South Platte River Basin
Tri-Lakes Project: Sedimentation at Bear Creek, Chatfield, and Cherry Creek Lakes
1950 – 2016

US Army Corps of Engineers ®
Omaha District

Northwestern Division – Omaha District

Aerial view of Cherry Creek Lake, Colorado (RARE database file photo).

Updated by: **Engineering Division**
Hydrologic Engineering Branch
River & Reservoir Engineering Section

M.R.B. SEDIMENT MEMORANDUM No. 23b

February 2023

U.S. Army Corps of Engineers

Northwestern Division

The U.S. Army Corps of Engineers Missouri River Basin (M.R.B.) Sediment Memoranda Program was established for the development of practical sediment engineering for rational evaluation, regulation, and utilization of fluvial sediment phenomena. It was implemented as a comprehensive, Missouri River basin-wide program for coordination of studies of sediment problems in the overall basin program for flood control and allied purposes as well as for continuity and perspective in the planning and design of individual projects. The program includes both investigations for the development of sediment transport theory and observation of existent and occurring phenomena for the purpose of developing the applications of theory to practical problems, developing empirical relationships, and providing aids to judgment.

ACKNOWLEDGEMENTS

M.R.B. Sediment Memorandum No. 23b, *Sedimentation at Bear Creek, Chatfield, and Cherry Creek Lakes, 1954 – 2016,* was prepared by the U.S. Army Corps of Engineers, Omaha District, Engineering Division, Hydrologic Engineering Branch, River & Reservoir Engineering Section (CENWO-EDH-F) as part of the M.R.B. Sediment Memoranda Program.

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EXECUTIVE SUMMARY

The purpose of the update to M.R.B. 23b is to document changes in surface area and storage capacity of each of the Tri-Lakes Reservoirs between the original and subsequent surveys with new 2016 survey data. The Tri-Lakes Reservoirs are located in the metropolitan area of Denver, Colorado and consist of Bear Creek Lake, Chatfield Lake, and Cherry Creek Lake.

Survey technology and the methodologies to calculate reservoir storage losses have changed throughout the project history. Each of the three Tri-Lakes Reservoirs was surveyed in the summer of 2016 with two discrete methods. The multi-beam fathometer was used to collect data to obtain dense coverage of the reservoir floor which is referred to as the High-Density Multi-Beam (HDMB) method in this report. The multi-beam collection covered the reservoir floor up to approximately three to four feet below the water surface. Above ground surveys using GPS survey methods were collected on the ranges to above the Maximum Pool elevation. A LiDAR data set from the state of Colorado was integrated with the 2016 multi-beam bathymetry to create a surface digital elevation model (DEM) for each project. Using the DEMs and the GIS method, the analysis for the three reservoirs resulted in increased storage capacities.

The GIS method is considered to be the most accurate method available at this time and is the basis for the official area-capacity analysis stated in this report using 2016 data. All previous area-capacity analyses are still considered valid within the context of their time and data collection method. However, because of the variation in data collection and analysis methods, trend analysis should only be done with common survey and analysis methods. Since the original survey and capacity analysis was performed with the best available method at the time, long term trends may be of lesser accuracy.

Gross Storage capacity results for the Tri-lakes:

Bear Creek Lake – Decrease from 78,139 acre-feet in 1980 to 77,948 acre-feet in 2016.

Chatfield Lake – Apparent increase from 349,404 ace-feet in 1977 to 352,961 acre-feet in 2016.

Cherry Creek Lake – Apparent increase from 248,353 acre-feet in 1950 to 274,504 acre-feet in 2016.

NOTE: All original capacity surveys and analysis were based on the best available survey data while the 2016 data set and analysis methods are based on new methodology.

<u>Bear Creek Lake</u> – Gross storage capacity in Bear Creek Lake has decreased from the original capacity of 78,139 acre-feet in 1980 to 77,948 acre-feet in 2016, based on the GIS method. This amounts to a total storage reduction of 191 acre-feet, or an average depletion rate of 5.3 acre-feet per year. The original projected storage depletion rate for Bear Creek Lake was approximately 20 acre-feet per year. The Bear Creek Lake Flood Control Pool storage capacity has decreased from 28,825 acre-feet in 1980 to 28,534 acre-feet in 2016, an average of 8 acre-feet per year.

Chatfield Lake – Gross storage capacity in Chatfield Lake has increased from the original capacity of 349,404 acre-feet in 1977 to 352,961 acre-feet in 2016, based on the GIS method. This amounts to a total storage increase of 3,557 acre-feet, or an average increase of 91 acre-feet per year. The original projected storage depletion rate for Chatfield Lake was approximately 189.5 acre-feet per year. The Chatfield Lake Flood Control Pool storage capacity has increased from 206,094 acre-feet in 1977 to 207,655 acre-feet in 2016, an average increase of 40 acre-feet per year.

Cherry Creek Lake – Gross storage capacity in Cherry Creek Lake has increased from the original capacity of 248,353 acre-feet in 1950 to 274,504 acre-feet in 2016, based on the GIS method. This amounts to a total storage increase of 26,151 acre-feet, or an average increase of 396 acre-feet per year. The original projected storage depletion rate for Cherry Creek Lake was approximately 151 acre-feet per year. The Cherry Creek Lake Flood Control Pool storage capacity has increased from 78,393 acre-feet in 1950 to 81,736 acre-feet in 2016, an average increase of 51 acre-feet per year.

Although deposition has not significantly impacted storage capacity, sediment related impacts within the Tri-Lakes Reservoirs have occurred. Impacted areas include the Plum Creek tributary arm within Chatfield Lake and potential long-term impacts from the Hayman fire of 2002.

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1 Project Introduction

1.1 Purpose

The U.S. Army Corps of Engineers Tri-Lakes Projects is made up of three separate flood control reservoirs: Bear Creek Lake, Chatfield Lake, and Cherry Creek Lake, located in metropolitan Denver, Colorado. The purpose of this M.R.B. Sediment Memorandum is to update geomorphic conditions and trends for each reservoir. The nature, extent, and quantification of sediment accumulation are specifically detailed in this report. Presented in the report are historical statistical data, cross section data, pool elevation records, and capacity and sediment depletion data. The report presents this data in a format, which may be used in subsequent studies to predict future conditions for the three reservoirs.

1.2 Scope of Work

The scope of work for this report is to update additional pertinent sediment information concerning Bear Creek, Chatfield, and Cherry Creek Lakes since publishing M.R.B. Sediment Memorandum 23a (July 2011); specifically, survey data collected in 2016. The report is to be used as a reference document that analyzes the data to determine trends in geomorphic changes over the life of each project.

1.3 Sedimentation Program Authorities

The authority for the Omaha District's Sedimentation Program is contained in EM 1110-2-4000, *Sedimentation Investigations of Rivers and Reservoirs*, dated 31 October 1995. The guidelines and instructions that are outlined in this EM include program planning, observation techniques, extent of surveys, analysis of basic data, and submission of technical memoranda and reports.

1.4 Related Manuals and Reports

Other pertinent information concerning sedimentation at the Tri-Lakes Reservoirs, including initial sedimentation rates, may be found in the reports listed in Table 1-1.

Table 1-1. Related Reports

1944		Cherry Creek – Definite Project Report
1966	DM No. PC-2	Chatfield - Hydrology
1970	DM No. PB-1	Bear Creek - Hydrology
2001	M.R.B. Sediment Memorandum 23	Tri-Lakes Sedimentation Studies Area-Capacity Report
2011	M.R.B. Sediment Memorandum 23a	Tri-Lakes Sedimentation Studies Area-Capacity Report

2 Project Data

2.1 Study Area

The Denver Tri-Lakes Projects are made up of three separate flood control reservoirs, Bear Creek Lake, Chatfield Lake, and Cherry Creek Lake, located in metropolitan Denver, Colorado (Figure 2-1 & Figure 2-2). The purpose of the Tri-Lakes Projects is to reduce the risk of flooding to the Denver metropolitan area from the South Platte River basin. Although USACE built the dams primarily for the purpose of flood control, each project offers other multipurpose features, including recreational opportunities for those interested in boating, camping, skiing, horseback riding, fishing, hiking, and nature study.

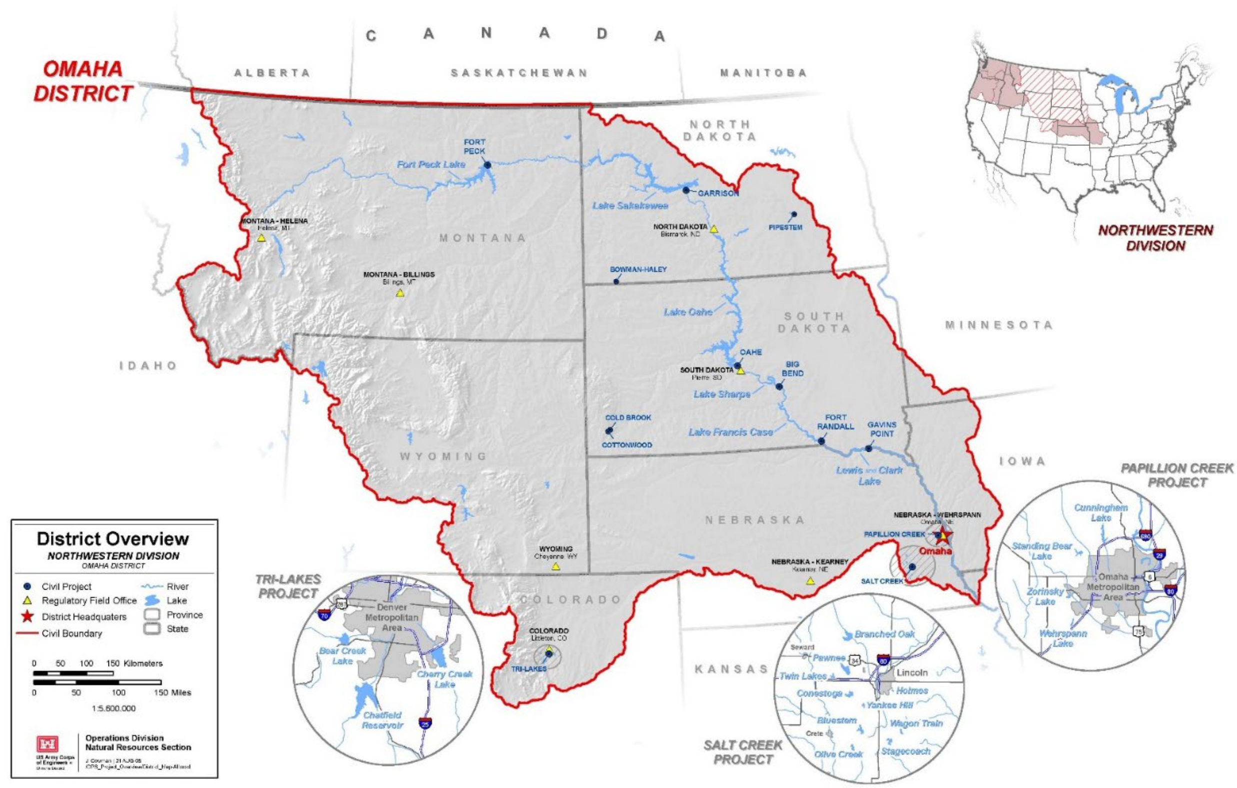

Figure 2-1. Omaha District Location Map

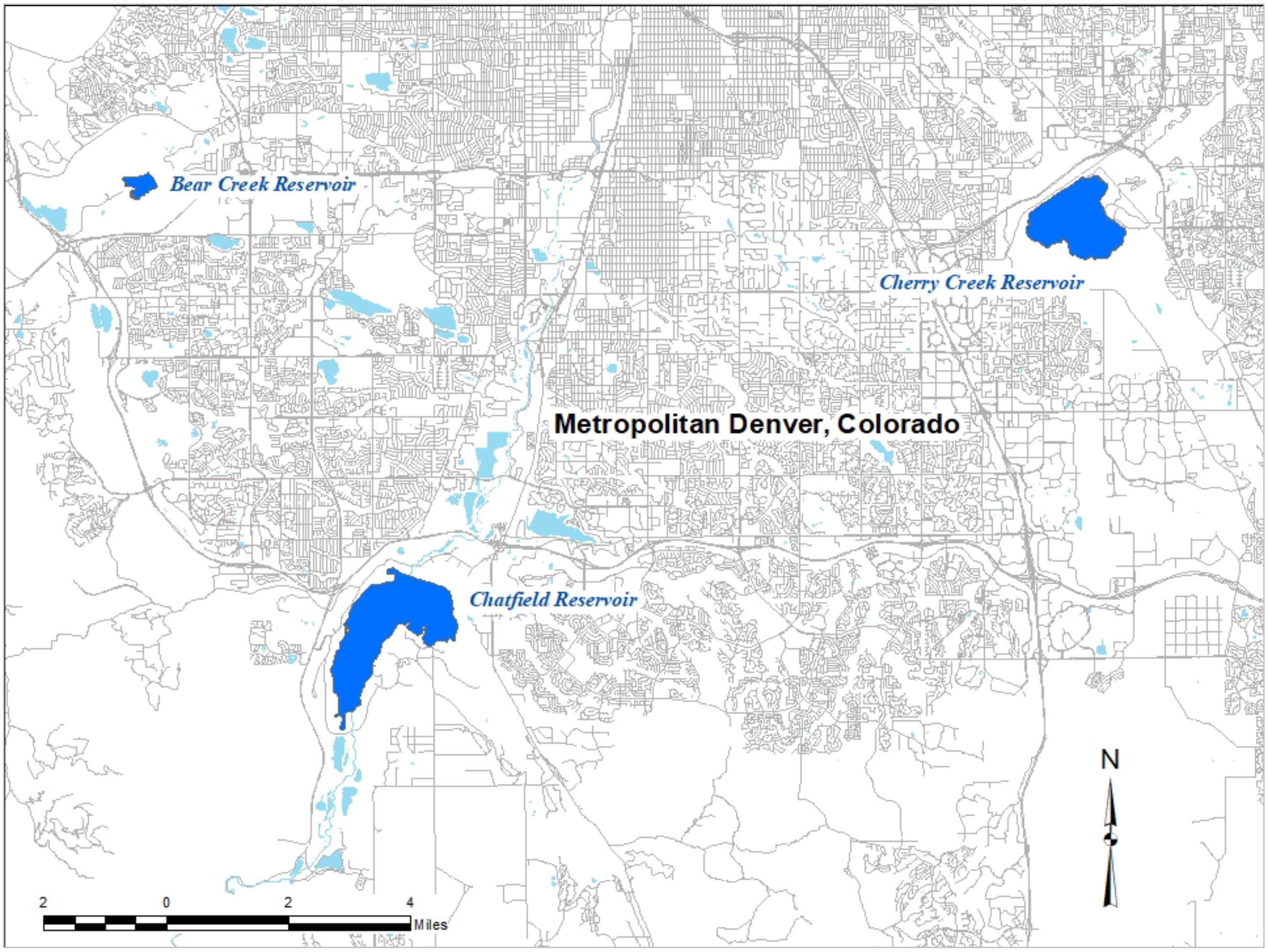

Figure 2-2. Tri-Lakes Location Map – Denver, Colorado

2.2 Project History

USACE is the owner and operator of the Bear Creek, Chatfield, and Cherry Creek Projects. Regulation of the three dams is through the Tri-Lakes Project Office located at the Chatfield Project site.

2.2.1 Bear Creek History

House Document No. 669, 80th Congress, 2nd Session, provided an evaluation of the flood and related water problems of the South Platte River basin based on levels of economic growth existing in 1945. The report included a plan for flood control on Bear Creek by means of a reservoir at the current Bear Creek Dam site. The project was authorized for construction by the Flood Control Act of 1968, substantially in accordance with the recommendations of the Chief of Engineers in Senate Document No. 87, 90th Congress, at an estimated cost of $32,314,000. The recommendations presented in the project document stated the project purposes as flood control, general recreation, and fish and wildlife recreation.

Bear Creek Dam was constructed by the Corps for the primary purpose of mitigating flood risk to the downstream metropolitan area of Denver from floods originating above the dam. Additional authorized purposes include water supply, recreation, and fish and wildlife enhancement. The percentages of benefits assigned to the authorized purposes during the original design were 92.2% for flood control and 7.8% for recreation and fish and wildlife enhancement.

2.2.2 Chatfield History

The need for flood risk mitigation in the growing Denver, CO area was recognized prior to World War II. Chatfield Dam and Reservoir, one of the South Platte River projects recommended in House Document No. 669, 80th Congress, 2nd Session, was authorized by Section 204 of the Flood Control Act of 1950. The original authorized purposes of the Chatfield Dam and Reservoir project were flood control and silt control. These purposes were later expanded to include recreation and fish and wildlife enhancement followed by water supply. Total project costs were estimated in 1945 at $26,300,000.

2.2.3 Cherry Creek History

A survey report on Cherry Creek dated March 1, 1939, prepared by the District Engineer, U.S. Engineer Office, Omaha, NE, was published as House Document No. 426, 76th Congress, 1st Session. The report presented a coordinated plan for the improvement of Cherry Creek. The report recommended the construction of Cherry Creek Dam for flood control and other purposes. This plan was subsequently authorized by the Flood Control Act (Public Law 228, 77th Congress, 1st Session), which was approved August 18, 1941. The plan included $8,000,000 for initiation and partial accomplishment of the Cherry Creek Project. Section 10 of the 1944 Flood Control Act (Public Law 534, 78th Congress, 2nd Session) approved December 22, 1944, authorized the completion of the Cherry Creek plan approved August 18, 1941. Cherry Creek Dam and Reservoir was also included in a comprehensive plan for the development of the Missouri River basin, which was approved in Section 9 of the 1944 Act.

2.3 Data Resources

The principal data source for this report are the sediment ranges at each of the Tri-Lakes Projects. Periodic surveys of these sediment ranges are the basis for calculating reservoir surface area, storage capacity, and storage depletion rates. Information is stored in the River and Reservoir Engineering Section's '*RARE*' database system of historical data and reports. The database includes information collected by the Omaha District as well as data compiled by other agencies; primarily the United States Geological Survey (USGS).

2.4 Real Estate Property Taking Line

2.4.1 Bear Creek Boundary

Land acquisition for the Bear Creek Project was done in accordance with Real Estate DM No. PC-5 from 1971. The guide taking line was established to the maximum elevation of 5,685.2 feet, Local Project Vertical Datum (LPVD), plus 5 feet of freeboard allowance or 300 feet horizontally from the pool, whichever was greater. The actual real estate boundary was delineated by blocking out close tangents rather than acquiring large blocks of land because of high property values in the area.

2.4.2 Chatfield Boundary

Land acquisition for the Chatfield Project was done in accordance with Real Estate DM No. PC-4, *Initial Construction Area,* from 1966. The guide taking line was established to an elevation of 5,500.0 feet, LPVD, plus 5 feet of freeboard allowance or 300 feet horizontally from the pool, whichever was greater. The actual real estate boundary was delineated by blocking out close tangents rather than acquiring large blocks of land because of high property values in the area.

2.4.3 Cherry Creek Boundary

The original real estate taking-line for Cherry Creek Lake was established at one-foot below the Maximum Pool elevation of 5,645.0 feet, LPVD. The Definite Project Report, *Kenwood Dam, Cherry Creek and Tributaries, Colorado,* dated January 1944 indicated the intent to acquire land in fee to elevation 5,623.0 feet, LPVD. Flowage easements would be obtained on lands from elevation 5,623.0 feet, LPVD, to elevation 5,639.0 feet, LPVD. Easements were eventually acquired only up to elevation 5,636.0 feet, LPVD; the approximate elevation of the Maximum Pool as determined in 1944.

2.5 Regional Topography

2.5.1 Bear Creek Topographic Features

The Bear Creek Project is located in the foothills of the Colorado Rocky Mountain Front Range. Mountainous terrain accounts for 90% of the basin. The remaining 10% of the basin is characterized by high plains and rolling foothills and is separated from the mountains by a prominent hogback that crosses the basin near the Morrison area. Elevation varies from 14,264 feet at the headwaters on Mount Evans to 5,295 feet at the USGS Bear Creek at Sheridan gaging station near the mouth.

2.5.2 Chatfield Topographic Features

The Chatfield Project lies within a transition zone between the foothills of the Rocky Mountains and the western limits of the Great Plains. The topography of the basin above the dam varies greatly. The eastern portion of the basin is characterized by high plains and rolling foothills. The lower elevations begin at approximately 5,400 feet, the high elevations on the plains are at 7,000 feet. Land in this part of the basin is largely grassland with some forested areas. About 10 miles southwest of the Chatfield Dam site, the Rocky Mountain Front Range crests near an elevation of 9,000 feet except where it is cut by stream canyons. This mountainous terrain extends some 30 miles to the west where it merges with the South Park area of the South Platte River. This is an area composed mainly of high meadow ground with elevations varying from 9,000 to 9,500 feet. The South Park is bordered on the north by the Continental Divide, with peak elevations exceeding 14,000 feet, and on the west and south by mountains, which separate the South Platte River and Arkansas River drainage areas. The South Park area is largely grassland while the mountain areas are forested.

2.5.3 Cherry Creek Topographic Features

The Cherry Creek basin upstream from Franktown, Colorado has steep to moderately rolling topography. A narrow belt across the central part of the basin, immediately upstream from Franktown, is characterized by sharp topographic relief. Canyon walls and mesa fronts, 200 to

400 feet high, are common in this belt. In the reach from near Franktown to near Parker, Colorado, Cherry Creek courses through a broad valley bordered by steep to rolling ridges and hills. Downstream from Parker, the upland area consists of rolling hills.

Cherry Creek Dam lies within the Colorado Piedmont section of the Great Plains physiographic province. The general topography of the Cherry Creek basin upstream of the dam consists of flat tablelands separated by flat-bottomed valleys ranging from about 5,500 feet to 7,500 feet. Cherry Creek is a tributary to the South Platte River, which flows northeastward through this section. Elevations for most of the Denver area are less than 6,000 feet, but the Rocky Mountain foothills rise as hogbacks immediately west of Denver. The high peaks of the Rocky Mountains west of the hogbacks exceed 14,000 feet.

The topography immediately adjacent to the reservoir is characterized by a 3,000-feet wide valley, with separating hills that rise 200 feet above the former valley floor. Slopes on the valley walls occasionally exceed 10%, but most slopes do not exceed 3%. Gentler slopes are found on the surrounding tablelands.

2.5.4 Runoff Characteristics

The mountainous character of the upper half of the Tri-Lakes watersheds and the steep slopes of the South Platte River, Plum Creek, Cherry Creek, and Bear Creek causes rapid runoff from the basin. Major floods are usually caused by short periods of intense rainfall occurring over a small portion of the basin, or a series of intense storm centers scattered over the basin. The majority of the floods from these streams have occurred from May to September.

2.5.5 Sources & Distribution of Sediment

Sediment deposition can negatively impact recreation, water quality, and wildlife habitat and can cause localized flooding problems. Increased stages associated with deposition in the backwater reaches of the Tri-Lakes Reservoirs can impact non-project lands and increase flooding of urban areas. A more detailed discussion of sediment deposition in a reservoir can be found in the USACE Manual EM 1110-2-4000, Sedimentation Investigations of Rivers and Reservoirs dated 31 October 1995.

The primary source of sediment deposited in the project comes from watershed sheet, rill, and gully erosion. An additional and non-quantified source of sediment is from shoreline erosion. As a shoreline erodes, the eroded material generally moves to lower elevations. While this erosion increases the capacity at higher reservoir elevations, storage capacity allocated for specific purposes at lower elevations is reduced. In all the Tri-Lakes Reservoirs, most of the incoming sediment is transported via the inflowing rivers and creeks. A delta forms at the junction of the river or creek and the lake where the majority of sediment drops out into the lake. Initially, the delta grows in both the downstream and upstream direction with most of the growth in the downstream direction. As the delta matures, a stable slope is established at the headwaters and the delta then progresses into the reservoir. In the reservoir, sediment generally settles in the low spots, filling in the old channel, and smoothing out any roughness in the topography.

2.5.6 Groundwater

The Front Range metro area, including the areal extent of this report, uses bed-rock aquifers of the Denver Basin as a significant groundwater asset. The Denver Basin aquifer system includes four individual aquifers underlying a 6,500 mi² area. Currently, the Omaha District does not monitor groundwater levels at any of the Tri-Lakes Projects.

2.6 Watershed Characteristics

The headwaters of the South Platte River originate along the eastern slope of the Continental Divide and flows in a southeasterly direction through Antero, Spinney Mountain, Eleven Mile Canyon, Cheesman, and Strontia Springs Reservoirs and then downstream into Chatfield Reservoir. River slopes vary from 70 to 80 feet per mile in the upstream reach to 30 to 40 feet per mile in the lower reaches. Table 2-1 is a listing of major dams in the upper South Platte River basin while Table 2-2 tabulates drainage basin data. Figure 2-3 is a map of each drainage basin.

Table 2-1. Existing Reservoirs in the Upper South Platte River Basin

Reservoir	Stream	Storage Capacity (Acre-Feet)	Dam Closure	Operating Agency
Antero	S.Platte River	19,881	1907	DWB
Spinney Mountain	S. Platte River	53,651	1981	COA
Eleven Mile Canyon	S. Platte River	97,779	1932	DWB
Tarryall Dam	Tarryall Creek	1,990	1930	CDW
Cheesman Lake	S. Platte River	79,064	1902	DWB
Strontia Springs	S. Platte River	7,863	1982	DWB & COA
Chatfield	S. Platte River	349,454	1973	USACE
Bear Creek	Bear Creek	46,995	1977	USACE
Cherry Creek	Cherry Creek	175,460	1950	USACE

DWB Denver Water Board
COA City of Aurora, Colorado
CDW Colorado Division of Wildlife
USACE U.S. Army Corps of Engineers

Table 2-2. Major and Tributary Drainage Basins

Drainage Basin Description	Basin Area (mi²)
Total South Platte River Basin	**24,030**
Total above Bear Creek Dam	**262**
Bear Creek above Bear Creek Dam	186
Turkey Creek	52
Miscellaneous smaller tributaries	24
Total above Chatfield Dam	**3,018**
Chatfield Dam to Strontia Springs Dam – Incremental Drainage	96
Plum Creek Tributary	324
Total above Cherry Creek Dam	**386**

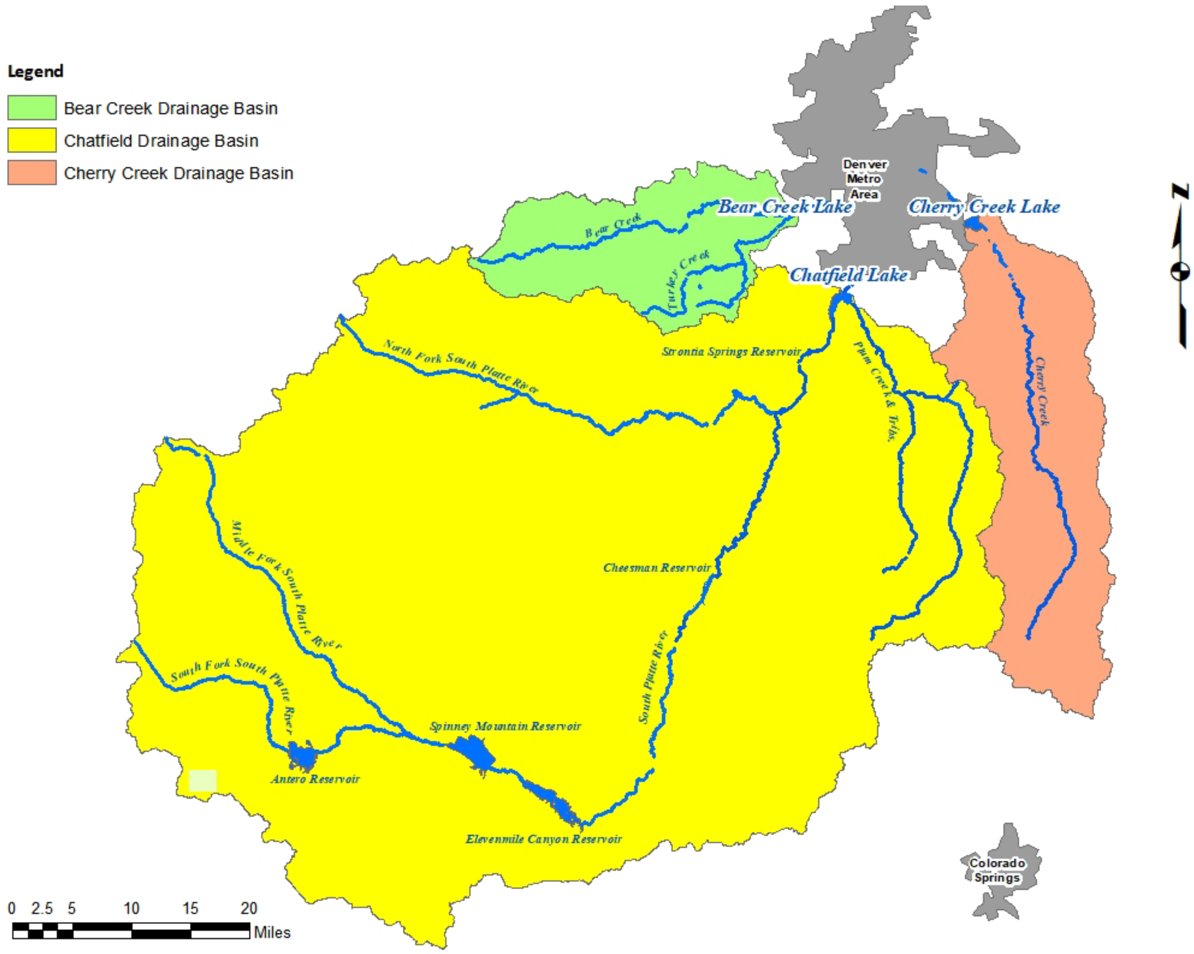

Figure 2-3. Map of the Upper South Platte River Watershed

2.6.1 Bear Creek Watershed

Bear Creek is a left bank tributary of the South Platte River near Morrison, a suburb of Denver, Colorado (Figure 2-3). The basin drains a total of 262 square miles, of which 90 percent is made up of the terrain found in the Rocky Mountain foothills located west of Denver. The remaining 10 percent of the basin is characterized by high plains and rolling foothills and is separated from the mountains by a prominent hogback ridge that crosses the basin near the Morrison area. The mountains are heavily forested; the terrain below the hogback is mostly grassland with some urban development.

The basin is elongated and narrow at the upstream end and wider at the midpoint of the basin toward the downstream end, approximately 36 miles long. The basin has a maximum width of about 13 miles. Stream flow originates near Summit Lake on the Mount Evans plateau, and the flow moves easterly picking up contributions from numerous small tributaries along the way through the Arapahoe National Forest. At Morrison, Colorado, the flow breaks out of the confinement of a canyon and spreads through the foothill region. The 52-square mile Turkey Creek drainage joins Bear Creek approximately two miles downstream from Morrison. Turkey Creek is the only major tributary into Bear Creek.

2.6.2 Chatfield Watershed

The South Platte River originates along the eastern slope of the Continental Divide and flows in a southeasterly direction through the South Park Meadow area to Eleven Mile Canyon Reservoir. Below Eleven Mile Canyon Dam, the South Platte enters a much narrower valley, where the surrounding terrain becomes considerably steeper. This stretch includes Cheesman Reservoir. Several major tributaries enter the South Platte River between Eleven Mile Canyon and the foothills including Tarryall Creek and the North Fork South Platte River. Plum Creek is a right bank tributary that joins the South Platte River just upstream of the dam in Chatfield Lake.

The drainage area upstream from Chatfield Lake contains 3,018 square miles, most of which is rugged mountainous terrain. The basin has a round shape, approximately 120 miles long and has a maximum width of about 90 miles. The lower section of the basin, elevation 5,500 to 7,000 feet, is a mixture of high plains and rolling foothills vegetated largely by grassland with some forested areas. The bulk of the watershed is comprised of mountainous terrain that begins approximately 10 miles upstream from the project. The terrain includes high mountain peaks ranging up to 13,000 feet and steep mountain valleys. The area is heavily forested and is liberally covered with normal forest duff. The headwaters region of the South Platte River is located along the western edge of the basin; it is comprised of about 270 square miles of extremely steep terrain. Elevations in the headwater region range from 9,500 feet to over 14,000 feet along the Continental Divide.

2.6.3 Cherry Creek Watershed

Cherry Creek is a right bank tributary of the South Platte River, and it enters the South Platte River in the highly developed business and industrial area of downtown Denver, Colorado. The basin drains a 410-square mile area located south of Denver. Cherry Creek Dam is located about 11.4 miles upstream from the mouth of Cherry Creek and controls 386 square miles of the basin's drainage area. The watershed is oblong in shape with a basin length of approximately 44 miles and an average width of approximately 9 miles.

The Cherry Creek basin, upstream from Franktown, Colorado, has steep to moderately rolling topography. Sharp topographic relief characterizes a narrow belt across the central part of the basin, immediately upstream from Franktown. Canyon walls and mesa fronts, 200 to 400 feet high, are common in this belt. In the reach from near Franktown to near Parker, Colorado, Cherry Creek courses through a broad valley bordered by steep to rolling ridges and hills. Downstream from Parker, the upland area consists of rolling hills. Vegetation in undeveloped areas is limited to groves of large cottonwoods and low shrubby growth bordering the creek channel. The basin elevation varies from about 7,700.0 feet at the source of Cherry Creek to about 5,170.0 feet at its confluence with the South Platte River.

