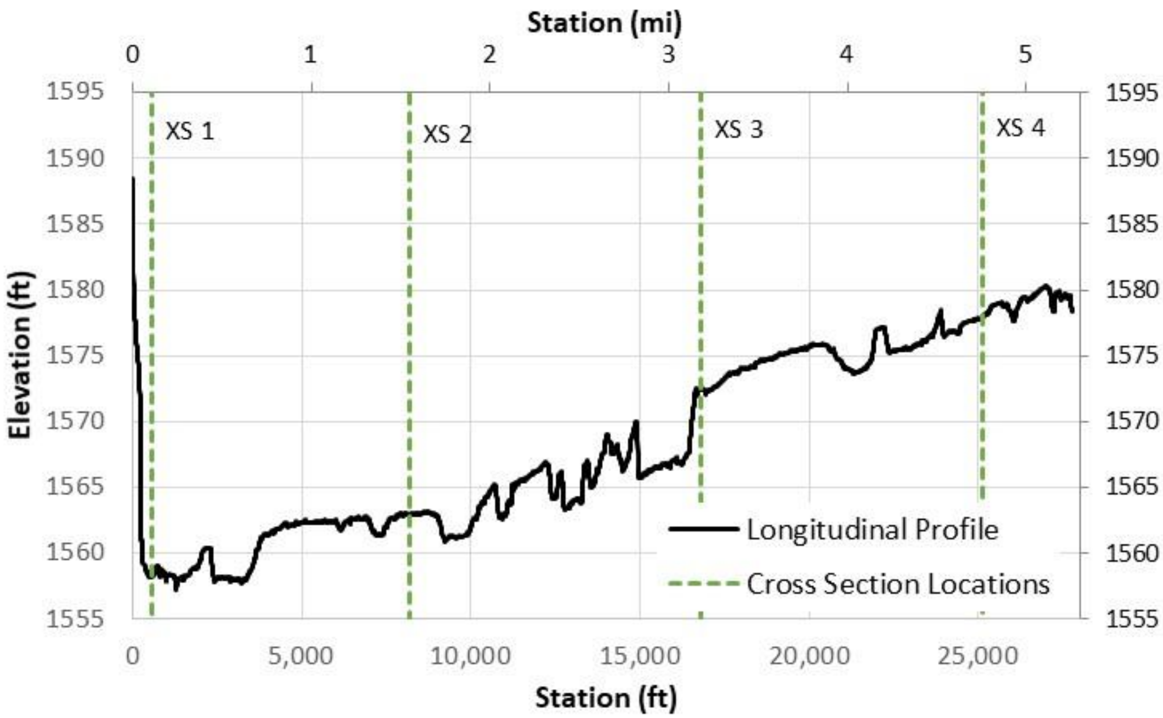

Figure 16. Longitudinal profile of Lovewell Reservoir bottom from the dam upstream to Hwy-14, the extent of the bathymetric survey. Green dotted lines indicate where the cross sections below were cut, moving from the dam face, upstream.

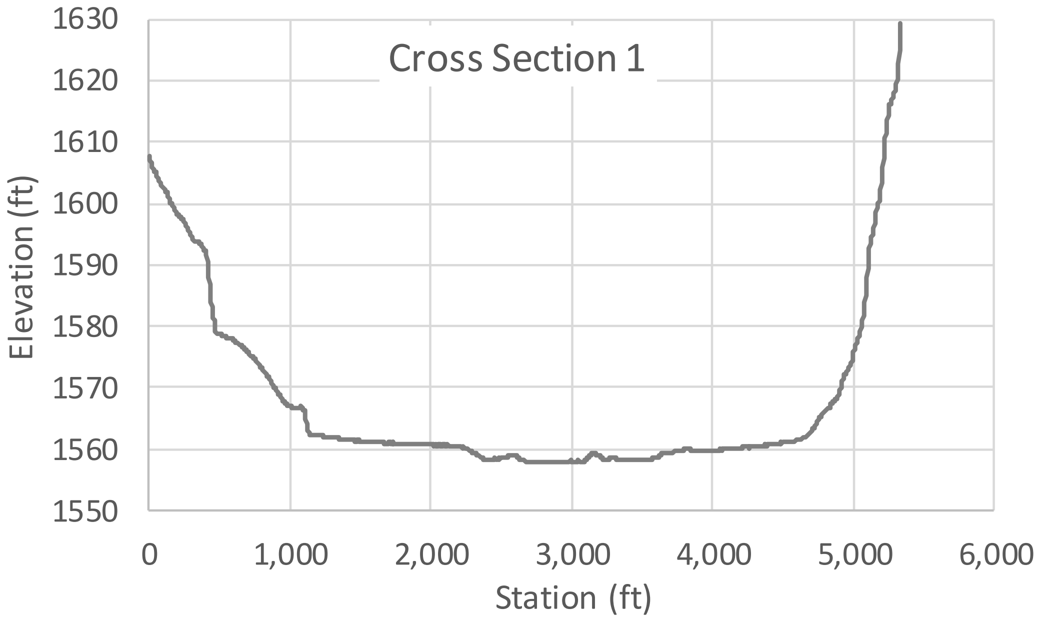

Figure 17. Representative cross section of the lower reservoir, 548 feet upstream from the Lovewell Dam. There is a relatively level surface across the dam face.

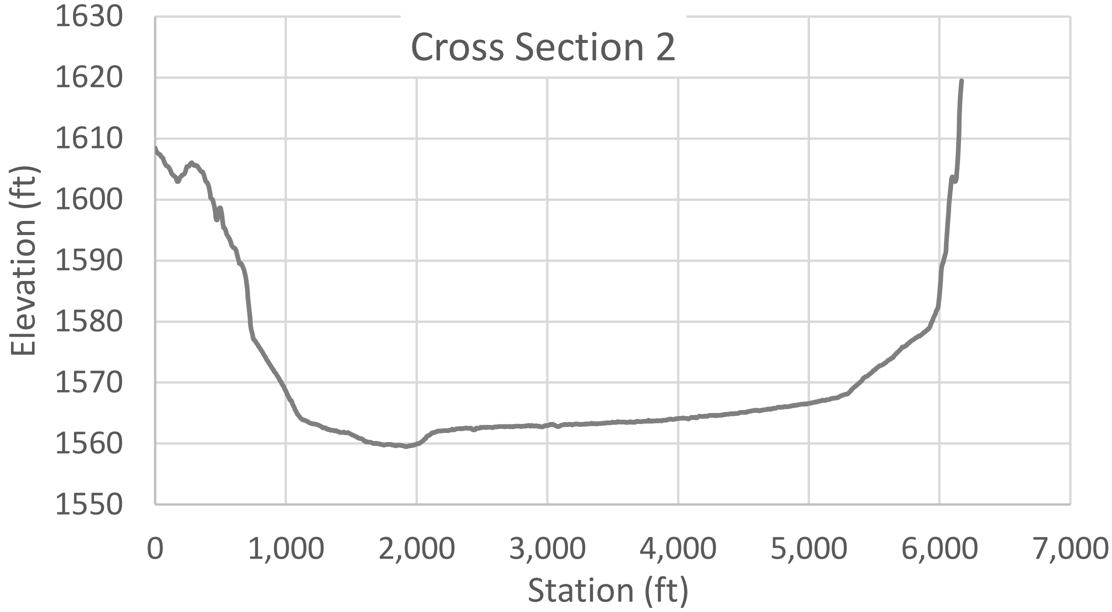

Figure 18. Representative cross section of the middle reservoir, 8,167 feet upstream from the Lovewell Dam.

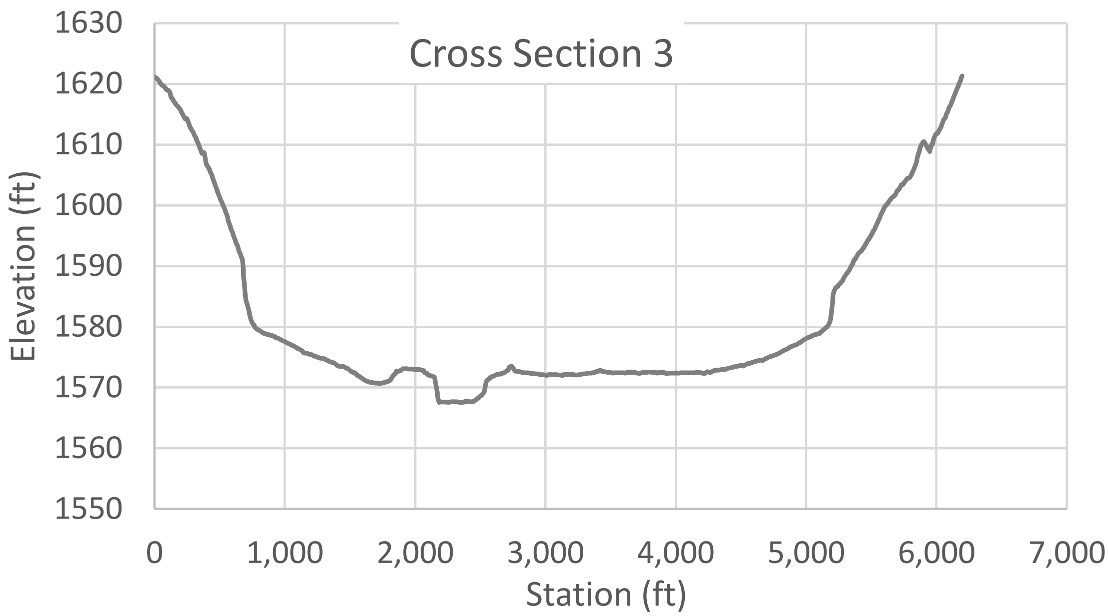

Figure 19. Representative cross section of the middle reservoir, 16,805 feet upstream from the Lovewell Dam. The original channel can clearly be seen near station 2,400 feet.

