RECLAMATION

Managing Water in the West

Technical Report No. ENV-2019-067

Hyrum Reservoir Bathymetric Survey

Hyrum Project, Utah
Upper Colorado Region

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

August 2019

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BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

Technical Report No. ENV-2019-067

Hyrum Reservoir Bathymetric Survey

Hyrum Dam
Hyrum Project, Utah
Upper Colorado Region

ROBERT HILLDALE Digitally signed by ROBERT HILLDALE
Date: 2019.08.30 12:26:23 -06'00'

Prepared: Robert C. Hilldale, M.S., P.E.
Hydraulic Engineer Sedimentation and River Hydraulics Group

KENT COLLINS Digitally signed by KENT COLLINS
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Peer Review: Kent Collins, P.E.
Hydraulic Engineer, Sedimentation and River Hydraulics Group

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Introduction

At the request of Reclamation's Dam Safety Office (DSO), The Sedimentation and River Hydraulics Group (SRHG) performed a bathymetric survey of Hyrum Reservoir. The requested purpose of the survey was to provide detailed bathymetry near the dam to assist in the construction of intake modifications. The SRHG proposed using an additional day in the field to provide a complete survey so that an area-capacity table could be generated. The DSO agreed to the fund the small additional cost to obtain the full survey.

The Hyrum Project is located 8 miles south of Logan in northern Utah (Figure 1). Construction of Hyrum Dam began in March 1934 and the first water was made available in July 1935. The structural and hydraulic heights of Hyrum Dam are 116 ft and 82 ft, respectively. The 220 mi^2 drainage basin has an average annual inflow of 63,350 acre-ft, while the dam's original storage capacity was 18,800 acre-ft. The reservoir stores and diverts water from the Little Bear River to furnish supplemental water to approximately 6,800 acres of cultivated land. The Project includes Hyrum dam and reservoir and associated canal and appurtenant structures (Project Data, Reclamation 1981). Other relevant dimensions of Hyrum Dam are summarized below:

- Crest Elevation ……..4,680 ft
- Crest Length …… .540 ft
- Top Width …….35 ft
- Max. Base Width ……...600 ft
- Spillway ……Three 16' x 12' radial gates
- Spillway Crest Elev. …..4,660 ft

Generalized geology in the Little Bear River drainage upstream of Hyrum Reservoir consists of sandstone and mudstone in the Salt Lake Formation (State Geologic Map Compilation Geodatabase, https://www.sciencebase.gov/catalog/item/5888bf4fe4b05ccb964bab9d). The climate is semi-arid with soils dominated by silty loam and silty clay loam on hill slopes and in the lower valley (USDA Web Soil Survey, https://websoilsurvey.nrcs.usda.gov/app/). Annual precipitation in the basin is 16.5 inches.

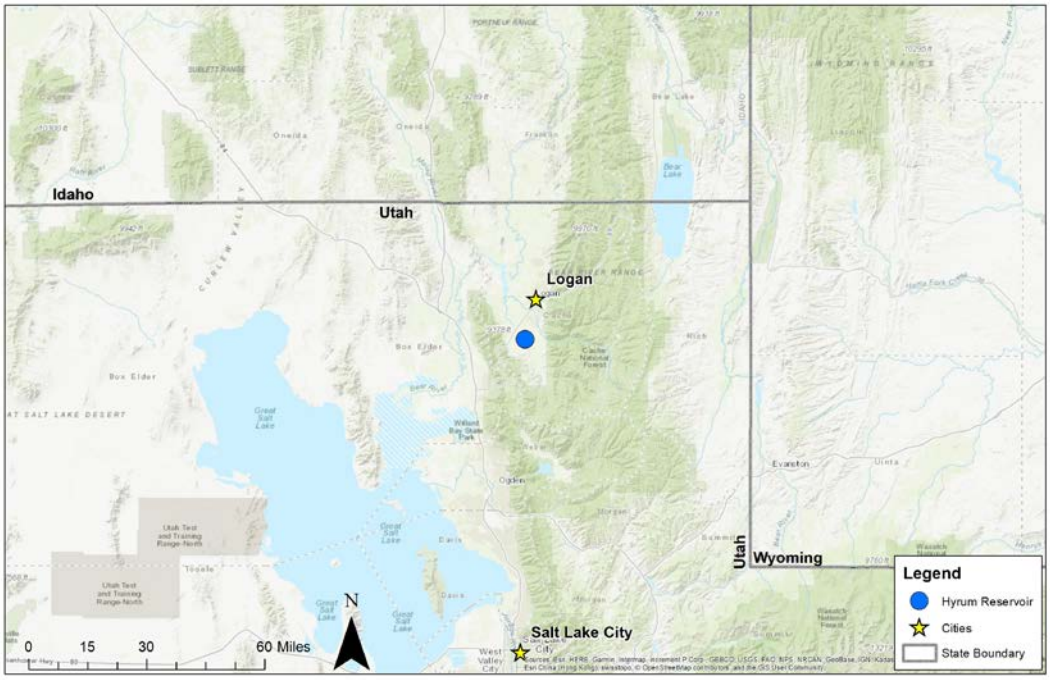

Figure 1. Location map of Hyrum Reservoir.

The primary purpose for this reservoir survey was to provide a high-resolution survey of the lower portion of the reservoir near the dam. Reclamation's Technical Service Center (TSC) is designing modifications for the intake structure and spillway. The design group has an interest in the reservoir bottom elevations near the reservoir intake. At the request of the Sedimentation and River Hydraulics Group, the remainder of the reservoir was surveyed to provide a complete map, and a new area-capacity table was generated.

Previous Surveys

Pre-Dam Survey

A pre-dam map of Hyrum Reservoir was obtained from the Provo Area Office's aperture microfiche cards and is included in Appendix A. The horizontal and vertical datums of the original survey are uncertain. Included in the Appendix A data are the original area-capacity curves, which indicate a surface area just under 480 acres (exact number not included on the graph) with a total capacity of 18,686 acre-ft at elevation 4672 ft (top of spillway gates).

2006 Survey

In June 2006 a bathymetric survey was completed by the Provo Area Office using a single beam transducer and RTK (Real Time Kinematic) GPS (Global Positioning System) for horizontal positions, collected in NAD83 and converted to NAD27. Elevations for this survey were tied to the water surface elevation as reported from the gage readings. At the time of the 2006 reservoir survey the relationship between the reported water surface elevations and the Hyrum Project Datum (HPD) was uncertain. A brief report of that survey is contained in Appendix B. It is believed that the gage reporting reservoir elevations may not be calibrated properly, especially at low elevations (pers. Comm. with Troy Ethington, UC Region GIS Coordinator). The relationship between the reservoir gage datum, NAVD88, NGVD29, and HPD is uncertain as of publication of the 2018 survey report. The 2006 survey indicates that the total capacity of the reservoir was 17,746 acre-ft at elevation 4672.5 ft.

2018 Survey Control

All survey data were collected using RTK GPS in NAD83 (2011), Utah State Plane North Zone, US survey feet horizontally and NAVD88, Geoid 12A, US survey feet vertically. Water surface, dam crest, spillway crest, and other dam feature elevations were measured in this datum. Approximately 500 survey points were collected outside of the reservoir in the upper delta to assist with generating a complete reservoir map. Those RTK GPS measurements [corrected to corresponding Online Positioning User Service (OPUS) derived elevations during post processing] were compared to water surface elevation gage records provided by the Provo Area Office to determine the vertical difference between NAVD88, Geoid 12A and the reservoir elevation gage readings. At the time of the survey the gage reading was 4.16 ft below NAVD88, Geoid 12A and 0.12 ft below the Hyrum Project Datum (HPD). It is important to note that the reservoir elevation gage values do not correspond to the Hyrum Project Datum (HPD) for Hyrum Dam.

SRHG personnel discussed the HPD with the Provo Area Office survey team (Dave Harris), who performed the control survey for this reservoir. The Provo survey team has identified the NGS point identified as 10+00 which is a brass cap along the centerline of the dam on top of the bench north of the spillway as primary control for Hyrum Dam and Reservoir.

The Hyrum Project Datum is noted as a shift from NAD83/NAVD88 as follows. All units are US Survey feet. All reservoir survey data documented in this report were shifted as indicated below.

Horizontal Coordinate Shift:

Convert data from NAD83 (2011) to Hyrum Project Datum by translating horizontal data as follows:

- Distance = 3.29 feet
- Azimuth (from the north) = 111°57'50"

Elevation Shift:

- NGVD29 minus Hyrum Project Datum = 0.53 ft
- NAVD88 minus Hyrum Project Datum= 4.04 ft
- HPD minus Gage = 0.12 ft

During both days of the 2018 hydrographic survey, the GPS base was set up over a wooden hub with a PK nail located in a grassy area northwest of the boat launch near a fish cleaning station (Figure 2). Coordinates for the GPS base point were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS). Users upload GPS data files collected with a survey grade receiver to the OPUS website (www.ngs.noaa.gov/OPUS/). OPUS utilizes the uploaded GPS data file, along with minimal user input, and coordinates from the NGS' Continuously Operating Reference Station (CORS) network to compute the user's base position on the high-accuracy National Spatial Reference System (NSRS). Base coordinates are provided to the user via email in latitude, longitude, and ellipsoid height as well as UTM and state plane coordinates and orthometric height (ground elevation). GPS data files were submitted to OPUS for both days the Reclamation survey crew was on site. Each GPS base session was at least 6 hours long, well beyond the OPUS time requirements to obtain a static solution (OPUS requires at least two hours of continuous GPS base data to compute a static solution for a given point). GPS base sessions were submitted to OPUS more than two weeks following the survey to allow OPUS to access the most precise satellite orbits and CORS data for computation of the most accurate coordinates possible.