2.6.4 Adjacent Land Use

Land use in the Upper South Platte River basin is listed in Table 2-3. Data includes all or parts of Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, Elbert, Gilpin, Jefferson, Larimer, and Weld Counties.

Table 2-3. Adjacent Land Use

Source: Colorado Natural Resources Conservation Service (2011)

Type	Acres	Percentage
Agricultural Land	25,041	0.3%
Dry Land Farming	11,149,157	14.7%
Irrigated Farming	380,639	4.9%
Commercial/Residential	295,828	3.8%
Riparian	180,869	2.3%
Forest	1,716,527	22.0%
Rangeland	3,918,493	50.2%
Water	70,747	0.9%
Other	69,307	0.9%
No Data	399	>0.1%

2.7 Climate

The diverse topography of the South Platte River basin above Denver, Colorado causes a remarkable variety of climates to occur within a short distance. The climate of the plains is distinctly continental. Situated a long distance from any moisture source and separated from the Pacific source of moisture by a high mountain barrier, the plains area normally experiences light rainfall, low relative humidity, a large daily range in temperature, a large amount of clear sky sunshine, moderately high wind movement, and few protracted cold spells in the winter. However, invasion of cold air from the north, combined with available moisture in the air and the high altitude, can result in abrupt and severe weather. In the mountain area, a decrease in temperature and an increase in precipitation and wind movement occur with increasing altitude.

2.7.1 Climate Variability

Much research has been conducted over the past several decades concerning the impacts of climate variability on different regions of the planet. One of the more frequent studied phenomena is the El Niño/Southern Oscillation (ENSO) cycle that is observed across the central and east-central equatorial Pacific. The impacts in the continental United States from the different cycles of ENSO are typically more pronounced along the Pacific coast and the southern tier states. However, some impacts have been attributed to the sub-basins of the Missouri River Basin. It is also important to note that impacts from the ENSO cycle are generally between the months of November and March, or from late fall into early spring.

2.7.2 Temperature

Temperatures in the Denver area can vary widely from day to day because of the impacts of large air masses moving from the north or south. Rapid warm-ups during the winter months are common because of the effects of Chinook winds. The hottest month of the year is July, when daily temperatures average 72 degrees Fahrenheit (°F) and high temps may exceed 100 °F. The coldest month of the year is January, when daily temperatures average 30 °F and low temps may fall below 0 °F.

2.7.3 Precipitation

Precipitation patterns within each basin vary dramatically due to the topographic influence on weather. Although not directly applicable to each basin, a summary of precipitation information at Denver, Colorado follows to provide general area information. The average annual precipitation at Denver is about 16 inches, most of which occurs as rain during the months of April through August. Thunderstorms, hailstorms, windstorms, and tornadoes are most frequent between May 15 and September 01. The largest amount of snow falls in January, February, and March. There is, on average, 41 days with snow cover per year. The average snow depth is 3 inches. Average monthly climate data for the weather station at Denver's Stapleton Airport is tabulated in Table 2-4.

Table 2-4. Average Monthly Climate Data

Source: https://wrcc.dri.edu/Climate/

Type	POR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. High Temp °F	1948-2016	43.9	46.7	52.9	61.4	70.7	81.7	88.3	86.0	77.5	66.2	52.7	45.0
Min. Low Temp °F	1948-2016	17.0	20.3	26.3	34.4	44.0	52.9	59.1	57.4	48.1	36.7	25.5	18.2
Total Rainfall (in)	1948-2016	0.50	0.57	1.21	1.76	2.40	1.67	2.03	1.70	1.13	1.01	0.80	0.58
Total Snowfall (in)	1948-2016	1	1	1	0	0	0	0	0	0	0	1	1
Wind Speed (mph)	1996-2006	9.7	9.7	10.7	11.8	10.5	10.1	9.5	9.6	9.4	9.6	9.6	9.6
Wind Direction	1992-2002	S	S	S	N	S	S	S	S	S	S	S	S

2.7.4 Evaporation

Evaporation from the three Tri-Lakes Reservoirs is calculated using a physically based evaporation model implemented in routine calculations in 2012. The model estimates evaporation from the flood control reservoirs in the Omaha District. The model has two components: the first component calculates the evaporation from the water surface using a Bulk Flux Algorithm and the second component estimates the vertical temperature profile of the reservoir based on a one-dimensional heat budget of the reservoir. Table 2-5 shows the estimated average pan evaporation for the Tri-Lakes Reservoirs.

Table 2-5. Estimate Average Pan Evaporation (inches)

	Type	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Losses	Monthly	1.2	1.1	1.9	3.6	6.2	8.4	9.3	9.3	7.5	4.9	2.4	1.3
	Daily	0.04	0.04	0.06	0.12	0.20	0.28	0.30	0.30	0.25	0.16	0.08	0.04

2.7.5 Wind Speed and Direction

Wind speeds are generally low to moderate. Monthly average wind speeds range from 9 to 11 mph. However, occasional wind gusts exceeding 50 mph do occur. Prevailing winds are generally from the south or south-southwest. During the winter, winds blowing from the north and northwest are generally colder than those blowing from the south. Western oriented Chinook winds, which are warmed as they descend to the plains east of the Rocky Mountains, can cause temperatures in the Denver area to suddenly increase by several degrees.

2.8 USGS Stream Gage Data

There are a number of USGS stream gaging stations providing data for the upper South Platte River basin. Gaging stations used in this report are summarized in Table 2-6 and shown in Figure 2-4. Note that the USGS gaging station 04464500 is no longer in use and not shown in the figure.

Table 2-6. USGS Stream Gaging Stations in the Study Reach

USGS 06710605 Bear Creek above Bear Creek Lake near Morrison, CO **Latitude: 39°39'07.3" Longitude: 105°10'23.7"** **Jefferson County, Colorado** **Hydrologic Unit: 10190002** **Drainage Area: 176 mi^2** **Contributing Drainage Area: 176 mi^2** **Datum of Gage: 5645 feet, NGVD29** **Data Type: Discharge (Q)**	USGS 06701900 S. Platte River below Brush Creek near Trumbull, CO **Latitude: 39°15'36" Longitude: 105°13'17"** **Douglas County, Colorado** **Hydrologic Unit: 10190002** **Drainage Area: 2,208 mi^2** **Contributing Drainage Area: 2,016 mi^2** **Datum of Gage: 6380 feet, NGVD29** **Data Type: Discharge (Q)**
USGS 06709530 Plum Creek at Titan Road Bridge near Louviers, CO **Latitude: 39°30'26.53" Longitude: 105°01'28.08"** **Douglas County, Colorado** **Hydrologic Unit: 10190002** **Drainage Area: 316 mi^2** **Datum of Gage: 5520 feet, NGVD29** **Data Type: Discharge (Q)**	USGS 04464500 Cherry Creek near Melvin, CO **Latitude: 39°36'18" Longitude: 104°49'19"** **Arapahoe County, Colorado** **Hydrologic Unit: 10190003** **Drainage Area: 360 mi^2** **Datum of Gage: 5608.21 feet, NGVD29** **Data Type: Discharge (Q), Suspended Sediment**
USGS 04464500 Cherry Creek near Parker, CO **Latitude: 39°31'09.0" Longitude: 104°46'45.0"** **Douglas County, Colorado** **Hydrologic Unit: 10190003** **Drainage Area: 287 mi^2** **Datum of Gage: 5805 feet, NGVD29** **Data Type: Discharge (Q)**	USGS 06712000 Cherry Creek near Franktown, CO **Latitude: 39°21'21" Longitude: 104°45'46"** **Douglas County, Colorado** **Hydrologic Unit: 10190003** **Drainage Area: 169 mi^2** **Datum of Gage: 6150 feet, NGVD29** **Data Type: Discharge (Q), Suspended Sediment**

Figure 2-4. Location of USGS Stream Gages

2.9 Bed Material Sediment Collection & Analysis

There is intermittent historical bed material data available at Bear Creek, Chatfield, and Cherry Creek Lakes. However, bed material sediment samples were collected by Omaha District personnel in 2016 at the same time as the collection of survey data. A USGS BM-54 sampler mounted in a boat was selected to use according to USGS protocol set in Open File Report 2005-1087. Usually, three to five samples per sediment range/cross section were collected at each reservoir. A shovel was used to collect a surface bed and bank material sample at the upstream sediment ranges. Additional upstream samples were collected at each channel where the stream became braided.

All samples were analyzed at the ERDC lab at Vicksburg, Mississippi for particle size analysis according to standards set in EM 1110-2-1906, *Laboratory Soils Testing*. The upstream samples collected by hand at each of the Tri-Lakes were analyzed using standard sieve series. Particle size analysis by laser diffraction (Malvern Analyzer) was used to measure the finer particles from 10 mm to 3 mm in the bed material samples collected by boat. Using the Malvern method, particle size is calculated by measuring the angle of light scattered by the particles as they pass through a laser beam.

3 Survey Methodology

3.1 Survey History

The original survey effort at each of the Tri-Lakes was performed by Omaha District personnel starting in 1950. The survey crew established survey control and completed the surveys along the newly established cross-sections. Subsequent surveys were completed as tabulated in Table 3-1.

Survey control points were originally two to three-inch diameter brass or aluminum survey caps (Figure 3-1) and witnessed with a 6-foot long, steel T-type fence post and witness plate combination. Each cross-section's end control points on the left and right banks were set above the Multipurpose Pool elevation and positioned far enough away from any high bank to prevent eventual loss from shoreline erosion. Additional survey control points were set using steel pipe or rebar and brass survey cap combinations and positioned at lower elevations to facilitate future surveys.

Monument maintenance and subsequent sediment range surveys have since replaced some of the old fence post/witness boards with fiberglass witness markers. Subsequent surveys were performed by either the Omaha District or independent survey companies under contract.

Figure 3-1. Example Survey Control Point and Witness Post

The survey data collected during 1981 through 1984 at each reservoir was not included in the analysis of this report. The data from these years were deemed to be unreliable because of unresolved survey issues. The Cherry Creek survey conducted in 1997 is also not included in this report due to unresolved data issues at sediment ranges CC-01 to CC-04.

Table 3-1. Tri-Lakes – Survey History

Lake	Survey Year										
Bear Creek	1980	1984	1987	1997	2006 R	2009					**2016**
Chatfield	1977	1981	1986	1988 P	1989 P	1991	1994	1997	2006 R	2010	**2016**
Cherry Creek	1950	1961	1965	1974	1982	1984	1988	2006 R	2009		**2016**

P = Partial survey taking one or more years to complete
R = Reconnaissance survey of selected sediment ranges

3.2 Survey Methodology

The original sediment range surveys and subsequent surveys into the late 1980's was completed using optical instruments, engineer's levels, ordinary taping, transits, and total stations. These surveys required a crew of at least an instrument operator, rod person, and a note taker. Line of sight between the instrument and the survey rod was required as well as two known survey control points for traversing (horizontal coordinates) and elevation. Often, a two-foot line-of-sight path had to be cut through the trees and brush to facilitate the surveying. The underwater portion of each cross section employed old-style, stylus driven fathometers where data was later scaled from a paper chart.

USACE survey methods and accuracy standards are defined in the following Engineering Manuals (EM's):

- EM 1110-1-1000, *Photogrammetric and LiDAR Mapping*
- EM 1110-1-1002, *Survey Markers and Monumentation*
- EM 1110-1-1003, *NAVSTAR Global Positioning System Surveying*
- EM 1110-1-1004, *Geodetic and Control Surveying*
- EM 1110-1-1005, *Control and Topographic Surveying*
- EM 1110-2-1003, *Hydrographic Surveying*

3.2.1 2016 Sediment Range Surveys

The X-Y-Z ground observations were obtained by Real Time Kinematic (RTK) GNSS methods performed at all three reservoirs in 2016. Observations were performed with Trimble R8 Model 3 GNSS receivers. Solutions for each point were referenced to a Local Site Control Station (Figure 3-2) and determined using Trimble Business Center.

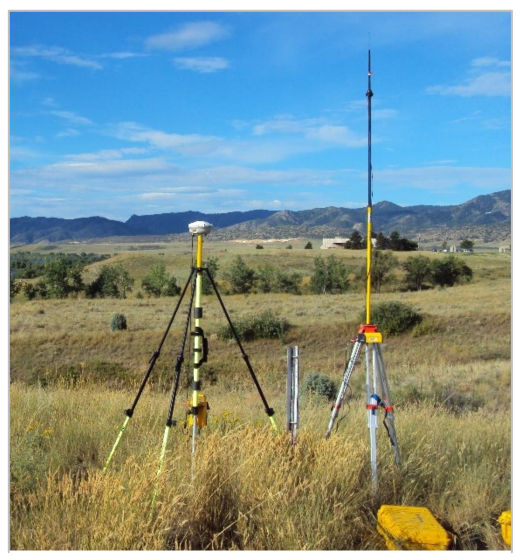

Figure 3-2. GPS Base Station Set-Up

Hydrographic survey data was collected in 2016 utilizing either a 20-foot Jon boat or a 22-foot custom built hydrographic survey vessel (Figure 3-3). Both boats are built with an in-hull transducer well. Each boat is equipped with an ODOM ECHOTRAC CVM single beam survey grade fathometer, a laptop computer, and a secondary helmsman's monitor for the pilot. HYPACK software was utilized for navigation and data collection.

Figure 3-3. Omaha District Survey Boats (#402 Left - #417 Right)

Differential corrections for horizontal positioning were based on GPS satellite corrections from a subscription-based service. An ODOM CVM fathometer was used to record the underwater sediment range cross section profiles. The CVM fathometer was calibrated by bar checking prior to collecting hydrographic survey data. The velocity of sound was further refined throughout the entire water column using an ODOM Digibar Pro Velocimeter. Wading (Figure 3-4) was used to collect shallow water data where boats could not be used.

Figure 3-4. Contractor Wading at Chatfield Lake (Stockwell Engineers)

3.2.2 High Density Bathymetry Collection

High Density Single-beam (HDSB) bathymetry was collected by Omaha District personnel. Sonar data was collected using a single-beam fathometer. Density of collection varied by reservoir, usually along cross-sections spaced between 100 and 200 ft. Further description of the HDSB collection is detailed in sections 5.3.4, 6.3.4, and 7.3.4 for Bear Creek, Chatfield, and Cherry Creek reservoirs, respectively.

High Density Multi-beam (HDMB) bathymetry was collected by the USACE Engineering, Research, and Development Center (ERDC). Sonar data was collected using a multi-beam fathometer along wide, overlapping swaths, providing 100% bed coverage in the boat-accessible areas of the reservoir. This data set, combined with the LiDAR topography (discussed in section 3.2.3) is the source for all area and capacity calculations used in this report.

3.2.3 2013 Colorado LiDAR Data

A USGS project, co-funded and coordinated with FEMA, the State of Colorado, and the Denver Regional Council of Governments (DRCOG), collected topographic LiDAR for areas devastated by extreme flooding of 2013 in the South Platte River watershed in Colorado. A contractor (Photo Science) was mobilized to collect and process the aerial data. Their data set included Denver, Colorado and the Tri-Lakes Projects and was shared with the Omaha District. Table 3-2 is a shortened metadata file of the LiDAR data.

Table 3-2. Metadata from 2013 Colorado LiDAR Survey

Owner	FEMA and the USGS, Colorado
Survey Date(s)	Fall 2013
Surveyed By	Photo Science, A Quantum Spatial Company USGS Contract No. G10PC00026, Task Order No. G14PD00001, CO_Flood_2014
Horizontal Datum	NAD 1983 UTM Zone 13N Meters
Vertical Datum	NAVD88, Geoid 12a
Units	Meters
Accuracy	Vertical – 11.2 cm @ 95% confidence interval

3.2.4 Vertical Datum Adjustments

3.2.4.1 Bear Creek Vertical Datum Adjustments

Elevations for Bear Creek Reservoir pool levels, survey control point elevations, and project drawings are based on the LPVD, which is very close to NGVD29 and approximately 3.0 feet lower than NAVD88. The LPVD has not been converted to NAVD88 to provide elevation data that is consistent with historical events and the original design drawings for the project. Elevations in this report for Bear Creek are reported in the NGVD29 vertical datum.

3.2.4.2 Chatfield Vertical Datum Adjustments

Elevations for Chatfield Reservoir pool elevations, control point elevations, and project drawings are based on the LPVD, which for Chatfield Dam and Reservoir is very close to NGVD29 and approximately 3.1 feet lower than NAVD88. The LPVD has not been converted to NAVD88 to provide elevation data that is consistent with historical events and the original design drawings for the project. Elevations in this report for Chatfield are reported in the NGVD29 vertical datum.

3.2.4.3 Cherry Creek Vertical Datum Adjustments

Cherry Creek Dam was built using elevations in a LPVD. The LPVD is approximately 1.27 feet above the NGVD29 datum and 1.76 feet below the NAVD88 datum. The NAVD88 datum is approximately 3.02 feet above the NGVD29 datum at Cherry Creek Dam. Any conversions between vertical datums should be carefully considered to ensure data accuracy since these values are approximations. Elevations in this report for Cherry Creek are reported in the NGVD29 vertical datum.

3.2.5 Sediment Range Labeling System

Two letters and a number designate each sediment range. The letters indicate the reservoir with the following designations: Bear Creek (BC), Chatfield (CH), and Cherry Creek (CC). The numbering system begins at the first cross section upstream from the dam and increases in the upstream direction. For example, the first cross sections upstream of the dam at Bear Creek Lake are BC-01 and BC-02.

4 Reservoir Storage Analysis Methodology

4.1 Reservoir Storage Zone Terminology

Figure 4-1 graphically explains common USACE terms for the various reservoir pool zones in the Omaha District. Individual tables and plots will contain the proper terminology for the analysis of each reservoir or group of reservoirs.

4.1.1 Exclusive Flood Control/Surcharge Pool Zone

This top zone in each reservoir is reserved exclusively for flood storage. This storage space is utilized only for the detention of extreme flood events and is evacuated as quickly as possible within any limitations imposed by downstream flooding.

4.1.2 Flood Control/Multiple Use & Flood Control/Replacement/Surcharge Pool Zone

This upper normal operating pool zone is reserved for the retention of normal flood events and for annual multiple use regulation. The Flood Control Pool Zone is normally evacuated to a pre-determined pool elevation in the spring to provide adequate reservoir storage capacity for the new flood season.

4.1.3 Carryover/Multiple Use/Multipurpose/Joint Use Pool Zone

The intermediate Multipurpose Pool Zone provides a storage reserve for irrigation, navigation, power generation, fish and wildlife interests, and recreation as well as maintaining downstream flows through a succession of below normal runoff.

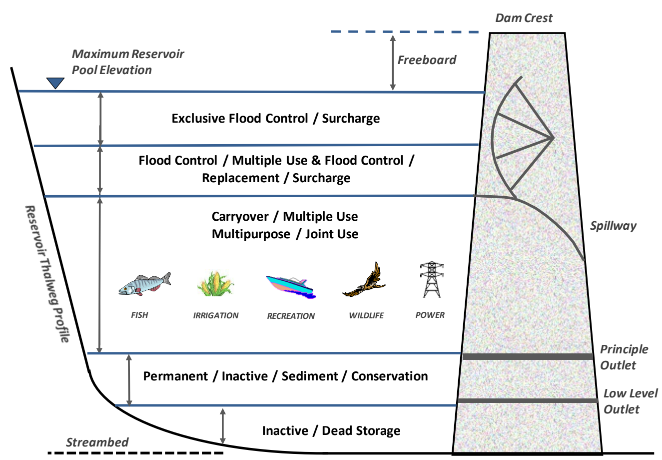

Figure 4-1. Schematic of USACE Reservoir Storage Terminology

4.1.4 Inactive/Permanent/Dead Storage Pool Zone

The Inactive Pool Zone is the lowest zone at each reservoir. This zone provides minimum power head for power generation and sediment storage capacity and the minimum pool for recreation, fish and wildlife interests, and water diversion. Reservoir drawdown into this zone is only used in an emergency.

4.2 Reservoir Surface Area & Storage Capacity Calculations using the Modified End Area Method (MAEA) and the Omaha Utilities Program (OUP)

The MAEA method is used by the Omaha District for determining reservoir surface area and storage capacity tables by elevation. This is a modification to the traditional “average-end-area” method; adjusted to include factors that consider the non-uniformity of reservoir contours. Portions of the reservoir bounded by one or more sediment ranges and the dam crest contour are considered as segments for determining storage capacity. Those portions of a segment situated between consecutive contours are referred to as sub-segments.

The Omaha Utilities Program (OUP) for Microsoft Windows provides a series of interactive programs for analysis of cross section data, area-capacity tables, and bed material data for the Omaha District. Originally written in FORTRAN language, the program was updated in 2013 to allow the user to examine and output data in a variety of ways.

The results from the MAEA method that are presented in this report are for comparison with the GIS method, which replaced the MAEA method as the official analysis method in 2016. The additional results from the OUP (MAEA method) that are presented in this report are the results of intermediate steps in the analysis that can be obtained much more efficiently with the OUP than with other methods such as the GIS method.

4.2.1 Problems with the Early Reservoir Surveys

The original sediment range surveys of the Tri-Lakes Projects collected overbank data using optical instruments to the farthest permanent sediment monument on either side of the reservoir. However, overbank data for some subsequent surveys were only collected to the sediment monument nearest to the water's edge. These shortened surveys used the previous survey overbank data between intermediate monuments for use in calculating reservoir area-capacity curves. The Flood Control and Surcharge Pools are affected most by this procedure. Reporting sediment changes between survey periods where sediment range overbanks were copied from previous surveys will not accurately reflect sediment aggradation or degradation, or anthropogenic impacts for these survey periods.

4.2.2 Reservoir Cross Section Hydraulic Elements

The hydraulic parameters (elements) are an intermediate output option that is calculated from the OUP. Parameters analyzed from the channel geometry for each cross section include cross section top width, area, average depth, average bed elevation, and thalweg elevation. All parameters except the thalweg elevation depend on a reference plane elevation. The reference plane elevation used in this report is the Top of Flood Control Pool:

- Bear Creek Elevation 5,635.5 feet, NGVD29
- Chatfield Elevation 5,500.0 feet, NGVD29
- Cherry Creek Elevation 5,598.0 feet, NGVD29

The cross-section top width is the total top width of water if the cross section is inundated to the level of the Flood Control Pool. The reference plane may be divided by islands or other features. The total width is calculated based on all segments where the reference plane is higher than the channel bottom or banks. The cross-section area is the area below the reference plane and above the channel bottom or banks. A larger cross section area compared to previous surveys at the same cross section indicates that the channel has been degrading and/or widening. Average depth represents the average depth from the reference plane to the bed. The thalweg elevation is the lowest observed elevation in the cross section. It does not depend on the reference plane elevation.

The OUP reads cross-section data for each sediment range and computes cross-section width, area, average depth, and average bed elevation. In processing the data, the program uses successive pairs of x-y input points to break the data up into slices that are used to determine the aforementioned hydraulic parameters. The elevation that the calculations are based on is specified by the user and should be equal to the reference plane elevation.

4.2.3 Reservoir Storage Volume by Segment Tables

Reservoir volume by segment tables is another intermediate output from the OUP. Reservoir segments are defined by the sediment ranges at the upstream and downstream end of each segment. Using the range cross-section data, the volume of a segment at a reference elevation can be determined. Segment volumes were calculated at 10-foot intervals for the Tri-Lake Projects for each survey year. Segment volumes at elevation 1,423.0 (Maximum Pool elevation) were determined using linear interpolation.

4.3 Reservoir Surface Area & Storage Capacity Calculations using the GIS Method – Reservoir Inundation Calculator (RIC)

4.3.1 RIC Introduction

Reservoir Inundation Calculator (RIC) is an ESRI ArcGIS add-in that calculates area and capacity values for all reservoir water levels and develops GIS layers as output. Inundation GIS layers and elevation-area and elevation-capacity relationships provide important information for reservoir management. Calculating this information by hand can be laborious and time consuming, so a method was needed to calculate areas, capacities, and GIS inundation layers for many elevations at the click of a button. In addition, only a moderate amount of GIS experience is needed to run the calculator. The RIC gives users various input and output options, including the ability to calculate area and capacity at multiple water elevations at once and the ability to create output GIS datasets in various formats.

4.3.2 Digital Elevation Model (DEM) Development

DEMs were developed for Bear Creek, Chatfield, and Cherry Creek Lakes. To create a DEM for each reservoir, bathymetric data that was collected by USACE was merged with LiDAR data that had been collected by the State of Colorado in 2013.

For the land surface areas surrounding the lakes, bare-earth DEM tiles were downloaded from the Colorado GeoData Cache (https://geodata.co.gov/). These DEM tiles were created from LiDAR data that were collected after 2013 Colorado flooding. The LiDAR data had a resolution of 0.75 meters and used a vertical datum of NAVD88. The tiles for each reservoir were combined to create a DEM surface for each lake, projected to the Central Colorado State Plane coordinate system with a 3-foot cell resolution and converted from vertical units of meters to US survey feet.

The land surface DEMs did not include any bathymetric data so separate raster DEMs were created for each lake bottom. To create each lake-bottom DEM, a triangulated irregular network (TIN) was first created using the bathymetric data points and the surrounding LiDAR shoreline ground points as the mass points that defined the TIN elevation values. The LiDAR shoreline data that was used was a subset of the LiDAR collection that occurred after the 2013 Colorado floods.

After the TIN was created, it was converted to a raster DEM and clipped to the lake shoreline as defined by the LIDAR ground points. DEM surfaces were created for each lake by combining the high-density bathymetry with the 2013 Colorado LiDAR. Final HDSB and HDMB DEM surfaces were then created for each lake by clipping the DEMs to the reservoir area so that they could then be used in the RIC. The HDMB DEM surface was the final version used for area and capacity analysis in this report.

4.3.3 RIC Processing

To calculate reservoir surface area and storage capacity values, the RIC version 2.1 was used in ArcMap 10.4.1 on each final DEM that was created. In addition to calculating the area and capacity tables, a water extent dataset was created for each water surface elevation. The RIC calculates the inundated area by determining the number of raster cells that are inundated for a given water surface elevation and then multiplying the number of cells by the area of each cell. To calculate the capacity, the mean water depth is determined for the given water surface elevation and then that number is multiplied by the total inundated area.

4.4 Sediment Depletion Rates

The sediment depletion rate is a useful metric that can be computed from capacity changes and indicates how quickly storage capacity is lost. Factors in depletion rate variation includes:

(1) Natural Variability. Sediment depletion will vary between survey periods due to natural factors such as land use changes that affect sediment yield, variability in annual runoff volume, precipitation intensity, and similar. The computational methodology also affects results.

(2) Methodology. When switching data collection and analysis methodologies, computational differences can occur due to the change in methodology rather than an actual variation in the depletion rate. Therefore, it is recommended to compute capacity with both methods when a methodology change is made. This provides the ability to examine any shift in capacity that may be associated with the change in methodology.

(3) Accuracy. Data collection methods have evolved over time that has affected data accuracy due to changes in vertical point accuracy and point density.

(4) Localized Elevation Change. The MAEA method depletion that relies on average end area is accentuated when the original ratio table has diminished reliability. Computed storage loss (depletion) for each segment occurs when the bounding sediment range average end area changes. Therefore, minor localized sediment range elevation changes have magnified impacts on capacity. Examples of small-scale construction projects that affect capacity are land use site grading, environmental restoration, and road construction.

As a result of changing methodologies from the MAEA method to the GIS method, care must be taken when performing depletion trend analysis and comparisons.

5 Bear Creek Lake

5.1 Bear Creek Lake – Project Background

Bear Creek Dam and Reservoir (Figure 5-1) is located in Jefferson County, Colorado on Bear Creek about eight miles upstream from its confluence with the South Platte River in Denver. It was built by the U.S. Army Corps of Engineers for the primary purpose of mitigating flood risk to the downstream metropolitan area of Denver from floods originating above the dam.

Bear Creek is a left bank tributary of the South Platte River that runs through Lakewood, Colorado and empties into the South Platte River near Sheridan, a suburb of Denver, located in the southwestern portion of the Denver metropolitan area. The dam is located 2½ miles east of Morrison, Colorado. The basin drains a total of 262 square miles. Bear Creek Lake was closed in July 1977 and initial filling was completed in May 1979. The lake covers approximately 106 acres at the Multipurpose Pool elevation of 5,558.0 feet, NGVD29. Engineering data for the Bear Creek project is summarized in Table 5-1.

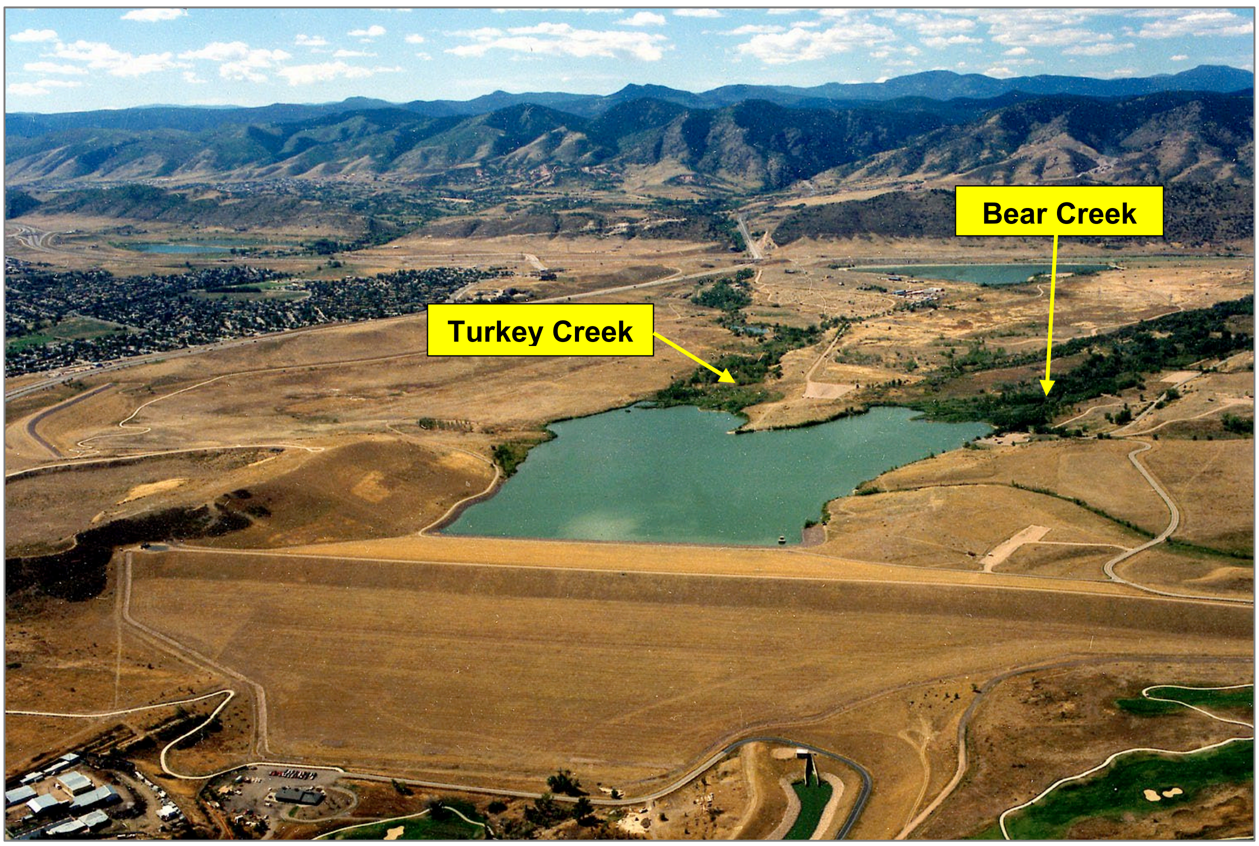

Figure 5-1. Aerial Photograph of Bear Creek Lake (RARE database file photo)

Table 5-1. Bear Creek Lake – Summary of Engineering Data

ITEM NO.	SUBJECT	BEAR CREEK LAKE	
	GENERAL		
1	Location of Dam	3 miles southwest of Denver, Colorado.	
2	River & River Mile	Bear Creek @ RM 8	
3	Drainage Area	262 mi^2	
4	Reservoir Length	0.5 miles @ Elevation 5,558.0 feet, NGVD29	
5	Location of Dam Tender	At Chatfield Dam	
6	Travel Time to Missouri River	2 weeks	
7	Maximum Discharge of Record	8,600 cfs	July 1896
8	Maximum Pool of Record	5,607.8 feet, NGVD29	September 2013
	DAM AND EMBANKMENT		
9	Top of Dam	5,689.5 feet	
10	Length of Dam	5,300 feet – Main Section/2,100 feet – South Section	
11	Height of Dam	179.5 feet – Main Section/65 feet – South Section	
12	Stream Bed	5,510.0 feet, NGVD29	
13	Abutment Formation	Clay-Shale-Siltstone-Sandstone	
14	Type of Fill	Rolled Earth	
15	Fill Quantity	11,346,000 yds^3 – Main Section/ 770,000 yds^3 – South Section	
16	Date of Closure	July 1977	
17	Date of Initial Fill (Base F.C.)	May 1979	
	SPILLWAY		
18	Discharge Capacity	153,500 cfs @ Elevation 5,684.5 feet, NGVD29	
19	Crest Elevation	5,667.0 feet, NGVD29	
20	Width	800 feet	
21	Gates, Number, Size, Type	Ungated Earth Channel	
	RESERVOIR POOL BY ELEVATION	**ELEVATION (NGVD29) & SURFACE AREA – 2016 DEM Surface**	
22	**Maximum Pool**	**5,684.5 feet**	**1,259 acres**
23	**Top of Flood Control Pool**	**5,635.5 feet**	**721 acres**
24	**Top of Multipurpose Pool**	**5,558.0 feet**	**102 acres**
25	**Top of Inactive Pool**	**5,528.0 feet**	**12 acres**
	RESERVOIR STORAGE ZONES	**ELEVATION (NGVD29) & STORAGE CAPACITY – 2016 DEM Surface**	
26	**Surcharge**	**5,635.5 feet – 5,684.5 feet**	**47,666 acre-feet**
27	**Flood Control**	**5,558.0 feet – 5,635.5 feet**	**28,534 acre-feet**
28	**Multipurpose**	**5,528.0 feet – 5,558.0 feet**	**1,721 acre-feet**
29	**Inactive**	**5,510.0 feet – 5,528.0 feet**	**27 acre-feet**
30	**GROSS STORAGE**	**Thalweg – 5,684.5 feet**	**77,948 acre-feet**
	OUTLET WORKS		
31	Number and Size – Conduits	1 – 7 feet Circular – Upstream	
		1 – 7 X 10.5 feet – Downstream	
32	Conduit Length	1,690 feet	
		Ungated drop inlet – Elevation 5,558.0 feet, NGVD29	
33	Number – Size – Type Gates	2 – 3 X 6 feet Hydraulic Slide	
		2 – 1 X 1 feet Slide – Gate on Gate	
34	Discharge Capacity	2,160 cfs @ Elevation 5,667.0 feet, NGVD29	
35	**POWER INSTALLATION**	None	

5.2 Bear Creek Lake – Reservoir Inflow, Outflow, and Pool Elevation

Pool elevation data has been collected at Bear Creek Lake since 1977. Operation of the Tri-Lakes Reservoirs generally require both individual and system reservoir regulation. The maximum and minimum pool elevations of record are tabulated in Table 5-2. A historical pool elevation profile is shown in Figure 5-2.