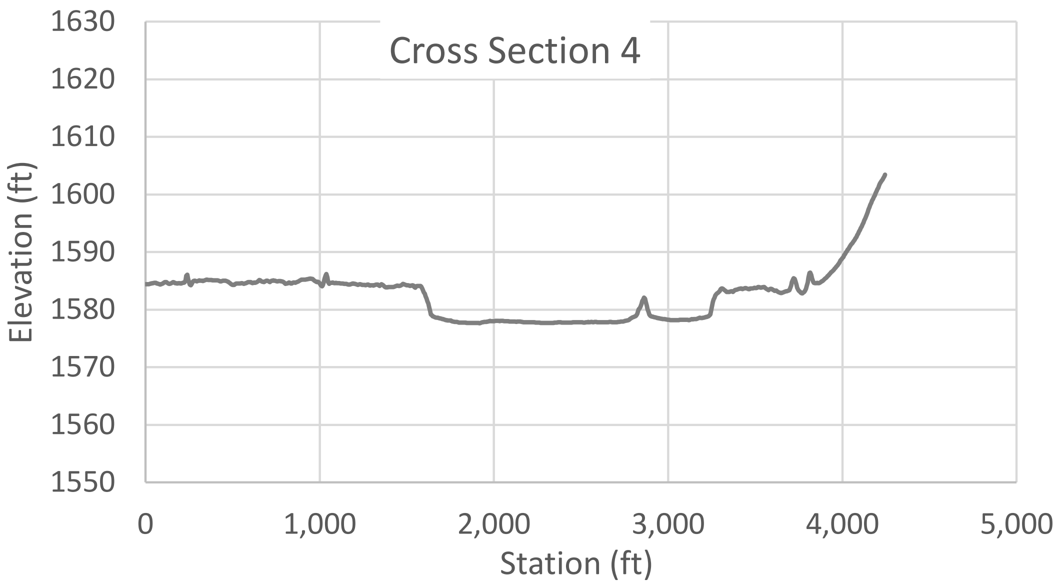

Figure 20. Representative cross section within the reservoir delta, 27,766 feet upstream from the Lovewell Dam. The remnant historic channel appears to be filled in with sediment.

7. Sedimentation Trends

The largest change in sediment volume appears to have occurred between 1957 and 1995 (Figure 21 and Figure 22). Between 1957 and 1995, sedimentation rates were estimated to be 158 acre-feet per year within the active pool and 89 acre-feet per year within the dead storage zone. These results prove that sedimentation is occurring within all elevations, but percent of storage loss is higher within the dead storage pool. This would be expected given that the surrounding landscape likely produces fine, silt-sized sediment, which would easily be flushed through the reservoir. However, the change in volume could partially be attributed to differing survey techniques.

Sedimentation rates decreased substantially between 1995 and 2020. Sedimentation rates were calculated to be 20.5 acre-feet per year below elevation 1582.6 feet and 21.4 acre-feet per year below elevation 1562.07 feet (within the dead storage pool). It should be noted that different instruments with differing precision were used between the three documented surveys below water. The above water data were developed from significantly different data sources with very different resolutions. USGS quad maps typical provide topographic data through 10-feet contours. LiDAR, on the other hand, is very detailed, providing centimeter (0.03 feet) precision on a 1-meter (3.28 feet) grid-cell spacing in this case. Therefore, it is likely that some of the change in reservoir storage is due to variable survey techniques and best available topographic data.

Sediment eventually accumulates at all reservoir elevations including against the dam. Results indicate that sedimentation has mostly filled in the dead storage near the dam face. By comparing the 1957 and 2020 data, 17 percent of the dead storage capacity is currently available (top elevation is 1562.07 feet, RPVD; Figure 23). As predictive sedimentation modeling or analysis was not scoped for this study, we can predict future sediment trends based on historic rates. Assuming a continued sedimentation rate of 21 acre-feet per year in the dead storage, it will fill in approximately 40 years. The minimum reservoir elevation (against the dam face) has increased by 19 feet since filling in 1957. That means 70 percent of the height between the original reservoir bottom and the top elevation of the dead storage pool has filled since 1957. In June 2020, the minimum elevation of the reservoir was recorded to be 1554.0 feet. The lowest level outlet is the canal outlet corresponding to the same elevation as the top of dead pool storage. It has an invert elevation of 1562.07 feet, approximately 8 feet above the accumulating sediment. The rate of reservoir bottom elevation increase was 0.40 feet per year (feet/year) between 1957 and 1995, and 0.15 feet/year between 1995 and 2020, leading to a total of 0.30 feet/year. Assuming the similar rates (0.15 feet/year and 0.30 feet/year), the lower level outlet will not be impacted for another 26 to 54 years. However, the rate of sedimentation within the dead storage pool is higher; therefore, dead storage may fill within this timeframe.

Most of the sedimentation has occurred below the inactive storage pool (top elevation of 1571.7 feet): 61 percent of the original capacity exists below this elevation. The lowest outlet is located at the canal and is 1562.07 feet in elevation. Historically, the reservoir has operated around the top of active pool elevation of 1582.6 feet. At this elevation and below, 6,798 acre-feet of sediment has accumulated, leaving 84 percent of the original capacity. When looking at the capacity below the surcharge pool elevation (1610.3 feet), 97 percent of the original capacity is available according to the 2020 survey. There is no record of the reservoir ever operating above a water surface elevation 1595.3 feet. Operating the reservoir at a higher water surface elevation will increase the storage capacity.

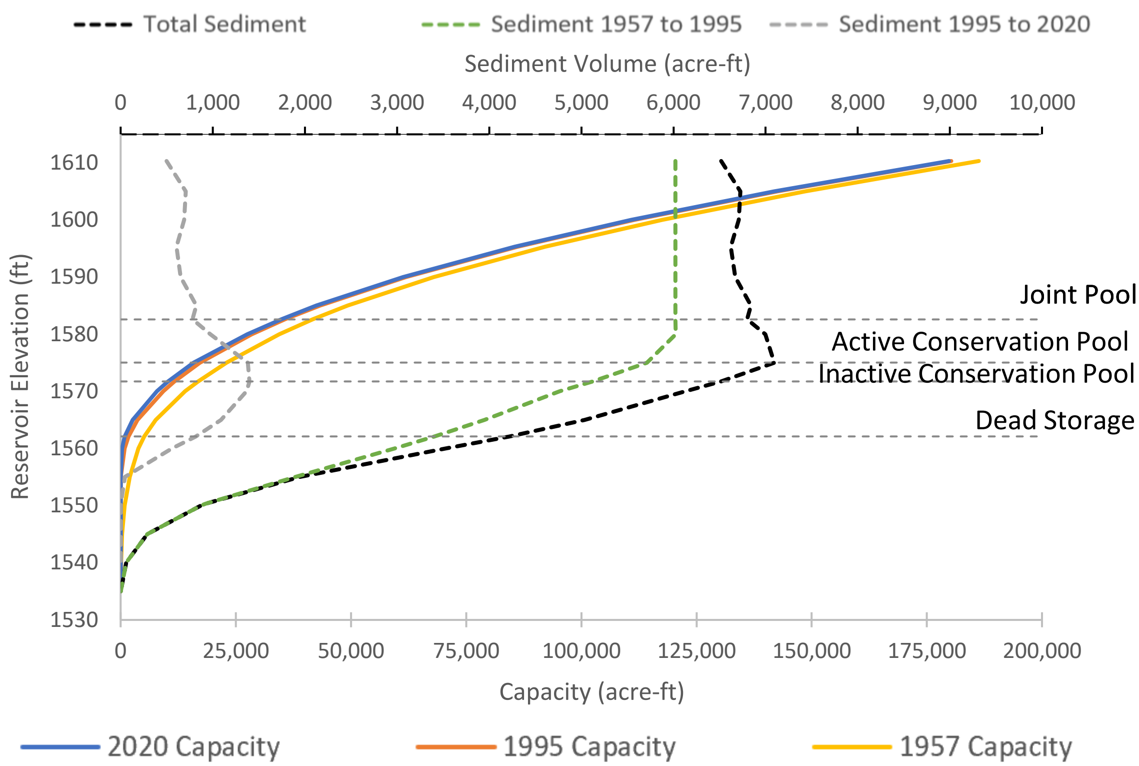

Figure 21. Solid lines represent reservoir capacity by elevation. Dashed lines represent sediment distribution by elevation. The gray and green dashed line represents sedimentation accumulation by elevation in the two time periods between surveys. The black long dashed line represents the total sediment accumulation between dam closure in 1957 and the 2020 survey. The plot indicates that the maximum sedimentation volume occurs near the top of the active conservation pool (elevation 1582.6 feet, RPVD). As elevation increases, the amount of sediment that has deposited in the upper reservoir pool decreases. This is likely due to sediment redistribution within the lower reservoir when water levels are drawn down.

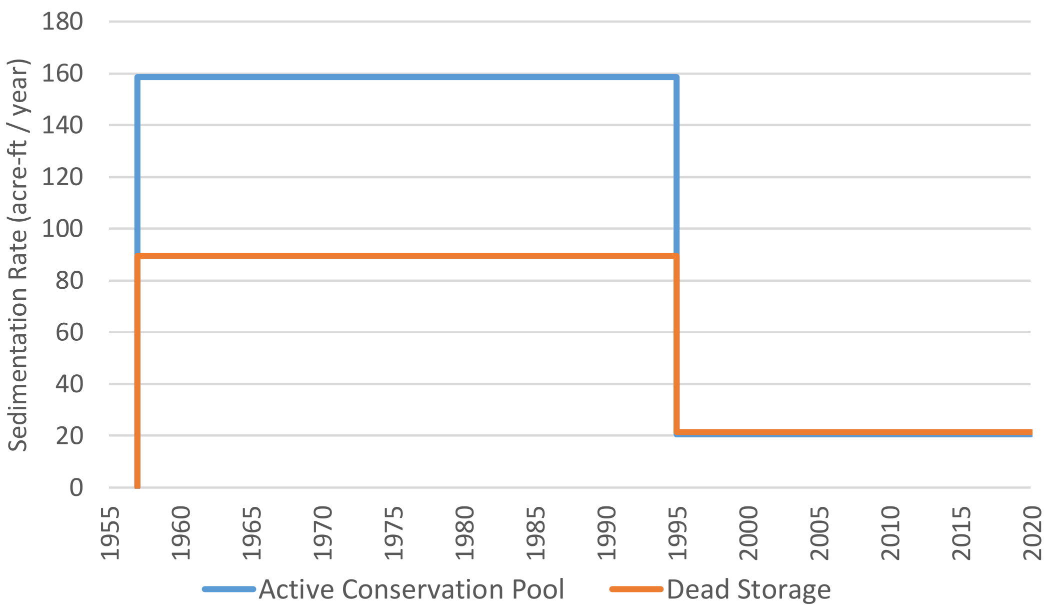

Figure 22. Sedimentation rates within the active conservation pool and below (1582.6 feet, RPVD), and the dead storage zone (1562.07 feet, RPVD).