Figure 2. Photograph of partial set-up of the GPS base station at Hyrum Reservoir. The view is looking southwest across the reservoir. The dam is just to the right of the tripods, obscured by vegetation.

Hydrographic Survey Equipment and Method

The 2018 hydrographic survey consisted of the collection of two types of data: ground survey and bathymetric survey data. Ground survey data consisted of all point measurements collected above the water and was used primarily to confirm horizontal and vertical datums and to obtain a survey of the upper portion of the reservoir which was dry at the time. Bathymetric survey data included all the underwater point measurements used to develop the reservoir bottom topography for updated maps as well as area and capacity computations.

Both types of surveys were conducted using RTK GPS equipment for positioning. RTK GPS calculates horizontal coordinates in real-time relative to its known base point and orthometric elevations based on ellipsoid and geoid models selected. The GPS base receiver is set up over a point on shore with known coordinates. Position corrections are transmitted to the GPS rover receiver using an external GPS radio and UHF antenna. The base station is powered by a 12-volt battery.

The rover component consists of a second GPS receiver with internal radio and external antenna mounted on a range pole (ground survey) or survey vessel (bathymetric survey). The rover, reading the same satellites as the base at the same time, receives the corrected positions from the base, resulting in real-time positions with accuracies on the order of 2 centimeters horizontally and 3 centimeters vertically over relatively large survey areas. All the 2018 hydrographic survey points used to map Hyrum Reservoir were collected within 2 miles of the GPS base station. Given the stated accuracy of RTK dual phase GPS receivers (1 centimeter ± 1 part per million), measurements collected on land and on the water would be expected to have errors less than 0.51 inches (1.3 centimeters) over the distances surveyed at Hyrum Reservoir.

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The bathymetric survey equipment was mounted on an 18-foot, flat-bottom aluminum boat powered by outboard jet and kicker motors (Figure 3). Survey equipment mounted to the boat included dual RTK GPS receivers for position and heading, multibeam transducer to measure depths, and laptop computer with hydrographic survey software (HYPACK) to collect and combine all the position and depth data. Power to all the hydrographic survey equipment was supplied by an inverter powered by a single 12-volt battery.

Figure 3. Survey vessel with bathymetric equipment mounted used for the 2018 survey of Hyrum Reservoir.

The multibeam echo sounder used for the 2016 survey (Odom MB1) consisted of a variable-frequency transducer with integrated motion reference unit, near-surface sound velocity probe, two GPS receivers, an external GSP radio, and processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data. The multibeam transducer emits up to 512 beams (user selectable) capable of projecting a swath width up to 120^{o} in over 390 feet (120 meters) of water. Sound velocity profiles were collected over the full water depth at two different locations along the reservoir to measure the speed of sound

through the water column. The speed of sound through the water column can be affected by various factors such as temperature and salinity. The sound velocity profile was used to correct the depth values obtained by the SONAR during post-processing.

A laptop on the boat 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 through cable connections to the processor box. Hydrographic survey software (HYPACK) on the laptop collects and combines positions and depths to provide reservoir bottom topography in the user selected coordinate system.

The Hyrum Reservoir survey was conducted over a two-day period from October 29 through October 30, 2018 between water surface elevations 4651.77 ft. and 4652.03 ft, (as recorded by the Hyrum Reservoir gage). Survey system software on the laptop combined the continuously recorded depth and position data and provided guidance to the boat operator as the boat traveled along gridlines established by the survey crew to cover the underwater portion of the reservoir. Surveyed lines were primarily aligned parallel to the historic low flow channel with some cross sections perpendicular to the dam in the lower reservoir and perpendicular to the low flow channel in the shallow upper reservoir. A path along the shoreline in shallow water, completely enclosing the boat-accessible areas was surveyed to help with the transition between underwater and above water data during mapping.

As each survey line was traversed, the depth and position data were recorded on the laptop computer hard drive for subsequent processing, resulting in complete reservoir bottom coverage in most areas accessed by the survey vessel (it would have been extremely time consuming and unnecessary to attain complete bottom coverage in shallow areas of reservoir). The water surface elevations recorded at the dam gage during the time of the bathymetric survey were used to convert the SONAR depth measurements to reservoir-bottom elevations tied to the Hyrum Project Datum.

Additional information on collection and analysis procedures is outlined in Chapter 9 of the Erosion and Sedimentation Manual (Ferrari and Collins, 2006).

Bathymetric Data Processing

The bathymetry data were processed using HYPACK software. Heave, pitch, roll, and sound velocity data were examined for irregularities, which were removed as needed. Latency between the position provided by the GPS and depth provided by the echosounder was examined for irregularities, none were found. Filters were run on the point data including beam angle limits (55 degrees), over/under (run twice), and a matrix filter for above and below a 4-sigma median. All data files were examined for irregular returns that were deleted from the point set. Once all

data were processed, they were exported as X-Y-Z comma delimited text files. For the high-resolution data near the dam, data were exported to include a median bed elevation at a 1-foot resolution. These data were shared with the design group. Data to be used for the reservoir map to create the area-capacity table were exported as an X-Y-Z comma delimited files to include a median bed elevation with a 3-foot resolution. These data were converted to shapefiles in Arc GIS for surface development.

Topography Development

Sources used for the development of a complete reservoir DEM consist of the bathymetry collected in October 2018 and airborne LiDAR collected between September and November 2017. The airborne LiDAR was obtained from the state of Utah (https://gis.utah.gov/data/elevation-and-terrain/2016-lidar-blbrcvuwv/) and was used for the above-water portion of the reservoir. The LiDAR data were delivered in NAD83(2011), UTM Zone 12, meters (horizontal) and NAVD88 GEOID12B (vertical). These points were converted to match the Hyrum project datum using AutoCAD.

Both sets of point data (bathymetry and LiDAR) were combined in ArcGIS and contours with a 2-foot interval were created. There is approximately an 18 ft vertical gap between the bathymetry and LiDAR, over which a linear interpolation was necessary to create the surface. This gap in data is due to the low water condition during the hydrographic survey and the high water condition during the LiDAR survey. Ground survey data collected in October 2018 was compared to the LiDAR data collected a year prior and it was determined that the match was within the survey error. It was decided that the LiDAR data would be used to generate the contours for the mapping of the reservoir, as it has a much greater density. The LiDAR and bathymetry point clouds and the resulting surface are shown in Figure 4. Contour map sheets are included in Appendix C.

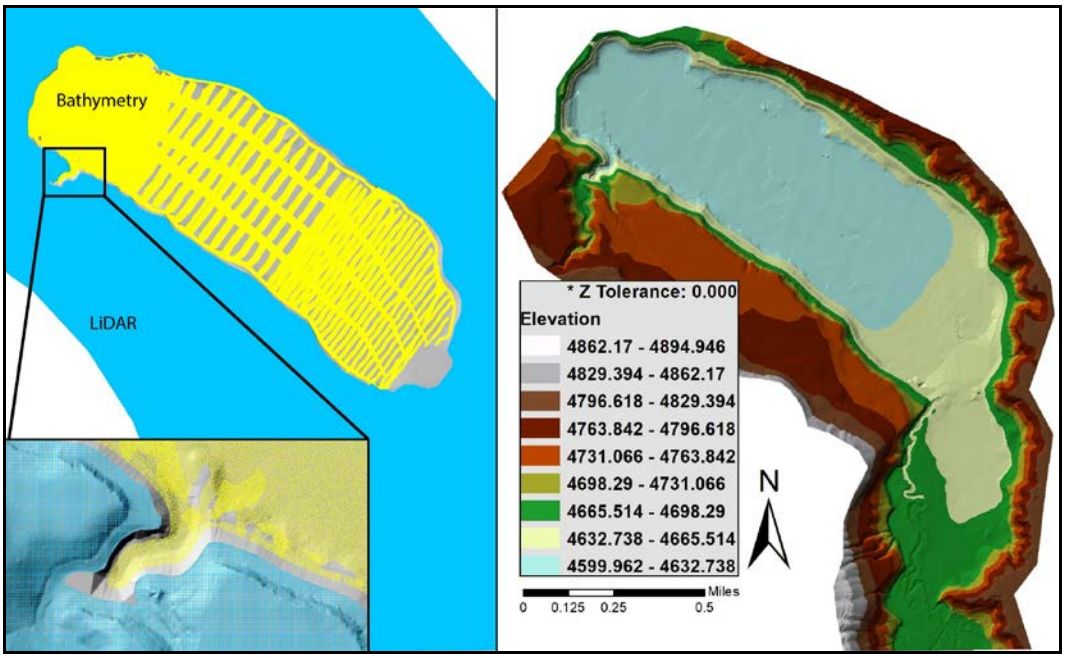

Figure 4. The left pane shows the point clouds of the LiDAR and bathymetry used to construct the surface. The inset shows the gap between the LiDAR and the bathymetry. The right pane shows the resulting surface.

2018 Surface Area Methods

The surface area was determined at 1-foot increments from elevation 4600 to 4672 ft using code written by the Sedimentation Group in ArcMap. Surface area was also calculated over the same elevation range at 0.1-foot increments using a routine included in ArcMap. These methods provided the same results. Due to the lack of an overlap in the bathymetry and LiDAR data there is a discontinuity in the area curve from approximately elevation 4642 and 4660 ft. Elevation 4672.5 ft corresponds with the top of the radial gates and is the maximum water surface elevation.