Table 5-2. Bear Creek Lake – Summary of Reservoir Inflow, Outflow, & Pool Elevation Events

Daily Inflow and Date			Maximum Pool Elevation (NGVD29) and Date		
Highest	1,183 cfs	10 May 2015	**Highest**	5,607.8 feet	21 Sep 2013
2nd	1,172 cfs	16 Sep 2013	**2nd**	5,602.6 feet	25 May 2015
3rd	910 cfs	30 Apr 1980	**3rd**	5,587.1 feet	17 Jun 1995
Daily Outflow and Date			**Minimum Pool Elevation (NGVD29) and Date**		
Highest	800 cfs	11 Jun 1979	**Lowest**	5,549.2 feet	18 Oct 1999
2nd	800 cfs	04 May 1980	**2nd**	5,553.2 feet	03 Nov 2015
3rd	612 cfs	23 Jun 1995	**3rd**	5,554.4 feet	03 Nov 2016

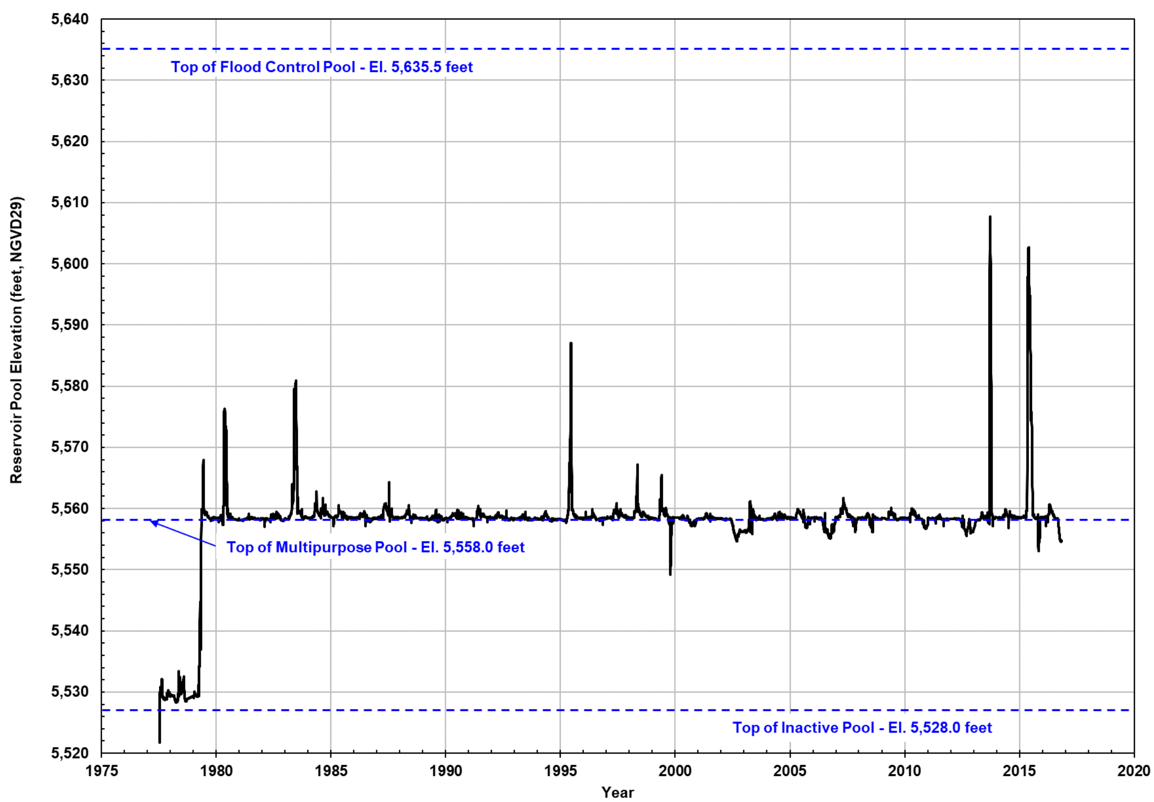

Figure 5-2. Bear Creek Lake – Reservoir Pool Elevations

5.3 Bear Creek Lake – Survey Data

5.3.1 Bear Creek Lake Sediment Ranges

There are eleven (11) established sediment aggradation ranges that are used to monitor sedimentation at Bear Creek Lake as shown in Figure 5-3. In addition, two (2) degradation ranges were established to monitor channel changes below the dam. Individual sediment range cross section profiles are shown in Appendix A. Each profile shows the entire surveyed cross section from end monument left bank to end monument right bank. Analysis of changes in the sediment range profiles are discussed in Section 5.3.3.

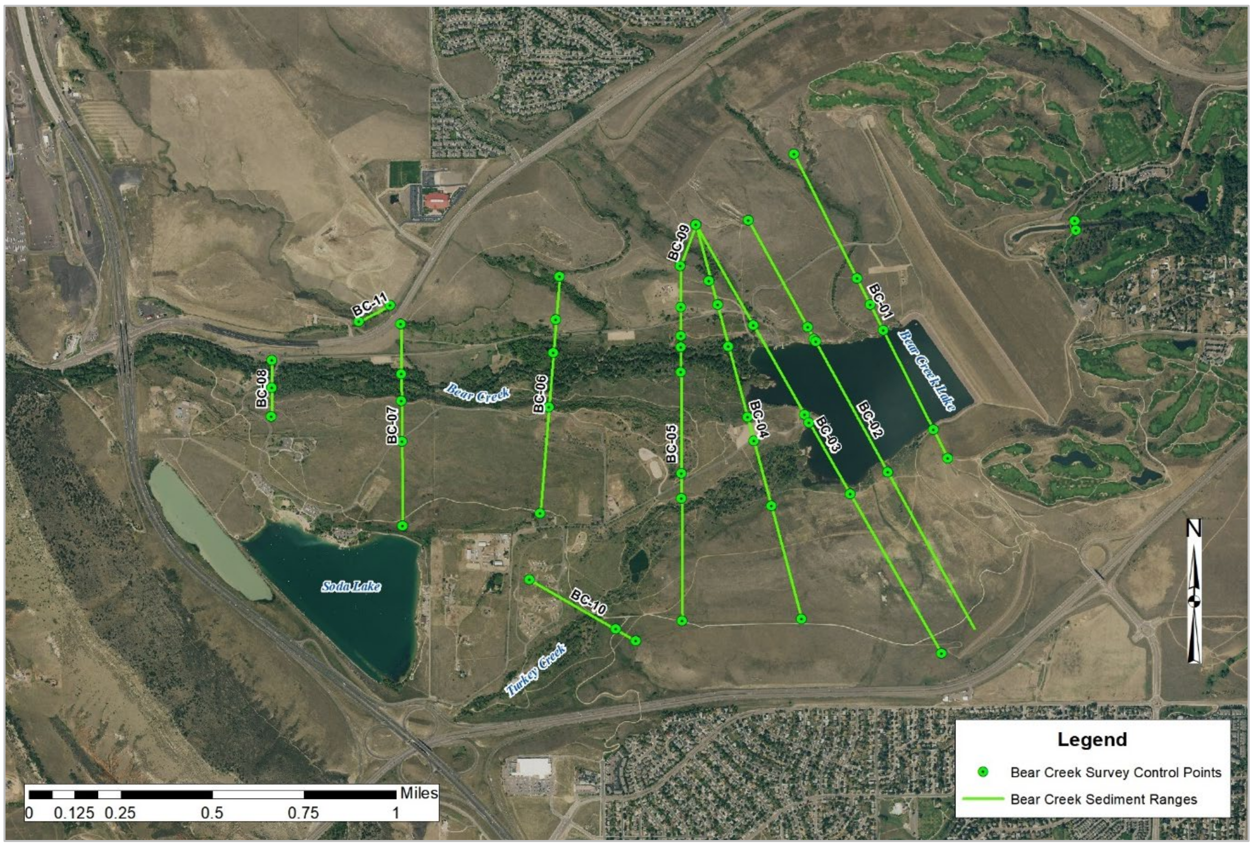

Figure 5-3. Bear Creek Lake – Sediment Range Location Map

5.3.2 2016 Sediment Range Surveys

Traditional cross section surveys of the 13 sediment ranges at Bear Creek Lake were completed in 2016 by Omaha District personnel. A shortened metadata file for these surveys is found in Table 5-3.

Table 5-3. Bear Creek Lake – Brief Metadata for 2016 Sediment Range & HDSB Surveys

Location	Bear Creek Lake
Survey Date(s)	August 01 – 02, 2016
Surveyed By	Omaha District, River and Reservoir Engineering Section (CENWO-ED-HF)
Equipment	TRIMBLE R8 GPS Receivers, TD 450 H Radios, & Geomatics Office Software ODOM CV100 Echo Sounder, Digibar Pro Sound Velocity Profiler HYPACK® Hydrographic Surveying Software Boat, Boat #402, 20-feet long
Horizontal Datum	Colorado State-Plane Coordinate System, NAD83, Central Zone 0502
Vertical Datum	NAVD88 & converted to NGVD29 using USACE CorpsCon 6.0.1 software
Units	U.S. Survey Feet
Accuracy	3rd Order Horizontal & Vertical Accuracy per EM 1110-2-1003, *Hydrographic Surveying*

5.3.3 Analysis of 2016 Sediment Range Cross Section Data

Cross sectional plots are shown in Appendix A. Analysis of the changes in the sediment range cross sections are as follows.

5.3.3.1 Sediment Ranges BC-01, BC-02, BC-03, & BC-04

These four ranges are mostly underwater when they cross Bear Creek Lake when the pool is at the top of the Multipurpose Pool (elevation 5,558.0 feet, NGVD29). All four ranges show approximately 3 to 5 feet of deposition across the bottom of the lake between 1980 and 2016. The original Bear Creek channel is nearly buried at ranges BC-01 through BC-03 but clearly visible at range BC-04.

5.3.3.2 Sediment Range BC-05

This sediment range remains mostly unchanged with the exception of 1 to 2 feet of deposition in the old Bear Creek channel (left bank) between 1980 and 2016.

5.3.3.3 Sediment Range BC-06, BC-07, & BC-10

These two sediment ranges remain mostly unchanged between 1980 and 2016.

5.3.3.4 Sediment Range BC-08

A road was built near the right bank of sediment range BC-08 sometime between 1987 and 1997. A comparison of the 1980 and 2016 surveyed cross sections (Figure 3-4) reveal a considerable loss of bank line in elevation from the original survey in this area. The 1987 and 1997 surveys did not cover the outer extents of all the range lines for the overbank and used 1980 data to complete the lines for the area-capacity programs to reach comparable survey elevations. Due to the data repetition, the 1987 and 1997 data in the Flood Control and Surcharge Pools are not reflective of the changes and are not reported. Note the 2009 and 2016 sediment range surveys covered the entire length of the range lines.

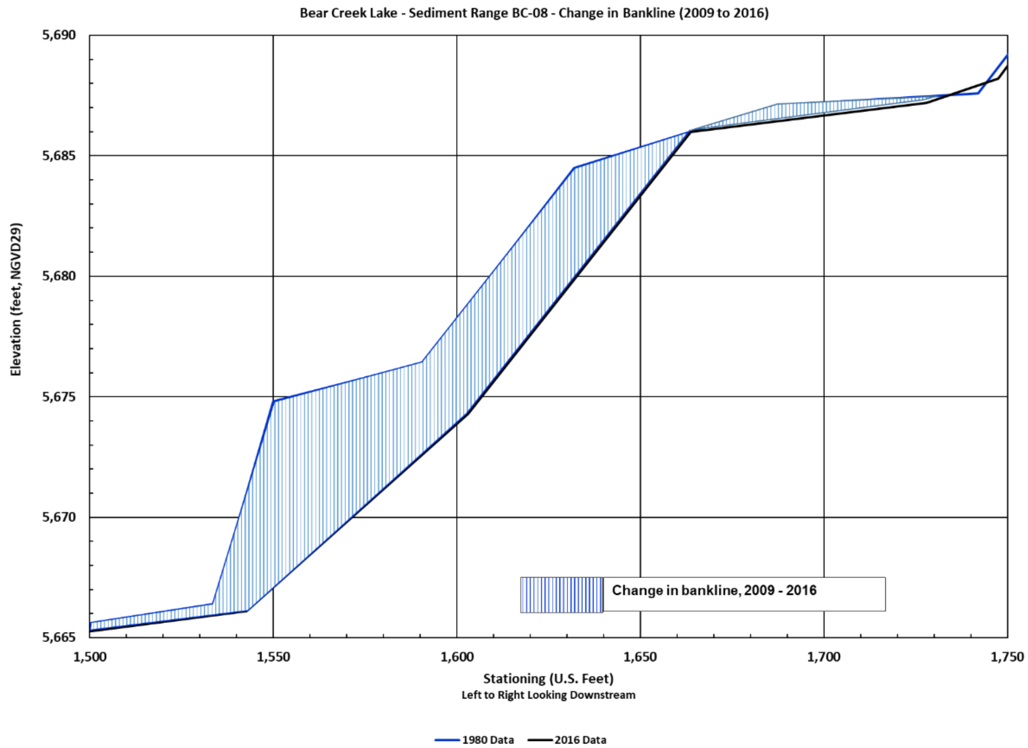

Figure 5-4. Right Bank Window of Cross Section for Sediment Range BC-08

5.3.3.5 Sediment Range BC-09

This sediment range has 1 to 2 feet of deposition across the original channel between 1980 and 2016.

5.3.3.6 Sediment Range BC-11

This sediment range has 2 to 3 feet of deposition across the original channel between 1980 and 2016.

5.3.3.7 Degradation Ranges BC-12 & BC-13

These two ranges were established below Bear Creek Dam to monitor channel degradation and erosion. There is only one survey of each so no comparison can be made.

5.3.4 2016 High Density Survey Bathymetry

Both HDSB and HDMB bathymetry were collected. For the HDSB, the first survey line at Bear Creek was established 25 feet parallel from where water's edge meets the embankment of the dam. Additional upstream survey lines were spaced parallel to the first, approximately 100 feet apart as shown in Figure 5-5. Data was collected in areas where navigation by boat was possible, usually at depths three feet or greater. Two survey lines circled the perimeter of the shoreline as close to the bank as possible. One survey line circled at ± 50 feet while the second circled ± 100 feet from the bank to ensure shallow water coverage. No wading was attempted because of personal safety concerns.

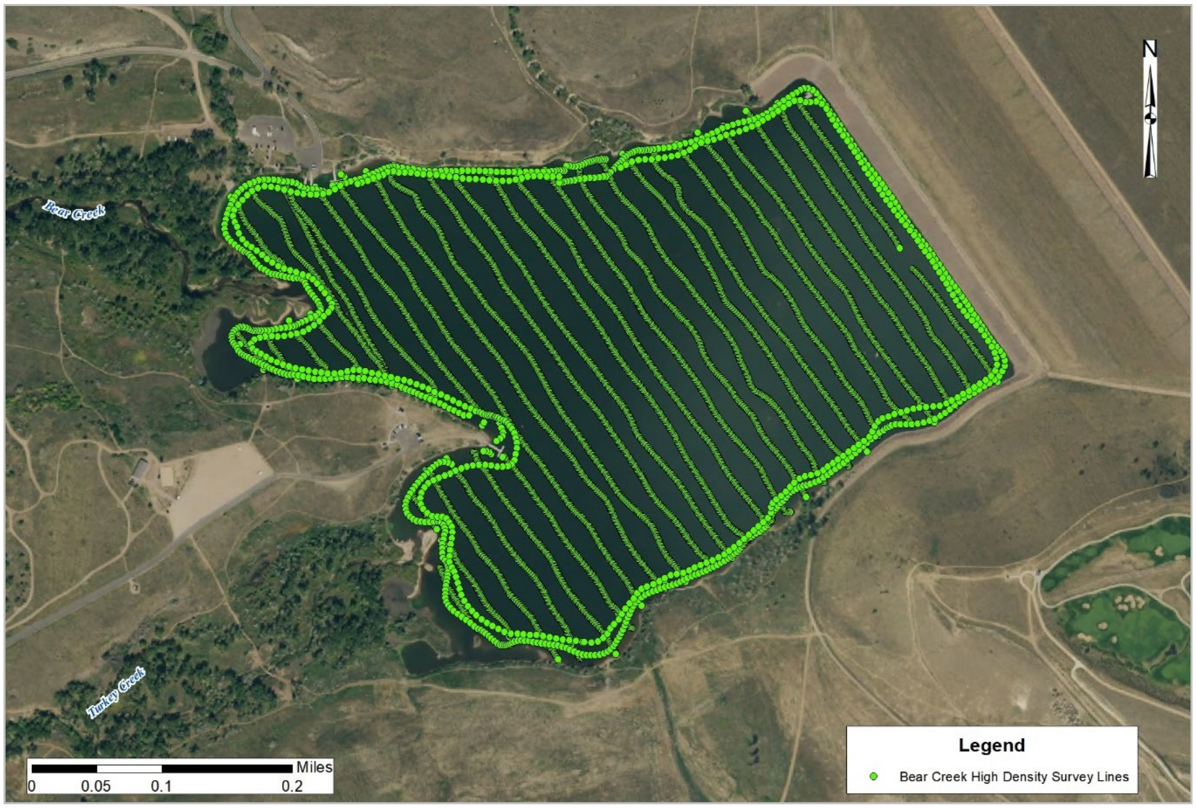

Figure 5-5. Bear Creek Lake – 2016 HDSB Survey Lines Map

5.3.5 2016 Reservoir Contour Map from LiDAR & HDSB Bathymetric DEM Surface

A product of the GIS method of the combined 2016 LiDAR/high density DEM surface are reservoir contours. Figure 5-6 shows the shaded contours in 10-foot increments for Bear Creek Lake created from the HDSB surface. Note that part of Bear Creek spillway is covered by the 5,685-foot NAVD88 contour. There is no earlier contour data to make surface area or volume comparisons.

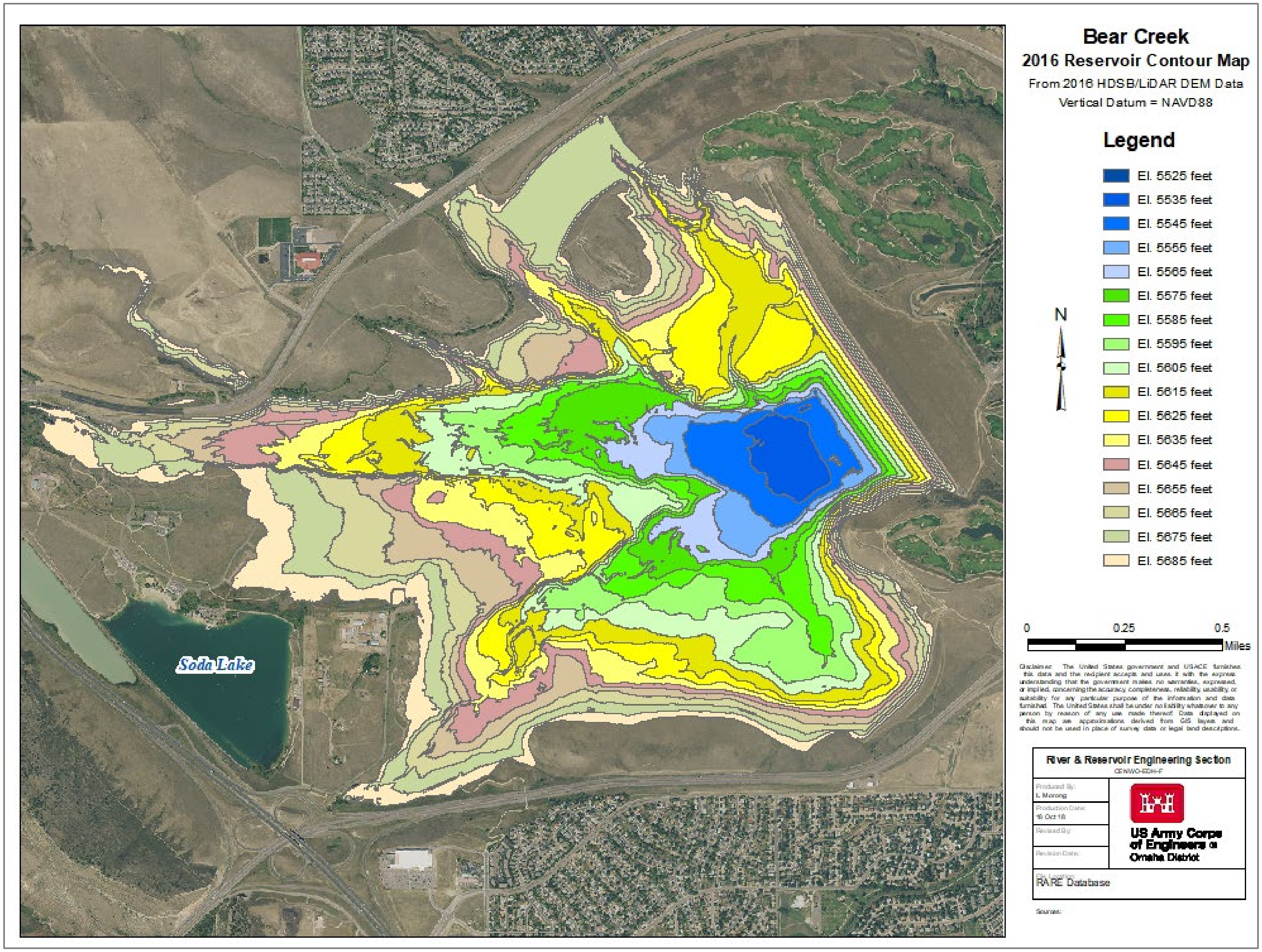

Figure 5-6. Bear Creek Lake – 2016 Reservoir Contour Map

5.4 Bear Creek Lake – Analysis of Shoreline Erosion

Sediment ranges BC-01, BC-02, and BC-03 cross Bear Creek Lake at the Multipurpose Pool elevation of 5,558.0 feet, NGVD29. Cross section analysis of the left and right banks of these three ranges indicate that no appreciable shoreline erosion has occurred between 1980 and 2016.

5.5 Bear Creek Lake – Analysis of 2016 Bed Material Data

The primary process responsible for the depletion of Bear Creek reservoir storage capacity is the delivery and deposition of sediment from the Bear Creek and Turkey Creek tributary streams. Bed material samples were collected during the 2016 surveys. Each sample was graded by mechanical sieve analysis in accordance with ASTM D422 and EM 1110-2-1960. The 2016 Bear Creek bed material data set (including data tables, Malvern and sieve analysis, and photographs) is tabulated in Appendix B. A location map of where individual samples was collected is shown in Figure 5-7.

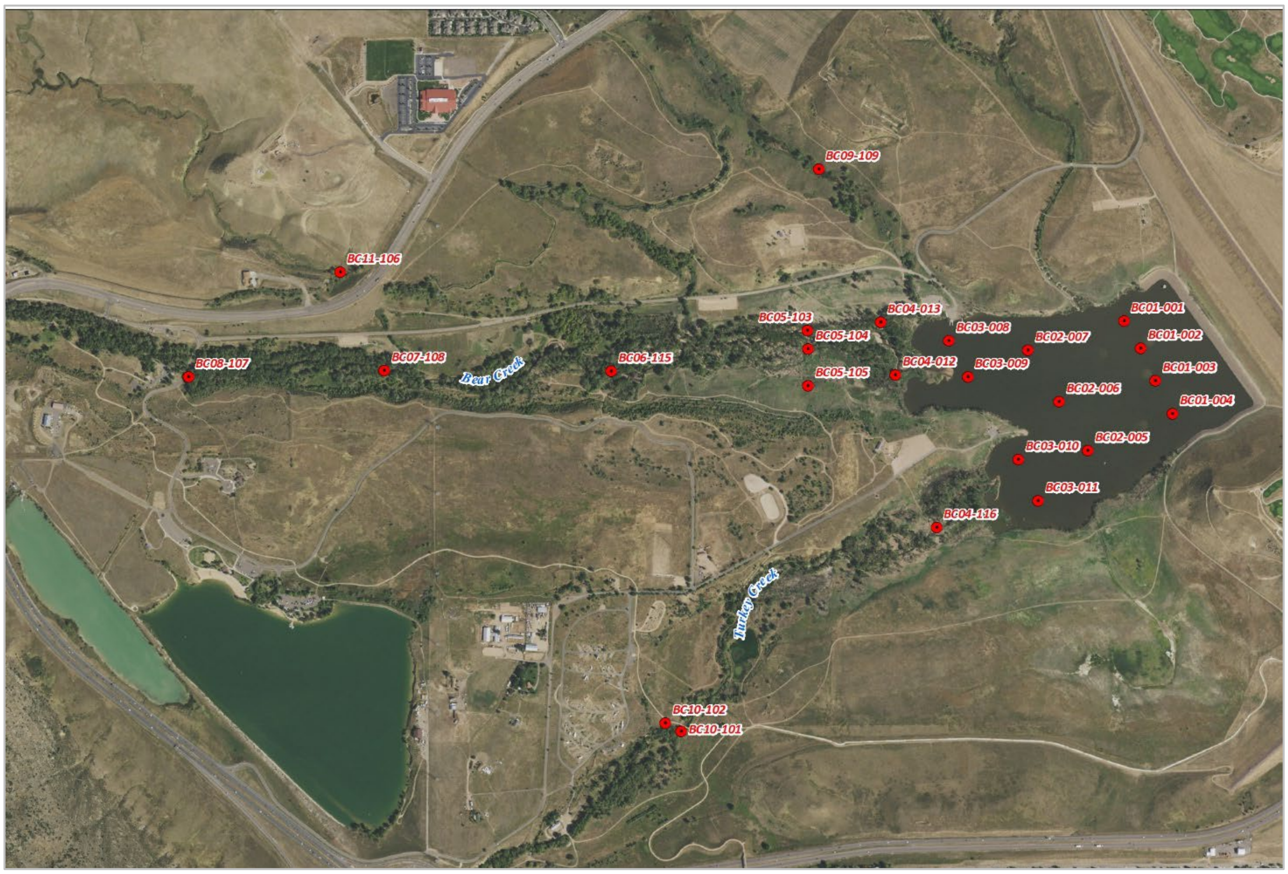

Figure 5-7. Bear Creek Lake – 2016 Bed Material Sample Locations

5.5.1 Analysis of Bed Material Samples (Bear Creek Lake)

The Bear Creek Lake bed material samples were collected from a boat using a USGS BM-54 bed material sampler and then placed in glass jars for transport. The samples collected in the lake reflect silts and some fine sands with an average D_{50} particle size of about 0.024 mm (medium silt). A Malvern analysis plot can be found in Figure B-2 in Appendix B.

5.5.2 Analysis of Bed Material Samples (Bear Creek and Turkey Creek)

The upstream bed material samples at the Bear Creek and Turkey Creek channels were collected by hand with a shovel and placed in glass jars for transport. Mechanical analysis of the bed material outside of the Multipurpose Pool indicate an average D_{50} particle size of about 1.28 mm (very coarse sand) for the Bear Creek samples and about 1.67 mm (very coarse sand) for the Turkey Creek samples. A sieve analysis plot of the upstream samples is found in Figure B-3 in Appendix B.

5.6 Bear Creek Lake – Reservoir Hydraulic Elements

Reservoir hydraulic elements are a tool for the analysis of five channel geometry parameters relative to a reference plane elevation. Parameters analyzed include the active channel width, cross sectional area, average channel depth, average bed elevation, and thalweg elevation. Only average channel depth, average bed elevation, and thalweg elevation data was used in this report. These factors are calculated from cross section data sets for each sediment range for selected survey years during the reservoir surface area and storage capacity analysis process. The reference plane elevation chosen for Bear Creek Lake was elevation 5,635.5 feet, NGVD29, which is the top of the Flood Control Pool. Hydraulic element calculations, generated by the OUP, have been compiled for the 1980, 1987, 1997, 2009, and 2016 surveys.

5.6.1 Analysis of Changes in Cross Section Average Depth Profiles

Cross section average depth data for Bear Creek and Turkey Creek are tabulated in Table 5-4, and plotted profiles are shown in Figure 5-8 and Figure 5-9. The average depth at the Bear Creek tributary channel decreased < 1.1 foot for sediment ranges BC-02 through BC-07 from 1980 to 2016. During this period, the average depth decreased 1.8 feet at sediment range BC-01 suggesting aggradation has occurred near the dam.

The average depth at the Turkey Creek tributary decreased generally < 1.0 foot for sediment ranges BC-04 through BC-10 from 1980 to 2016.