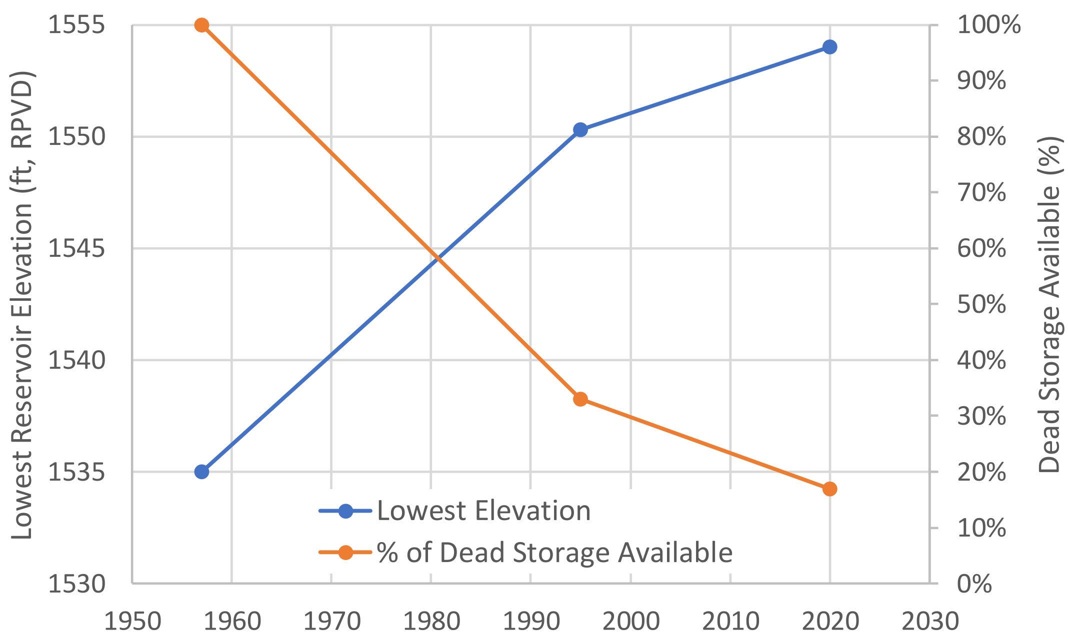

Figure 23. Lowest reservoir elevation and percent of dead storage available in Lovewell Reservoir.

8. Conclusions and Recommendations

8.1. Survey Methods and Data Analysis

The 2020 bathymetric survey, combined with above-water topography, has been used to produce a digital surface of the reservoir bottom. There was a gap between the bathymetric and 2010 LiDAR data. The shoreline during the 2017 NAIP imagery was used to provide one contour line between the two data sets. Linear interpolation was applied to fill the void between the data sets.

It should be noted that LiDAR topography was flown surrounding the reservoir in 2017. However, these data have not been published and were not available at the time this report was prepared. The 2017 LiDAR products are anticipated to be released in the 2021 calendar year. Once these data are available; the TSC recommends updating the surface and area capacity tables to more accurately represent the above water portion of the reservoir.

Reservoir surface areas and volumes were computed from this digital surface at 1-foot intervals to determine the 2020 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 the differences in survey methods. The latest surface area and storage capacity curves compare reasonably well to the 1995 area and storage capacity curves. Both curves show less storage capacity than the original 1957 curves. The use of modern survey methods (RTK-GPS, multibeam depth sounder, LiDAR) have produced a more accurate and precise digital surface of the reservoir bottom than past surveys using older methods (photogrammetry and a single beam depth sounder). Comparison of capacities computed from data collected using different methods makes it difficult to accurately determine the rate of sedimentation within Lovewell Reservoir over time.

8.2. Sedimentation Progression and Location

Over the span of 63 years, sedimentation has filled in 16 percent of the original storage capacity at the top of the active conservation pool. The 2020 reservoir survey indicates that most of this sedimentation is in the lowest portions of the reservoir and 17 percent of the dead storage capacity remains as of 2020. Two surveys have been conducted since the original filling in 1957, and the difference in reservoir capacity between those two surveys is minimal. Furthermore, the three surveys (including the original) have been conducted with very different technology and topographic data above the water surface. These two factors make it difficult to determine whether capacity loss is primarily due to sedimentation or discrepancy between datasets (see Section 8 Sedimentation Trends). The lowest dam outlet is at an elevation of 1562.07 feet. As the dead storage pool fills with sediment, the outlet is at a greater risk for being blocked. Two metrics were assessed to estimate the timeframe in which sediment may impact reservoir operations. Sedimentation rate within the dead pool storage and minimum reservoir elevation and estimate that sediment could impact operations in 40 to 54 years, respectively. Landslides, fires or other natural disasters would increase sedimentation rates throughout the watershed, decreasing this timeframe.

8.3. Recommendation for Next Survey

The frequency of the survey is dependent on the risk(s) imposed by sediment impacting reservoir operations. While the area capacity curves are comparable between 1995 and 2020, only 17 percent of the dead storage remains and sediment is approximately 8 feet below the lowest level outlet. Another survey should be conducted within the next ten years, by 2030, assuming no changes in dam and reservoir operations and no natural disasters. If operations change or an extreme event occurs within the watershed, then an emergency survey is recommended as soon as possible after the change.

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Appendix A — Hydrographic Survey Equipment and Methods

The 2020 bathymetric survey was conducted from June 2 to June 5, 2020. During this period, reservoir water surface elevations varied from 1582.91 to 1582.95 feet (RPVD).

The survey was conducted along a series of cross section, longitudinal, and shore line survey lines (Figure 10). The survey lines were spaced closely enough so there would overlapping coverage from the multibeam depth sounder near the dam. Throughout the remainder of the reservoir the survey lines were close enough that liner interpolation of 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 24). Reservoir depths were measured using 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 24. 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 degrees 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 12 and Figure 13). 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 25). The base station was powered by a 12-volt battery.

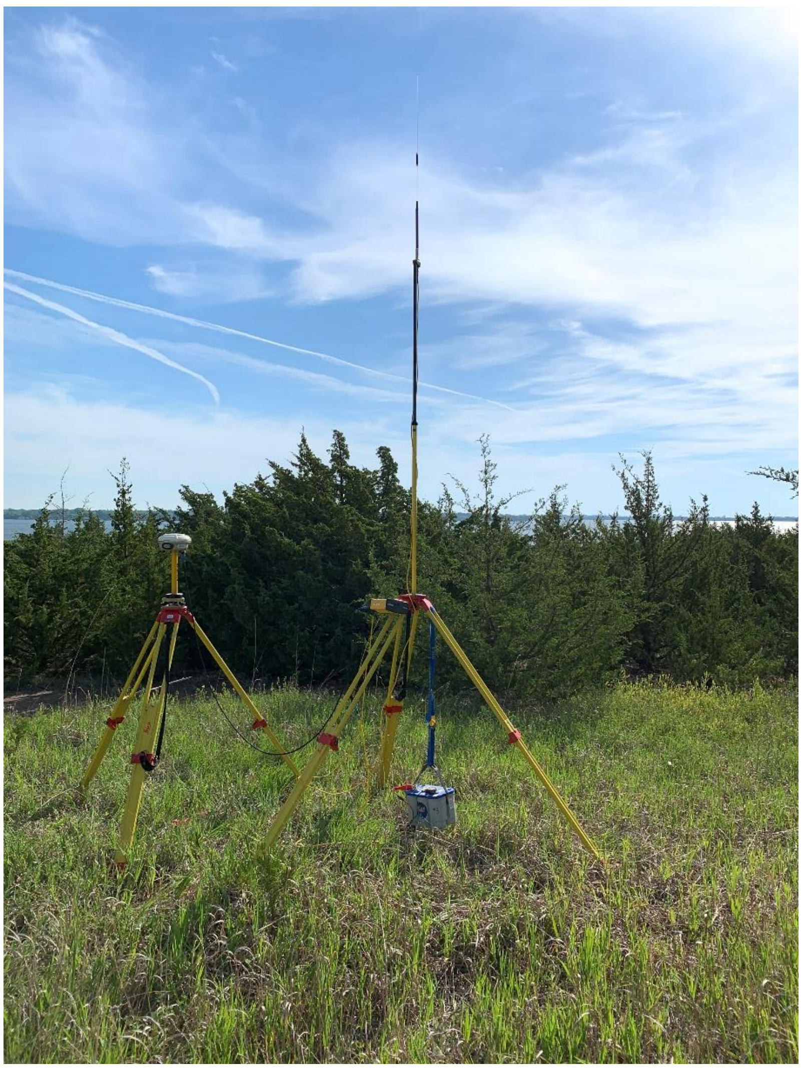


Figure 25. The RTK-GPS base station set-up used during the 2020 Lovewell Reservoir survey.

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 and within ±20 cm for the moving survey boat.