2018 Storage Capacity Methods

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation, 1985). The ACAP program computes the area and capacity at elevation increments from 0.01 to 1.0 foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit (error limit set at 0.000001 for Hyrum Reservoir). The capacity equation is then used over the full range of intervals fitting within the allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that

interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Through differentiation of the capacity equations, which are of second order polynomial form, final area equations are derived:

$$y = a_1 + a_2x + a_3x_2$$

where: y = capacity, x = elevation above a reference base, a_1 = intercept, a_2 and a_3 = coefficients.

2018 Surface Area and Capacity Results

The reservoir bottom centerline profile is shown in Figure 5 and includes the intake near the dam. Results of the 2018 Hyrum Reservoir area and capacity computations are listed in tables given reservoir levels for 0.1 and 1-foot elevation increments. These tables are shown in Appendix D. The Area-Capacity curves are shown in Figure 6. The discontinuity in the area curve is the result of the data gap between the LiDAR and the bathymetry.

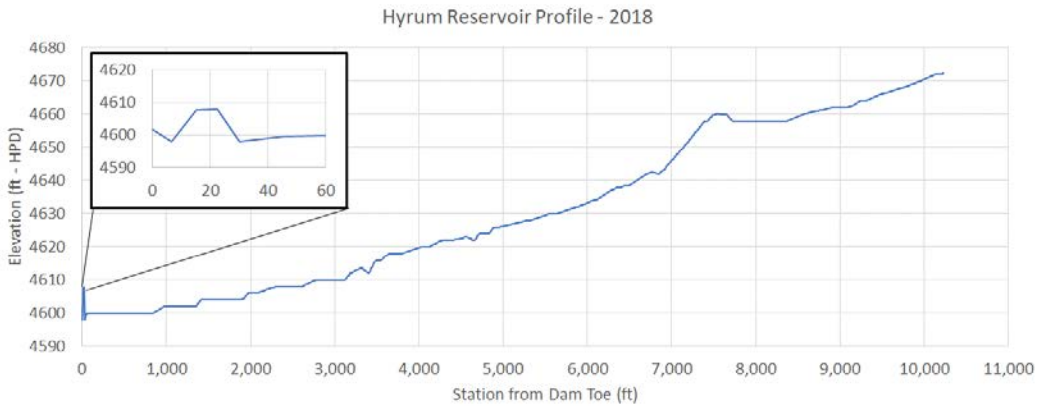

Figure 5. Figure showing the profile of Hyrum Reservoir using the 2018 survey data. The inset shows the intake structure.

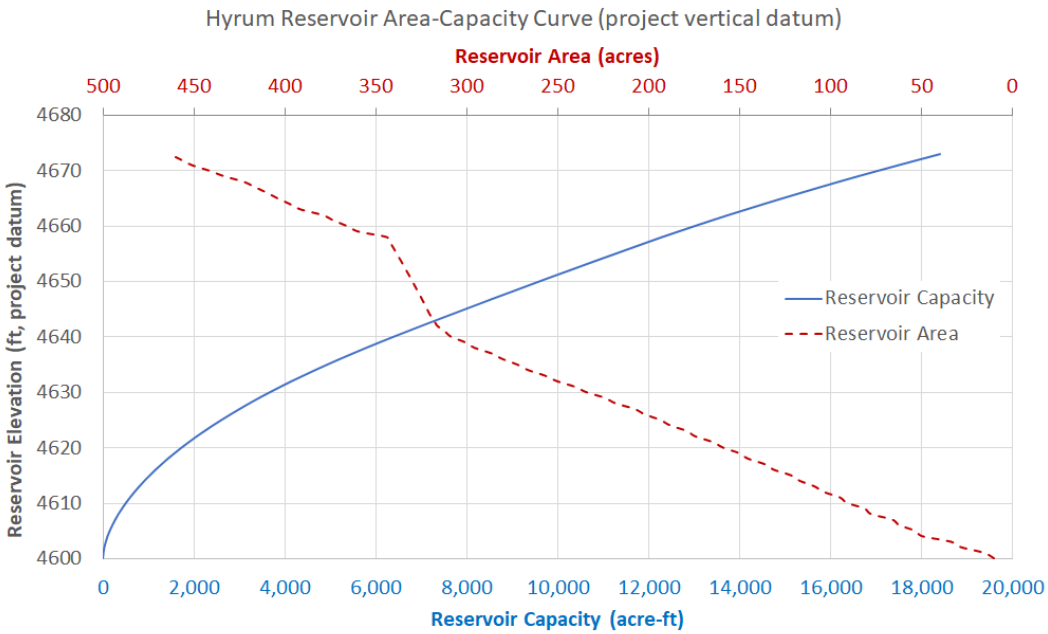

Figure 6. Area-Capacity curves resulting from the 2018 survey. The discontinuity in the area curve due to interpolation over missing data between elev. 4642 and 4660 ft.

The top of the radial gates (elevation 4672.5 feet) is used to calculate the total area and capacity of the reservoir. The 2018 survey indicates that the total area for Hyrum Reservoir is 460.4 acres and the total capacity is 18,221 acre-feet. The 2006 survey indicated a total capacity (at 4,672.5 ft) of 17,746 acre-feet.

The difference between reservoir capacity comparing the 2006 survey to the 2018 survey is 2.6%. This slight increase in capacity from 2006 to 2018 can be attributed to one or more of a few causes. Systematic equipment errors exist and are unavoidable with all survey and SONAR equipment. Differing survey techniques can also contribute to different reservoir capacities. The 2006 survey utilized a single beam transducer while the 2018 survey utilized a multi-beam transducer, which resulted in a greater portion of the reservoir being surveyed. The above-water portion of the 2018 survey includes the entire delta portion of the reservoir and was obtained from aerial LiDAR that was flown since the 2006 survey. The 2006 survey was performed at a much higher water elevation than in 2018 and most, if not all, of the delta was underwater. Vegetation in the delta may have fouled SONAR readings, providing a higher-than-actual bottom elevation, although similar inaccuracies may exist in the LiDAR used in the 2018 survey. The uncertainty in the HPD and gage readings of water elevation may also contribute to differing reservoir capacities.

The 2006 survey report states a total capacity at construction of 18,685 acre-ft. The Project Data Book (Reclamation 1981) states an original capacity of 18,800 acre-feet, however this capacity is at an elevation of 4672 ft as opposed to elevation 4672.5 ft used for the 2006 and 2018 surveys. The source of the original capacity of 18,685 acre-feet stated in the 2006 survey is not provided.

Conclusions

The 2018 survey provided dense bathymetry near the dam (downstream third of the reservoir) for the TSC design group to aid their effort in designing modifications to the outlet works. This dense survey included details of the outlet works including a cone of depression around outlet tower. Additionally, the entire reservoir was surveyed to provide an updated area-capacity table.

Recommendations

The two post-dam surveys of Hyrum Reservoir indicate similar results regarding reservoir volume. However, there is uncertainty in these results due to differing survey methods and uncertainty in vertical datums. Additionally, there is uncertainty regarding the current project datum and the original survey. This uncertainty prevents an accurate accounting of sedimentation since the dam's construction. It is recommended that a complete investigation into the Hyrum Project Datum take place and how this vertical datum ties to the original survey and the gage datum currently used for operations. Without a clear understanding of these differences, reservoir capacity, sedimentation rates, and operations will exist with uncertainties greater than necessary.

References

Ferrari, R.L. and Collins, K. (2006). *Reservoir Survey and Data Analysis*, Chapter 9, Erosion and Sedimentation Manual. US Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, CO. www.usbr.gov/tsc/tscorganization/services/8240services.html.

US Bureau of Reclamation (1985). *ACAP85 User's Manual.* Technical Service Center, Surface Water Branch, Denver CO.