Table 5-4. Bear Creek Lake – Changes in Cross Section Average Depth Profiles (Feet)

Tributary Stream	Sediment Range	Survey Year					
		1980	1987	1997	2009	2016	1980 – 2016
Bear Creek Channel	BC-01	-55.8	-55.6	-55.1	-54.6	-54.0	**+1.8**
	BC-02	-57.3	-57.1	-57.0	-56.9	-56.4	**+0.9**
	BC-03	-60.2	-60.1	-60.0	-59.4	-59.2	**+1.1**
	BC-04	-46.8	-46.6	-46.4	-46.6	-46.1	**+0.7**
	BC-05	-39.9	-39.7	-39.7	-39.9	-39.8	**+0.1**
	BC-06	-24.9	-24.4	-24.4	-24.5	-24.2	**+0.8**
	BC-07	-3.5	-3.5	-2.9	-3.5	-3.1	**+0.4**
Turkey Creek Channel	BC-04	-46.8	-46.6	-46.4	-46.6	-46.1	**+0.7**
	BC-05	-39.9	-39.7	-39.7	-39.9	-39.8	**+0.1**
	BC-10	-2.7	-3.0	-3.0	-2.4	-2.4	**+0.3**

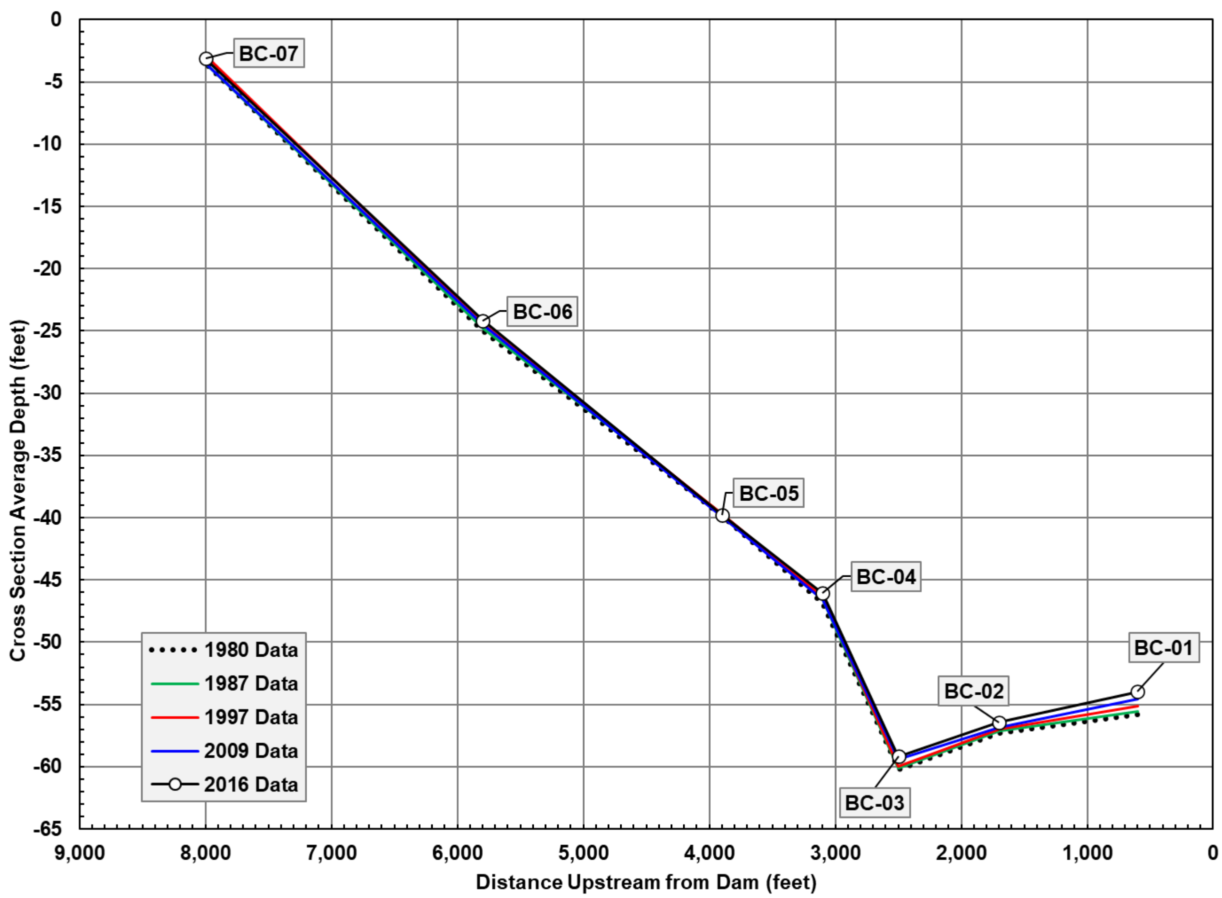

Figure 5-8. Bear Creek – Changes in Cross Section Average Depth Profiles

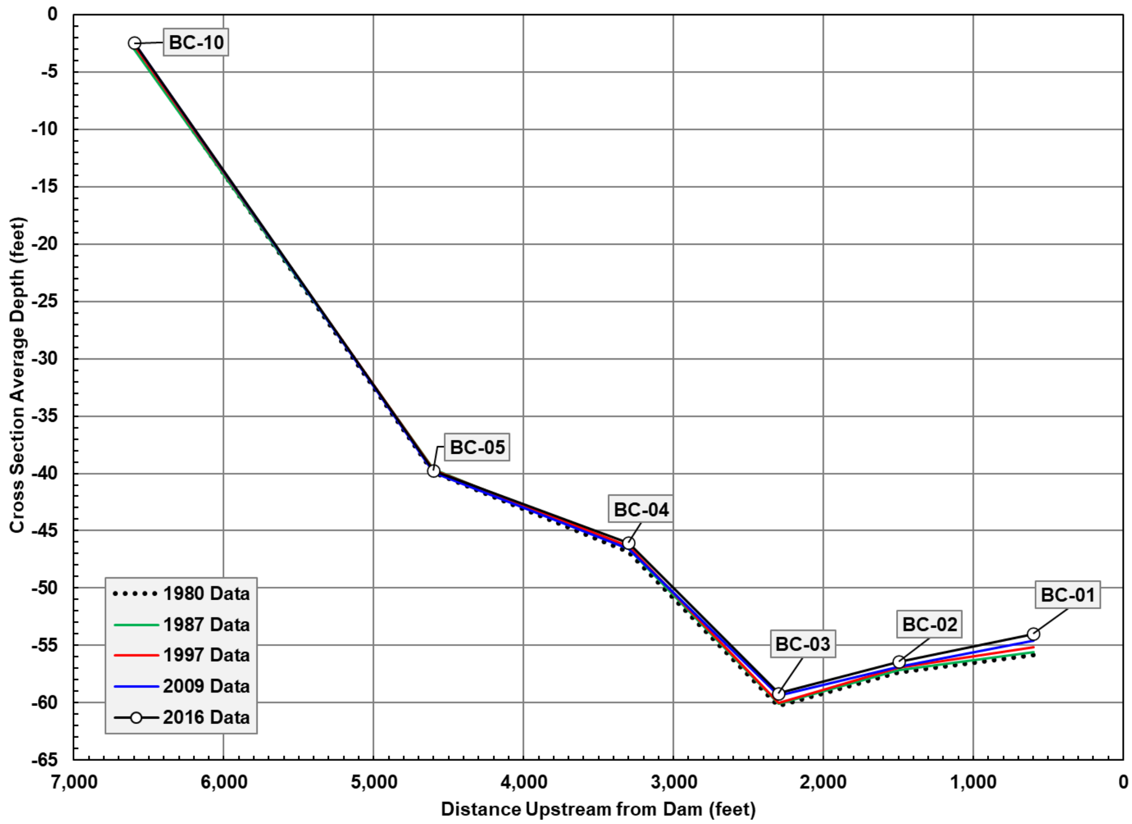

Figure 5-9. Turkey Creek – Changes in Cross Section Average Depth Profiles

5.6.2 Analysis of Changes in Cross Section Average Bed Elevation Profiles

Cross section average bed elevation data for Bear Creek and Turkey Creek are tabulated in Table 5-5, and plotted profiles are shown in Figure 5-10 and Figure 5-11. The average bed elevation increased < 1.1 foot for sediment ranges BC-02 through BC-07 from 1980 to 2016. During this period, the average bed elevation increased 1.8 feet at sediment range BC-01 suggesting aggradation has occurred near the dam.

The average bed elevation at the Turkey Creek tributary increased < 1.0 foot for sediment ranges BC-04 through BC-10 from 1980 to 2016.

Table 5-5. Bear Creek Lake – Changes in Cross Section Average Bed Elevations (Feet, NGVD29)

Tributary Stream	Sediment Range	Survey Year 1980	1987	1997	2009	2016	1980 – 2016
Bear Creek Channel	BC-01	5,579.7	5,579.9	5,580.4	5,580.9	5,581.5	**+1.8**
	BC-02	5,578.2	5,578.4	5,578.6	5,578.7	5,579.1	**+0.9**
	BC-03	5,575.3	5,575.4	5,575.5	5,576.1	5,576.3	**+1.1**
	BC-04	5,588.7	5,588.9	5,589.1	5,588.9	5,589.4	**+0.7**
	BC-05	5,595.6	5,595.9	5,595.8	5,595.6	5,595.7	**+0.1**
	BC-06	5,610.6	5,610.7	5,611.1	5,611.0	5,611.3	**+0.8**
	BC-07	5,632.0	5,632.0	5,632.6	5,632.0	5,632.4	**+0.4**
Turkey Creek Channel	BC-04	5,588.7	5,588.9	5,589.1	5,588.9	5,589.4	**+0.7**
	BC-05	5,595.6	5,595.9	5,595.8	5,595.6	5,595.7	**+0.1**
	BC-10	5,632.8	5,632.5	5,632.9	5,633.1	5,633.1	**+0.3**

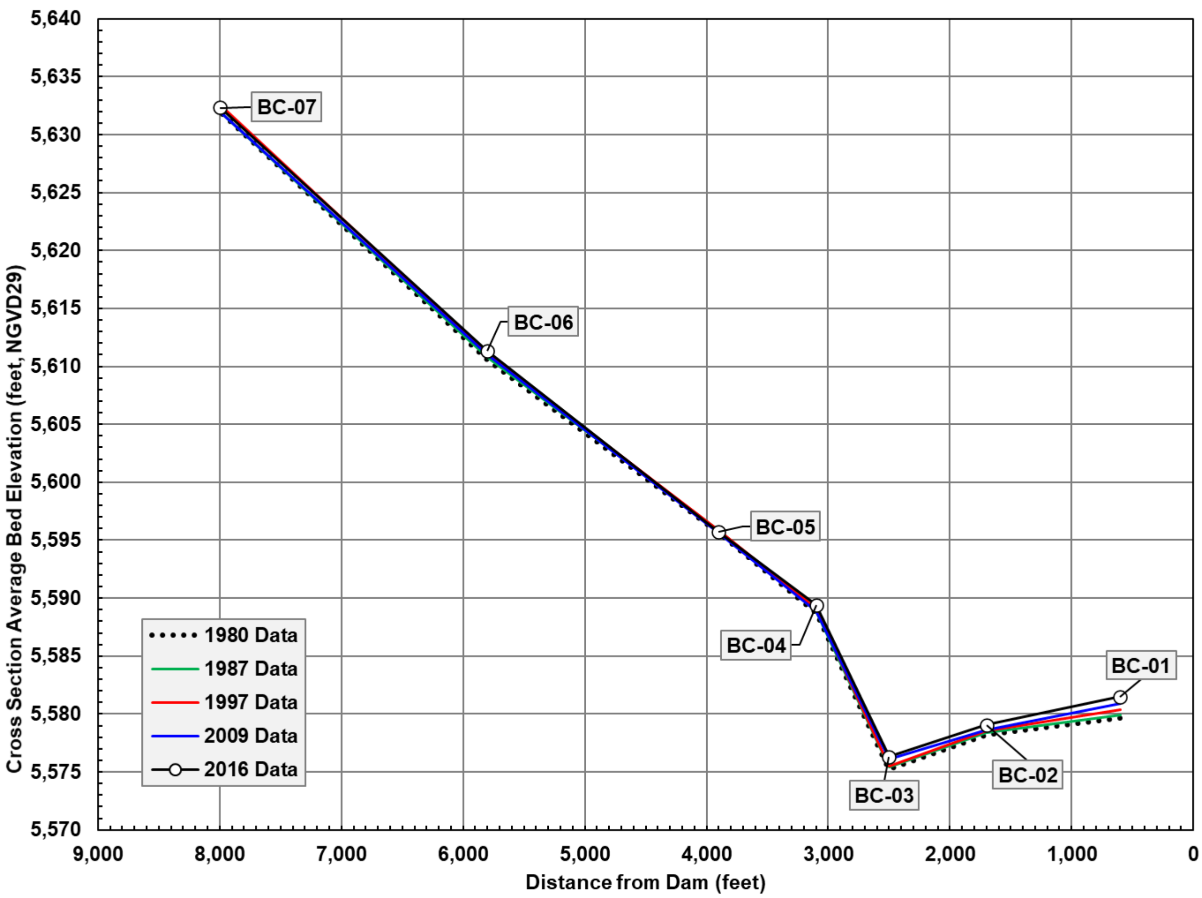

Figure 5-10. Bear Creek – Changes in Cross Section Average Bed Elevation Profiles

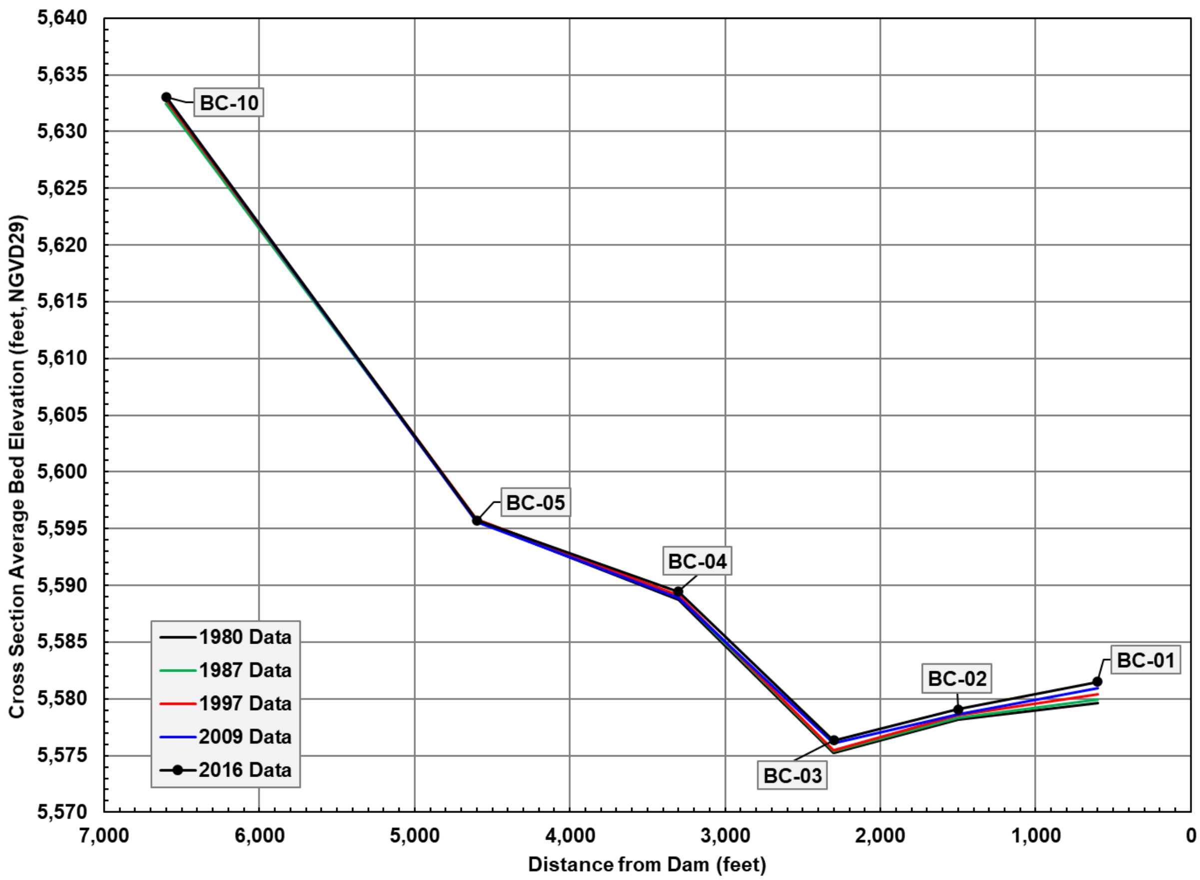

Figure 5-11. Turkey Creek – Changes in Cross Section Average Bed Elevation Profiles

5.6.3 Analysis of Changes in Cross Section Thalweg Elevation Profiles

Bear Creek and Turkey Creek thalweg elevation data is presented in Table 5-6. Plotted thalweg profiles for Bear Creek and Turkey Creek are shown in Figure 5-12 and Figure 5-13. The thalweg elevation at sediment range BC-08 has decreased 1.3 feet between 1980 and 2016. The degradation at this range is probably caused by channel narrowing and increased channel velocity because of the range's proximity just downstream of the park bridge over Bear Creek. The thalweg profiles from BC-07 through BC-01 have increased consistently from +0.9 feet at range BC-07 downstream to +5.0 feet at BC-01.

The thalweg profiles for the Turkey Creek tributary show that this is an aggrading reach. Thalweg elevations have increased from +2.0 feet at BC-04 upstream to +0.2 feet at BC-10.

Sediment ranges BC-09 and BC-11 are located on unnamed tributaries of Bear Creek Lake and are not included in any figure. The thalweg elevation has increased +1.8 feet at BC-09 and decreased -0.8 feet at BC-11, respectively. Changes at these two sediment ranges are probably the result of channel geometry changes from runoff events.

Table 5-6. Bear Creek Lake – Changes in Cross Section Thalweg Elevations (Feet, NGVD29)

Sediment Range	Survey Year					
	1980	1987	1997	2009	2016	1980 – 2016
BC-01	5,516.2	5,518.3	5,519.9	5,518.8	5,521.2	**+5.0**
BC-02	5,530.5	5,531.2	5,532.1	5,531.7	5,533.3	**+2.8**
BC-03	5,537.5	5,538.7	5,539.9	5,541.3	5,542.6	**+5.1**
BC-04	5,555.7	5,554.8	5,556.6	5,556.1	5,557.7	**+2.0**
BC-05	5,560.9	5,561.4	5,564.0	5,563.0	5,563.7	**+2.8**
BC-06	5,592.6	5,591.6	5,591.6	5,593.1	5,593.6	**+1.0**
BC-07	5,624.9	5,625.2	5,625.5	5,625.4	5,625.8	**+0.9**
BC-08	5,655.0	5,654.7	5,655.2	5,655.0	5,653.7	**-1.3**
BC-09	5,606.4	5,607.0	5,608.1	5,607.9	5,608.2	**+1.8**
BC-10	5,626.9	5,627.4	5,627.7	5,627.5	5,627.1	**+0.2**
BC-11	5,648.1	5,649.9	5,651.1	5,648.6	5,647.3	**-0.8**

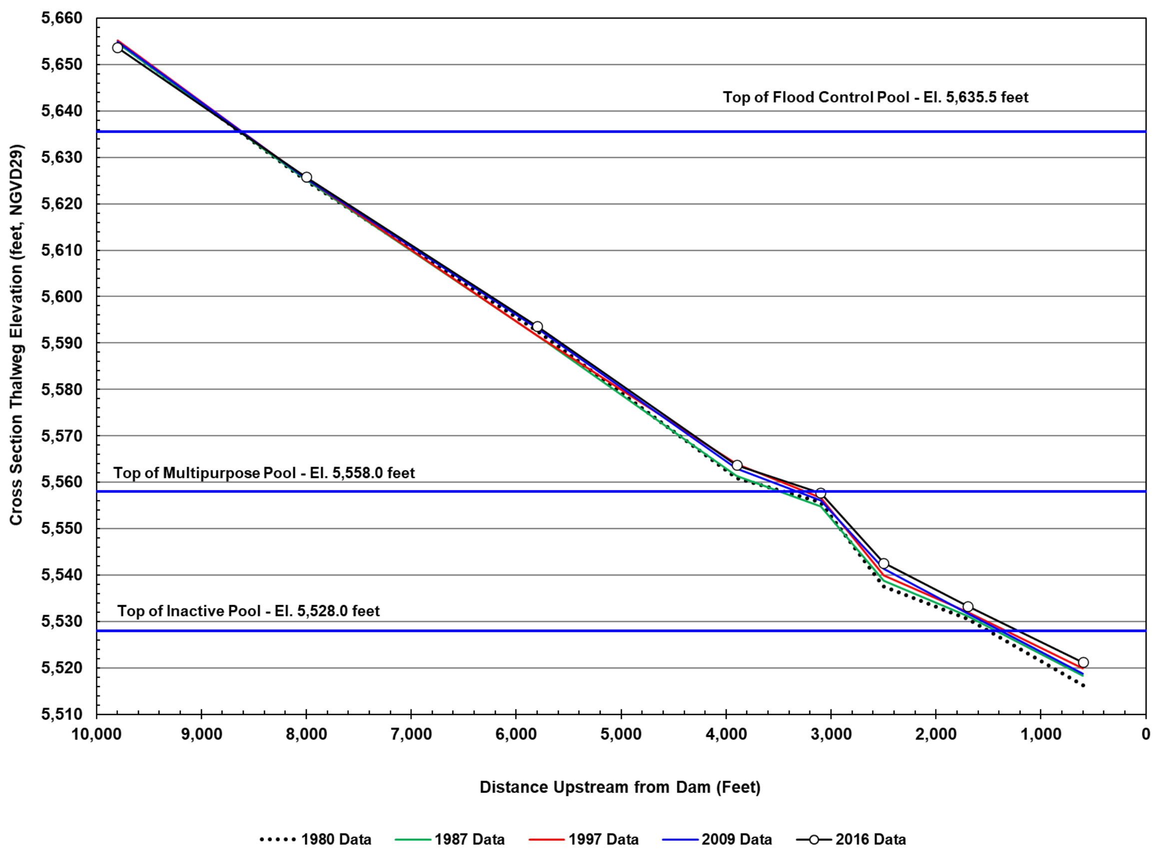

Figure 5-12. Bear Creek – Changes in Cross Section Thalweg Elevations

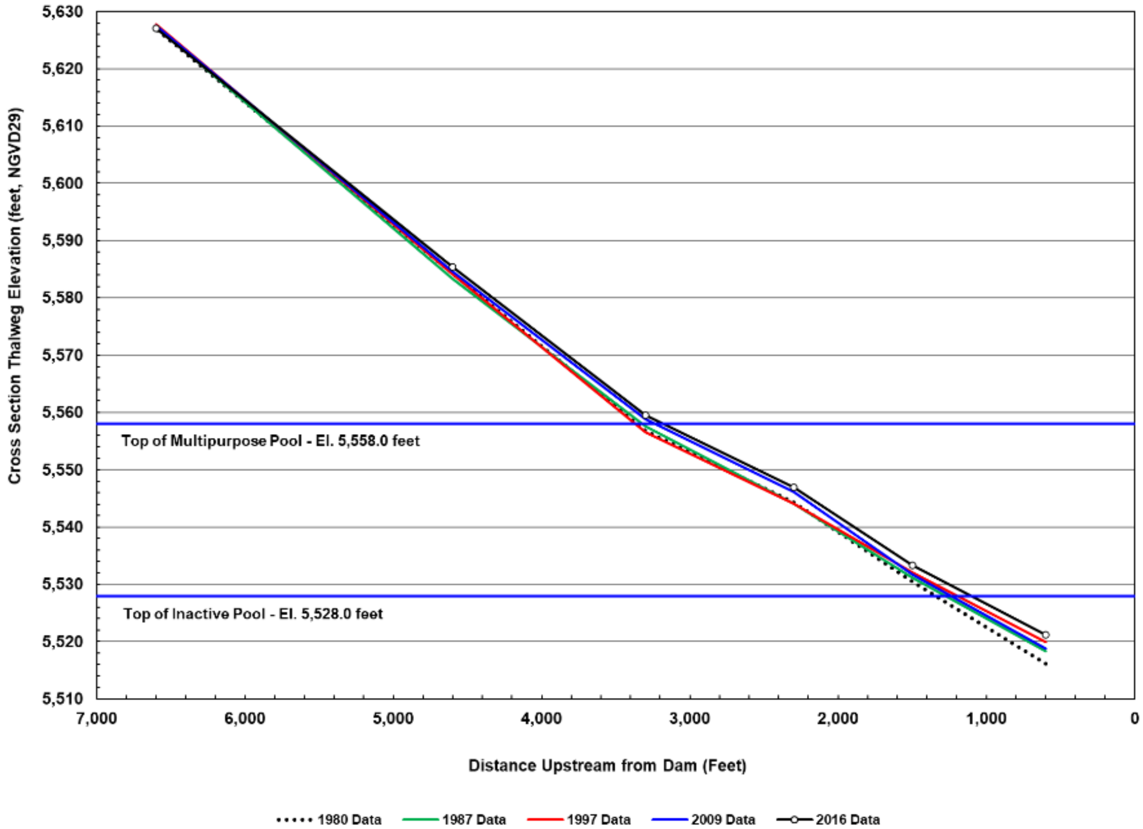

Figure 5-13. Turkey Creek – Changes in Cross Section Thalweg Elevations

5.7 Bear Creek Lake – Reservoir Surface Area and Storage Capacity

Table 5-7 lists pertinent pool elevation and pool zones for Bear Creek Lake. In the following sections, 2016 Bear Creek Lake surface area and storage capacity data is compared with surveyed sediment range data using the MAEA method; and directly from the 2016 LiDAR/HDMB DEM surface using the GIS method.

Variations between the MAEA method results and the GIS method results may be attributed to variations in the reservoir bed and banks not accounted for during the collection of sediment range data. The variation between the range data (MAEA) and 2016 LiDAR/HDMB DEM surface is the direct result of the increased resolution of the survey data.

Area and capacity tables for Bear Creek Lake calculated at 0.1-foot increments are in Appendix D. The capacity tables computed at 0.01-foot increments are not presented in this report but are available from the Omaha District River and Reservoir Engineering Section.

Table 5-7. Bear Creek Lake – Pertinent Pool Elevations

Top of Pool	Pool Elevation (Feet, NGVD29)	Pool Zone	Pool Zone Elevations (Feet, NGVD29)
Maximum Pool	5,684.5	Surcharge	5,635.5 – 5,684.5
Flood Control Pool	5,635.5	Flood Control	5,558.0 – 5,635.5
Multipurpose Pool	5,558.0	Multipurpose	5,528.0 – 5,558.0
Inactive Pool	5,528.0	Inactive	Thalweg El. – 5,528.0
		GROSS STORAGE	**Thalweg El. – 5,635.5**

5.7.1 Analysis of Reservoir Surface Area by Pool Elevation

A comparison of Bear Creek surface area tables calculated from surveyed sediment range data using the MAEA method and GIS method are tabulated in Table 5-8. Surface area profiles are plotted in Figure 5-15. Results indicate that surface area between 1980 and 2016 using the surveyed range data has remained nearly constant.

Table 5-8 also indicates that between 1980 and 2016, surface area calculated from the 2016 LiDAR/HDMB DEM surface using the GIS method are greater at the top of the Maximum Pool (+27 acres) and at the top of the Flood Control Pool (+3 acres). At the lower pool elevations, surface area has decreased at the Multipurpose Pool (-7 acres) and below the Inactive Pool (-4 acres).

Table 5-8. Bear Creek Lake – Changes in Reservoir Surface Area (Acres)

Operational Pool	Sediment Range Surveys (MAEA)					2016 GIS (DEM)	1980 – 2016	
	1980	1987	1997	2009	2016		MAEA	GIS
Maximum	1,232	1,229	1,230	1,230	1,233	1,259	+1	+27
Flood Control	718	717	716	715	716	721	-2	+3
Multipurpose	109	108	107	108	106	102	-3	-7
Inactive	16	17	17	17	17	12	+1	-4

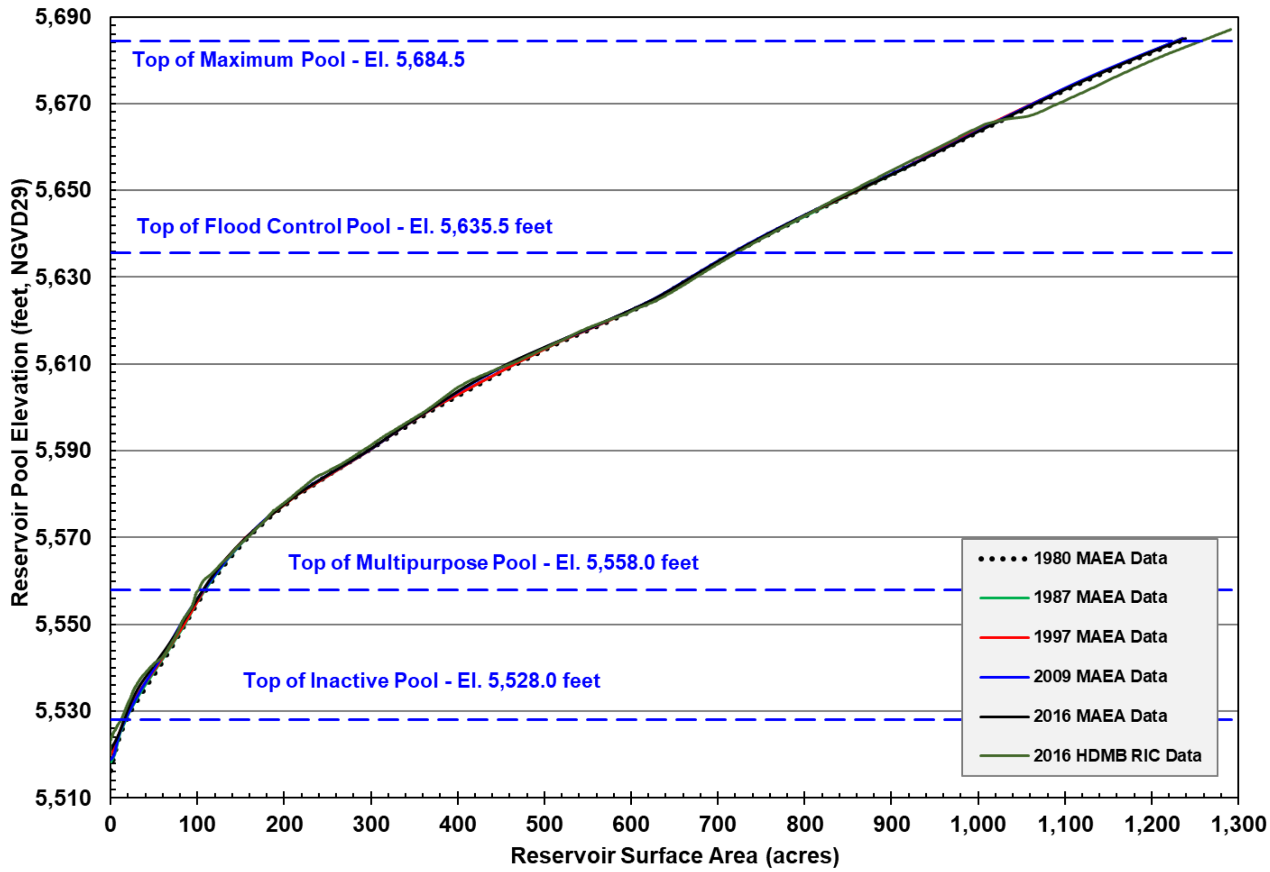

Figure 5-14. Bear Creek Lake – Reservoir Surface Area Profiles

5.7.2 Analysis of Reservoir Storage Capacity by Pool Elevation

Table 5-9 tabulates historical Bear Creek Lake storage capacity data. Storage capacity profiles are shown in Figure 5-15 and Figure 5-16. Results indicate that between 1980 and 2016 reservoir storage capacity has decreased between surveys and methodologies at the four operational pool elevations. Using the GIS method, the Maximum Pool decreased by 191 acre-feet, the Flood Control Pool decreased by 522 acre-feet, the Multipurpose Pool decreased by 231 acre-feet, and the Inactive Pool decreased by 47 acre-feet between 1980 and 2016.

In summary:

- MAEA method capacity results show a decrease in capacity since 1980.
- GIS method capacity results show a decrease in capacity since 1980.

Table 5-9. Bear Creek Lake – Changes in Reservoir Storage Capacity by Pool Elevation (Acre-Feet)

Operational Pool	Sediment Range Surveys (MAEA)					2016 GIS (DEM)	1980 – 2016	
	1980	1987	1997	2009	2016		MAEA	GIS
Maximum	78,139	77,995	77,845	77,653	77,623	77,948	-515	-191
Flood Control	30,804	30,706	30,629	30,454	30,336	30,282	-468	-522
Multipurpose	1,979	1,955	1,899	1,854	1,786	1,748	-192	-231
Inactive	74	69	58	63	47	27	-27	-47

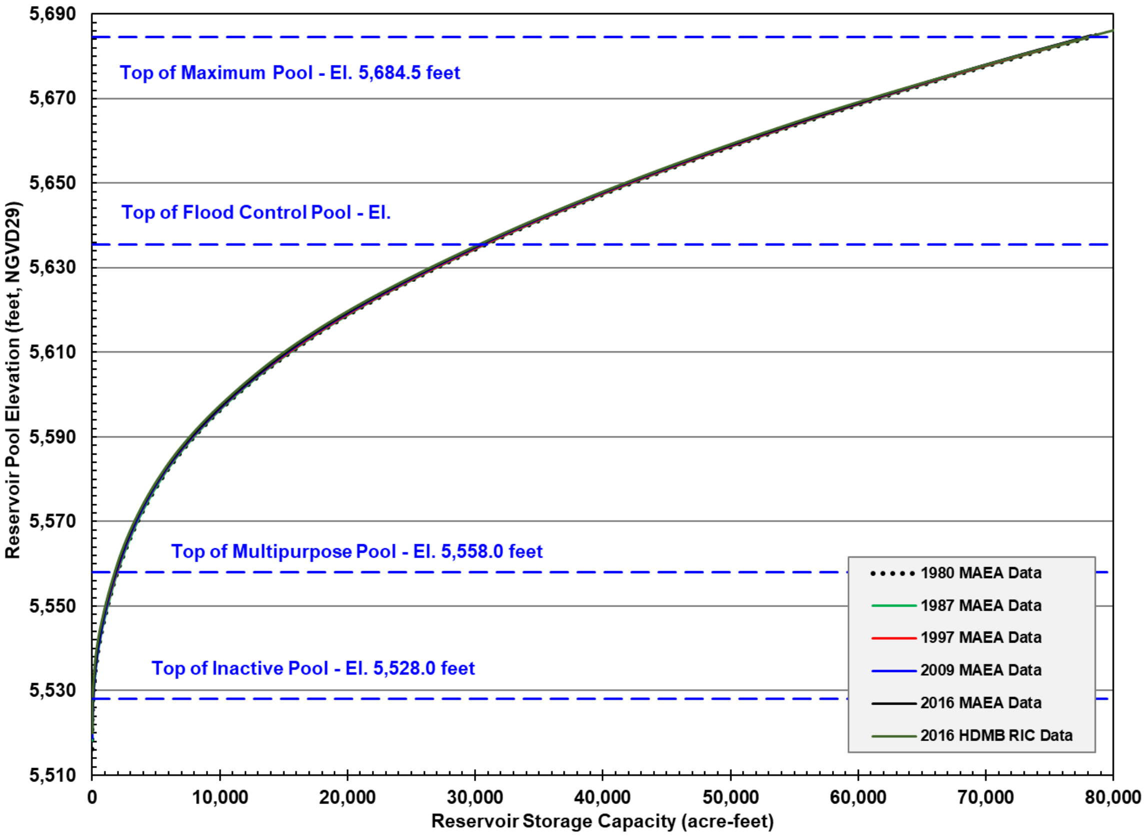

Figure 5-15. Bear Creek Lake – Reservoir Storage Capacity Profiles

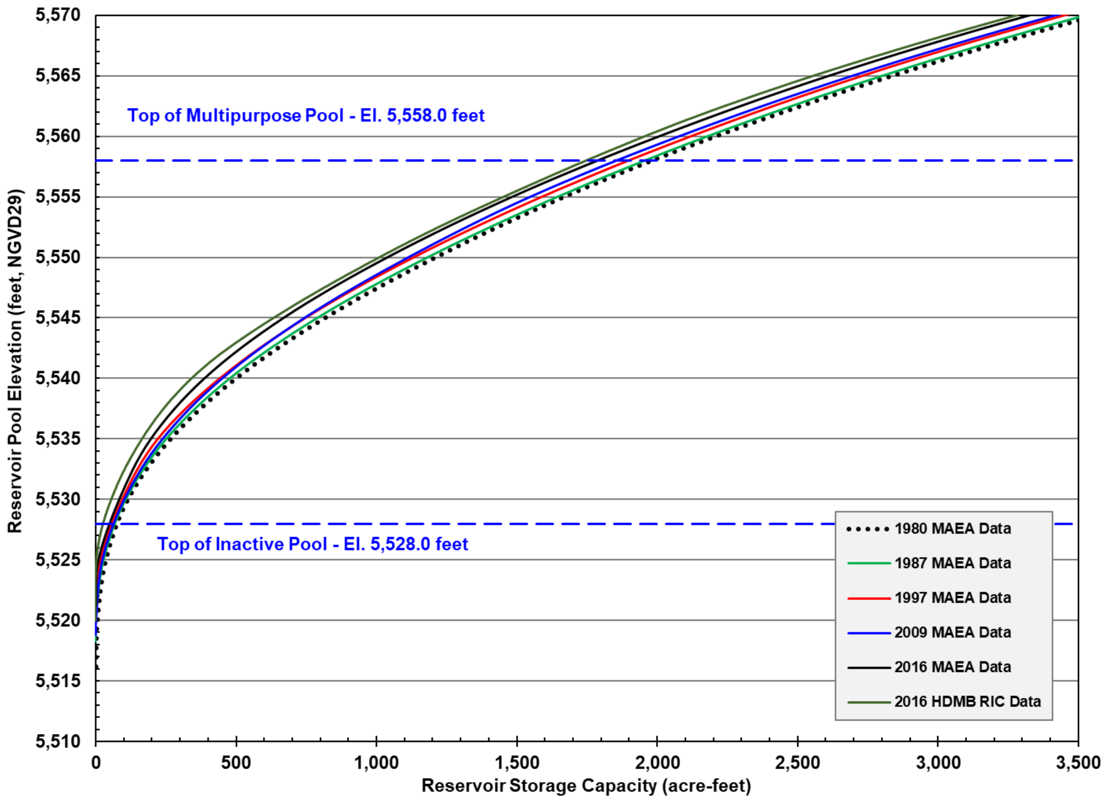

Figure 5-16. Bear Creek Lake – Reservoir Storage Capacity Profiles (El. 5510 – 5570)

5.7.3 Analysis of Reservoir Storage Capacity by Storage Zone

The changes in reservoir storage capacity for the different pool zones were analyzed to show the effects of sedimentation on a zone-by-zone basis. Table 5-10 tabulates reservoir capacity by zone for each sediment range survey and the 2016 LiDAR/HDMB DEM surface. A comparison of reservoir storage capacity between the 1980 and the 2016 sediment range data shows a steady decline in storage capacity at all pool zones.