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 map the reservoir bathymetry in the NAD 1983 State Plane coordinates, Kansas North. 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. Final processing of the bathymetric data resulted in over one million data points used in the development of the reservoir surface. Filtering of this large data file is necessary, so a raster mesh is created in GIS (e.g. 5-foot square cells). For each raster mesh cell, the reservoir bottom elevation is assigned equal to the median elevation of all available data points within that raster cell. The use of the median value reduces the influence of the highest and lowest elevations within the cell.

Appendix B — Above Water Survey Methods

The best available USGS National Elevation Data (NED) were downloaded from the USGS National Map website (www.viewer.nationalmap.gov) to represent the above water data reservoir topography. The most applicable dataset was the 2010 LiDAR data.

Data from the 2010 LiDAR survey were used to represent the above-water reservoir topography. These data were produced by the U.S. Geological Survey (USGS). There is a gap between the bathymetric and topographic data. A water surface elevation contour was digitized based on the 2017 aerial imagery to add another data point for linear interpolation.

The LiDAR data were flown between December 13 and 17, 2010 and published in 2014. The reservoir pool gage recorded a forebay elevation of 1579.27 feet. However, the LiDAR data assigned a water surface elevation of 1577.97 feet. The discrepancy in water surface elevation is likely due to propagated error from various compiling methods specific to this dataset. As the wetted area within the LiDAR were excluded from the surface, this discrepancy does not impact the final surface produced for this study. In fact, the average error between topography survey points and the LiDAR was within 0.1 feet. Therefore, all data outside of the wetted perimeter is within the error of the survey. The NAIP aerial imagery was flown on August 17, 2017 at a water surface elevation of 1578.91 feet. The contour line used to tie the LiDAR and the bathymetric datasets together was assigned an elevation of 1578.91 feet, RVPD.

The Lidar were flown 10 years prior to the bathymetric survey. Based on reservoir operations and the watershed geology, it is unlikely the surrounding hillslopes have significantly changed within the 10 years between surveys. It was assumed that above water elevations remained unchanged to develop the surface and area capacity tables.

Appendix C — 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 elevation (LiDAR) data. The computation of a relationship between reservoir capacity and elevation is necessary for reservoir operations. The Area Capacity Program (ACAP) Version 2.0 computes the reservoir surface area and reservoir capacity for every 0.01-foot increment given the surface area and reservoir capacity at every 1 feet increment. ACAP V2.0 is a replacement for the ACAP85 program .

The surface area and storage capacity tables for Lovewell Reservoir were generated from the 2020 survey. Reservoir surface areas and capacities at 1-foot increments were first computed using the ArcGIS ACAP toolset, developed at Reclamation. Reclamation's Area-Capacity Program was then used to generate the area and capacity tables at 1-foot, 0.1-foot, and 0.01-foot increments for the full range of reservoir elevations.

The reservoir storage capacity interpolates the reservoir storage capacity at the i^{th} interpolation point between 1-foot intervals using the following equation:

$$V_i = V_b + A_b(y_i - y_b) + C(y_i - y_b)^m \quad (1)$$

where: V_i = storage capacity (acre-feet)
y_i = reservoir elevation,
y_b = reservoir elevation at bottom of elevation increment,
V_b = Storage capacity at elevation y_b (acre-feet),
A_b = Surface area at elevation y_b (acres)
C= Coefficient for nonlinear rate of increase in storage capacity
m= Exponent of nonlinearity in the increase in storage capacity

Area is then calculated as the derivative with respect to y_i of the volume equation:

$$A_i = A_b + Cm(y_i - y_b)^{m-1} \quad (2)$$

where: A_i= Surface area (acres),
A_b = Area at elevation y_b

The coefficients C and m are chosen so that the surface areas (determined using GIS software) and the 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.

Enforcing that the storage volume (V_t) at the top of the elevation increment equals that from the GIS analysis and then solving equation (1) for C gives:

$$C = \frac{V_t - V_b - A_b \Delta y}{\Delta y^m}$$

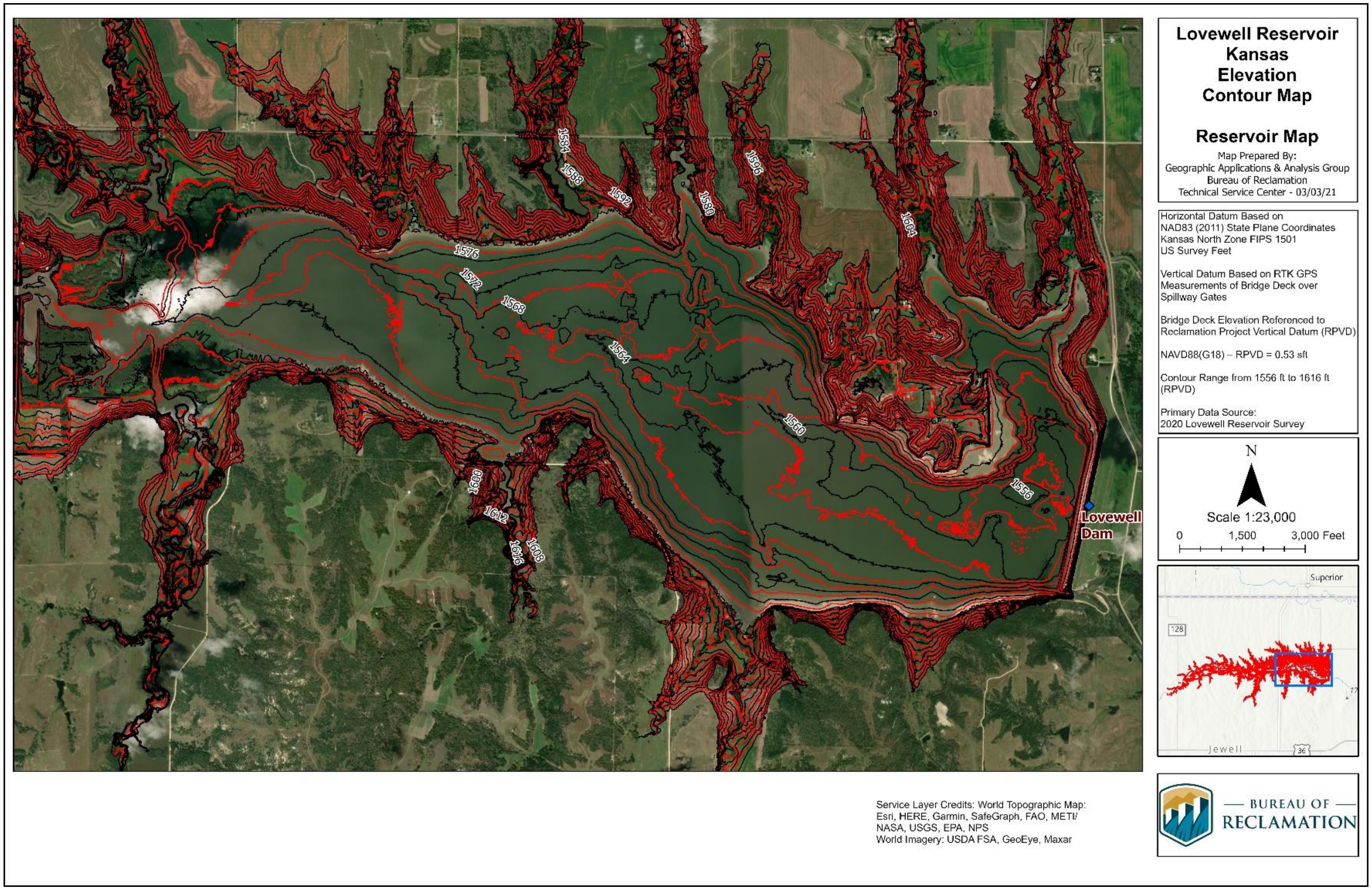
where Δy = $y_t - y_b$, and y_t is the elevation at the top of the elevation increment. Enforcing that the surface area (A_t) at the top of the elevation increment equals that from the GIS analysis and then substituting into equation (2) gives and the equation for m:

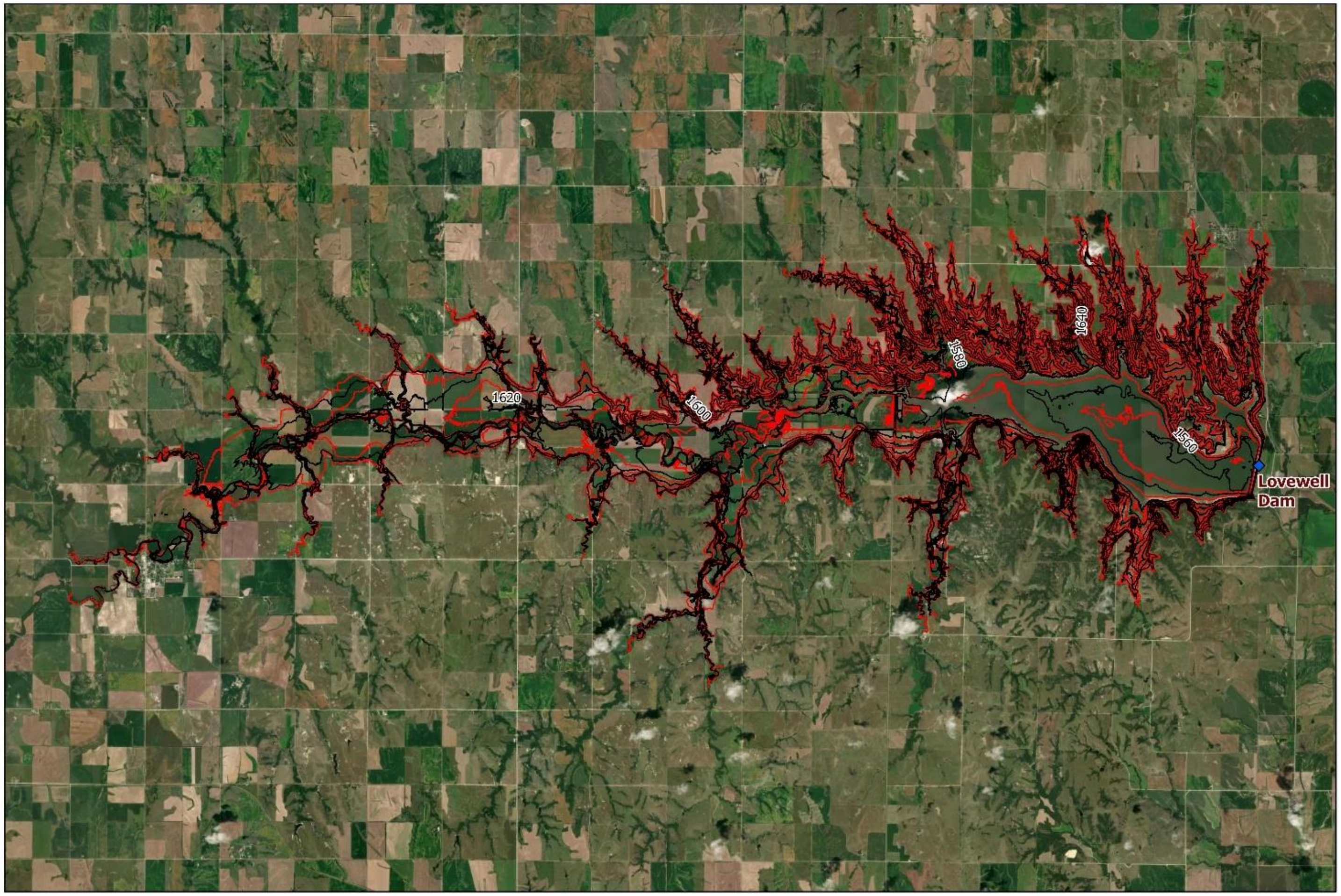
$$m = \frac{(A_t - A_b)\Delta y}{V_t - V_b - A_b \Delta y}$$