Appendix A

Original Contour Maps and Area-Capacity Curves

SPECIFICATIONS No. 552

DRAWING No. 2

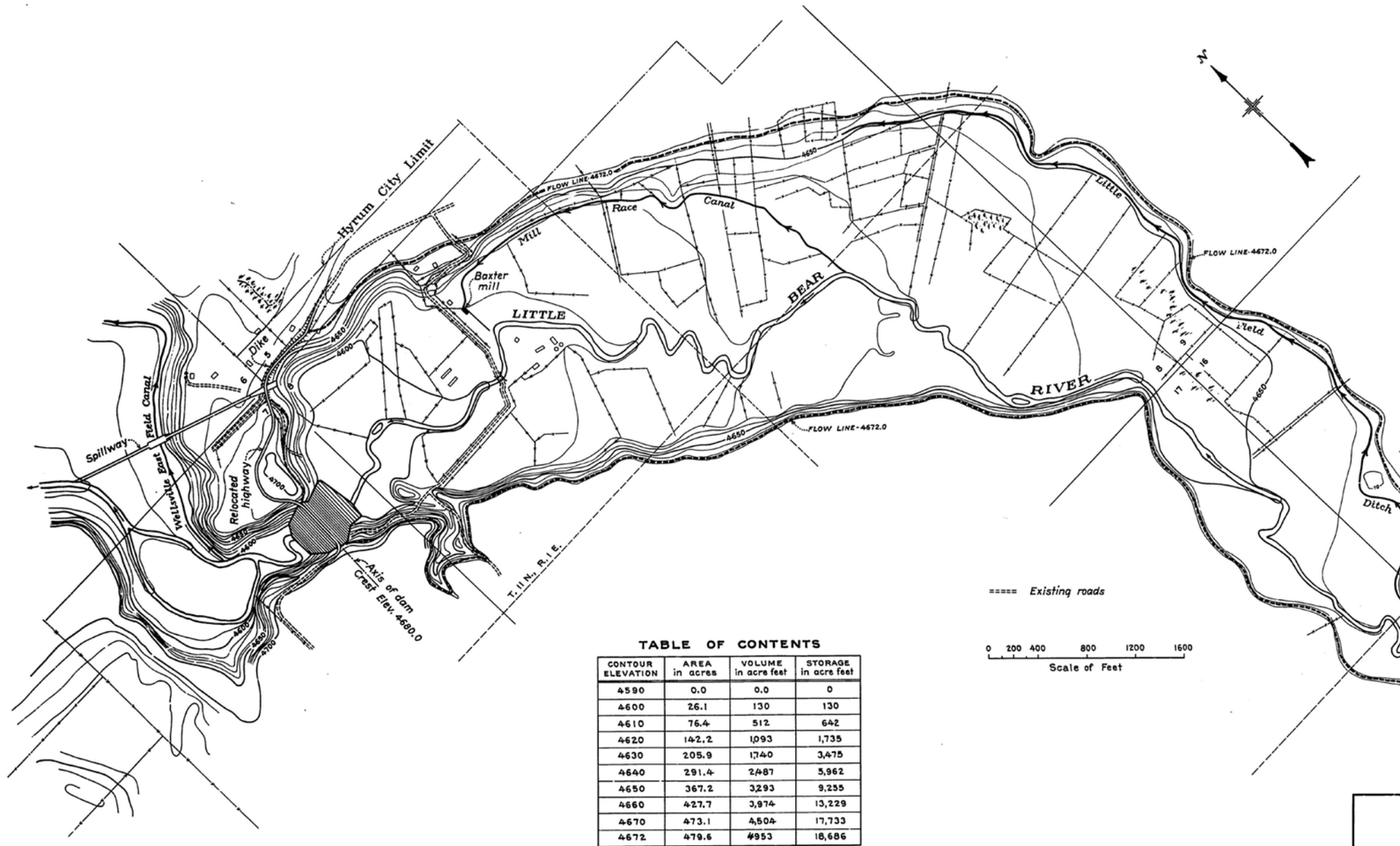

TABLE OF CONTENTS

CONTOUR ELEVATION	AREA in acres	VOLUME in acre feet	STORAGE in acre feet
4590	0.0	0.0	0
4600	26.1	130	130
4610	76.4	512	642
4620	142.2	1,093	1,735
4630	205.9	1,740	3,475
4640	291.4	2,487	5,962
4650	367.2	3,293	9,255
4660	427.7	3,974	13,229
4670	473.1	4,504	17,733
4672	479.6	4953	18,686

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT - UTAH

HYRUM DAM
GENERAL MAP OF RESERVOIR AREA

DRAWN: K.W.K.	SUBMITTED: B. K. Steele		
TRACED: C.S.M.	RECOMMENDED: J. L. Savage		
CHECKED: M.E.S.	APPROVED: [illegible]		
24848	DENVER, COLO., OCT. 30, 1933	198-D-16	

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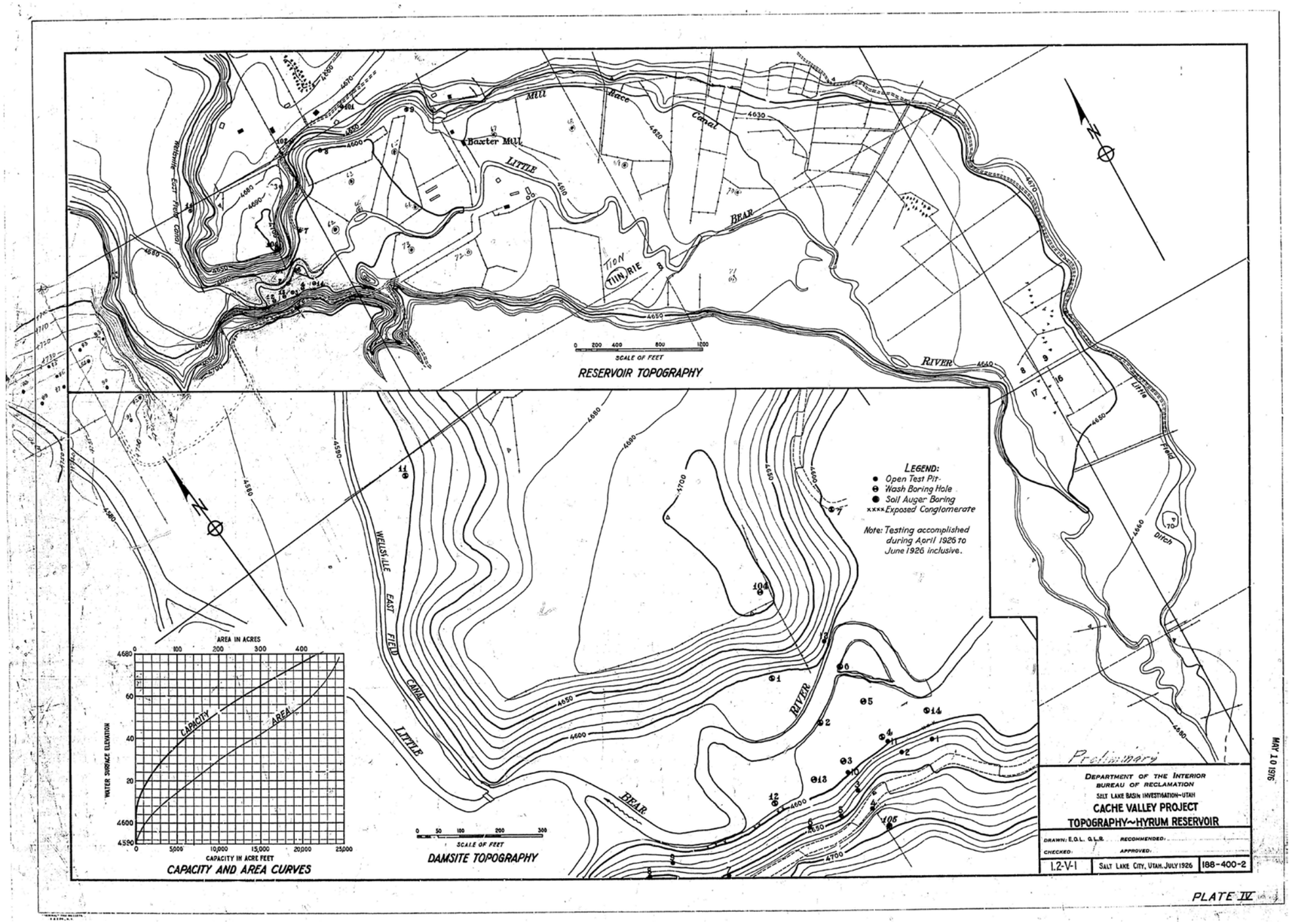
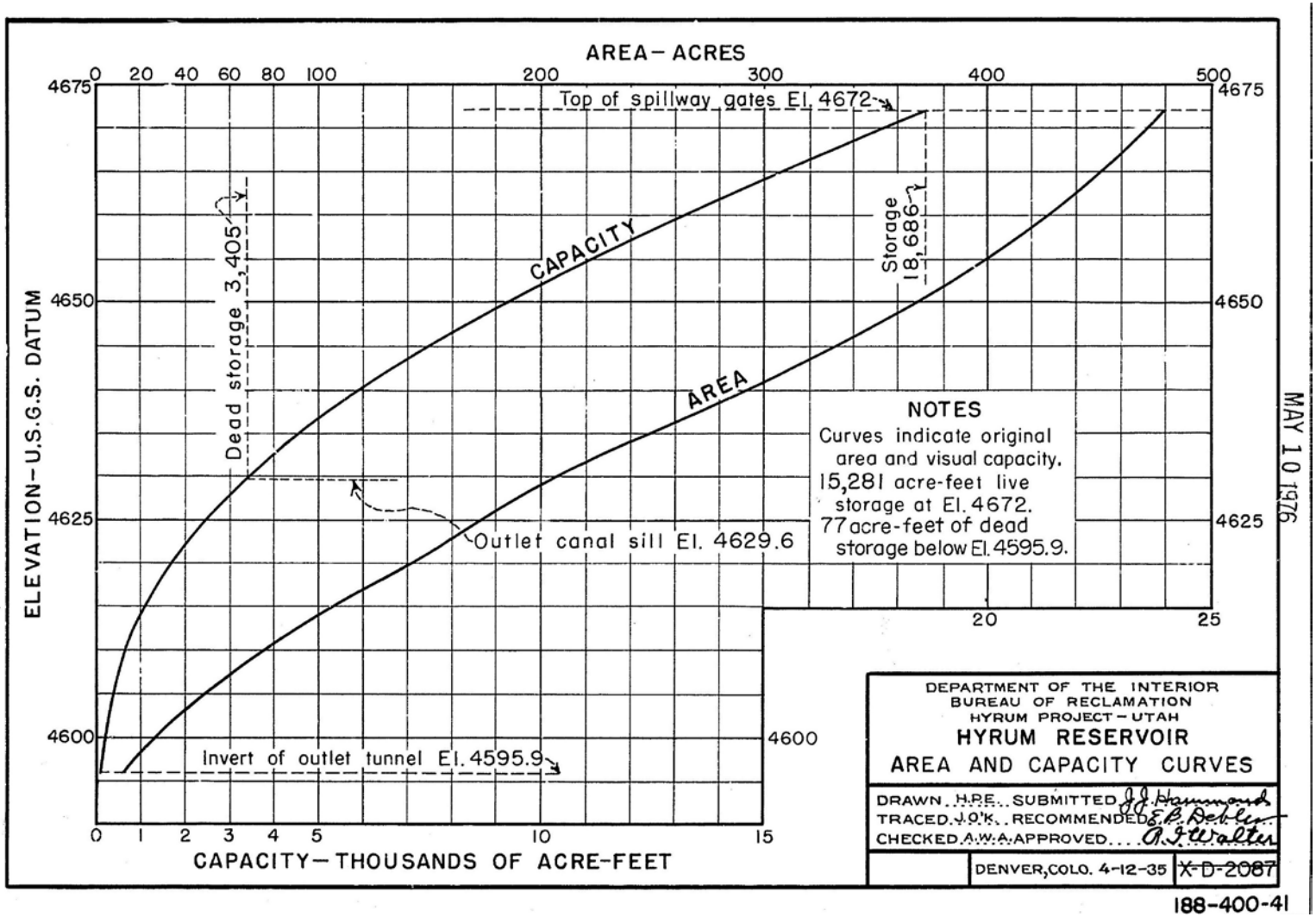