Table 5-11 presents changes in reservoir capacity by pool zone. Figure 5-17 depicts the changes in reservoir storage capacity over time for each pool zone.

- The Gross Storage Pool Zone (elevation 5,510.0 – 5,635.5 feet, NGVD29) has experienced a < 1.0% decrease in storage capacity between 1980 and 2016.
- The Surcharge Pool Zone (elevation 5,635.5 – 5,684.5 feet, NGVD29) has experienced a < 1.0% increase in storage capacity between 1980 and 2016 using the GIS method.
- The Flood Control Pool Zone (elevation 5,558.0 – 5,635.5 feet, NGVD29) has experienced a 1.0% decrease in storage capacity between 1980 and 2016.
- There was also a 9.6% decrease in reservoir storage capacity for the Multipurpose Pool Zone (elevation 5,528.0 – 5,558.0 feet, NGVD29) using the GIS method.
- The largest decrease was in the Inactive Pool Zone (elevation 5,516.0 – 5,528.0 feet, NGVD29) where most sedimentation is occurring.
- There has been a 63.6% decline using the 2016 LiDAR/HDMB DEM surface data.

Table 5-10. Bear Creek Lake – Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Operational Pool Zone	Sediment Range Surveys (MAEA)					2016 GIS (DEM)
	1980	1987	1997	2009	2016	
GROSS STORAGE	**78,139**	**77,995**	**77,845**	**77,653**	**77,623**	**77,948**
Surcharge	47,335	47,289	47,216	47,199	47,288	47,666
Flood Control	28,825	28,752	28,730	28,600	28,550	28,534
Multipurpose	1,905	1,886	1,841	1,791	1,740	1,721
Inactive	74	69	58	63	47	27

Table 5-11. Bear Creek Lake – Changes in Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Operational Pool Zone	Sediment Range		2016 GIS (DEM)	1980 – 2016 MAEA		1980 – 2016 GIS	
	1980	2016		Change	% Rem.	Change	% Rem.
GROSS STORAGE	**78,139**	**77,623**	**77,948**	**-515**	**99.3**	**-191**	**99.8**
Surcharge	47,335	47,288	47,666	-47	99.9	+331	100.7
Flood Control	28,825	28,550	28,534	-276	99.0	-291	99.0
Multipurpose	1,905	1,740	1,721	-165	91.3	-184	90.4
Inactive	74	47	27	-27	63.0	-47	36.4

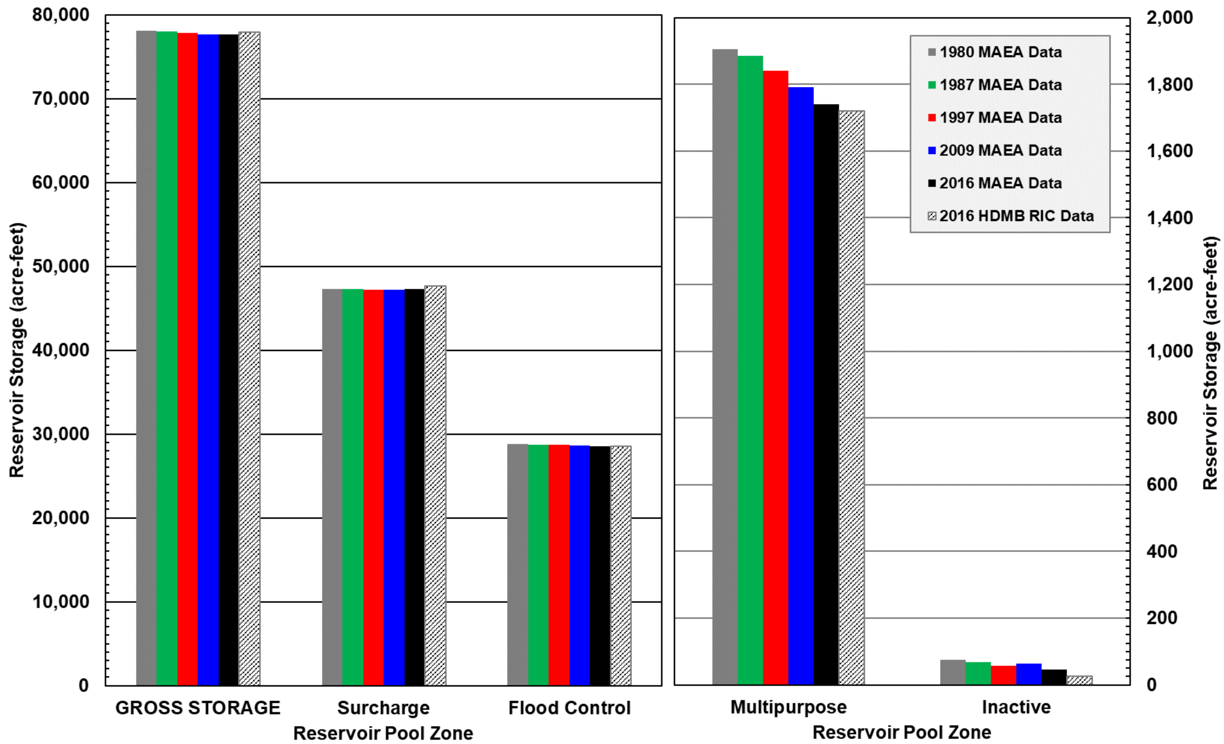

Figure 5-17. Bear Creek Lake – Changes in Reservoir Storage Capacity by Pool Zone (Acre-Feet)

5.8 Bear Creek Lake – Reservoir Storage Depletion

The purpose of this report was to evaluate the loss of reservoir storage volume due to sedimentation impacts at Bear Creek Lake as monitored by the Omaha District. Original sediment yield calculations, historical sediment depletion rates, and future aggradation trends will be evalutated in this section.

5.8.1 Original Sediment Yield Calculations

The original sediment yield calculations for Bear Creek were first reported in 1970 in DM No. PB-1 *Hydrology.* There were few observed historical sediment measurements for the Bear Creek basin. USGS sediment measurements on Clear Creek plus reservoir survey data on Cheesman Lake on the South Platte River and Nederlands Reservoir on Middle Boulder Creek provided the only basis for calculating sediment depletion rates. This data, adjusted for the characteristics of the Bear Creek basin and future urban development, provided a sediment depletion yield of 150 tons/mi^2 of basin per year. The total estimated sediment load from the Bear Creek basin was approximately 35,000 tons/year.

The design reservoir storage depletion rate for Bear Creek Lake was 20 acre-feet per year based on the calculated annual sediment yield rate of 150 tons/mi^2, a reservoir trap efficiency of 95%, and an average sediment deposit density of 75 lb/ft^3.

5.8.2 Analysis of Reservoir Sediment Depletion using Volume by Segment Tables

Bear Creek Lake volume by segment tables were calculated in 5-foot increments for all five surveys using the MAEA method. Individual segment tables are located in Appendix C. Table 5-12 tabulates reservoir volume by segment changes between 1980 and 2016 from the surveyed sediment ranges.

Data shows at the predominantly lake segments (001 through 004), there has been an average decrease of reservoir storage of 95.2 acre-feet (-0.9%). The upstream segments (005 through 012) show an average decrease of reservoir storage of 16.8 acre-feet (-0.4%). Only at segment 009 has there been an increase in reservoir storage of 6.0 acre-feet (+2.9%).

Table 5-12. Bear Creek Lake – Changes in Reservoir Storage Volume X Segment (Acre-Feet)

Seg. No.	Bounding Sediment Ranges	Sediment Range (MAEA)					1980 – 2016	
		1980	1987	1997	2009	2016	Change	%
001	DAM – BC-01	10,162	10,157	10,157	10,069	10,049	-113	-1.1
002	BC-01 – BC-02	13,393	13,378	13,378	13,297	13,263	-130	-1.0
003	BC-02 – BC-03	9,728	9,716	9,716	9,663	9,652	-76	-0.8
004	BC-03 – BC-04	12,175	12,163	12,163	12,122	12,113	-62	-0.5
005	BC-04 – BC-05	11,028	11,007	11,007	10,998	10,998	-30	-0.3
006	BC-05 – BC-06	13,273	13,241	13,241	13,218	13,236	-37	-0.3
007	BC-06 – BC-07	4,906	4,896	4,896	4,884	4,873	-33	-0.7
008	BC-07 – BC-08	1,377	1,374	1,374	1,351	1,356	-21	-1.5
009	BC-08 – END	209	208	208	204	215	+6	+2.9
010	BC-11 – END	166	157	157	163	162	-3	-1.9
011	BC-10 – END	1,184	1,180	1,180	1,163	1,183	-1	-0.1
012	BC-09 – END	1,155	1,133	1,133	1,135	1,140	-15	-1.3

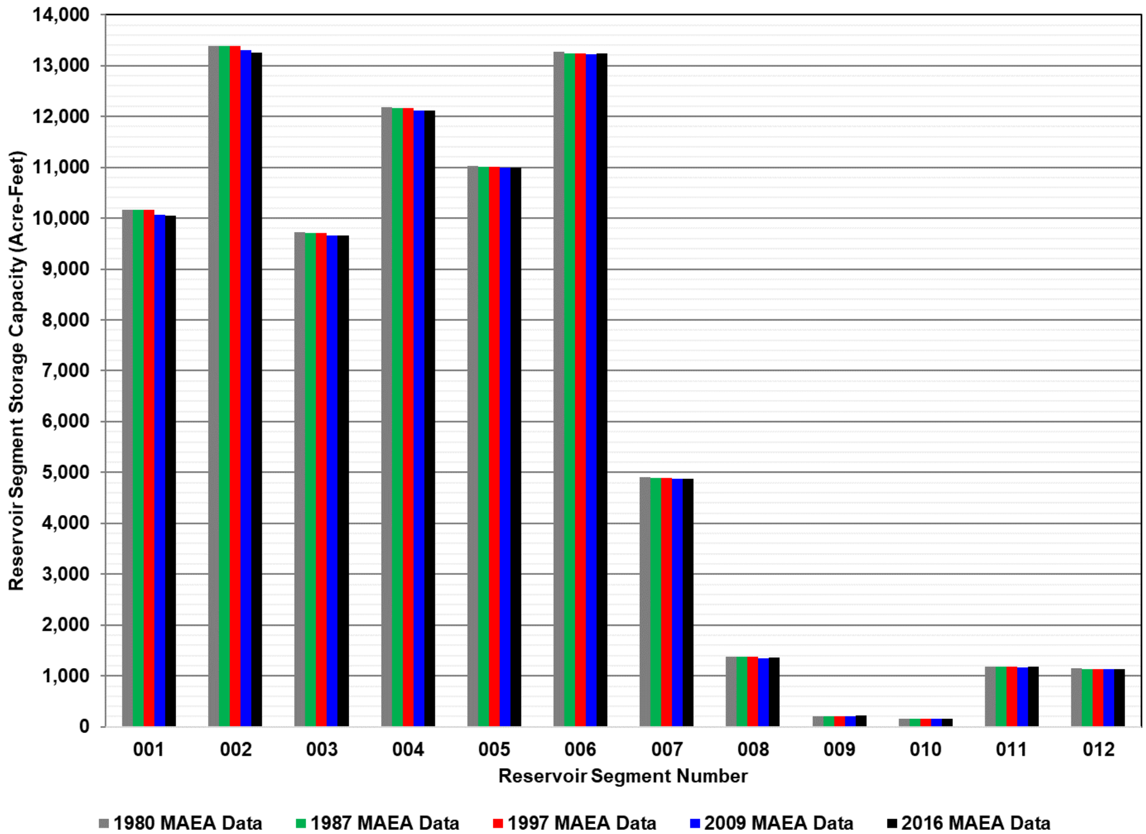

Figure 5-18. Bear Creek Lake – Changes in Reservoir Storage Volume X Segments

5.8.3 Analysis of Reservoir Storage Depletion Rates

The volume of sediment that entered the reservoir between surveys is represented by the reservoir storage capacity depletion rates as shown in Table 5-13. Gross storage depletion, between 1980 and 2016, at Bear Creek was a decrease of 14.3 acre-feet per year as generated by the MAEA method and a decrease of 5.3 acre-feet per year as generated by the GIS method. Both of these results were less than the design depletion rate of 20 acre-feet per year.

Table 5-13. Bear Creek Lake – Summary of Reservoir Storage Depletion Rates

(Sediment Range Surveys – MAEA and GIS Calculations)

Period [1980 – 2016] (Years)		**36**	
Drainage Area (mi²)		262	
Design Storage Depletion Rate (AF/YR)		20.0	
		MAEA	GIS
Total Reservoir Storage	% Storage Remaining	99.3	99.8
	% Annual Storage Depletion	-0.018	-0.007
	Depletion Rate (AF/YR)	-14.3	-5.3
	Normalized Depletion Rate (AF/mi²/YR)	-0.0546	-0.0202
Surcharge Storage	% Storage Remaining	99.9	100.7
	% Annual Storage Depletion	-0.003	0.019
	Depletion Rate (AF/YR)	-1.3	9.2
	Normalized Depletion Rate (AF/mi²/YR)	-0.0050	0.0351
Flood Control Storage	% Storage Remaining	99.0	99.0
	% Annual Storage Depletion	-0.027	-0.028
	Depletion Rate (AF/YR)	-7.7	-8.1
	Normalized Depletion Rate (AF/mi²/YR)	-0.0292	-0.0309
Multipurpose Storage	% Storage Remaining	91.3	90.4
	% Annual Storage Depletion	-0.241	-0.268
	Depletion Rate (AF/YR)	-4.6	-5.1
	Normalized Depletion Rate (AF/mi²/YR)	-0.0175	-0.0195
Inactive Storage	% Storage Remaining	63.0	36.4
	% Annual Storage Depletion	-1.027	-1.766
	Depletion Rate (AF/YR)	-0.8	-1.3
	Normalized Depletion Rate (AF/mi²/YR)	-0.0029	-0.0050

5.8.4 Analysis of Future Reservoir Storage Depletion

One of the objectives of M.R.B. Sediment Memorandum 23b was to predict future sediment conditions at Bear Creek Lake for 50 years into the future (2066). The assessment used area and capacity data and previously calculated depletion rates to estimate the change in reservoir storage capacity that might occur. Table 5-13 above lists the depletion rates, generated by both the MAEA and GIS methods between 1980 and 2016, that were used for this analysis. The results of this analysis can be seen below in Table 5-14.

Table 5-14. Future Bear Creek Lake – 2066 Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Pool Zone	Elevation Range (Feet, NGVD29)	1980 MAEA	2066 MAEA	Percentage Lost/Gained by 2066 (MAEA)*	2066 GIS	Percentage Lost/Gained by 2066 (GIS)*
Surcharge	5,635.5 – 5,684.5	47,335	47,222	-0.24%	48,126	+1.67%
Flood Control	5,558.0 – 5,635.5	28,825	28,167	-2.28%	28,129	-2.28%
Multipurpose	5,528.0 – 5,558.0	1,905	1,510	-20.71%	1,466	-9.64%
Inactive	Thalweg – 5,528.0	74	9	-87.85%	0	-100.00%

*Loss indicated by minus (-) sign, and gain indicated by plus (+) sign.

The 50-year projection shows an apparent increase in capacity with both methods. However, the changes since 1980 is well within the noise of the data and the limited accuracy of the capacity estimation methods. It would be foolhardy to predict the reservoir will gain capacity based on these small, measured changes over the last 36 years. Under normal climate conditions, the reservoir will likely not experience a capacity increase, rather it will retain its current capacity for the next 50 years.

5.9 Bear Creek Lake – Engineering Form 1787 (Reservoir Sediment Data Summary)

Engineering Form 1787, “Reservoir Sedimentation Data Summary” is presented in Appendix G. The purpose of this form is to provide a means for the uniform documentation of pertinent Bear Creek Lake sedimentation data.

6 Chatfield Lake

6.1 Chatfield Lake – Project Background

Chatfield Dam and Reservoir are located on the South Platte River immediately downstream of the confluence of the South Platte River and Plum Creek at RM 321. The dam and reservoir are in the South Platte River basin about 8 miles south of Denver, Colorado. The right abutment of the dam is located in Douglas County and the left abutment is located in Jefferson County.

Chatfield Dam was constructed by the U.S. Army Corps of Engineers for the primary purpose of mitigating flood risk to downstream metropolitan Denver from floods originating above the dam. Additional authorized purposes include water supply, recreation, and fish and wildlife enhancement. The dam provides additional benefit from the development and use of the multipurpose zone for recreation purposes.

The dam is constructed of rolled, zoned earthfill with a crest length of 13,057 feet, top of dam elevation of 5,527.0 feet, LPVD, and a crest width of 30 feet. The maximum height of the embankment is approximately 137 feet across the valley and 147 feet where it crosses the South Platte River. The spillway is located on the left abutment. The spillway crest elevation is 5,500.0 feet, LPVD.

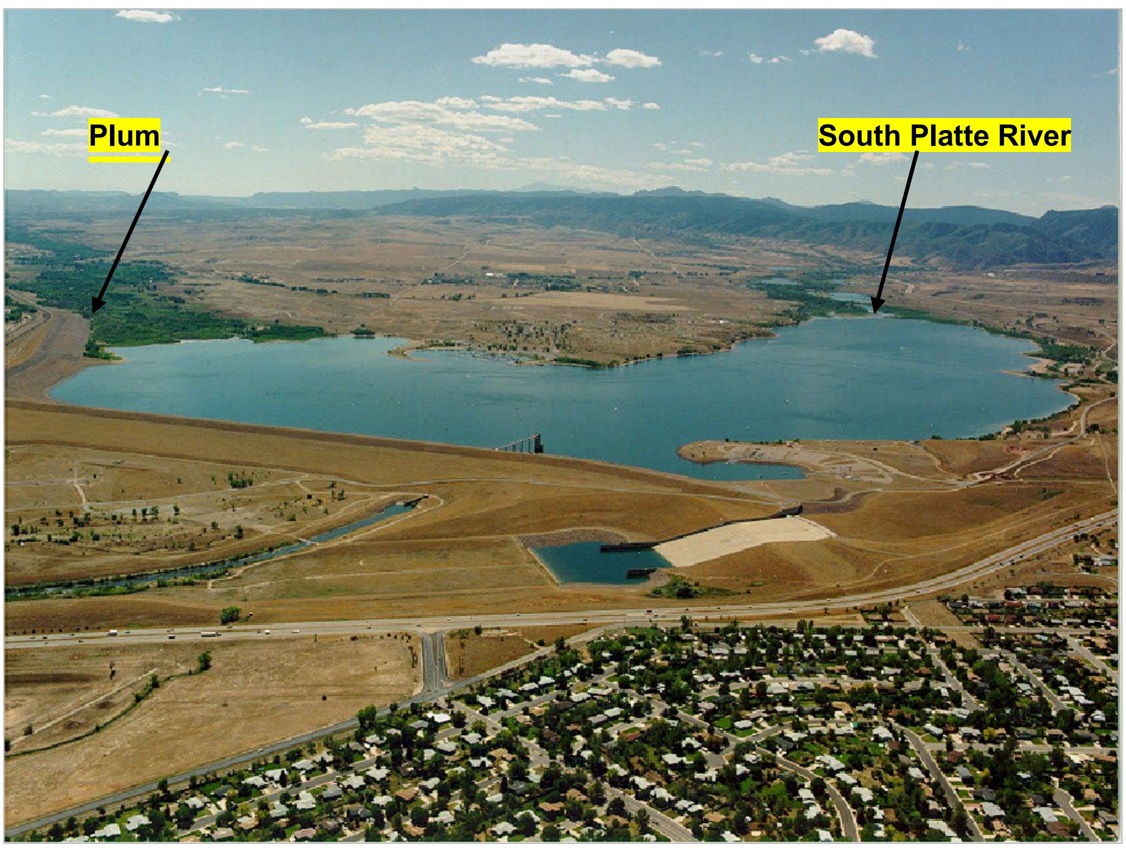

Figure 6-1. Aerial Photograph of Chatfield Lake (RARE database file photo)

Table 6-1. Chatfield Lake – Summary of Engineering Data

ITEM NO.	SUBJECT	CHATFIELD LAKE	
	GENERAL		
1	Location of Dam		8 miles south of Denver, Colorado
2	River & River Mile		South Platte River @ RM 321
3	Drainage Area		3,018 mi^2
4	Reservoir Length		2.0 mi @ Elevation 5,430.0 feet, NGVD29
5	Location of Dam Tender		On Site
6	Travel Time to Missouri River		2 weeks
7	Maximum Discharge of Record	110,000 cfs	June 1965
8	Maximum Pool of Record	5,448.5 feet, LPVD	June 2015
	DAM AND EMBANKMENT		
9	Top of Dam		5,527.0 feet, NGVD29
10	Length of Dam		13,136 feet
11	Height of Dam		147 feet
12	Stream Bed		5,380.0 feet, NGVD29
13	Abutment Formation		Sandy Overburden – Dawson Formation
14	Type of Fill		Rolled Earth
15	Fill Quantity		14,650.000 yds^3
16	Date of Closure		August 1973
17	Date of Initial Fill (Base F.C.)		June 1979
	SPILLWAY		
18	Discharge Capacity		188,000 cfs @ Elevation 5,521.6 feet, NGVD29
19	Crest Elevation		5,500.0 feet, NGVD29
20	Width		500 feet
21	Gates, Number, Size, Type		Ungated Converging Chute
	RESERVOIR POOL BY ELEVATION	**ELEVATION (NGVD29) & SURFACE AREA – 2016 DEM Surface**	
22	**Maximum Pool**	**5,521.6 feet**	**6,004 acres**
23	**Top of Flood Control Pool**	**5,500.0 feet**	**4,739 acres**
24	**Top of Multipurpose Pool**	**5,432.0 feet**	**1,487 acres**
25	**Top of Inactive Pool**	**5,385.0 feet**	**39 acres**
	RESERVOIR STORAGE ZONES	**ELEVATION (NGVD29) & STORAGE CAPACITY – 2016 DEM Surface**	
26	**Surcharge**	**5,500.0 feet – 5,521.6 feet**	**116,486 acre-feet**
27	**Flood Control**	**5,432.0 feet – 5,500.0 feet**	**207,655 acre-feet**
28	**Multipurpose**	**5,385.0 feet – 5,432.0 feet**	**28,521 acre-feet**
29	**Inactive**	**5,377.0 feet – 5,385.0 feet**	**299 acre-feet**
30	**GROSS STORAGE**	**Thalweg – 5,521.6 feet**	**352,961 acre-feet**
	OUTLET WORKS		
31	Number and Size – Conduits		2 – 11 X 16 feet, Oval
32	Conduit Length		1,280 feet
33	Number – Size – Type Gates		2 – 6 X 13.5 feet, Hydraulic Slide
			2 – 2 X 2 feet, Slide Gate on Gate
			1 – 72-inch Butterfly
34	Discharge Capacity		8,400 cfs @ Elevation 5,500.0 feet, LPVD
35	**POWER INSTALLATION**		None

6.2 Chatfield Lake – Reservoir Inflow, Outflow, and Pool Elevation

Pool elevation data has been collected at Chatfield Lake since 1977. Operation of the Tri-Lakes Reservoirs generally require both individual and system reservoir regulation. The maximum and minimum pool elevations of record are tabulated in Table 6-2. A historical pool elevation profile is shown in Figure 6-2.

Table 6-2. Chatfield Lake – Summary of Reservoir Inflow, Outflow, & Pool Elevation Events

Daily Inflow and Date			Maximum Pool Elevation (NGVD29) and Date		
Highest	3,896 cfs	12 Jun 2015	**Highest**	5,448.5 feet	06 Jul 1995
2nd	3,394 cfs	01 Jul 1995	**2nd**	5,447.6 feet	25 May 1980
3rd	3,370 cfs	29 May 1983	**3rd**	5,447.1 feet	29 Jun 1983
Daily Outflow and Date			**Minimum Pool Elevation (NGVD29) and Date**		
Highest	3,350 cfs	06 Jul 1995	**Lowest**	5,422.9 feet	31 Oct 2006
2nd	3,067 cfs	19 Jun 2015	**2nd**	5,423.0 feet	29 Aug 2003
3rd	3,034 cfs	14 May 1984	**3rd**	5,423.1 feet	03 Aug 2004

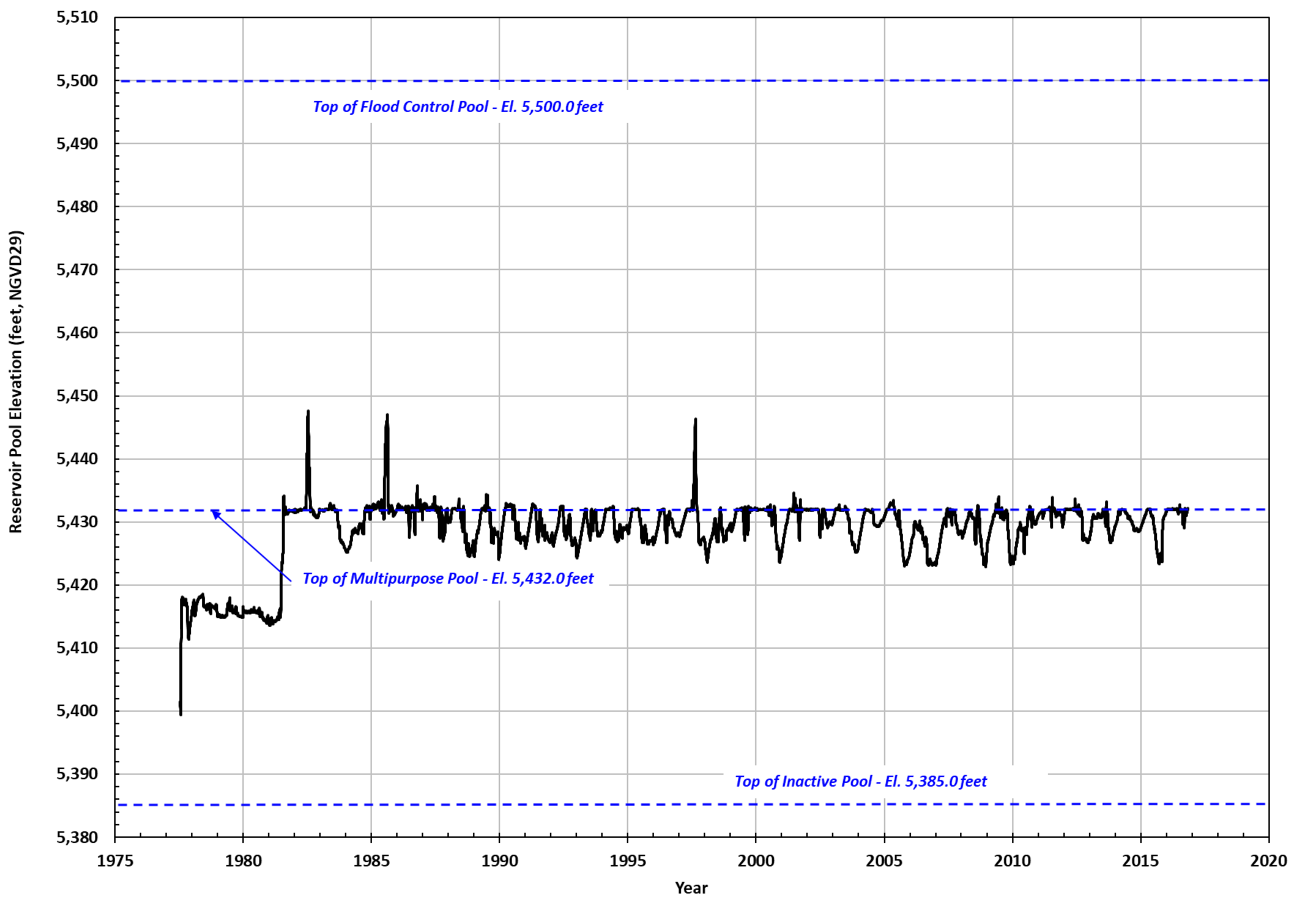

Figure 6-2. Chatfield Lake – Reservoir Pool Elevations

6.3 Chatfield Lake – Survey Data

6.3.1 Chatfield Sediment Ranges

There are twenty-two (22) established sediment aggradation ranges that are used to monitor sedimentation at Chatfield Lake as shown in Figure 6-3. Individual sediment range cross section profiles are shown in Appendix A. Each profile shows the entire surveyed cross section from end monument left bank to end monument right bank. Analysis of changes in the sediment range profiles are discussed in Section 6.3.3.