This method ensures that the surface areas and capacities as determined from GIS software at the 1-foot intervals are not changed and there is a smooth transition in the interpolated values at the 0.1 and 0.01-foot intervals.

The sedimentation volume can be computed by subtracting the digital surface of the predam reservoir from the 2020 digital reservoir surface. The development of a pre-dam digital surface map (rectified in Kansas State Plane Coordinates) was beyond the scope of this study. The area capacity tables from the original survey were available. The sedimentation volume could be estimated by subtracting the predam storage volume curve from the 2020 storage volume curve (Table 2).

Maps


Lovewell Reservoir
Kansas
Elevation
Contour Map
Reservoir Map
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 03/03/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates
Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 0.53 sft
Contour Range from 1556 ft to 1616 ft
(RPVD)
Primary Data Source:
2020 Lovewell Reservoir Survey
N
Scale 1:23,000
0 1,500 3,000 Feet
Lovewell Dam
Superior
Jewell
Service Layer Credits: World Topographic Map:
Esri, HERE, Garmin, SafeGraph, FAO, METI/
NASA, USGS, EPA, NPS
World Imagery: USDA FSA, GeoEye, Maxar
BUREAU OF RECLAMATION



Lovewell Reservoir Kansas Elevation Contour Map

Overview Map

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates

Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

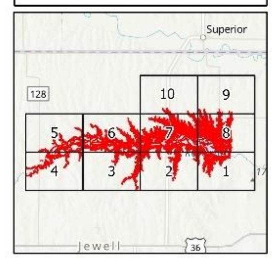
###0 - Black Contours
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

Scale 1:80,000

0 5,000 10,000 Feet



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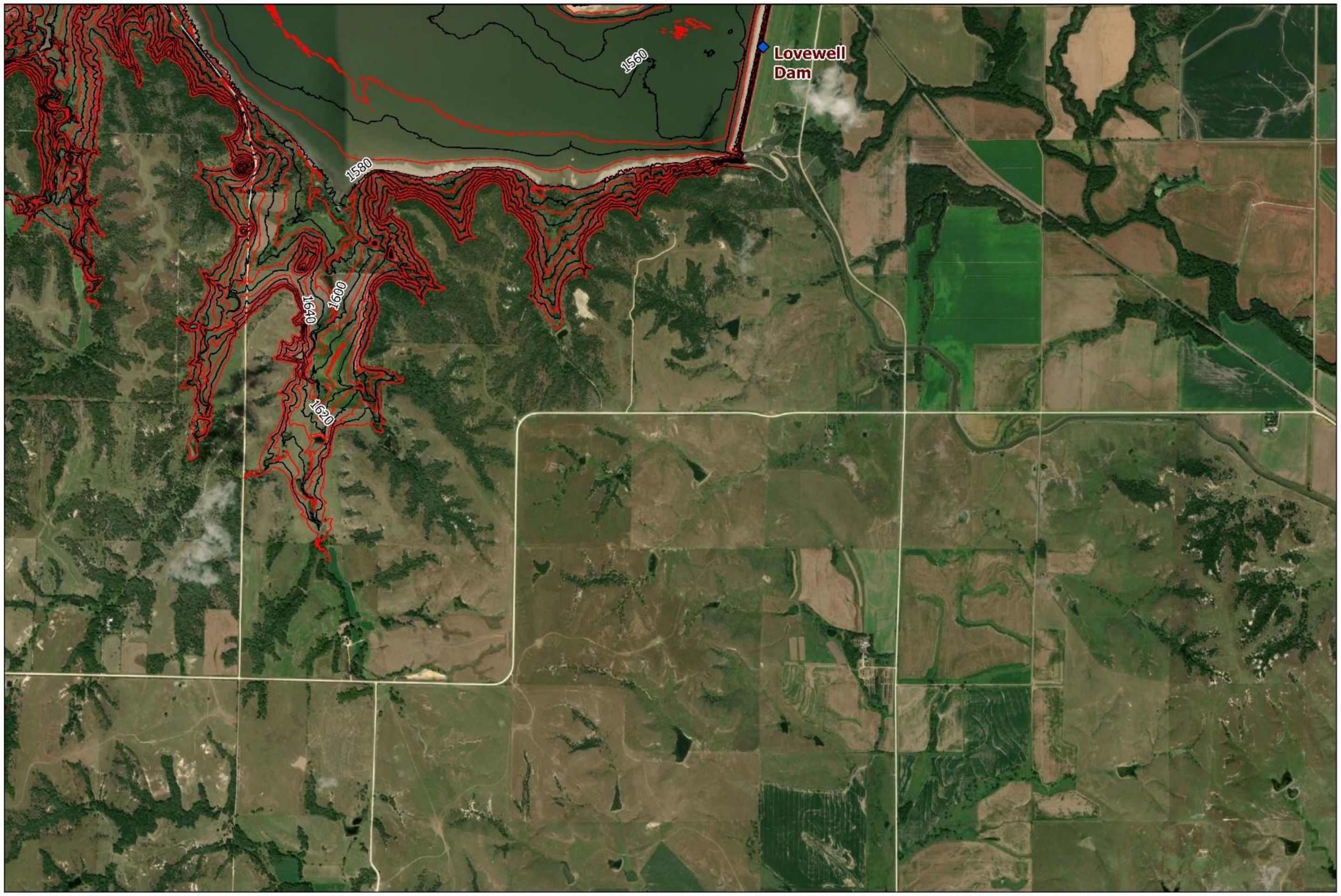
Service Layer Credits: World Topographic Map:
Esri, HERE, Garmin, SafeGraph, FAO, METI/
NASA, USGS, EPA, NPS
World Imagery: USDA FSA, GeoEye, Maxar



Lovewell Reservoir Kansas Elevation Contour Map

Sheet 1

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Bridge Deck over Spillway Gates

Bridge Deck Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

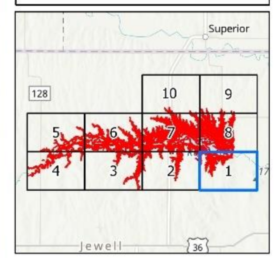
###0 - Black Contours
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Topographic Map:
Esri, HERE, Garmin, SafeGraph, FAO, METI/
NASA, USGS, EPA, NPS
World Imagery: USDA FSA, GeoEye, Maxar

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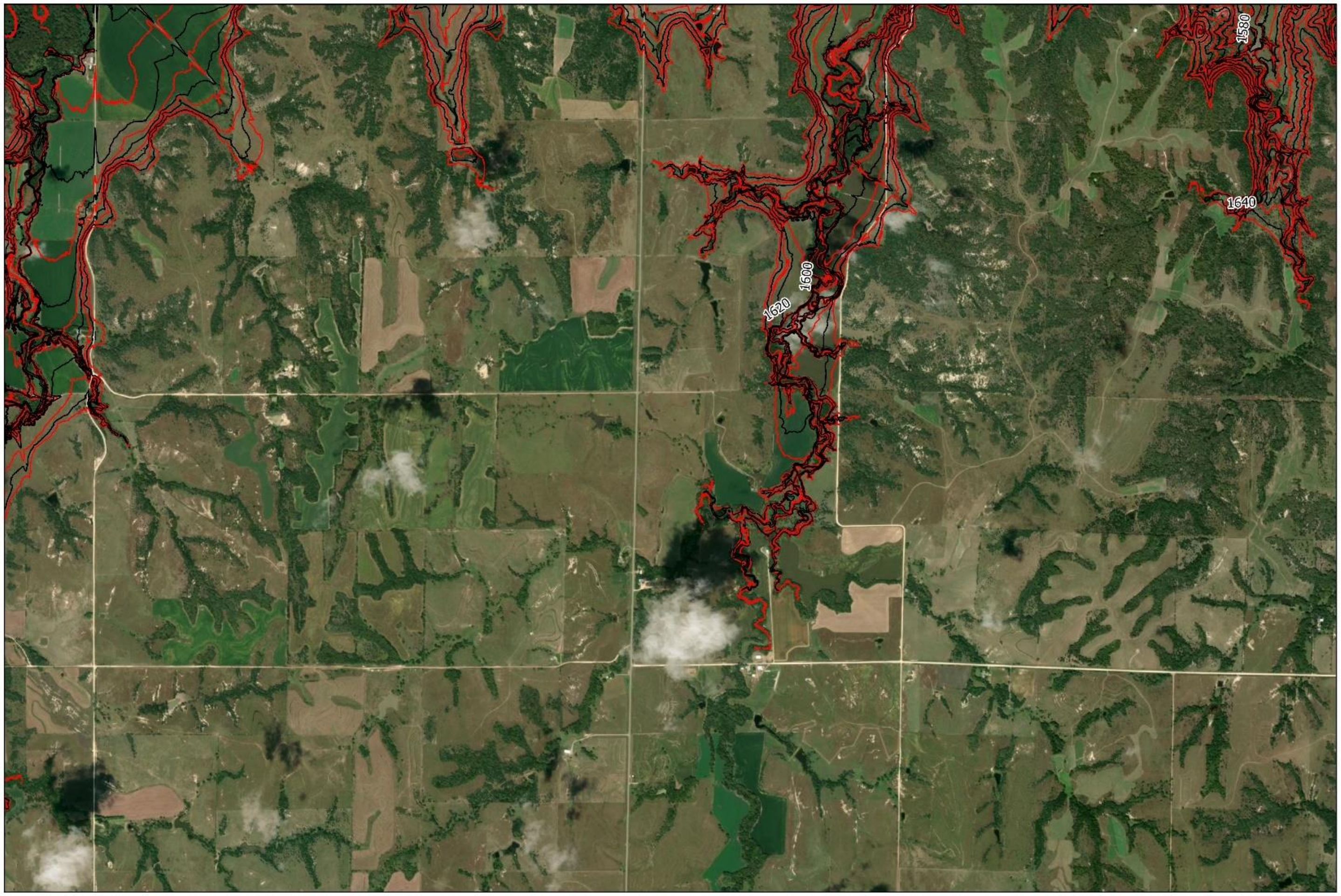