Baxter Mill
Mill Race Canal
LITTLE BEAR RIVER
Wellsville East Field Canal
SCALE OF FEET
RESERVOIR TOPOGRAPHY
LEGEND:
Open Test Pit
Wash Boring Hole
Soil Auger Boring
Exposed Conglomerate
Note: Testing accomplished during April 1926 to June 1926 inclusive.
AREA IN ACRES
CAPACITY
AREA
WATER SURFACE ELEVATION
CAPACITY IN ACRE FEET
CAPACITY AND AREA CURVES
SCALE OF FEET
DAMSITE TOPOGRAPHY
Preliminary
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT LAKE BASIN INVESTIGATION-UTAH
CACHE VALLEY PROJECT
TOPOGRAPHY~HYRUM RESERVOIR
DRAWN: E.O.L. G.L.R.
RECOMMENDED:
CHECKED:
APPROVED:
I.2-V-1
SALT LAKE CITY, UTAH, JULY 1926
188-400-2
MAY 10 1926
PLATE IV


AREA – ACRES
0 20 40 60 80 100 200 300 400 500
4675
4650
4625
4600
ELEVATION – U.S.G.S. DATUM
Top of spillway gates El. 4672
Dead storage 3,405
CAPACITY
AREA
Storage 18,686
Outlet canal sill El. 4629.6
Invert of outlet tunnel El. 4595.9
NOTES
Curves indicate original area and visual capacity.
15,281 acre-feet live storage at El. 4672.
77 acre-feet of dead storage below El. 4595.9.
0 1 2 3 4 5 10 15 20 25
CAPACITY – THOUSANDS OF ACRE-FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT – UTAH
HYRUM RESERVOIR
AREA AND CAPACITY CURVES
DRAWN H.P.E. SUBMITTED J.J. Hammond
TRACED J.O'K. RECOMMENDED E.B. Debler
CHECKED A.W.A. APPROVED A.F. Walter
DENVER, COLO. 4-12-35 X-D-2087
188-400-41
MAY 10 1976

Appendix B

2006 Hyrum Bathymetric Survey

Hyrum Reservoir Data Comparison

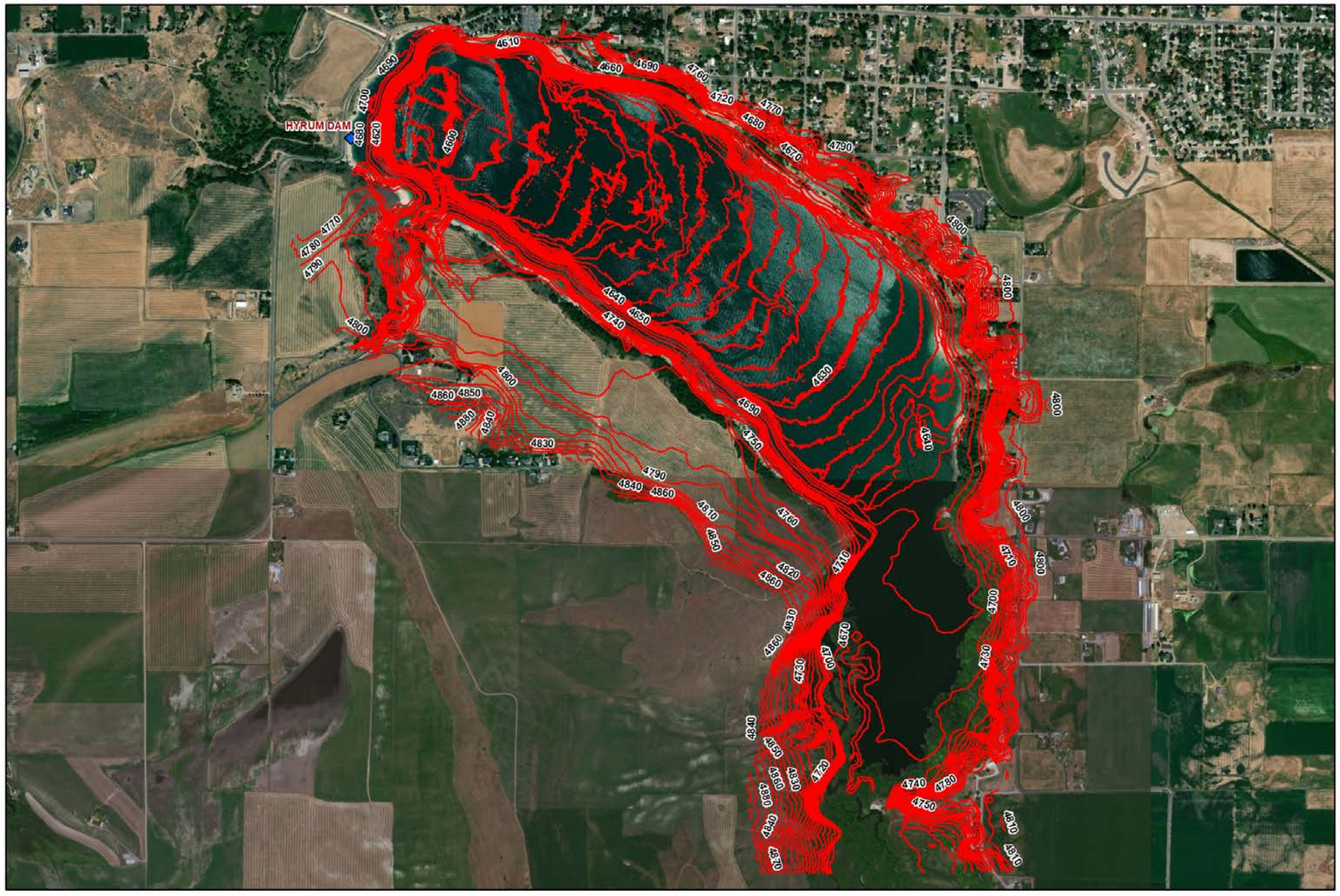
	Elevation	1946 survey (Acre-feet)	2006 survey (Acre-feet)	% Change
Total Capacity	Streambed to 4672.5 ft	18,685	17,746	-5%
Dead Storage	Streambed to 4629.6 ft	3,405	3,012	-12%
Live Capacity	4629.6 ft to 4672.5 ft	15,280	14,734	-4%
Inactive Capacity	4629.6 ft to 4633.5 ft	840	853	+2%
Active Conservation Capacity	4633.5 ft to 4672.5 ft	14,440	13,881	-4%
Surcharge Capacity	—	—	—	—

Capacity Change from Original Survey

The June 2006 bathymetric survey of Hyrum Reservoir determined a total capacity of 17,746 AF, a decrease of 939 AF (5%) from the 1946 survey. 42% of this difference in capacity (393 AF) is located in the Dead Storage. Because of the differences in survey methods and technology from 1946 to 2006, it is difficult to draw many conclusions in comparing the data. The 2006 survey will likely serve as a baseline for future determination of reservoir sedimentation.

Appendix C

Reservoir maps



Hyrum Reservoir
Utah
Elevation
Contour Map

Overview Map

Horizontal Coordinate Shift:
Convert data from NAD83 (2011) to HPD as follows:
Distance = 3.29 feet
Azimuth (from the north) = 111°57'50"

Elevation Shift:
NGVD29 minus HPD = 0.53 ft
NAVD88 minus HPD= 4.04 ft
HPD minus Gage = 0.12 ft

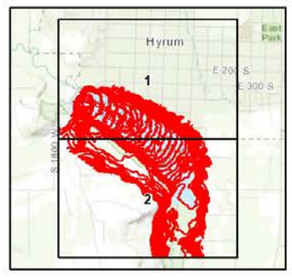
2 ft contour interval,
10 ft index coutours