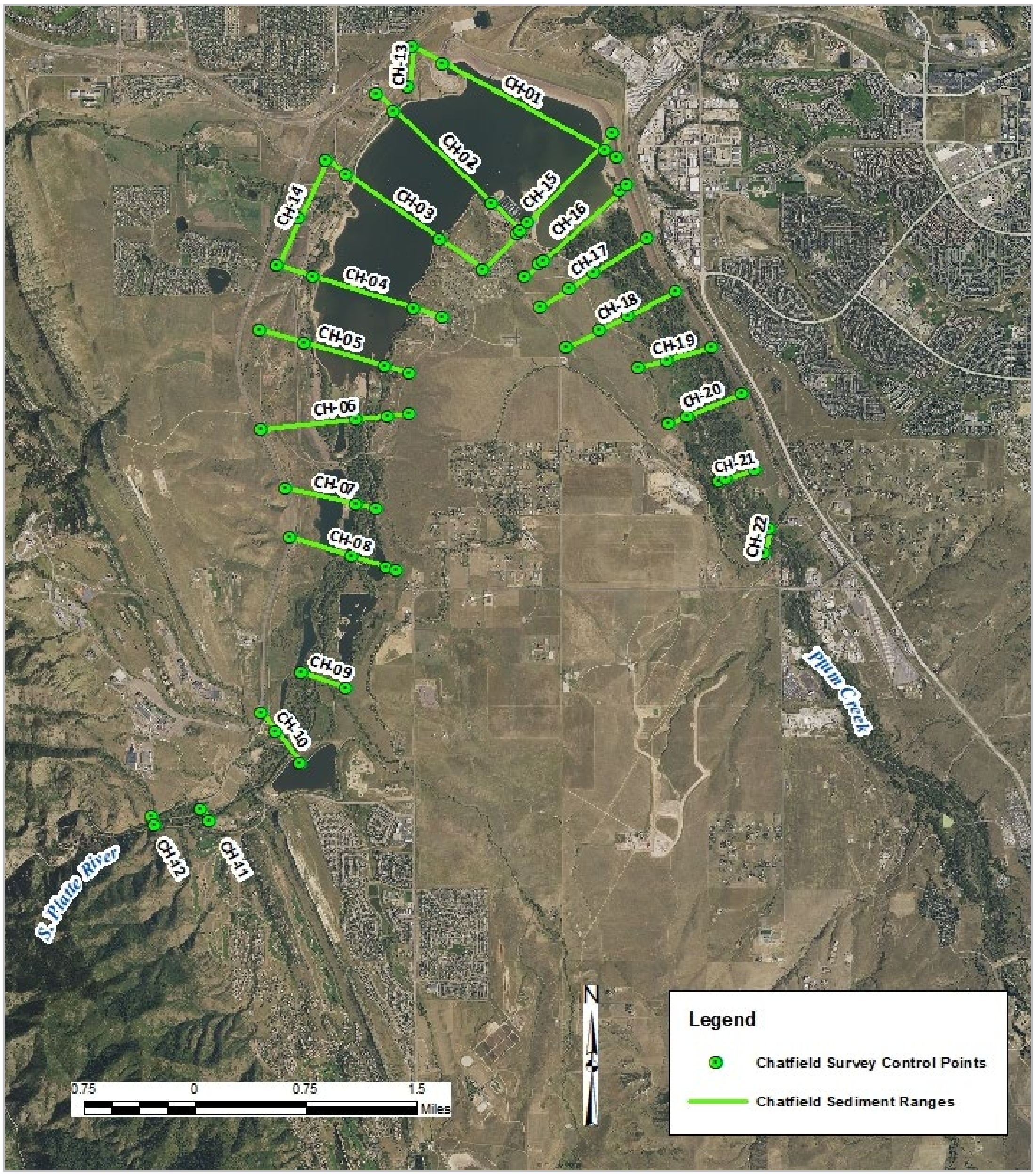

Figure 6-3. Chatfield Lake – Sediment Range Location Map

6.3.2 2016 Chatfield Sediment Range Surveys

A survey crew under Architect-Engineer (A-E) contract to the Omaha District completed surveys for all 22 sediment ranges at Chatfield Lake. Additionally, the Omaha District in-house survey crew collected high-density hydrographic survey data at 200-feet line spacing for mapping purposes at the lake. Shortened metadata files for these surveys are found in Table 6-3 and Table 6-4, respectively.

Table 6-3. Chatfield Lake – Brief Metadata from the Sediment Range Surveys Completed by A-E Contract in 2016

Location	Chatfield Lake
Survey Date(s)	October 01 – 04, 2016
Surveyed By	Stockwell Engineer, Contract W9128F-14-D-0001, Delivery Order No. 0004
Equipment	TRIMBLE R8 GPS Receivers TRIMBLE TDL450 Radios TRIMBLE Business Center HYPACK® Hydrographic Surveying Software ODOM CVM Echo Sounder ODOM Digibar Pro Sound Velocity Profiler Boat, 24-feet long w/cabin
Horizontal Datum	Colorado State-Plane Coordinate System, NAD83, Central Zone 0502
Vertical Datum	NAVD88 & converted to NGVD29 using USACE CorpsCon 6.0.1 software
Units	U.S. Survey Feet
Accuracy	3rd Order Horizontal & Vertical Accuracy per EM 1110-2-1003

Table 6-4. Chatfield Lake – Brief Metadata for 2016 HDSB Surveys

Location	Chatfield Lake
Survey Date(s)	August 03 – 05, 2016
Surveyed By	Omaha District, River and Reservoir Engineering Section (CENWO-ED-HF)
Equipment	TRIMBLE R8 GPS Receivers,TD 450 H Radios, & Geomatics Office Software HYPACK® Hydrographic Surveying Software ODOM CV100 Echo Sounder, Digibar Pro Sound Velocity Profiler Boat, Boat #417, 22-feet long w/cabin Boat, Boat #402, 20-feet long
Horizontal Datum	Colorado State-Plane Coordinate System, NAD83, Central Zone 0502
Vertical Datum	NAVD88 & converted to NGVD29 using USACE CorpsCon 6.0.1 software
Units	U.S. Survey Feet
Accuracy	3rd Order Horizontal & Vertical Accuracy per EM 1110-2-1003

6.3.3 Analysis of 2016 Sediment Range Cross Section Data

Cross sectional plots are shown in Appendix A. Analysis of the changes in the sediment range cross sections are as follows.

6.3.3.1 Sediment Ranges CH-01, CH-02, CH-03, CH-04, CH-05, & CH-15

These six ranges are mostly underwater when the pool is at the top of the Multipurpose Pool (elevation 5,432.0 feet, NGVD29). All six ranges show approximately 1 to 3.5 feet of deposition across the bottom of the lake between 1977 and 2016. The Plum Creek range line CH-15 intersects the South Platte range line CH-01 and connects to the end points of the range lines CH-02, and CH-03 as shown in Figure 6-3. The original South Platte River channel is generally visible along range lines CH-01 and CH-03 through CH-05.

6.3.3.2 Sediment Ranges CH-06, CH-07, CH-08, CH-09, & CH-10

These sediment ranges have 1 to 5 feet of deposition across the original channel between 1977 and 2016.

6.3.3.3 Sediment Ranges CH-11 & CH-12

These sediment ranges have 1 to 3 feet of deposition across the original channel between 1977 and 2016.

6.3.3.4 Sediment Ranges CH-13 & CH-14

These sediment ranges have 1 to 3.5 feet of deposition across the original channel between 1977 and 2016.

6.3.3.5 Sediment Ranges CH-16, CH-17, CH-18, CH-19, CH-20, CH-21, & CH-22

These sediment ranges have 1 to 5.5 feet of deposition across the original channel between 1977 and 2016.

6.3.4 2016 High Density Survey Bathymetry

Both HDSB and HDMB bathymetry were collected. For the HDSB, the first survey line at Chatfield was established 25 feet parallel from where the water's edge meets the embankment of the dam. Additional upstream survey lines were spaced parallel to the first, approximately 200 feet apart. In the southern end of the South Platte River arm of the reservoir, survey lines were established perpendicular to the rest of the survey lines for the reservoir as shown in Figure 6-4. Data was collected in areas where navigation by boat was possible, usually at depths of three feet or greater. Two survey lines circled the perimeter of the shoreline as close the bank as possible. One survey line circled at ± 50 feet while the second circled ± 100 feet from the bank to ensure shallow water coverage. No wading was attempted because of personal safety concerns.

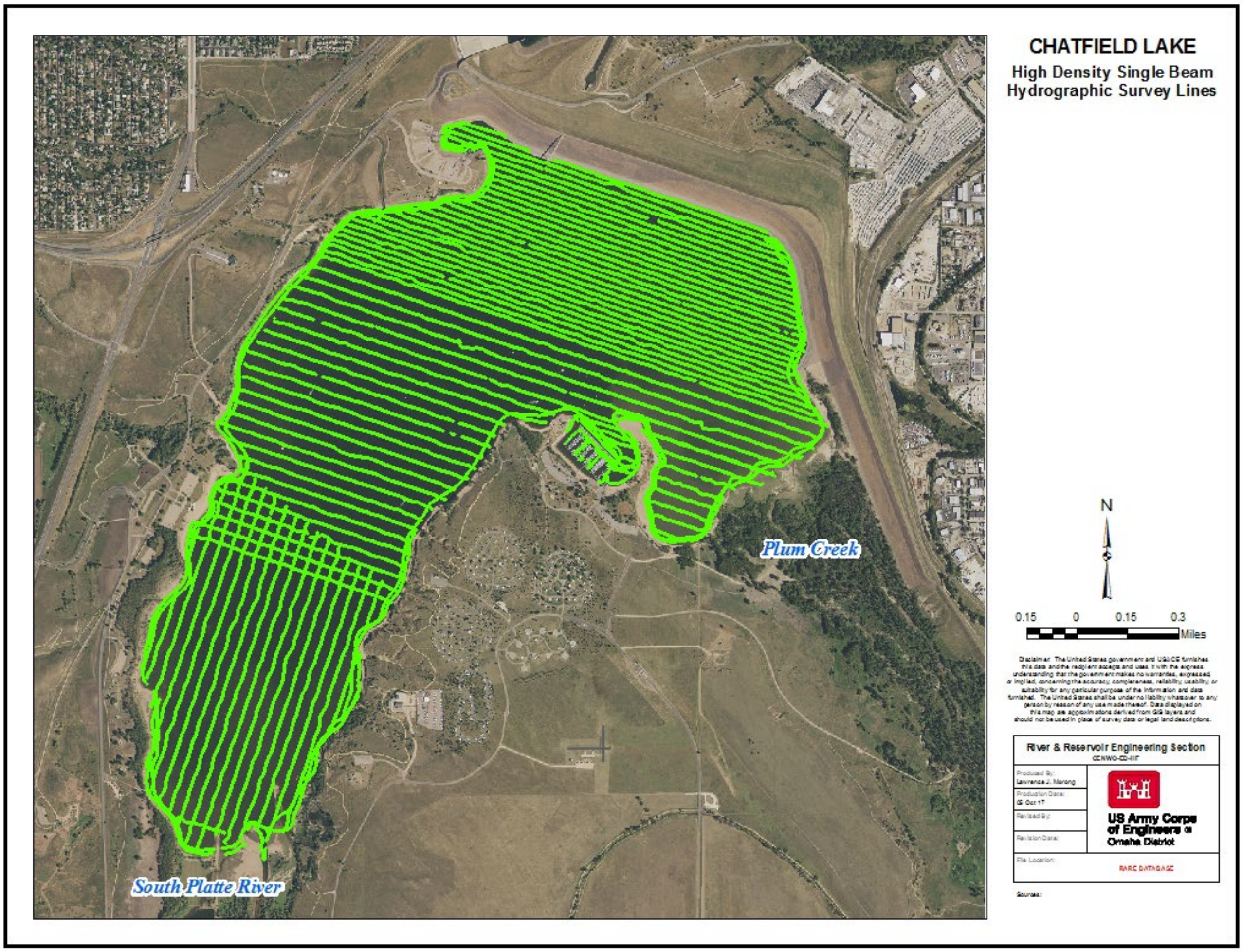

Figure 6-4. Chatfield Lake – HDSB Survey Lines Location Map

6.3.5 2016 Reservoir Contour Map from LiDAR & HDSB Bathymetric DEM Surface

A product of the GIS method of the combined 2016 LIDAR/high density DEM surface are reservoir contours. Figure 6-5 shows the shaded contours in 5-foot increments for Chatfield Lake created from the HDSB surface. There is no earlier contour data to make surface area or volume comparisons.

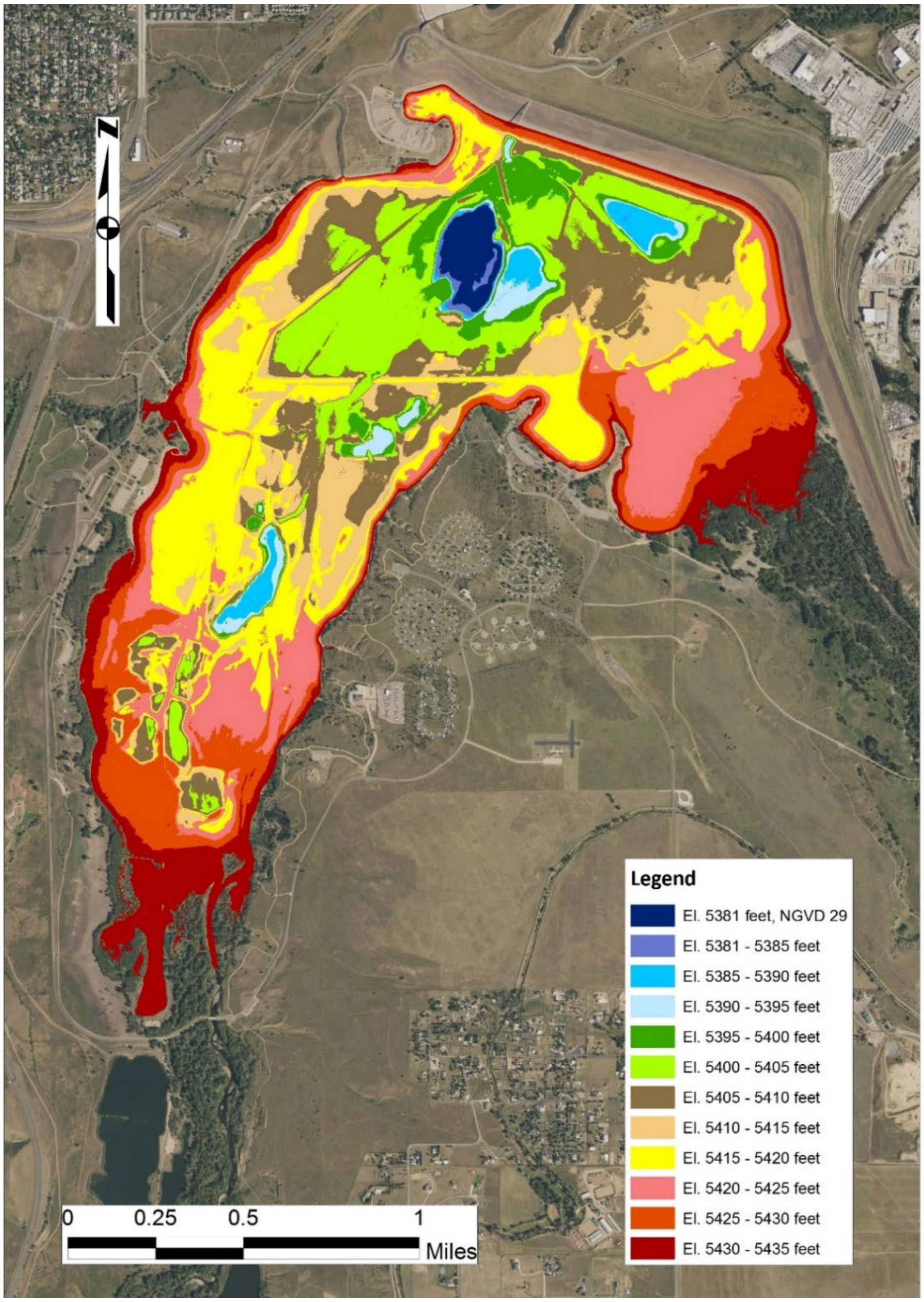

Figure 6-5. Chatfield Lake – Lake Contour Map from 2016 HDSB Surveys (NGVD29)

6.4 Chatfield Lake – Analysis of Shoreline Erosion

Sediment ranges CH-01 through CH-05 and CH-15 cross Chatfield Lake at the Multipurpose Pool elevation of 5,432.0 feet, NGVD29. Cross section analysis of the left and right banks of these six ranges indicate that no appreciable shoreline erosion has occurred between 1977 and 2016.

6.5 Chatfield Lake – Analysis of 2016 Bed Material Data

There is only a limited amount of bed material data available for Chatfield Lake. Additional bed material was collected at all sediment ranges during the 2016 USACE cross section surveys. Each sample was graded by mechanical sieve analysis in accordance with ASTM D422 and EM 1110-2-1960. The 2016 Chatfield bed material data set (including data tables, Malvern and sieve analysis, and photographs) is tabulated in Appendix B. A location map of where individual samples were collected is shown in Figure 6-6.

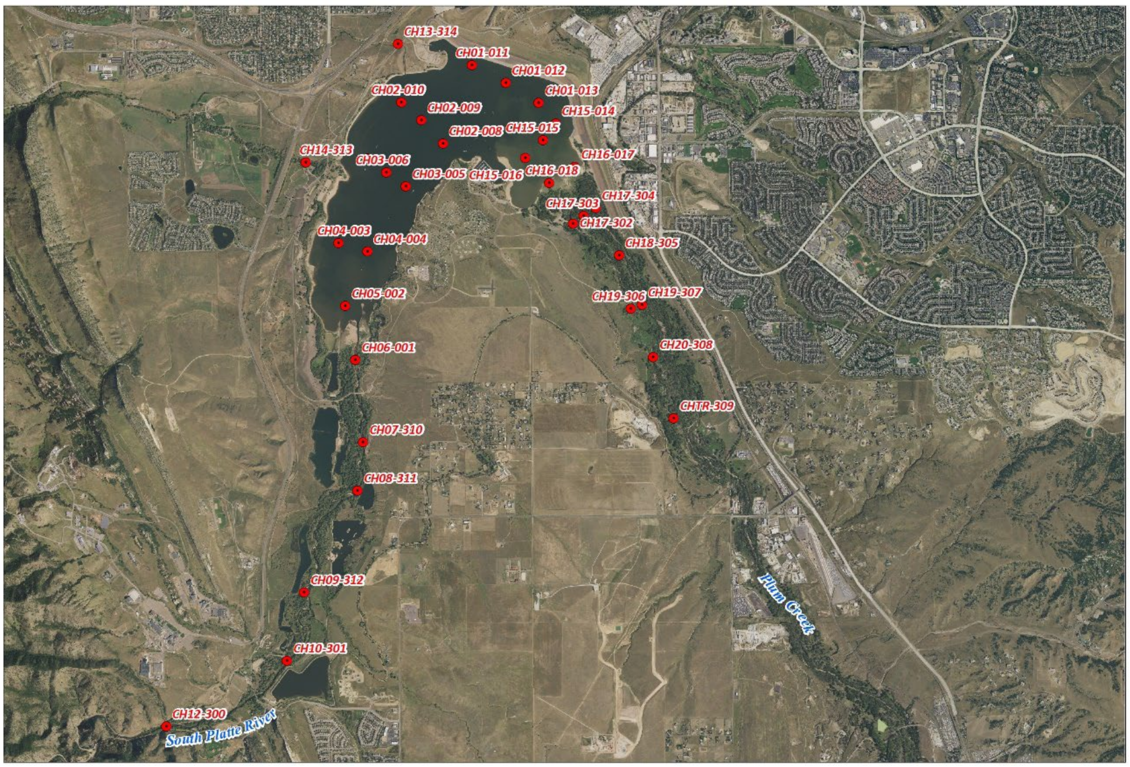

Figure 6-6. Chatfield Lake – 2016 Bed Material Sample Locations

6.5.1 Analysis of Bed Material Samples (Chatfield Lake)

Bed material samples were collected by boat in 2016. These samples were analyzed using the Malvern Analysis method, and their particle sizes are plotted in Figure B-6 in Appendix B. Analysis indicates that the samples are predominantly silts with an average D_{50} particle size of about 0.013 mm (fine silt). A sieve analysis plot can be found in Figure B-7 in Appendix B.

6.5.2 Analysis of Bed Material Samples (South Platte River and Plum Creek)

The upstream bed material samples at the South Platte River and Plum Creek channels were collected by hand with a shovel and placed in glass jars for transport. Mechanical analysis of the bed material outside of the Multipurpose Pool indicate an average D_{50} particle size of about 0.858 mm (coarse sand) for the South Platte River samples and about 1.67 mm (very coarse sand) for the Plum Creek samples. Sieve analysis plots of the upstream samples can be found in Figure B-8 and Figure B-9 in Appendix B. A special set of samples were collected in 1994 in support of a sediment investigation of the Plum Creek tributary arm, and the particle size distribution plot of these samples can be seen in Figure B-10 in Appendix B.

6.6 Chatfield Lake – Reservoir Hydraulic Elements

Reservoir hydraulic elements are a tool for the analysis of five channel geometry parameters relative to a reference plane elevation. Parameters analyzed include the active channel width, cross sectional area, average channel depth, average bed elevation, and thalweg elevation data was used in this report. These factors are calculated from cross section data sets for each sediment range for selected survey years during the reservoir surface area and storage capacity analysis process. The reference plane elevation chosen for Chatfield Lake was elevation 5,500.0 feet, NGVD29, which is the top of the Flood Control Pool.

Hydraulic element calculations, generated by the OUP, have been compiled for the 1977, 1991, 1998, 2010, and 2016 surveys.

6.6.1 Analysis of Cross Section Average Depth Profiles

Cross section average depth data for the South Platte River and Plum Creek are tabulated in Table 6-5, and plotted profiles are shown in Figure 6-7 and Figure 6-8. The average depth at the South Platte River channel decreased < 0.6 feet for sediment ranges CH-01 through CH-06 from 1977 to 2016. During this period, the average depth decreased 0.6 feet at sediment range CH-01 suggesting aggradation has occurred near the dam. The average depth at the South Platte River channel decreased < 0.3 feet for sediment ranges CH-07 through CH-11 from 1977 to 2016.

The average depth at the Plum Creek tributary increased < 0.5 feet from 1977 to 2016.

Table 6-5. Chatfield Lake – Changes in Cross Section Average Depth Profiles (Feet)

Tributary Stream	Sediment Range	Survey Year					
		1977	1991	1998	2010	2016	1977 – 2016
South Platte River Channel	CH-01	-86.5	-86.5	-86.0	-85.7	-85.9	**+0.6**
	CH-02	-81.5	-81.5	-81.3	-81.3	-81.3	**+0.2**
	CH-03	-59.6	-59.4	-59.5	-59.5	-59.2	**+0.4**
	CH-04	-62.6	-62.2	-62.5	-61.5	-61.6	**+1.0**
	CH-05	-64.2	-64.0	-63.5	-63.1	-63.3	**+0.9**
	CH-06	-52.8	-52.7	-52.7	-52.8	-52.6	**+0.3**
	CH-07	-44.4	-44.4	-44.4	-44.2	-44.5	**-0.1**
	CH-08	-49.6	-49.8	-49.7	-50.0	-50.1	**-0.5**
	CH-09	-28.6	-28.8	-28.7	-28.5	-28.7	**0.0**
	CH-10	-11.9	-11.5	-11.0	-12.1	-12.3	**-0.5**
	CH-11	-2.5	-2.9	-3.1	-3.1	-2.9	**-0.4**
	CH-12						
Plum Creek Channel	CH-15	-63.8	-63.5	-63.3	-63.4	-63.4	**+0.4**
	CH-16	-53.7	-53.2	-53.3	-52.4	-53.2	**+0.5**
	CH-17	-48.3	-47.7	-47.9	-47.9	-48.0	**+0.4**
	CH-18	-35.8	-35.5	-35.3	-36.0	-36.0	**-0.1**
	CH-19	-34.4	-35.5	-33.8	-33.8	-33.5	**+0.9**
	CH-20	-21.9	-21.0	-21.0	-21.2	-21.6	**+0.3**
	CH-21	-6.1	-6.0	-5.8	-5.7	-5.7	**+0.4**
	CH-22						

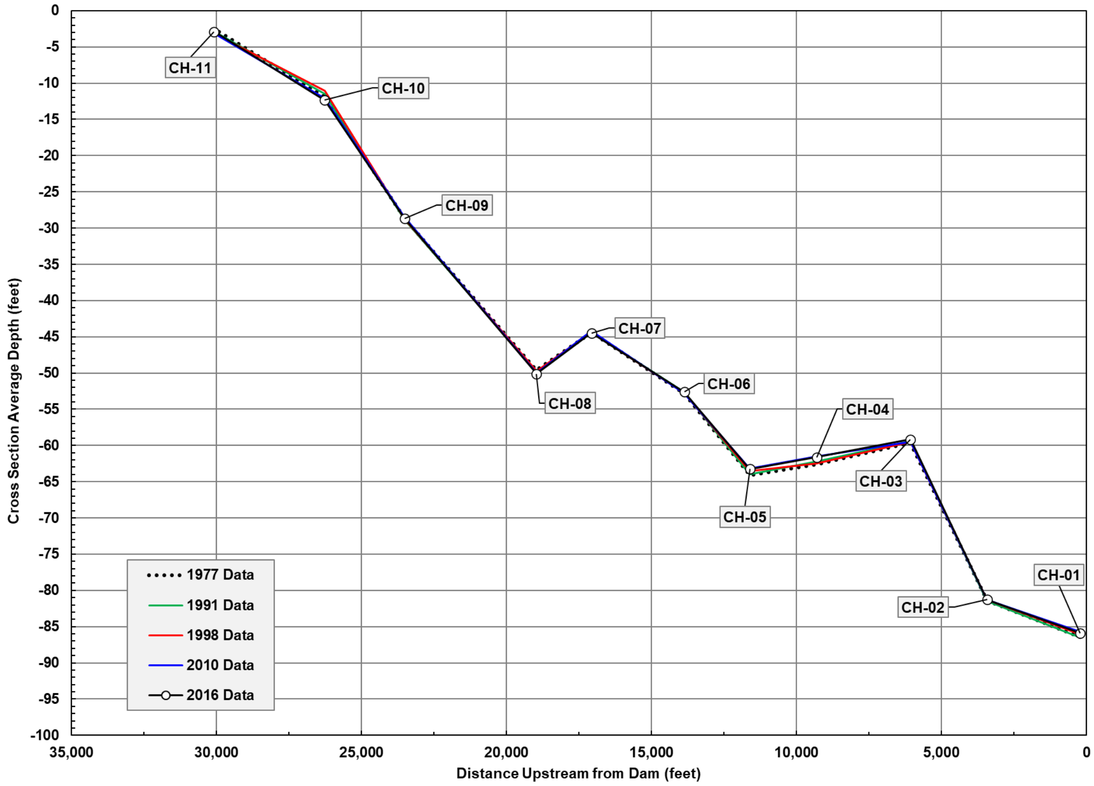

Figure 6-7. South Platte River – Changes in Cross Section Average Depth Profiles

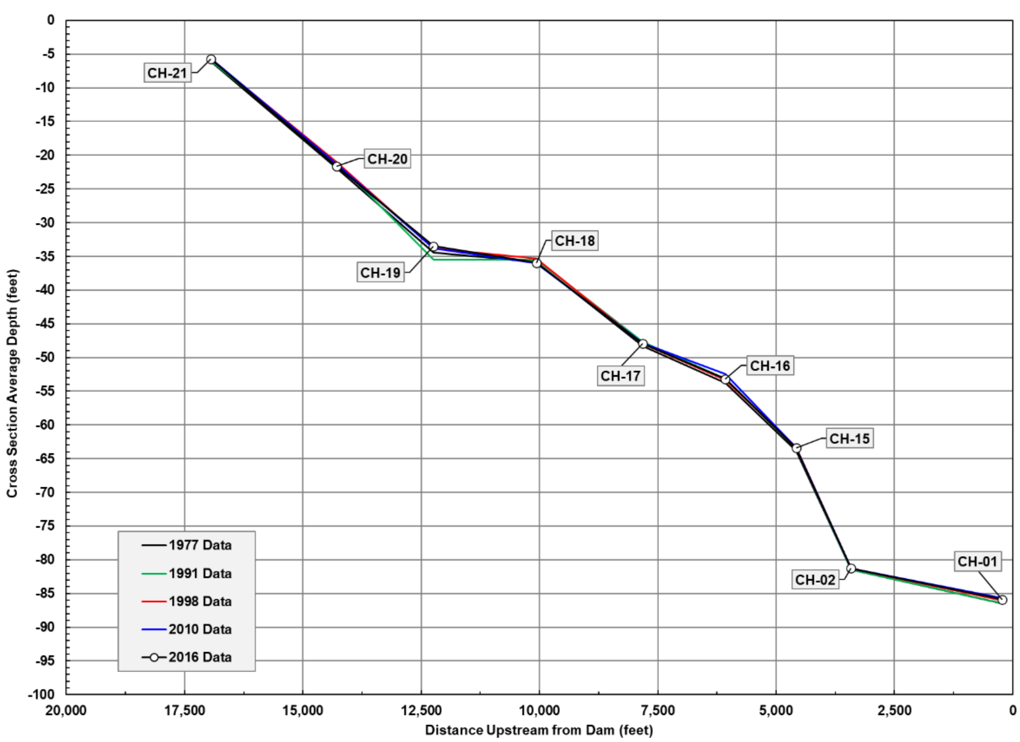

Figure 6-8. Plum Creek – Changes in Cross Section Average Depth Profiles

6.6.2 Analysis of Cross Section Average Bed Elevation Profiles

Cross section average bed elevation data for the South Platte River and Plum Creek are tabulated in Table 6-6, and plotted profiles are shown in Figure 6-9 and Figure 6-10. The average bed elevation at the South Platte River channel increased < 1.0 foot for sediment ranges CH-01 through CH-06 from 1977 to 2016 while the average depth at the South Platte River channel decreased < 0.5 feet for sediment ranges CH-07 through CH-11 from 1977 to 2016. During this period, the average bed elevation increased 0.6 feet at sediment range CH-01 suggesting limited aggradation has occurred near the dam.

The average bed elevation at the Plum Creek tributary increased < 1 foot for sediment ranges CH-16 through CH-21 from 1977 to 2016.

Table 6-6. Chatfield Lake – Changes in Cross Section Average Bed Elevations (Feet, NGVD29)

Tributary Stream	Sediment Range	Survey Year					
		1977	1991	1998	2010	2016	1977 – 2016
South Platte River Channel	CH-01	5,413.5	5,413.5	5,414.0	5,414.3	5,414.1	**+0.6**
	CH-02	5,418.5	5,418.5	5,418.7	5,418.7	5,418.7	**+0.2**
	CH-03	5,440.4	5,440.6	5,440.5	5,440.6	5,440.8	**+0.4**
	CH-04	5,437.4	5,437.8	5,437.5	5,438.5	5,438.4	**+1.0**
	CH-05	5,435.9	5,436.0	5,436.5	5,436.9	5,436.7	**+0.9**
	CH-06	5,447.2	5,447.3	5,447.3	5,447.2	5,447.4	**+0.2**
	CH-07	5,455.6	5,455.6	5,455.6	5,455.8	5,455.5	**-0.1**
	CH-08	5,450.4	5,450.2	5,450.3	5,450.0	5,449.9	**-0.5**
	CH-09	5,471.4	5,471.2	5,471.3	5,471.5	5,471.3	**0.0**
	CH-10	5,488.2	5,488.6	5,489.0	5,487.9	5,487.7	**-0.5**
	CH-11	5,497.5	5,497.1	5,496.9	5,496.9	5,497.1	**-0.4**
	CH-12						
Plum Creek Channel	CH-15	5,436.2	5,436.5	5,436.7	5,436.7	5,436.6	**+0.4**
	CH-16	5,446.3	5,446.8	5,446.7	5,447.6	5,446.8	**+0.5**
	CH-17	5,451.7	5,452.3	5,452.1	5,452.1	5,452.0	**+0.4**
	CH-18	5,464.2	5,464.5	5,464.7	5,464.0	5,464.0	**-0.1**
	CH-19	5,465.6	5,464.5	5,466.2	5,466.2	5,466.5	**+0.9**
	CH-20	5,478.1	5,479.0	5,479.0	5,478.8	5,478.4	**+0.3**
	CH-21	5,493.9	5,495.0	5,494.2	5,494.3	5,494.3	**+0.4**
	CH-22						

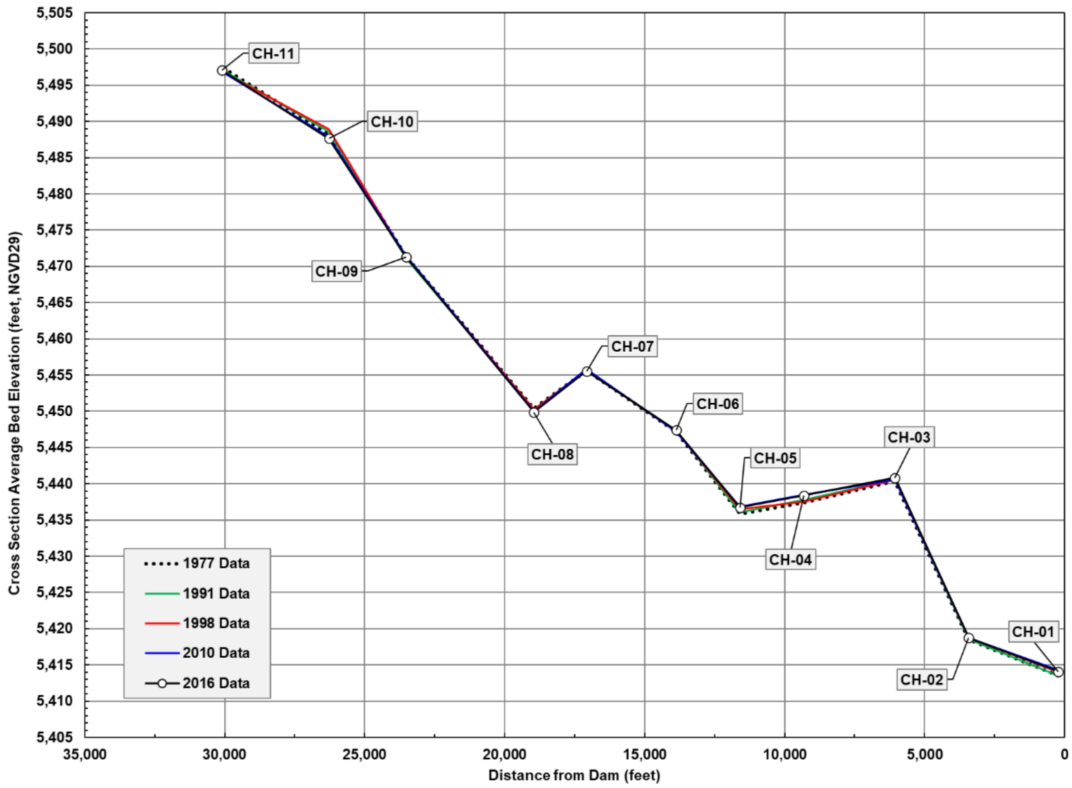

Figure 6-9. South Platte River – Changes in Cross Section Average Bed Elevation Profiles

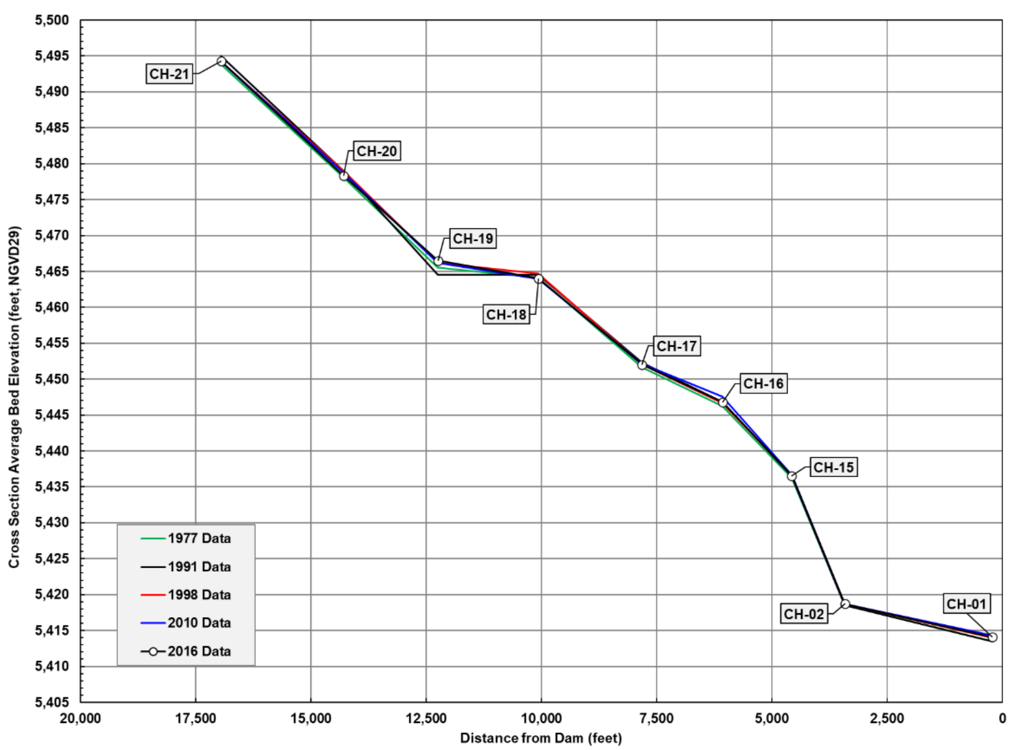

Figure 6-10. Plum Creek – Changes in Cross Section Average Bed Elevation Profiles

6.6.3 Analysis of Cross Section Thalweg Profiles

The channel thalweg is the lowest, surveyed elevation in the cross section for each sediment range line at Chatfield Lake. Increases in thalweg elevations result from sediment deposition in the stream channel and the old overbanks. The South Platte River and Plum Creek thalweg elevation data is presented in Table 6-7. Plotted thalweg profiles for the South Platte River and Plum Creek are shown in Figure 6-11 and Figure 6-12. For sediment ranges CH-01 through CH-06, the thalweg elevation increased from +0.3 feet at sediment range CH-02 to +8.8 feet at sediment range CH-05. For sediment ranges CH-07 through CH-12, the thalweg elevation increased from +0.9 feet at sediment range CH-07 to -1.6 feet at sediment range CH-10.