Lovewell Reservoir
Kansas
Elevation
Contour Map

Sheet 2

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates

Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

###0 - Black Contours

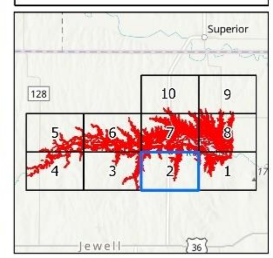
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

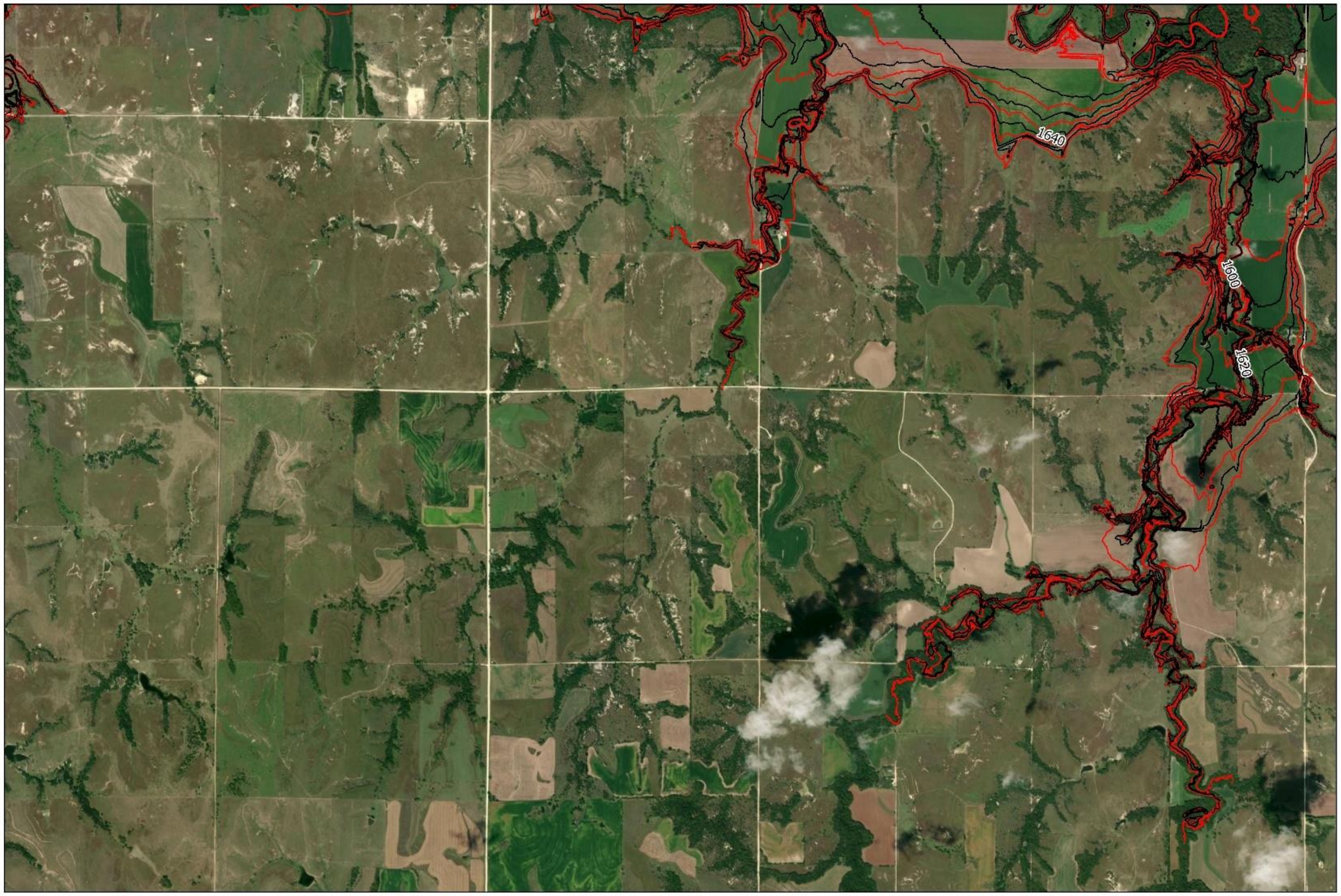
Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Topographic Map:
Esri, HERE, Garmin, SafeGraph, FAO, METI/
NASA, USGS, EPA, NPS
World Imagery: USDA FSA, GeoEye, Maxar

BUREAU OF RECLAMATION



Lovewell Reservoir
Kansas
Elevation
Contour Map

Sheet 3

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates

Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

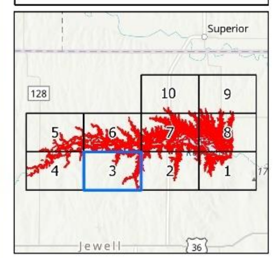
###0 - Black Contours
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

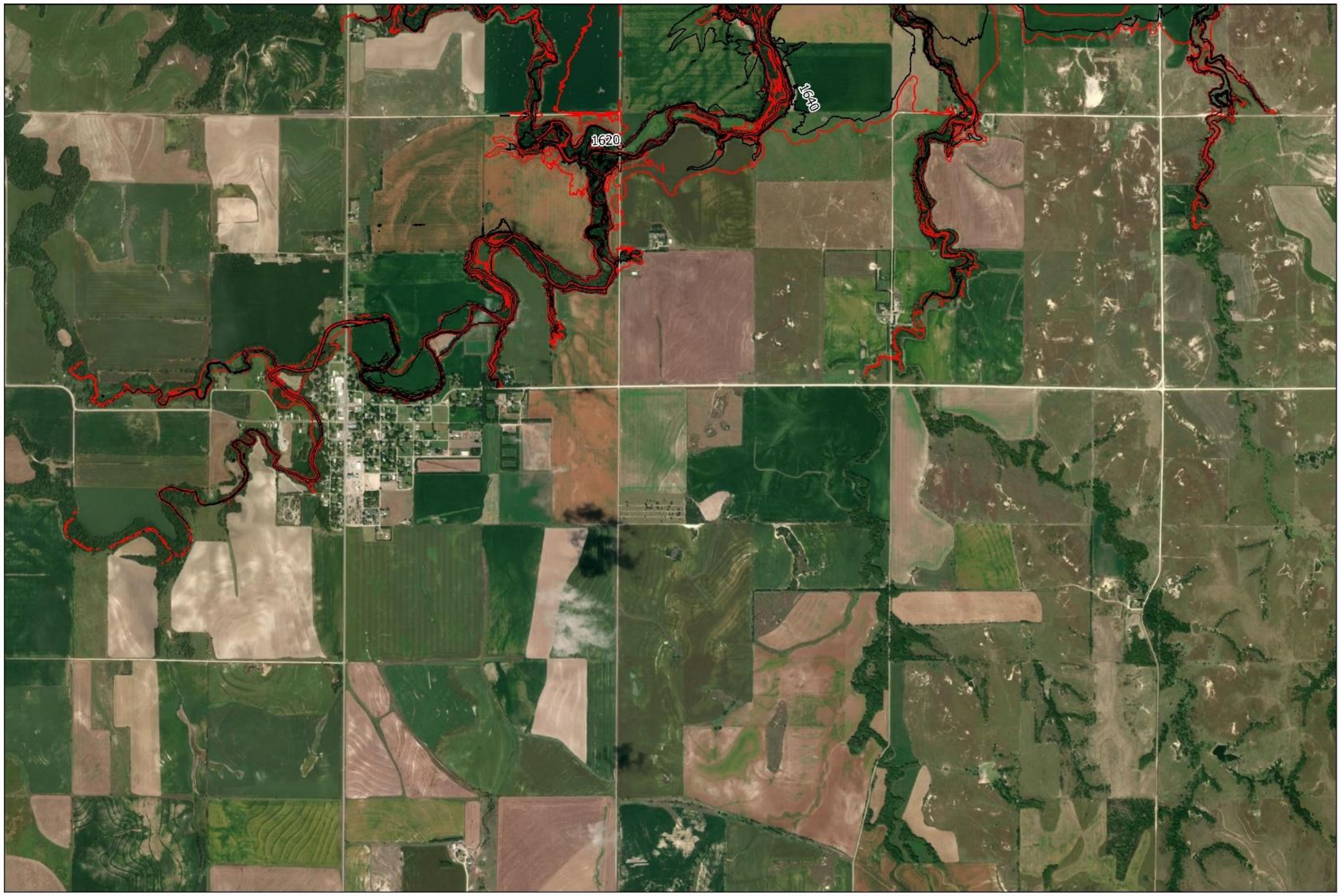
Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Imagery: Earthstar Geographics
World Topographic Map: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