Primary Data Source:
2018 Reservoir Survey and
2017 LiDAR

N

Scale 1:12,000

0 900 1,800 Feet



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

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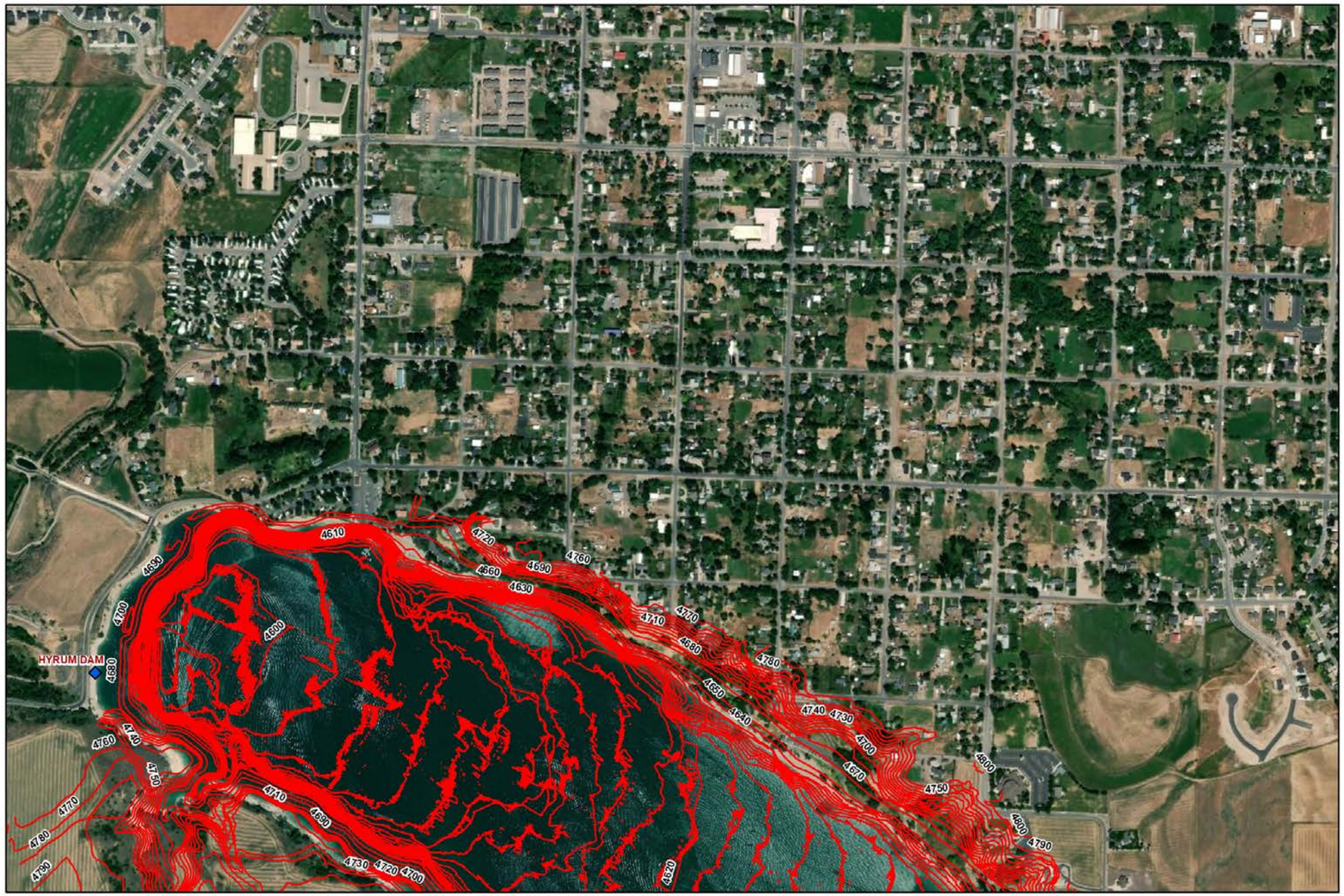


Hyrum Reservoir
Utah
Elevation
Contour Map

Sheet 1

Horizontal Coordinate Shift:
Convert data from NAD83 (2011) to HPD as follows:
Distance = 3.29 feet
Azimuth (from the north) = 111°57'50"

Elevation Shift:
NGVD29 minus HPD = 0.53 ft
NAVD88 minus HPD= 4.04 ft
HPD minus Gage = 0.12 ft

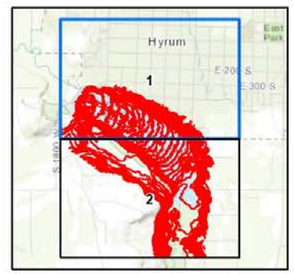
2 ft contour interval,
10 ft index coutours

Primary Data Source:
2018 Reservoir Survey and
2017 LiDAR

N

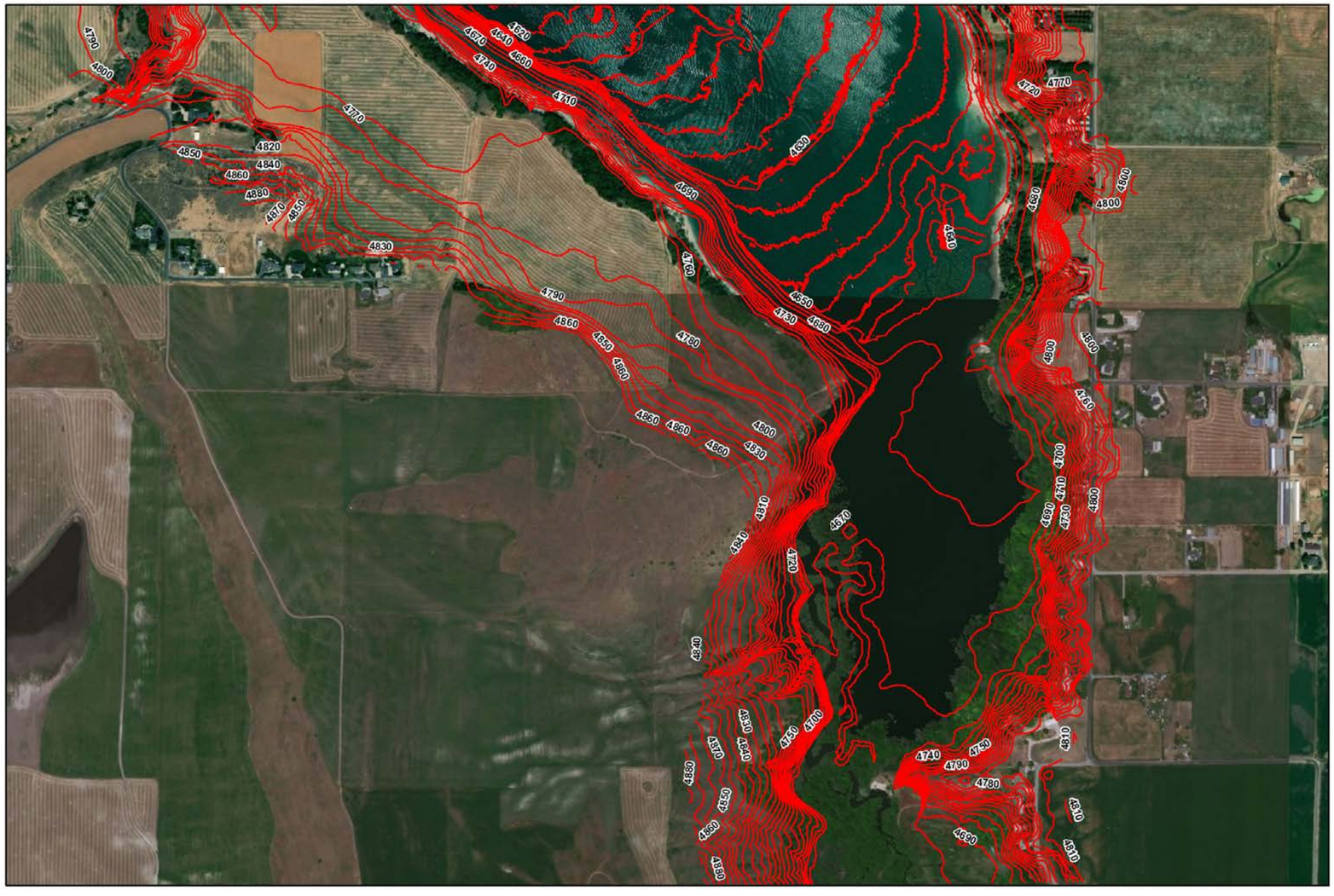
Scale 1:8,000

0 600 1,200 Feet



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

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION



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

Hyrum Reservoir
Utah
Elevation
Contour Map

Sheet 2

Horizontal Coordinate Shift:
Convert data from NAD83 (2011) to HPD as follows:
Distance = 3.29 feet
Azimuth (from the north) = 111°57'50"

Elevation Shift:
NGVD29 minus HPD = 0.53 ft
NAVD88 minus HPD= 4.04 ft
HPD minus Gage = 0.12 ft

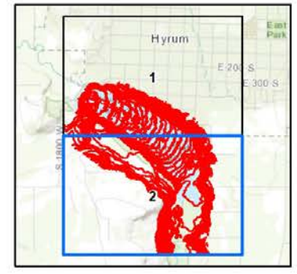
2 ft contour interval,
10 ft index coutours

Primary Data Source:
2018 Reservoir Survey and
2017 LiDAR

N

Scale 1:8,000

0 600 1,200 Feet



U.S. DEPARTMENT OF THE INTERIOR
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Appendix D