The thalweg profiles for the Plum Creek tributary show that this is a dynamic reach with both aggrading and degrading areas. Thalweg elevations have increased +1.6 feet at CH-17 to +6.0 feet at CH-22 while CH-18 decreased -3.7 feet and CH-19 decreased -1.0 feet, respectively.

Sediment ranges CH-13 and CH-14 are located on two unnamed tributaries of Chatfield Lake and are not included in any figure. The thalweg elevation has increased +0.9 feet at CH-13 and increased +1.4 feet at CH-14, respectively. Changes at these two sediment ranges are probably the result of channel geometry changes from runoff events.

Table 6-7. Chatfield Lake – Changes in Cross Section Thalweg Elevations (Feet, NGVD29)

Sediment Range	Survey Year					
	1977	1991	1998	2010	2016	1977 – 2016
CH-01	5,375.9	5,378.3	5,379.9	5,380.9	5,381.0	**+5.1**
CH-02	5,394.8	5,394.8	5,396.2	5,396.6	5,395.1	**+0.3**
CH-03	5,399.6	5,399.8	5,400.8	5,401.5	5,401.5	**+1.9**
CH-04	5,395.0	5,401.5	5,396.9	5,398.9	5,398.0	**+3.0**
CH-05	5,392.4	5,392.7	5,399.3	5,401.5	5,401.2	**+8.8**
CH-06	5,408.0	5,408.0	5,408.0	5,410.1	5,410.9	**+2.9**
CH-07	5,419.1	5,419.1	5,419.1	5,420.4	5,420.0	**+0.9**
CH-08	5,423.3	5,423.3	5,423.3	5,423.1	5,421.9	**-1.4**
CH-09	5,459.0	5,458.9	5,459.5	5,459.2	5,459.2	**+0.2**
CH-10	5,475.4	5,475.6	5,475.6	5,474.5	5,473.8	**-1.6**
CH-11	5,493.9	5,492.9	5,493.4	5,494.0	5,493.2	**-0.7**
CH-12	5,506.2	5,503.5	5,504.9	5,505.2	5,504.8	**-1.4**
CH-13	5,458.8	5,458.3	5,458.1	5,459.0	5,459.7	**+0.9**
CH-14	5,435.0	5,435.3	5,435.6	5,436.4	5,436.4	**+1.4**
CH-15	5,408.2	5,409.3	5,410.8	5,411.4	5,411.2	**+3.0**
CH-16	5,421.8	5,426.2	5,425.9	5,426.9	5,425.3	**+3.5**
CH-17	5,431.8	5,430.3	5,428.6	5,430.9	5,433.4	**+1.6**
CH-18	5,443.5	5,445.8	5,442.4	5,437.1	5,439.8	**-3.7**
CH-19	5,456.0	5,465.1	5,458.3	5,459.1	5,455.0	**-1.0**
CH-20	5,469.6	5,469.8	5,470.0	5,470.8	5,471.5	**+1.9**
CH-21	5,486.8	5,486.3	5,484.7	5,490.8	5,490.5	**+3.7**
CH-22	5,503.6	5,507.3	5,508.9	5,506.1	5,509.6	**+6.0**

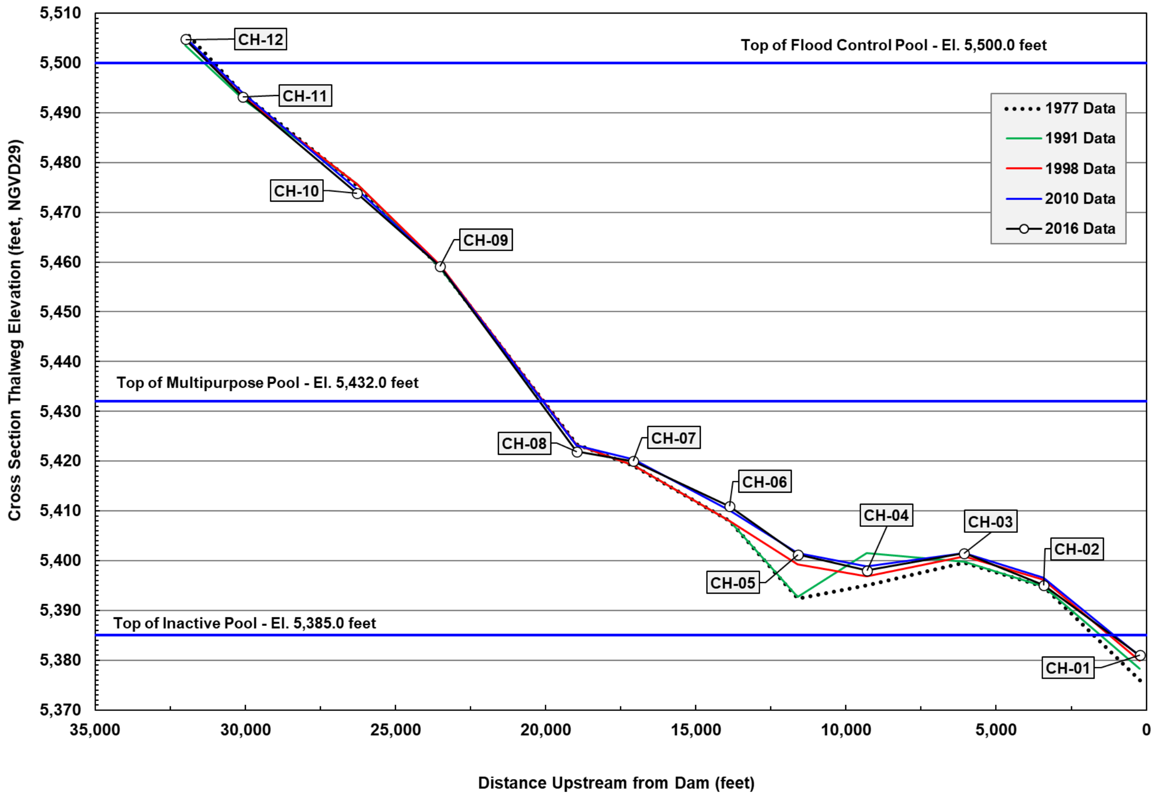

Figure 6-11. South Platte River – Changes in Cross Section Thalweg Elevations

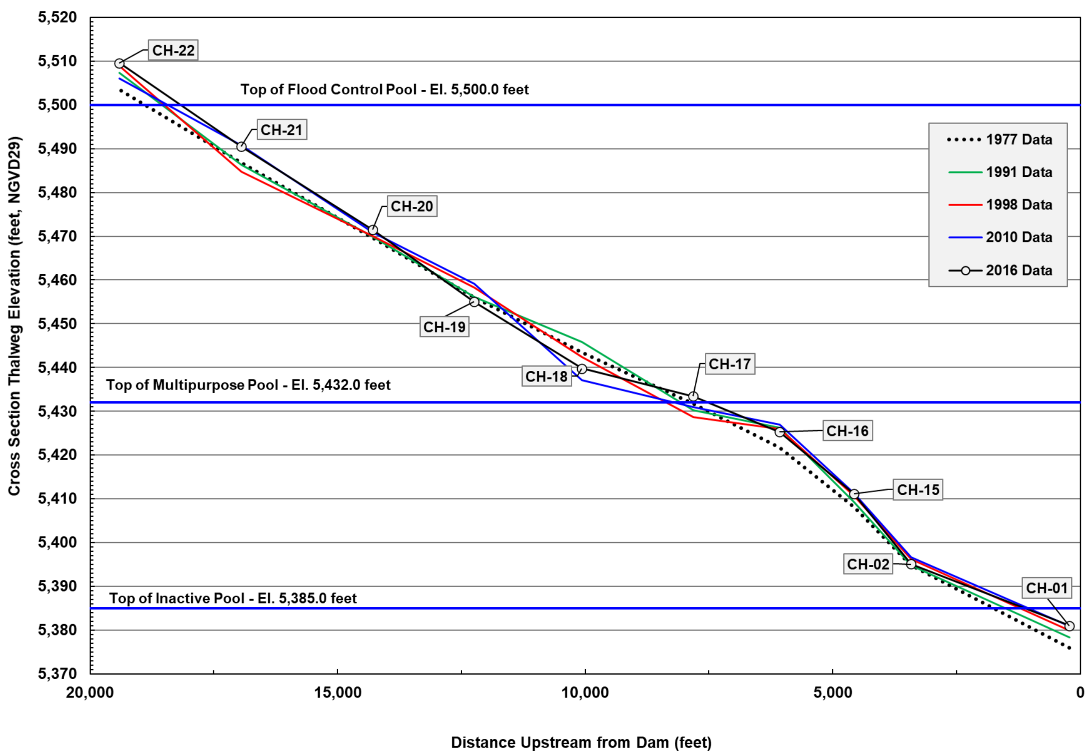

Figure 6-12. Plum Creek – Changes in Cross Section Thalweg Elevations

6.7 Chatfield Lake – Reservoir Surface Area & Storage Capacity

Table 6-8 lists pertinent pool elevation and pool zones for Chatfield Lake. In the following sections, 2016 Chatfield Lake surface area and capacity data is compared with the surveyed sediment range data using the MAEA method; and directly from the 2016 LiDAR/HDMB DEM surface using the GIS method.

Variations between the MAEA method results and the GIS method results may be attributed to variations in the reservoir bed and banks not accounted for during the collection of sediment range data. The variation between the range data (MAEA) and 2016 LiDAR/HDMB DEM surface is the direct result of the increased resolution of the survey data.

Area-capacity tables for Chatfield Lake calculated at 0.1-foot increments are located in Appendix D. The capacity tables computed at 0.01-foot increments are available from the Omaha District River and Reservoir Engineering Section.

Table 6-8. Chatfield Lake – Pertinent Pool Elevations

Top of Pool	Pool Elevation (Feet, NGVD29)	Pool Zone	Pool Zone Elevations (Feet, NGVD29)
Maximum Pool	5,521.6	Surcharge	5,500.0 – 5,521.6
Flood Control Pool	5,500.0	Flood Control	5,432.0 – 5,500.0
Multipurpose Pool	5,432.0	Multipurpose	5,385.0 – 5,432.0
Inactive Pool	5,385.0	Inactive	Thalweg El. – 5,385.0
		GROSS STORAGE	**Thalweg El. – 5,521.6**

6.7.1 Analysis of Reservoir Surface Area by Pool Elevation

A comparison of Chatfield surface area tables calculated from surveyed sediment range data using the MAEA method are tabulated in Table 6-9. Surface area profiles are plotted in Figure 6-13. Results indicate that surface area between 1977 and 2016 using the surveyed range data has increased for the Maximum and Flood Control Pools and has decreased for the Multipurpose and Inactive Pools.

Table 6-9 also indicates that between 1977 and 2016, surface area calculated from the 2016 LiDAR/HDMB DEM surface using the GIS method has increased at the top of the Maximum Pool (+92 acres) and has decreased at the top of the Flood Control Pool (-9 acres). At the lower pool elevations, surface area has increased at the Multipurpose Pool (+50 acres) and below the Inactive Pool (+26 acres).

Table 6-9. Chatfield Lake – Changes in Reservoir Surface Area (Acres)

Operational Pool	Sediment Range Surveys (MAEA)					2016 GIS (DEM)	1977 – 2016	
	1977	1991	1998	2010	2016		MAEA	GIS
Maximum	5,912	5,910	5,929	5,937	5,970	6,004	+58	+92
Flood Control	4,748	4,747	4,758	4,751	4,777	4,739	+29	-9
Multipurpose	1,438	1,435	1,427	1,412	1,418	1,487	-19	+50
Inactive	13	13	10	9	8	39	-4	+26

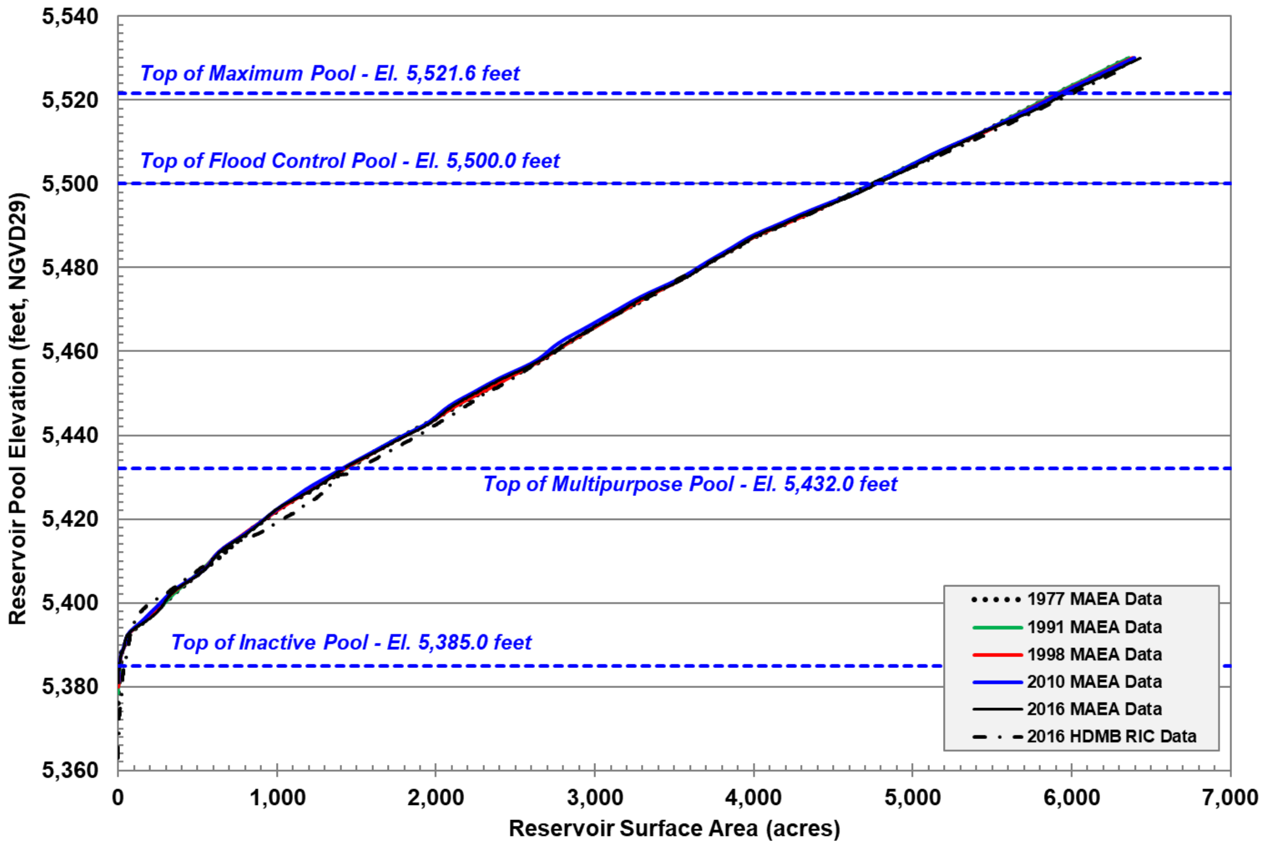

Figure 6-13. Chatfield Lake – Reservoir Surface Area Profiles

6.7.2 Analysis of Reservoir Storage Changes by Pool Elevation

Table 6-10 tabulates the historical Chatfield Lake storage capacity data. Storage capacity profiles are shown in Figure 6-14 and Figure 6-15. Results indicate that between 1977 and 2016 reservoir capacity has generally increased between surveys and methodologies at the four operational pool elevations. Using the GIS method, the Maximum Pool increased by 3,557 acre-feet, the Flood Control Pool increased by 2,523 acre-feet, the Multipurpose Pool increased by 962 acre-feet, and the Inactive Pool increased by 267 acre-feet between 1977 and 2016.

In summary:

- MAEA method capacity results show a decrease in capacity since 1977.
- GIS method capacity results show an increase in capacity since 1977.
- Apparent increase in reservoir capacity is largely due to a change in methodology, using the GIS method instead of the MAEA method in order to calculate the reservoir capacity.
- An increase of 154 acre-feet is noted for the Maximum Pool zone between 1977 and 2016 using the MAEA method. This slight increase is likely due to the addition of several of the ponds adjacent to the South Platte River during the 2016 survey.

Table 6-10. Chatfield Lake – Changes in Reservoir Storage Capacity by Pool Elevation (Acre-Feet)

Operational Pool	Sediment Range Surveys (MAEA)					2016 GIS (DEM)	1977 – 2016	
	1977	1991	1998	2010	2016		MAEA	GIS
Maximum	349,404	349,173	349,462	347,065	349,557	352,961	+154	+3,557
Flood Control	233,952	233,796	233,839	231,531	233,513	236,475	-439	+2,523
Multipurpose	27,858	27,539	27,438	27,134	27,587	28,820	-271	+962
Inactive	32	30	25	17	16	299	-16	+267

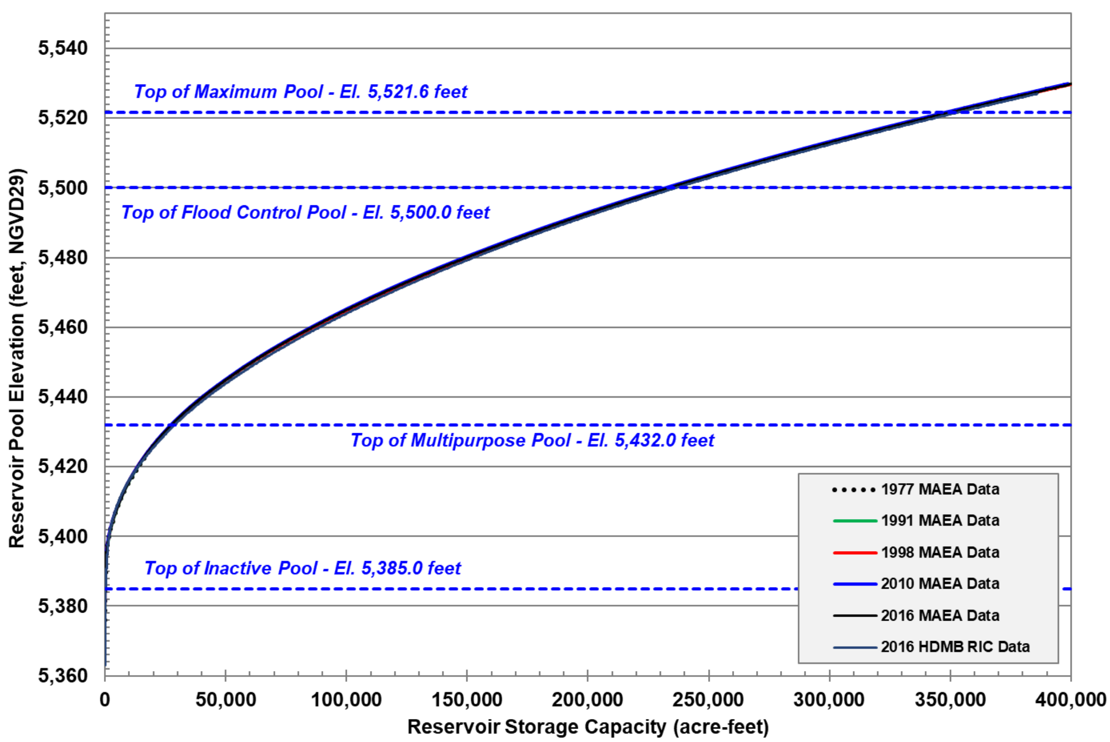

Figure 6-14. Chatfield Lake – Reservoir Storage Capacity Profiles

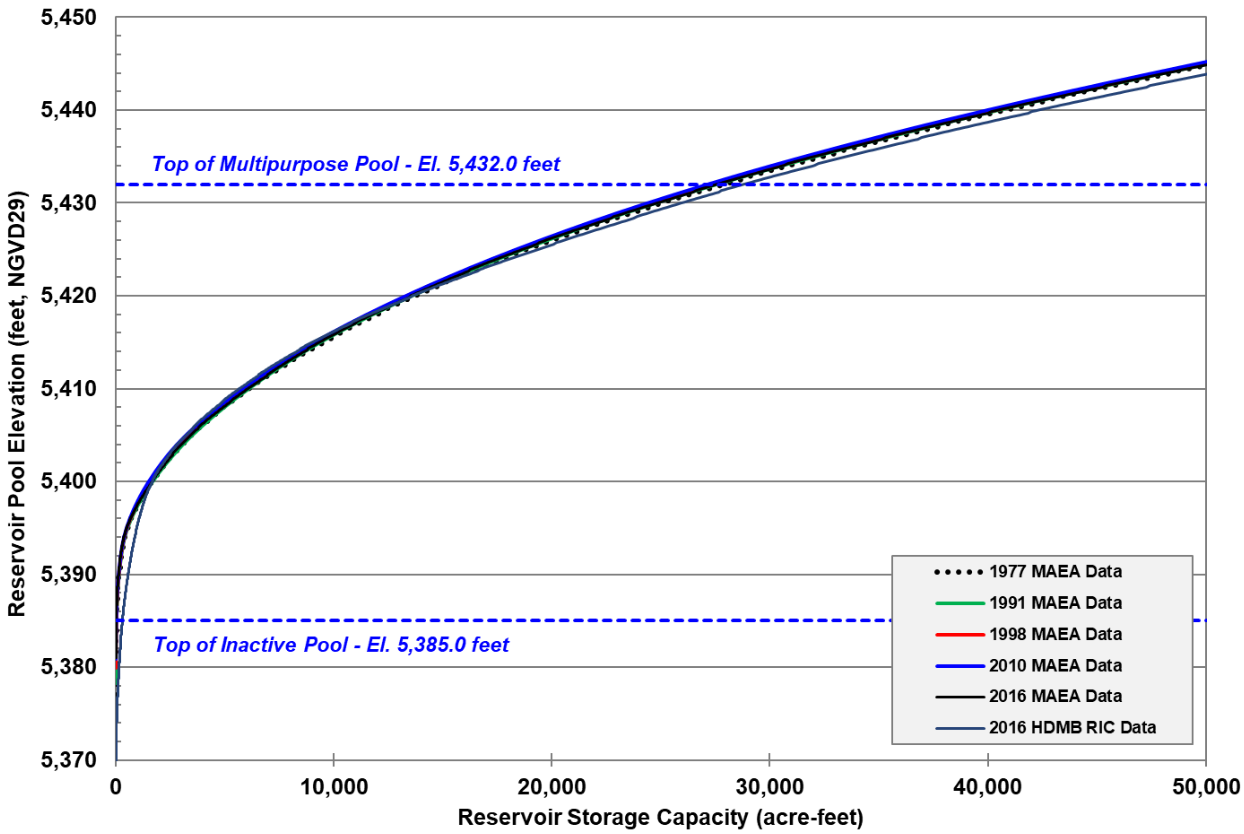

Figure 6-15. Chatfield Lake – Reservoir Storage Capacity Profiles (El. 5370 – 5450)

6.7.3 Analysis of Reservoir Storage Capacity by Storage Zone

The changes in reservoir storage capacity for the different pool or storage zones were analyzed to show the effects of sedimentation on a zone-by-zone basis. Table 6-11 tabulates reservoir capacity by pool zone for each sediment range survey and the 2016 LiDAR/HDMB DEM surface. A comparison of reservoir storage capacity between the 1977 and the 2016 sediment range data shows a steady decline in storage capacity at all pool zones.

Table 6-12 presents changes in reservoir capacity by pool zone. Figure 6-16 depicts the changes in reservoir storage capacity over time for each pool zone.

- Gross storage (elevation 5,377.0 – 5,521.6 feet, NGVD29) increased 3,557 acre-feet (+1.0%) using the GIS method.
- In the Surcharge Pool (elevation 5,500.0 – 5,521.6 feet, NGVD29), storage increased 1,034 acre-feet (+0.9%) using the GIS method.
- Storage in the Flood Control Pool (elevation 5,432.0 – 5,550.0 feet, NGVD29) increased 1,561 acre-feet (+0.8%) using the GIS method.
- Storage in the Multipurpose Pool (elevation 5,385.0 – 5,432.0 feet, NGVD29) increased 695 acre-feet (+2.5%) using the GIS method.

- Storage in the Inactive Pool (elevation 5,377.0 – 5,385.0 feet, NGVD29) increased 267 acre-feet (+846.2%) using the GIS method.
- The variation between the two methods of calculating reservoir storage capacity is the results of the increased resolution at the bottom contours of Chatfield Lake of the 2016 LiDAR/HDMB DEM Surface.
- The extreme difference between capacity values for the Inactive Pool likely indicates low density original survey data with associated error.

Table 6-11. Chatfield Lake – Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Operational Pool Zone	Sediment Range Surveys (MAEA)					2016 GIS (DEM)
	1977	1991	1998	2010	2016	
GROSS STORAGE	**349,404**	**349,173**	**349,462**	**347,065**	**349,557**	**352,961**
Surcharge	115,452	115,378	115,622	115,535	116,045	116,486
Flood Control	206,094	206,257	206,402	204,396	205,926	207,655
Multipurpose	27,826	27,509	27,413	27,117	27,571	28,521
Inactive	32	30	25	17	16	299

Table 6-12. Chatfield Lake – Changes in Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Operational Pool Zone	Sediment Range (MAEA)		2016 GIS (DEM)	1977 – 2016 MAEA		1977 – 2016 GIS	
	1977	2016		Change	% Rem.	Change	% Rem.
GROSS STORAGE	**349,404**	**349,557**	**352,961**	**+154**	**100.0**	**+3,557**	**101.0**
Surcharge	115,452	116,045	116,486	+593	100.5	+1,034	100.9
Flood Control	206,094	205,926	207,655	-168	99.9	+1,561	100.8
Multipurpose	27,826	27,571	28,521	-256	99.1	+695	102.5
Inactive[1]	32	16	299	-16	50.6	+267	946.2

1. Note extreme difference between MAEA and GIS methods indicating low density original data.

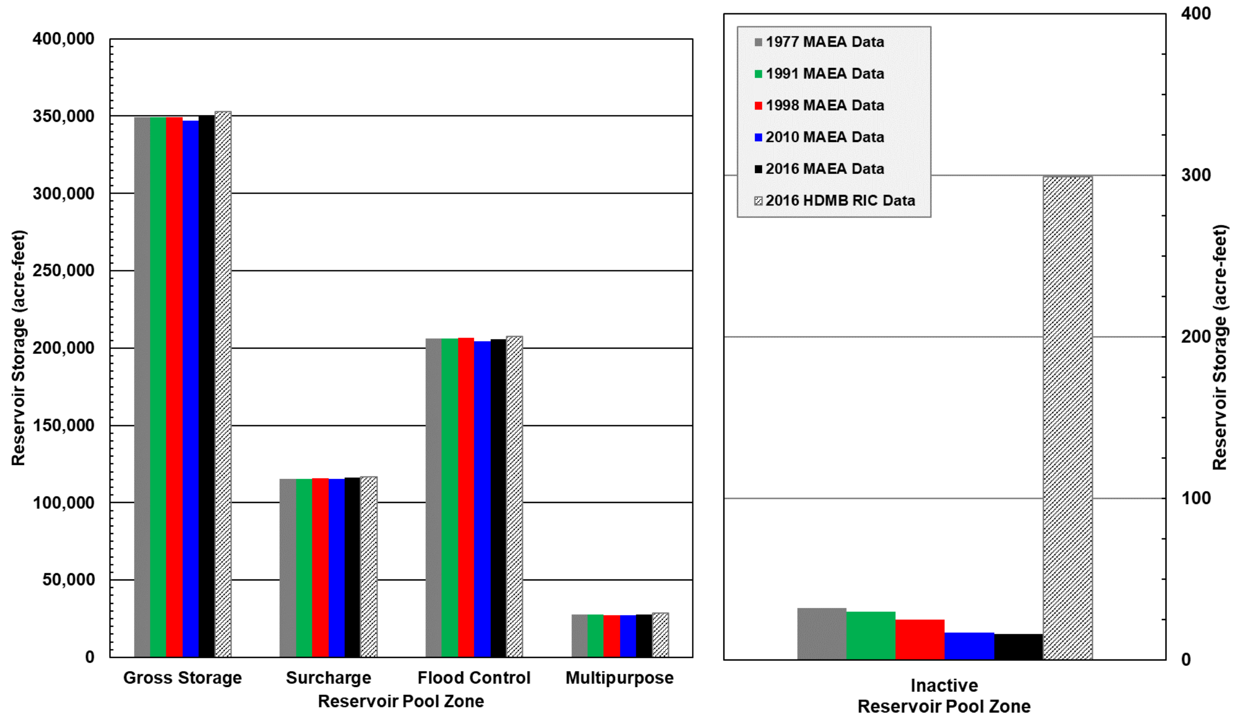

Figure 6-16. Chatfield Lake – Changes in Reservoir Storage Capacity by Pool Zone (Acre-Feet)

6.8 Chatfield – Reservoir Storage Depletion

The purpose of this report was to evaluate the loss of reservoir storage volume due to sedimentation impacts at Chatfield Lake as monitored by the Omaha District. Original sediment yield calculations, historical sediment depletion rates, and future aggradation trends will be evaluated in this section.

6.8.1 Original Sediment Yield Calculations

Chatfield Reservoir was designed to contain a sediment yield for a 100-year period. Based on an eight-year suspended sediment load record on the South Platte River at Littleton, Colorado, a 23-year runoff record at this same location, and a similar 17-year record on Plum Creek at Louviers, Colorado, the pre-design depletion rate of reservoir storage from sedimentation was estimated to be an average of 189.5 acre-feet per year, or a total of 18,950 acre-feet over 100 years. The sedimentation was anticipated to deposit approximately 15% of the sediment in the flood control zone while the remaining 85% of the sediment would be deposited below the level of the Multipurpose Pool. The original sediment analysis also considered the sedimentation rates observed at Cherry Creek reservoir located in the adjacent drainage basin to the east of the Plum Creek tributary arm and the abnormal sediment runoff from the Plum Creek basin for the period of time it takes for the presently torn and deteriorated channel to naturally heal. The observed rates at the Cherry Creek project included the record runoff contribution from the 16-17 June 1965 flood.