BUREAU OF RECLAMATION



Lovewell Reservoir Kansas Elevation Contour Map

Sheet 4

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates

Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

###0 - Black Contours

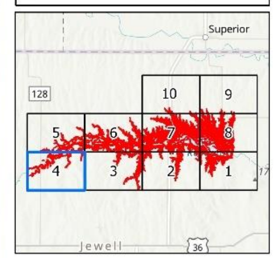
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

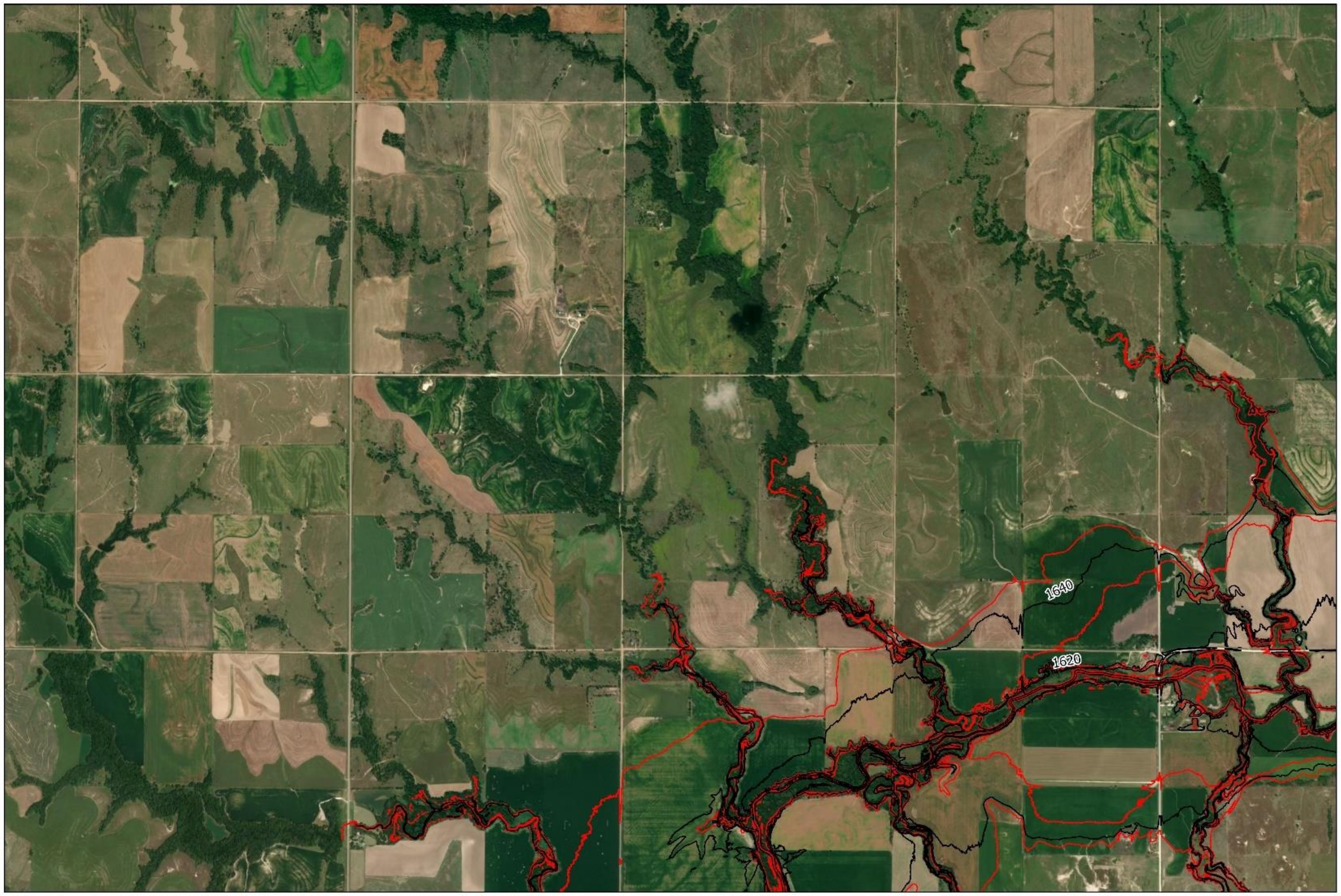
Scale 1:20,000

0 1,500 3,000 Feet



BUREAU OF RECLAMATION

Service Layer Credits: World Topographic Map:
Esri, HERE, Garmin, SafeGraph, FAO, METI/
NASA, USGS, EPA, NPS
World Imagery: USDA FSA, GeoEye, Maxar



Lovewell Reservoir
Kansas
Elevation
Contour Map

Sheet 5

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates

Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

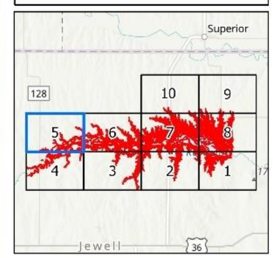
###0 - Black Contours
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

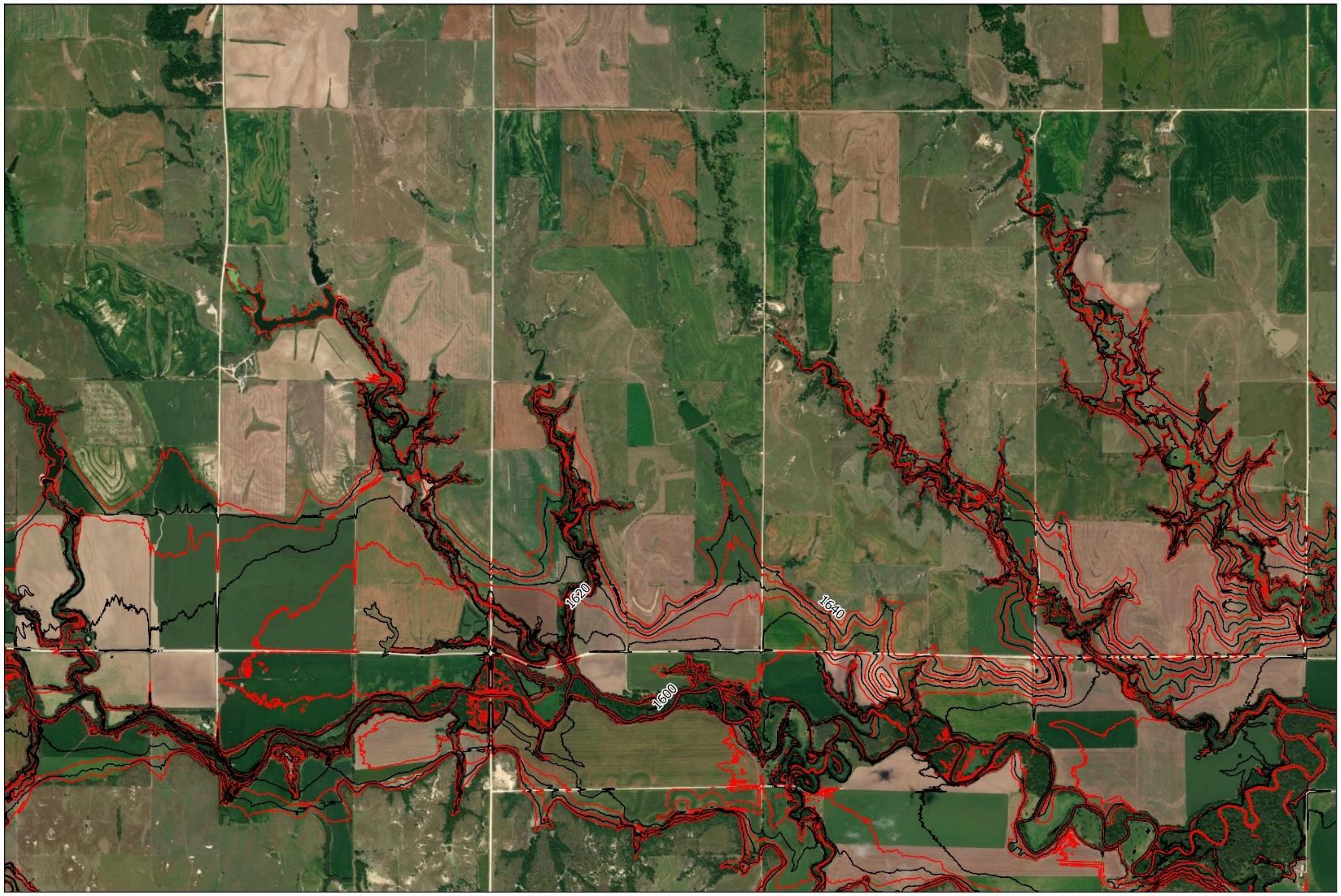
Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Topographic Map:
Esri, HERE, Garmin, SafeGraph, FAO, METI/
NASA, USGS, EPA, NPS
World Imagery: USDA FSA, GeoEye, Maxar

— BUREAU OF —
RECLAMATION



Lovewell Reservoir Kansas Elevation Contour Map

Sheet 6

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Bridge Deck over Spillway Gates

Bridge Deck Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

###0 - Black Contours

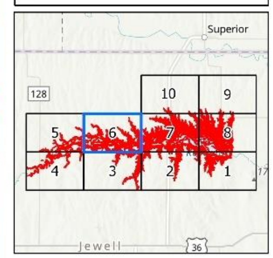
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