Area-Capacity Tables

Elev. (ft)	Area (acres)	Volume (acre-ft)	Elev. (ft)	Area (acres)	Volume (acre-ft)
4600	10	0.4	4637	286	5,497.7
4601	16	13.3	4638	296	5,787.2
4602	28	32.2	4639	301	6,085.4
4603	34	63.2	4640	309	6,389.1
4604	50	100.9	4641	312	6,699.5
4605	54	152.6	4642	316	7,013.5
4606	62	208.8	4643	318	7,330.7
4607	66	273.1	4644	320	7,649.8
4608	78	341.7	4645	322	7,971.0
4609	81	421.3	4646	323	8,293.7
4610	91	504.9	4647	325	8,618.0
4611	95	597.9	4648	327	8,943.9
4612	104	695.1	4649	328	9,271.4
4613	109	801.6	4650	330	9,600.5
4614	117	913.3	4651	332	9,931.4
4615	122	1,032.7	4652	333	10,263.9
4616	131	1,157.2	4653	335	10,598.1
4617	136	1,291.0	4654	337	10,934.0
4618	146	1,430.1	4655	339	11,271.7
4619	150	1,578.0	4656	340	11,611.1
4620	159	1,731.0	4657	342	11,952.3
4621	165	1,893.1	4658	344	12,295.4
4622	174	2,061.1	4659	360	12,652.2
4623	179	2,237.8	4660	366	13,014.8
4624	188	2,419.7	4661	373	13,385.2
4625	194	2,610.7	4662	379	13,761.4
4626	202	2,807.5	4663	391	14,149.6
4627	208	3,012.6	4664	397	14,544.0
4628	218	3,223.8	4665	404	14,945.3
4629	224	3,445.1	4666	410	15,352.2
4630	234	3,672.7	4667	416	15,765.5
4631	241	3,910.3	4668	423	16,184.9
4632	251	4,154.7	4669	434	16,614.8
4633	257	4,408.5	4670	442	17,052.2
4634	266	4,669.2	4671	451	17,500.4
4635	272	4,938.5	4672	457	17,954.6
4636	281	5,214.2			

Hyrum Reservoir - Hyrum Project, Utah (ACAP92) COMPUTED 7/16/2019

2018 AREA-CAPACITY TABLES (HPD) 14:38:15

THE **AREA TABLE** IS IN ACRES, THE ELEVATION INCREMENT IS IN ONE TENTH FOOT

ELEV. FT	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
4600	10.3	10.8	11.3	11.9	12.4	13.0	13.5	14.0	14.6	15.1
4601	15.7	16.9	18.2	19.4	20.7	21.9	23.2	24.5	25.7	27.0
4602	28.2	28.8	29.4	29.9	30.5	31.1	31.7	32.3	32.8	33.4
4603	34.0	35.6	37.1	38.7	40.3	41.8	43.4	45.0	46.5	48.1
4604	49.7	50.1	50.5	50.9	51.3	51.8	52.2	52.6	53.0	53.4
4605	53.9	54.7	55.6	56.4	57.3	58.1	59.0	59.8	60.7	61.5
4606	62.4	62.8	63.1	63.5	63.9	64.3	64.7	65.1	65.4	65.8
4607	66.2	67.4	68.5	69.7	70.9	72.0	73.2	74.3	75.5	76.7
4608	77.8	78.2	78.6	78.9	79.3	79.7	80.0	80.4	80.7	81.1
4609	81.5	82.4	83.4	84.3	85.3	86.2	87.2	88.1	89.1	90.0
4610	91.0	91.4	91.8	92.2	92.6	93.0	93.4	93.8	94.2	94.6
4611	95.0	95.9	96.8	97.7	98.6	99.5	100.4	101.2	102.1	103.0
4612	103.9	104.4	104.9	105.4	105.9	106.4	107.0	107.5	108.0	108.5
4613	109.0	109.8	110.6	111.4	112.2	113.0	113.8	114.7	115.5	116.3
4614	117.1	117.6	118.0	118.5	119.0	119.5	120.0	120.4	120.9	121.4
4615	121.9	122.8	123.8	124.7	125.6	126.6	127.5	128.5	129.4	130.4
4616	131.3	131.8	132.3	132.8	133.3	133.8	134.3	134.8	135.3	135.8
4617	136.3	137.2	138.1	139.1	140.0	140.9	141.8	142.8	143.7	144.6
4618	145.6	146.0	146.5	147.0	147.5	148.0	148.5	149.0	149.4	149.9
4619	150.4	151.3	152.2	153.1	153.9	154.8	155.7	156.6	157.5	158.3
4620	159.2	159.8	160.4	160.9	161.5	162.1	162.6	163.2	163.7	164.3
4621	164.9	165.8	166.8	167.7	168.7	169.6	170.5	171.5	172.4	173.4
4622	174.3	174.8	175.3	175.8	176.3	176.7	177.2	177.7	178.2	178.7
4623	179.2	180.1	181.0	181.9	182.8	183.7	184.6	185.5	186.4	187.3
4624	188.2	188.8	189.3	189.9	190.5	191.0	191.6	192.1	192.7	193.3
4625	193.8	194.6	195.5	196.3	197.2	198.0	198.8	199.7	200.5	201.4
4626	202.2	202.8	203.4	203.9	204.5	205.1	205.7	206.3	206.9	207.5
4627	208.0	209.1	210.1	211.2	212.2	213.2	214.3	215.3	216.3	217.4
4628	218.4	219.0	219.6	220.2	220.8	221.4	221.9	222.5	223.1	223.7
4629	224.3	225.3	226.3	227.3	228.3	229.3	230.3	231.3	232.3	233.3
4630	234.3	235.0	235.6	236.3	236.9	237.6	238.2	238.9	239.5	240.2
4631	240.8	241.8	242.8	243.8	244.7	245.7	246.7	247.7	248.6	249.6
4632	250.6	251.3	251.9	252.6	253.2	253.9	254.5	255.2	255.8	256.5
4633	257.1	258.0	259.0	259.9	260.8	261.7	262.7	263.6	264.5	265.4
4634	266.3	267.0	267.6	268.2	268.8	269.4	270.0	270.6	271.2	271.8

ELEV. FT	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
4635	272.4	273.2	274.0	274.9	275.7	276.5	277.3	278.1	278.9	279.8
4636	280.6	281.2	281.7	282.3	282.9	283.5	284.0	284.6	285.2	285.8
4637	286.3	287.3	288.2	289.1	290.1	291.0	291.9	292.9	293.8	294.8
4638	295.7	296.2	296.7	297.2	297.8	298.3	298.8	299.3	299.8	300.4
4639	300.9	301.7	302.4	303.2	304.0	304.7	305.5	306.3	307.1	307.8
4640	308.6	309.0	309.3	309.7	310.0	310.4	310.8	311.1	311.5	311.8
4641	312.2	312.6	313.0	313.4	313.9	314.3	314.7	315.1	315.5	315.9
4642	316.3	316.5	316.7	316.9	317.1	317.3	317.4	317.6	317.8	318.0
4643	318.2	318.4	318.6	318.8	319.0	319.3	319.5	319.7	319.9	320.1
4644	320.4	320.5	320.7	320.8	321.0	321.1	321.3	321.5	321.6	321.8
4645	321.9	322.1	322.2	322.4	322.6	322.7	322.9	323.0	323.2	323.3
4646	323.5	323.7	323.8	324.0	324.1	324.3	324.4	324.6	324.8	324.9
4647	325.1	325.2	325.4	325.6	325.7	325.9	326.1	326.2	326.4	326.5
4648	326.7	326.9	327.0	327.2	327.4	327.5	327.7	327.8	328.0	328.2
4649	328.3	328.5	328.7	328.8	329.0	329.2	329.3	329.5	329.6	329.8
4650	330.0	330.1	330.3	330.5	330.6	330.8	331.0	331.1	331.3	331.5
4651	331.7	331.8	332.0	332.2	332.3	332.5	332.7	332.8	333.0	333.2
4652	333.4	333.5	333.7	333.9	334.0	334.2	334.4	334.5	334.7	334.9
4653	335.1	335.2	335.4	335.6	335.7	335.9	336.1	336.3	336.4	336.6
4654	336.8	336.9	337.1	337.3	337.5	337.7	337.8	338.0	338.2	338.4
4655	338.5	338.7	338.9	339.1	339.3	339.4	339.6	339.8	340.0	340.1
4656	340.3	340.5	340.7	340.9	341.0	341.2	341.4	341.6	341.7	341.9
4657	342.1	342.3	342.5	342.7	342.9	343.1	343.3	343.4	343.6	343.8
4658	344.0	345.6	347.1	348.7	350.2	351.8	353.3	354.9	356.4	358.0
4659	359.5	360.2	360.8	361.4	362.1	362.7	363.3	364.0	364.6	365.2
4660	365.9	366.6	367.3	368.1	368.8	369.6	370.3	371.0	371.8	372.5
4661	373.2	373.9	374.5	375.1	375.7	376.4	377.0	377.6	378.2	378.9
4662	379.5	380.7	381.8	383.0	384.2	385.4	386.6	387.8	388.9	390.1
4663	391.3	391.9	392.5	393.2	393.8	394.4	395.0	395.6	396.2	396.8
4664	397.5	398.1	398.8	399.4	400.1	400.8	401.4	402.1	402.7	403.4
4665	404.1	404.6	405.2	405.8	406.4	407.0	407.5	408.1	408.7	409.3
4666	409.9	410.5	411.1	411.8	412.4	413.1	413.7	414.4	415.0	415.6
4667	416.3	416.9	417.6	418.2	418.9	419.5	420.2	420.8	421.5	422.1
4668	422.7	423.9	424.9	426.0	427.1	428.2	429.2	430.3	431.4	432.5
4669	433.5	434.3	435.1	435.9	436.7	437.5	438.3	439.2	440.0	440.8
4670	441.6	442.5	443.5	444.4	445.4	446.4	447.3	448.3	449.2	450.2
4671	451.1	451.8	452.4	453.0	453.6	454.2	454.9	455.5	456.1	456.7
4672	457.3	458.0	458.6	459.2	459.8	460.4	461.1	461.7	462.3	462.9
4673	463.5									

Hyrum Reservoir - Hyrum Project, Utah (ACAP92) COMPUTED
7/16/2019
2018 AREA-CAPACITY TABLES (HPD) 14:38:15

THE **CAPACITY TABLE** IS IN ACRE FEET, THE ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FT	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
4600	10.0	11.1	12.2	13.3	14.5	15.8	17.1	18.5	19.9	21.4
4601	23.0	24.6	26.4	28.2	30.2	32.4	34.6	37.0	39.5	42.2
4602	44.9	47.8	50.7	53.6	56.7	59.7	62.9	66.1	69.3	72.6
4603	76.0	79.5	83.1	86.9	90.9	95.0	99.2	103.6	108.2	113.0
4604	117.8	122.8	127.9	132.9	138.0	143.2	148.4	153.6	158.9	164.2
4605	169.6	175.0	180.5	186.1	191.8	197.6	203.5	209.4	215.4	221.5
4606	227.7	234.0	240.3	246.6	253.0	259.4	265.8	272.3	278.9	285.4
4607	292.0	298.7	305.5	312.4	319.4	326.6	333.8	341.2	348.7	356.3
4608	364.0	371.8	379.7	387.5	395.5	403.4	411.4	419.4	427.5	435.6
4609	443.7	451.9	460.2	468.6	477.0	485.6	494.3	503.0	511.9	520.9
4610	529.9	539.0	548.2	557.4	566.6	575.9	585.2	594.6	604.0	613.4
4611	622.9	632.5	642.1	651.8	661.6	671.5	681.5	691.6	701.8	712.0
4612	722.4	732.8	743.3	753.8	764.3	775.0	785.6	796.4	807.1	817.9
4613	828.8	839.8	850.8	861.9	873.1	884.3	895.7	907.1	918.6	930.2
4614	941.9	953.6	965.4	977.2	989.1	1001.0	1013.0	1025.0	1037.1	1049.2
4615	1061.3	1073.6	1085.9	1098.3	1110.8	1123.4	1136.2	1149.0	1161.8	1174.8
4616	1187.9	1201.1	1214.3	1227.5	1240.8	1254.2	1267.6	1281.0	1294.5	1308.1
4617	1321.7	1335.4	1349.1	1363.0	1377.0	1391.0	1405.1	1419.4	1433.7	1448.1
4618	1462.6	1477.2	1491.8	1506.5	1521.2	1536.0	1550.8	1565.7	1580.6	1595.6
4619	1610.6	1625.7	1640.9	1656.1	1671.5	1686.9	1702.4	1718.0	1733.7	1749.5
4620	1765.4	1781.4	1797.4	1813.4	1829.6	1845.7	1862.0	1878.3	1894.6	1911.0
4621	1927.5	1944.0	1960.6	1977.3	1994.2	2011.1	2028.1	2045.2	2062.4	2079.7
4622	2097.1	2114.5	2132.0	2149.6	2167.2	2184.8	2202.5	2220.3	2238.1	2255.9
4623	2273.8	2291.8	2309.8	2328.0	2346.2	2364.5	2382.9	2401.4	2420.0	2438.7
4624	2457.5	2476.3	2495.3	2514.2	2533.2	2552.3	2571.4	2590.6	2609.9	2629.2
4625	2648.5	2667.9	2687.4	2707.0	2726.7	2746.5	2766.3	2786.2	2806.2	2826.3
4626	2846.5	2866.8	2887.1	2907.4	2927.9	2948.3	2968.9	2989.5	3010.1	3030.9
4627	3051.6	3072.5	3093.4	3114.5	3135.7	3156.9	3178.3	3199.8	3221.4	3243.1
4628	3264.9	3286.7	3308.7	3330.6	3352.7	3374.8	3397.0	3419.2	3441.5	3463.8
4629	3486.2	3508.7	3531.3	3554.0	3576.7	3599.6	3622.6	3645.7	3668.9	3692.1
4630	3715.5	3739.0	3762.5	3786.1	3809.8	3833.5	3857.3	3881.2	3905.1	3929.1
4631	3953.1	3977.2	4001.5	4025.8	4050.2	4074.7	4099.4	4124.1	4148.9	4173.8
4632	4198.8	4223.9	4249.1	4274.3	4299.6	4324.9	4350.4	4375.8	4401.4	4427.0
4633	4452.7	4478.4	4504.3	4530.2	4556.3	4582.4	4608.6	4634.9	4661.3	4687.8
4634	4714.4	4741.1	4767.8	4794.6	4821.4	4848.3	4875.3	4902.3	4929.4	4956.6

ELEV. FT	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
4635	4983.8	5011.1	5038.4	5065.9	5093.4	5121.0	5148.7	5176.5	5204.3	5232.3
4636	5260.3	5288.4	5316.5	5344.7	5373.0	5401.3	5429.7	5458.1	5486.6	5515.1
4637	5543.7	5572.4	5601.2	5630.1	5659.0	5688.1	5717.2	5746.5	5775.8	5805.2
4638	5834.7	5864.3	5894.0	5923.7	5953.4	5983.2	6013.1	6043.0	6073.0	6103.0
4639	6133.0	6163.2	6193.4	6223.6	6254.0	6284.4	6315.0	6345.5	6376.2	6407.0
4640	6437.8	6468.7	6499.6	6530.5	6561.5	6592.5	6623.6	6654.7	6685.8	6717.0
4641	6748.2	6779.4	6810.7	6842.0	6873.4	6904.8	6936.2	6967.7	6999.3	7030.8
4642	7062.4	7094.1	7125.7	7157.4	7189.1	7220.8	7252.6	7284.3	7316.1	7347.9
4643	7379.7	7411.5	7443.4	7475.2	7507.1	7539.1	7571.0	7603.0	7634.9	7666.9
4644	7699.0	7731.0	7763.1	7795.1	7827.2	7859.3	7891.5	7923.6	7955.8	7987.9
4645	8020.1	8052.3	8084.5	8116.8	8149.0	8181.3	8213.5	8245.8	8278.2	8310.5
4646	8342.8	8375.2	8407.5	8439.9	8472.3	8504.8	8537.2	8569.7	8602.1	8634.6
4647	8667.1	8699.6	8732.2	8764.7	8797.3	8829.9	8862.4	8895.1	8927.7	8960.3
4648	8993.0	9025.7	9058.4	9091.1	9123.8	9156.6	9189.3	9222.1	9254.9	9287.7
4649	9320.5	9353.4	9386.2	9419.1	9452.0	9484.9	9517.8	9550.8	9583.7	9616.7
4650	9649.7	9682.7	9715.7	9748.7	9781.8	9814.9	9848.0	9881.1	9914.2	9947.3
4651	9980.5	10013.7	10046.9	10080.1	10113.3	10146.5	10179.8	10213.1	10246.4	10279.7
4652	10313.0	10346.3	10379.7	10413.1	10446.5	10479.9	10513.3	10546.8	10580.2	10613.7
4653	10647.2	10680.7	10714.3	10747.8	10781.4	10815.0	10848.6	10882.2	10915.8	10949.5
4654	10983.1	11016.8	11050.5	11084.2	11118.0	11151.7	11185.5	11219.3	11253.1	11286.9
4655	11320.8	11354.7	11388.5	11422.4	11456.4	11490.3	11524.2	11558.2	11592.2	11626.2
4656	11660.2	11694.3	11728.3	11762.4	11796.5	11830.6	11864.7	11898.9	11933.1	11967.2
4657	12001.4	12035.7	12069.9	12104.2	12138.5	12172.8	12207.1	12241.4	12275.8	12310.1
4658	12344.5	12379.0	12413.6	12448.4	12483.4	12518.5	12553.7	12589.1	12624.7	12660.4
4659	12696.3	12732.3	12768.3	12804.4	12840.6	12876.8	12913.1	12949.5	12985.9	13022.4
4660	13059.0	13095.6	13132.3	13169.1	13205.9	13242.8	13279.8	13316.9	13354.0	13391.2
4661	13428.5	13465.9	13503.3	13540.8	13578.3	13615.9	13653.6	13691.3	13729.1	13767.0
4662	13804.9	13842.9	13881.0	13919.3	13957.6	13996.1	14034.7	14073.4	14112.3	14151.2
4663	14190.3	14229.5	14268.7	14308.0	14347.3	14386.7	14426.2	14465.7	14505.3	14545.0
4664	14584.7	14624.5	14664.3	14704.2	14744.2	14784.2	14824.3	14864.5	14904.8	14945.1
4665	14985.4	15025.9	15066.4	15106.9	15147.5	15188.2	15228.9	15269.7	15310.5	15351.4
4666	15392.4	15433.4	15474.5	15515.6	15556.9	15598.1	15639.5	15680.9	15722.3	15763.9
4667	15805.5	15847.1	15888.9	15930.6	15972.5	16014.4	16056.4	16098.5	16140.6	16182.7
4668	16225.0	16267.3	16309.8	16352.3	16395.0	16437.7	16480.6	16523.6	16566.7	16609.8
4669	16653.1	16696.5	16740.0	16783.6	16827.2	16870.9	16914.7	16958.6	17002.5	17046.6
4670	17090.7	17134.9	17179.2	17223.6	17268.1	17312.7	17357.3	17402.1	17447.0	17492.0
4671	17537.0	17582.2	17627.4	17672.7	17718.0	17763.4	17808.8	17854.4	17899.9	17945.6
4672	17991.3	18037.0	18082.9	18128.8	18174.7	18220.7	18266.8	18312.9	18359.1	18405.4
4673	18451.7									