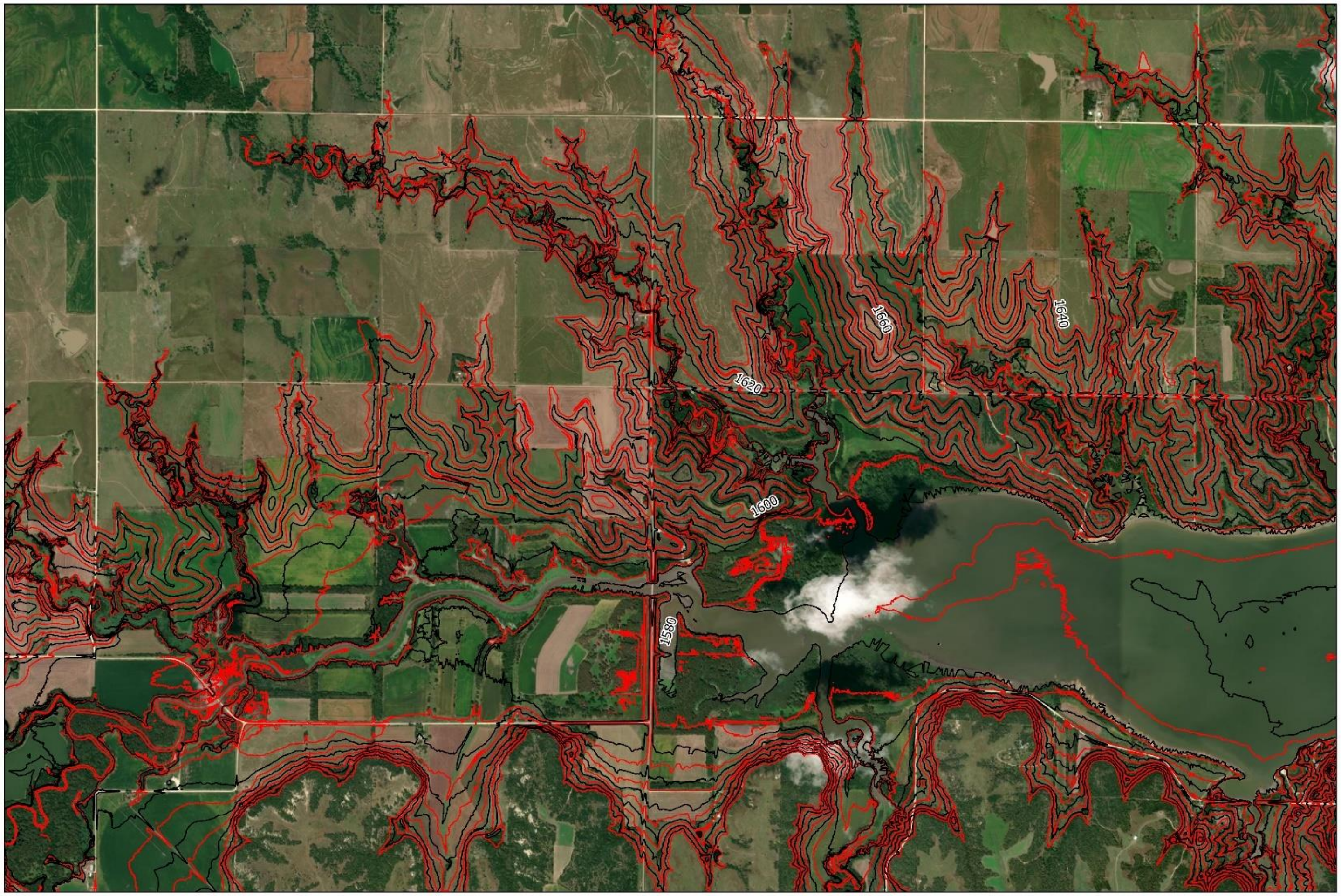
Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Imagery: Earthstar Geographics
World Topographic Map: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

BUREAU OF RECLAMATION



Lovewell Reservoir
Kansas
Elevation
Contour Map

Sheet 7

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates

Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

###0 - Black Contours

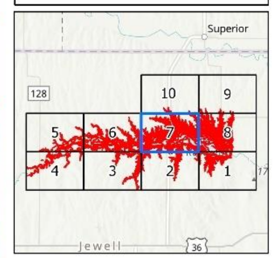
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

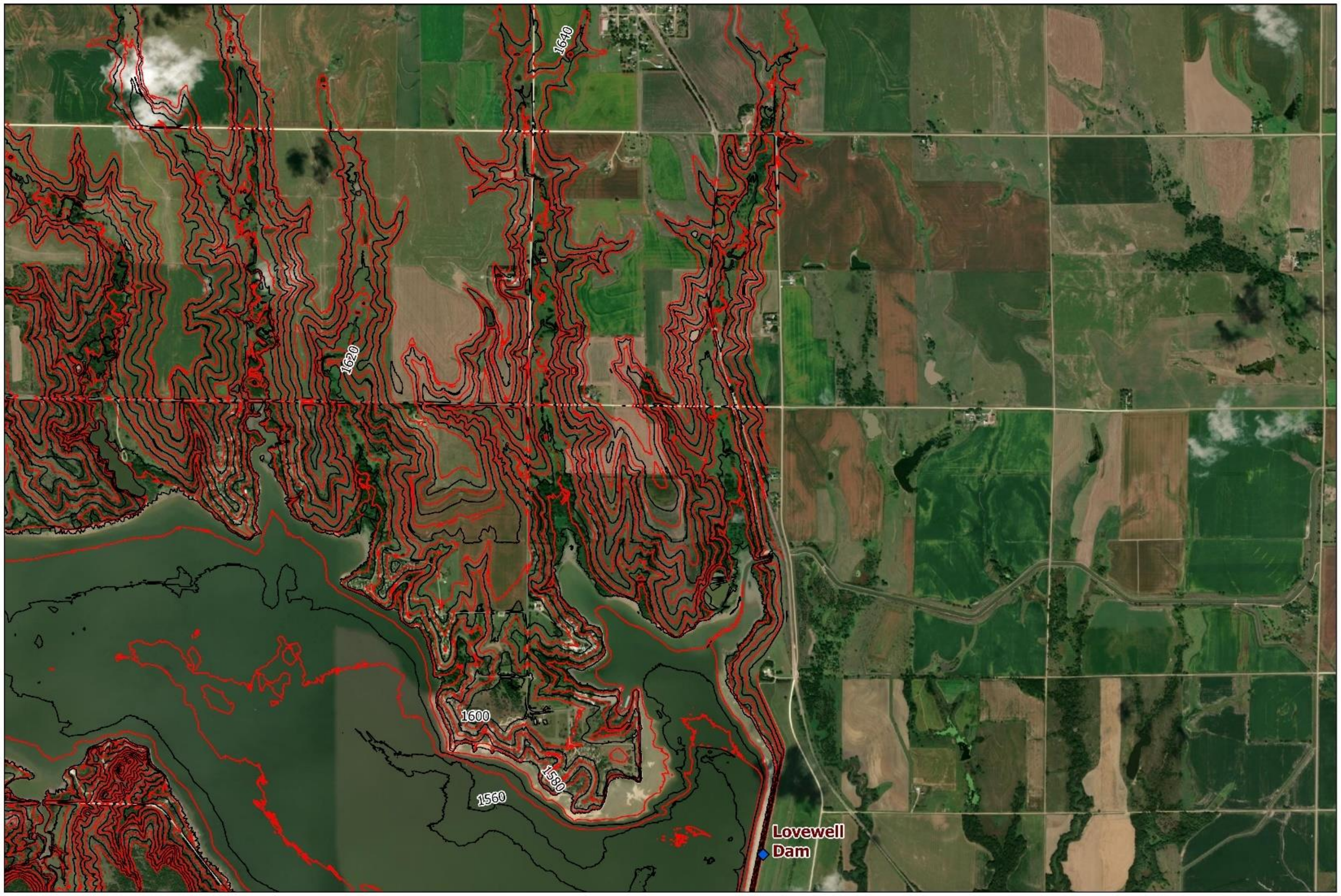
Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Topographic Map:
Esri, HERE, Garmin, SafeGraph, FAO, METI/
NASA, USGS, EPA, NPS
World Imagery: USDA FSA, GeoEye, Maxar

BUREAU OF RECLAMATION



Lovewell Reservoir
Kansas
Elevation
Contour Map

Sheet 8

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates

Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

###0 - Black Contours

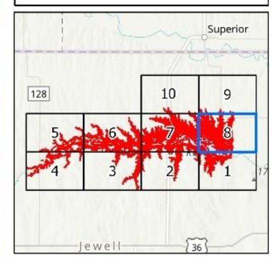
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Imagery: Earthstar Geographics
World Topographic Map: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

BUREAU OF RECLAMATION

Lovewell Reservoir
Kansas
Elevation
Contour Map

Sheet 9

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Bridge Deck over
Spillway Gates

Bridge Deck Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

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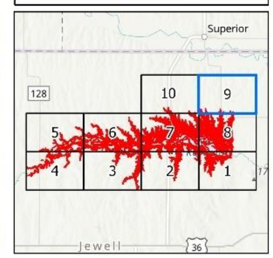
Primary Data Source:
2020 Lovewell Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Topographic Map:
Esri, HERE, Garmin, SafeGraph, FAO, METI/
NASA, USGS, EPA, NPS
World Imagery: USDA FSA, GeoEye, Maxar

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Lovewell Reservoir Kansas Elevation Contour Map

Sheet 10

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/20/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Kansas North Zone FIPS 1501
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Bridge Deck over Spillway Gates

Bridge Deck Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G18) – RPVD = 0.53 sft

###0 - Black Contours

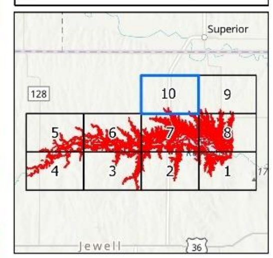
###5 - Red Contours

Primary Data Source:
2020 Lovewell Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Service Layer Credits: World Imagery: Earthstar Geographics
World Topographic Map: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

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