6.8.2 Analysis of Reservoir Sediment Depletion using Volume by Segment Tables

Chatfield Lake volume by segment tables were calculated in 5-foot increments for all five surveys using the MAEA method. Individual segment tables are located in Appendix C. Table 6-13 tabulates reservoir volume by segment changes between 1977 and 2016 from the surveyed sediment ranges, and Figure 6-17 shows the reservoir volume by segment changes between 1977 and 2016 from the surveyed sediment ranges as well.

Data shows that the predominantly lake segments (001 through 005 and 016), there has been an average increase of reservoir storage of 477.9 acre-feet (+1.2%). The upstream segments for the South Platte River (006 through 013) show an average decrease of reservoir storage of 1.5 acre-feet (-0.5%). The upstream segments for Plum Creek (017 through 023) show an average increase of reservoir storage of 8.8 acre-feet (+1.0%). The two unnamed tributary segments (014 and 015) show an average increase of reservoir storage of 7.7 acre-feet (+0.3%) and an average decrease of reservoir storage of 334.7 acre-feet (-1.7%), respectively.

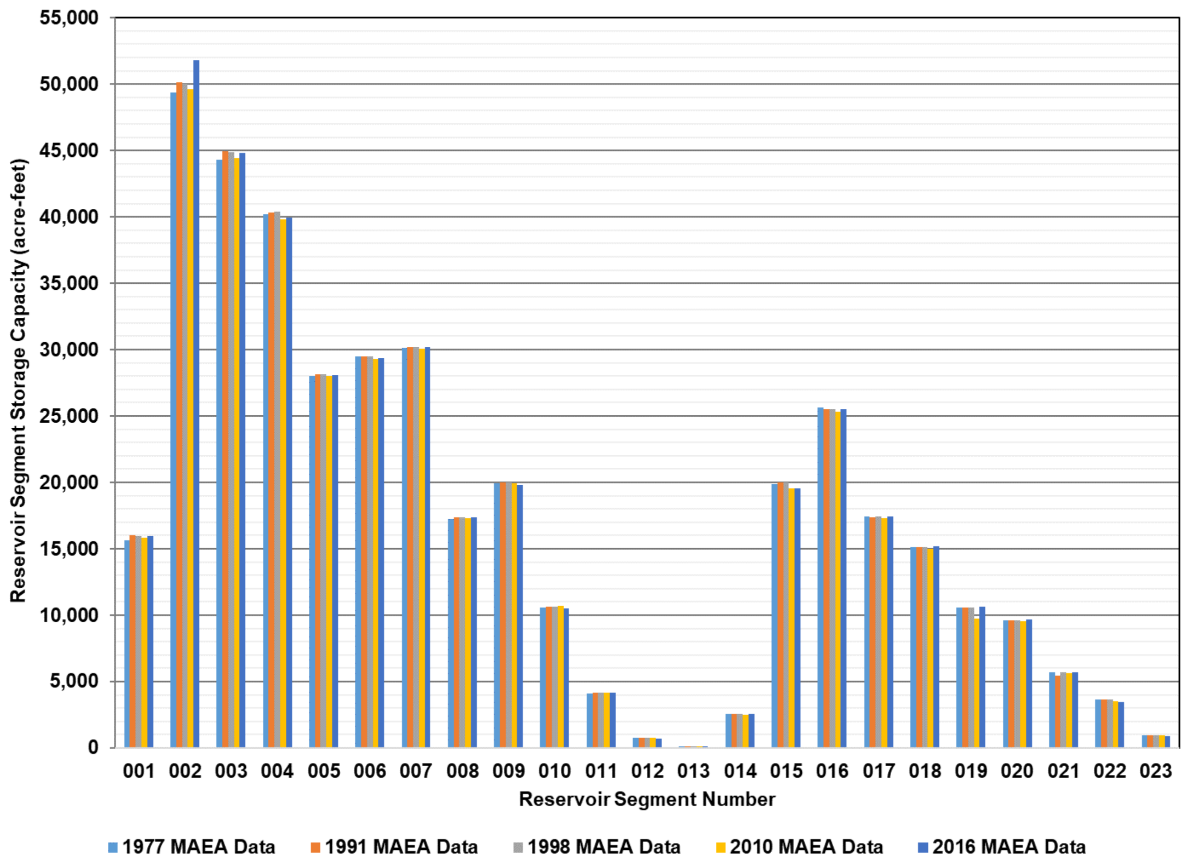

Figure 6-17. Chatfield Lake – Changes in Reservoir Storage Volume X Segments

Table 6-13. Chatfield Lake – Changes in Reservoir Storage Volume X Segment (Acre-Feet)

Seg. No.	Bounding Sediment Ranges	Sediment Range (MAEA)					1977 – 2016	
		1977	1991	1998	2010	2016	Change	%
001	DAM – CH-01	15,644	16,015	15,973	15,847	15,979	**+335**	**+2.1**
002	CH-01 – CH-02	49,389	50,108	49,981	49,626	51,830	**+2,441**	**+4.9**
003	CH-02 – CH-03	44,332	44,929	44,887	44,433	44,798	**+466**	**+1.1**
004	CH-03 – CH-04	40,182	40,323	40,376	39,843	39,925	**-257**	**-0.6**
005	CH-04 – CH-05	28,035	28,158	28,175	28,042	28,069	**+33**	**+0.1**
006	CH-05 – CH-06	29,465	29,466	29,474	29,300	29,386	**-79**	**-0.3**
007	CH-06 – CH-07	30,130	30,212	30,210	30,072	30,168	**+38**	**+0.1**
008	CH-07 – CH-08	17,249	17,353	17,347	17,328	17,388	**+139**	**+0.8**
009	CH-08 – CH-09	19,924	20,027	20,020	19,923	19,828	**-96**	**-0.5**
010	CH-09 – CH-10	10,560	10,640	10,619	10,679	10,491	**-69**	**-0.7**
011	CH-10 – CH-11	4,070	4,181	4,185	4,172	4,158	**+87**	**+2.1**
012	CH-11 – CH-12	752	768	763	737	721	**-30**	**-4.0**
013	CH-12 – END	132	136	135	129	130	**-2**	**-1.9**
014	CH-13 – END	2,540	2,576	2,575	2,505	2,548	**+8**	**+0.3**
015	CH-14 – END	19,891	19,971	19,979	19,552	19,556	**-335**	**-1.7**
016	CH-15 – CH-16	25,645	25,522	25,494	25,340	25,495	**-150**	**-0.6**
017	CH-16 – CH-17	17,457	17,383	17,430	17,302	17,432	**-26**	**-0.1**
018	CH-17 – CH-18	15,096	15,107	15,106	15,014	15,202	**+106**	**+0.7**
019	CH-18 – CH-19	10,561	10,599	10,572	9,715	10,658	**+97**	**+0.9**
020	CH-19 – CH-20	9,620	9,607	9,587	9,556	9,673	**+53**	**+0.6**
021	CH-20 – CH-21	5,670	5,429	5,678	5,668	5,691	**+22**	**+0.4**
022	CH-21 – CH-22	3,625	3,646	3,628	3,549	3,489	**-136**	**-3.8**
023	CH-22 – END	958	980	986	956	904	**-54**	**-5.7**

6.8.3 Analysis of Reservoir Storage Depletion Rates

The volume of sediment that entered the reservoir between surveys is represented by the reservoir storage capacity depletion rates as shown in Table 6-14. Gross storage change, between 1977 and 2016, at Chatfield was an increase of 3.9 acre-feet per year as generated by the MAEA method and an increase of 91.2 acre-feet per year as generated by the GIS method. Both of these results were less than the design depletion rate of 189.5 acre-feet per year. Since sediment inflow to Chatfield reservoir does occur, the accuracy of the estimated depletion rates may be less than desirable and a reflection of the original survey accuracy.

Table 6-14. Chatfield Lake – Summary of Reservoir Storage Depletion Rates

(Sediment Range Surveys – MAEA and GIS Calculations)

Period [1977 – 2016] (Years)		**39**	
Drainage Area (mi^2)		3,018	
Design Storage Depletion Rate (AF/YR)		189.5	
		MAEA	GIS
Total Reservoir Storage	% Storage Remaining	100.0	101.0
	% Annual Storage Depletion	0.001	0.026
	Depletion Rate (AF/YR)	3.9	91.2
	Normalized Depletion Rate (AF/mi^2/YR)	0.0013	0.0302
Surcharge Storage	% Storage Remaining	100.5	100.9
	% Annual Storage Depletion	0.013	0.023
	Depletion Rate (AF/YR)	15.2	26.5
	Normalized Depletion Rate (AF/mi^2/YR)	0.0050	0.0088
Flood Control Storage	% Storage Remaining	99.9	100.8
	% Annual Storage Depletion	-0.002	0.019
	Depletion Rate (AF/YR)	-4.3	40.0
	Normalized Depletion Rate (AF/mi^2/YR)	-0.0014	0.0133
Multipurpose Storage	% Storage Remaining	99.1	102.5
	% Annual Storage Depletion	-0.024	0.064
	Depletion Rate (AF/YR)	-6.6	17.8
	Normalized Depletion Rate (AF/mi^2/YR)	-0.0022	0.0059
Inactive Storage	% Storage Remaining	50.6	946.2
	% Annual Storage Depletion	-1.267	21.698
	Depletion Rate (AF/YR)	-0.4	6.9
	Normalized Depletion Rate (AF/mi^2/YR)	-0.0001	0.0023

6.8.4 Analysis of Future Reservoir Storage Depletion

One of the objectives of M.R.B. Sediment Memorandum 23b was to predict future sediment conditions at Chatfield Lake for 50 years into the future (2066). The assessment used area and capacity data and previously calculated depletion rates to estimate the change in reservoir storage capacity that might occur. Table 6-14 above lists the depletion rates, generated by both the MAEA and GIS methods between 1977 and 2016, that were used for this analysis. The results of this analysis can be seen below in Table 6-15.

Table 6-15. Future Chatfield Lake – 2066 Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Pool Zone	Elevation Range (Feet, NGVD29)	1977 MAEA	2066 MAEA	Percentage Lost/Gained by 2066 (MAEA)*	2066 GIS	Percentage Lost/Gained by 2066 (GIS)*
Surcharge	5,500.0 – 5,521.6	115,452	116,805	+1.17%	117,819	+2.05%
Flood Control	5,432.0 – 5,500.0	206,094	205,710	-0.19%	208,137	+0.99%
Multipurpose	5,385.0 – 5,432.0	27,826	27,243	-2.10%	29,431	+5.77%
Inactive[1]	Thalweg – 5,385.0	32	0	-100%	694	+2,097.42%

*Loss indicated by minus (-) sign, and gain indicated by plus (+) sign.
1. Note extreme difference between MAEA and GIS methods indicating lower accuracy / density original survey data. Due to this, use of the GIS method for the survey data at the inactive pool zone should not be compared when calculating for the future storage capacity.

The 50-year projection shows an apparent increase in capacity for the GIS method as well as an increase for the Surcharge Pool zone for the MAEA method. However, the changes since 1977 is well within the noise of the data and the limited accuracy of the capacity estimation methods. It would be foolhardy to predict the reservoir will gain capacity based on these small, measured changes over the last 39 years. Under normal climate conditions, the reservoir will likely not experience a capacity increase, rather it will retain its current capacity for the next 50 years.

6.9 Chatfield Lake – Engineering Form 1787 (Reservoir Sediment Data Summary)

Engineering Form 1787, "Reservoir Sedimentation Data Summary" is presented in Appendix G. The purpose of this form is to provide a means for the uniform documentation of pertinent Chatfield Lake sedimentation data.

6.10 Chatfield Lake – Special Problems

6.10.1 Plum Creek/Titan Road Bridge

Figure 6-18. Titan Road Bridge over Plum Creek

Plum Creek flows into the east arm of Chatfield Lake. The Plum Creek basin drains a total of 324 square miles. In the late 1980's and early 1990's, Plum Creek experienced a large influx of sediment causing excess deposition and delta buildup in the Plum Creek tributary arm of Chatfield Lake. This additional deposition changed the location of the channel, endangering the recreational facilities in this area of Chatfield Lake. The deposition has also decreased the flood conveyance capacity of the Titan Road Bridge, located approximately three miles upstream of the lake's Multipurpose Pool elevation. A 1989 internal draft report stated that there was only three feet of clearance at the Titan Road Bridge in 1989. Several studies were conducted around the early 1990's to determine the future of the Titan Road Bridge. Since 1990, the Titan Road Bridge has been replaced and a grade control structure has been built upstream of the bridge. The Plum Creek arm continues to be the source of the majority of the sediment entering Chatfield Lake.

6.10.2 Reallocation Study

During FY 2013, a reallocation study was completed for Chatfield Lake. The purpose of this study was to identify, compare, and select the best alternative for the reallocation of storage space for water supply purposes, based on the requests of water providers in the Denver metropolitan area. During this study, four alternatives were considered in detail.

The first alternative was the "No Action" alternative, which involved the construction and use of Penley Reservoir, use of non-tributary groundwater (NTGW) by upstream providers until Penley Reservoir is constructed, and the use of gravel pits for water storage by downstream providers in order to meet future water needs without any reallocation of storage at Chatfield Lake. The second alternative was the "Least Cost Alternative." This alternative involved upstream water providers using NTGW to provide a significant portion of the water needed while the downstream water providers developed gravel pits for water storage and use. Like the first alternative, this would not include any reallocation of storage at Chatfield Lake. The third alternative was the reallocation of an additional 20,600 acre-feet of storage from the Flood Control Pool to the Conservation Pool at Chatfield Lake. The fourth alternative was a combination consisting of the reallocation of an additional 7,700 acre-feet of storage from the Flood Control Pool to the Conservation Pool at Chatfield Lake in addition to the use of NTGW as well as the creation of gravel pit storage.

These four alternatives were then evaluated for environmental, social, cultural, and economic impacts as well as for engineering feasibility. Based on the evaluation of these factors, the third alternative was chosen to be implemented. It was determined to be the Least Cost Alternative (in total costs), the Locally Preferred Plan, the Least Environmentally Damaging Plan, and it would provide $8.42 million in annual National Economic Development (NED) benefits. As stated previously, this alternative would involve the reallocation of 20,600 acre-feet of storage from the Flood Control Pool to the Conservation Pool. This reallocation would provide an estimated average year yield of 8,539 acre-feet for Municipal and Industrial (M&I) water supply, and it would result in an approximate 12-foot increase in the top elevation of the Conservation Pool (5,432 feet, NGVD29, to 5,444 feet, NGVD29), depending on runoff and withdrawals by water providers. This increase in the top elevation of the Conservation Pool along with the proposed grading of the reservoir will cause the future capacity of the reservoir to differ from the calculated values in this report. A Recreation Facilities Modification Plan and a Compensatory Mitigation Plan were also implemented to relocate and replace existing recreation facilities, resources, and roads and to replace or compensate for the loss of habitat (including wetlands, bird habitat, and habitat for the federally threatened Preble's meadow jumping mouse) that would be impacted by the increase in pool elevation.

The reallocation implementation phase began in April 2020 when the recreation and environmental mitigation projects were completed. For further details regarding the Chatfield Lake Reallocation Study, see the Final Integrated Feasibility Report and Environmental Impact Statement for the Chatfield Reservoir Storage Reallocation (USACE, 2013).

7 Cherry Creek Lake

7.1 Cherry Creek Lake – Project Background

Cherry Creek Lake (Figure 7-1) is Arapahoe County, Colorado on Cherry Creek approximately ten miles southeast of Denver, Colorado. Chatfield Dam was constructed by the U.S. Army Corps of Engineers for the primary purpose of mitigating flood risk to downstream metropolitan Denver from floods originating above the dam. Additional authorized purposes include water supply, recreation, and fish and wildlife enhancement. The dam provides additional benefit from the development and use of the multipurpose zone for recreation purposes.

The Cherry Creek Dam is a rolled earth dam 14,300 feet long and 141 feet high containing 13,000,000 cubic yards of fill material. Cherry Creek Lake was closed in October 1948. The basin drains a total of 386 square miles. The lake is 1.5 miles long with five miles of shoreline at the Multipurpose Pool elevation of 5,548.7 feet, NGVD29, and it covers approximately 850 acres. The original estimated long-term average annual depletion rate for the lake was 151 acre-feet. Engineering data for the Cherry Creek project is summarized in Table 7-1.

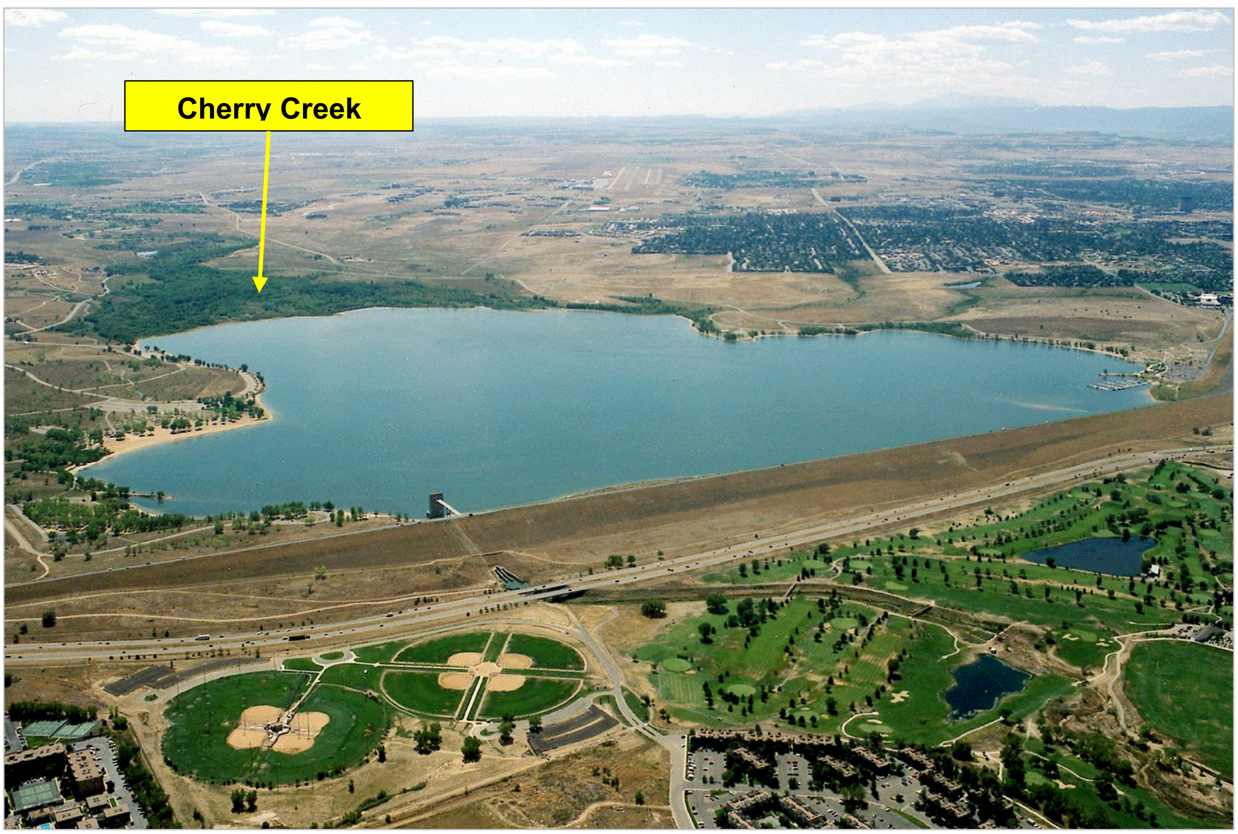

Figure 7-1. Aerial Photograph of Cherry Creek Lake (RARE database file photo)

Table 7-1. Cherry Creek Lake – Summary of Engineering Data

ITEM NO.	SUBJECT	CHERRY CREEK LAKE	
	GENERAL		
1	Location of Dam		10 miles southeast of Denver, Colorado.
2	River & River Mile		Cherry Creek @ RM 11.4
3	Drainage Area		386 mi^2
4	Reservoir Length		1.5 miles @ Elevation 5,550.0 feet, LPVD
5	Location of Dam Tender		At Chatfield Dam
6	Travel Time to Missouri River		2 weeks
7	Maximum Discharge of Record	58,000 cfs	June 1965
8	Maximum Pool of Record	5,565.8 feet, LPVD	June 1973
	DAM AND EMBANKMENT		
9	Top of Dam		5,645.0 feet, LPVD
10	Length of Dam		14,300 feet
11	Height of Dam		141 feet
12	Stream Bed		5,504 feet, LPVD
13	Abutment Formation		Sandstone-Clay-Silt
14	Type of Fill		Rolled Earth
15	Fill Quantity in cubic yards		13,000,000 yds^3
16	Date of Closure		October 1948
17	Date of Initial Fill (Base F.C.)		March 1960
	SPILLWAY		
18	Discharge Capacity		38,350 cfs @ Elevation 5,636.2 feet, LPVD
19	Crest Elevation		5,610.6 feet, LPVD
20	Width		67 feet
21	Gates, Number, Size, Type		Ungated Earth Channel
	RESERVOIR POOL BY ELEVATION	**ELEVATION (NGVD29) & SURFACE AREA – 2016 DEM Surface**	
22	**Maximum Pool**	**5,643.7 feet**	**5,196 acres**
23	**Top of Flood Control Pool**	**5,596.7 feet**	**2,668 acres**
24	**Top of Multipurpose Pool**	**5,548.7 feet**	**877 acres**
25	**Top of Inactive Pool**	**None**	**None**
	RESERVOIR STORAGE ZONES	**ELEVATION (NGVD29) & STORAGE CAPACITY – 2016 DEM Surface**	
26	**Surcharge**	**5,596.7 feet – 5,643.7 feet**	**179,611 acre-feet**
27	**Flood Control**	**5,548.7 feet – 5,596.7 feet**	**81,736 acre-feet**
28	**Multipurpose**	**5,502.7 feet – 5,548.7 feet**	**13,157 acre-feet**
29	**Inactive**	**None**	**None**
30	**Gross Storage**	**Thalweg – 5,643.7 feet**	**274,504 acre-feet**
	OUTLET WORKS		
31	Number and Size – Conduits		1 – 12 feet Circular
			2 – 8 X 12 feet Oval
32	Conduit Length		679.5 feet
33	Number – Size – Type Gates		5 – 6 X 9 feet Hydraulic Slide
34	Discharge Capacity		8,100 cfs @ Elevation 5,598.0 feet, LPVD
35	**POWER INSTALLATION**		None

7.2 Cherry Creek Lake – Reservoir Inflow, Outflow, and Pool Elevation

Pool elevation data has been collected at Cherry Creek Lake since 1955. Operation of the Tri-Lakes Reservoirs generally require both individual and system reservoir regulation. The maximum and minimum pool elevations of record are tabulated in Table 7-2. A historical pool elevation profile is shown in Figure 7-2.

Table 7-2. Cherry Creek Lake – Summary of Reservoir Inflow, Outflow, & Pool Elevation Events

Daily Inflow and Date			Maximum Pool Elevation (NGVD29) and Date		
Highest	6,150 cfs	16 Jun 1965	**Highest**	5,565.8 feet	03 Jun 1973
2nd	3,195 cfs	06 May 1973	**2nd**	5,562.5 feet	01 Aug 1965
3rd	1,440 cfs	24 Jul 1983	**3rd**	5,557.8 feet	28 Jul 1983
Daily Outflow and Date			**Minimum Pool Elevation (NGVD29) and Date**		
Highest	560 cfs	07 Aug 1965	**Lowest**	5,543.5 feet	29 Jan 1965
2nd	450 cfs	27 Mar 1960	**2nd**	5,545.0 feet	31 Jul 1964
3rd	402 cfs	28 Apr 2007	**3rd**	5,545.9 feet	23 Nov 1978

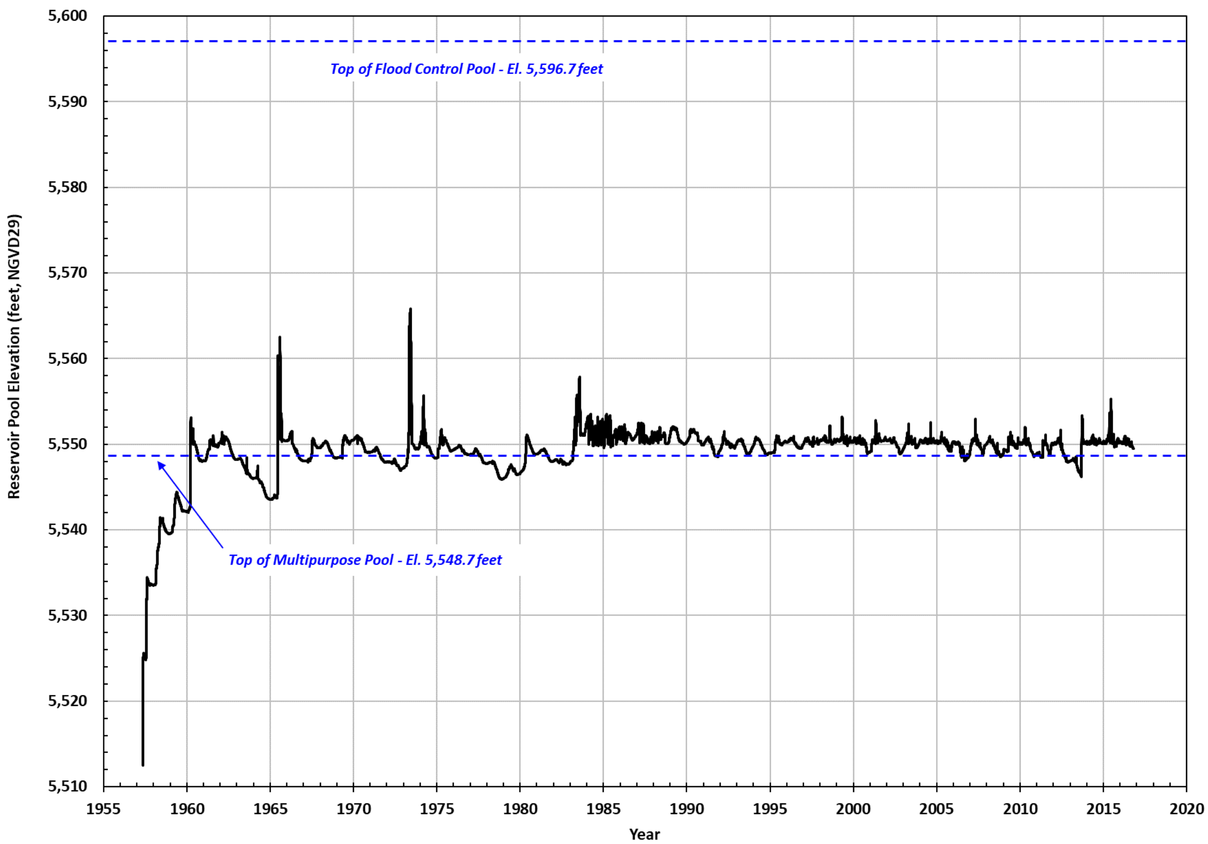

Figure 7-2. Cherry Creek Lake – Reservoir Pool Elevations

7.3 Cherry Creek Lake – Survey Data

7.3.1 Cherry Creek Lake Sediment Ranges

The original plan for establishing Cherry Creek sediment ranges was thirty-six (36) ranges spaced at 500-foot intervals. The number of ranges was reduced by the District Engineer (Memorandum dated 16 June 1944) to thirteen (13) ranges spaced at 2,000-foot intervals to lower survey costs. The current location of the 13 sediment ranges is shown in Figure 7-3. Individual sediment range cross section profiles are shown in Appendix A. Each profile shows the entire survey cross section from end monument left bank to end monument right bank. Analysis of changes in sediment range profiles are discussed in Section 7.3.3.

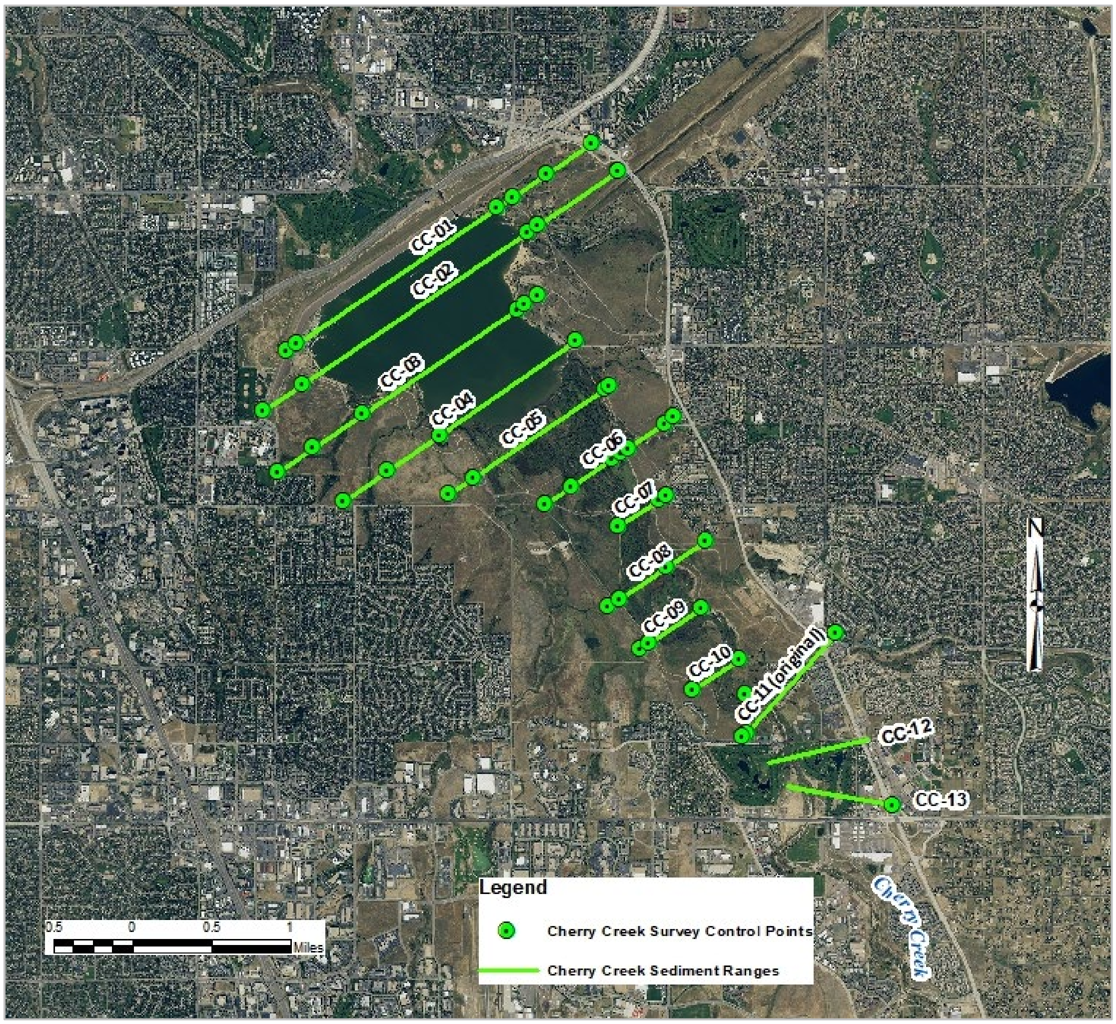

Figure 7-3. Cherry Creek Lake – Sediment Range Location Map

7.3.2 2016 Sediment Range Surveys

A survey crew under Architect-Engineer (A-E) contract to the Omaha District completed surveys for all 13 sediment ranges at Cherry Creek Lake. Additionally, the Omaha District survey crew collected high-density hydrographic survey data at 100-feet line spacing for mapping purposes at the lake. Two shortened metadata files for these surveys are found in Table 7-3 and Table 7-4 respectively.

Table 7-3. Chatfield Lake – Brief Metadata from the Sediment Range Surveys Completed by A-E Contract in 2016

Location	Cherry Creek Lake
Survey Date(s)	September 27 – 30, 2016
Surveyed By	Stockwell Engineer, Contract W9128F-14-D-0001, Delivery Order No. 0004
Equipment	TRIMBLE R8 GPS Receivers. TRIMBLE TDL450 Radios. TRIMBLE Business Center HYPACK® Hydrographic Surveying Software. ODOM CVM Echo Sounder. ODOM Digibar Pro Sound Velocity Profiler Boat, 24-feet long w/cabin
Horizontal Datum	Colorado State-Plane Coordinate System, NAD83, Central Zone 0502
Vertical Datum	NAVD88 & converted to NGVD29 using USACE CorpsCon 6.0.1 software
Units	U.S. Survey Feet
Accuracy	3rd Order Horizontal & Vertical Accuracy per EM 1110-2-1003

Table 7-4. Cherry Creek Lake – Brief Metadata for 2016 HDSB Surveys

Location	Cherry Creek Lake
Survey Date(s)	August 03 – 04, 2016
Surveyed By	Omaha District, River and Reservoir Engineering Section (CENWO-ED-HF)
Equipment	TRIMBLE R8 GPS Receivers, TD 450 H Radios, & Geomatics Office Software HYPACK® Hydrographic Surveying Software ODOM CV100 Echo Sounder, Digibar Pro Sound Velocity Profiler Boat, Boat #417, 22-feet long w/cabin Boat, Boat #402, 20-feet long
Horizontal Datum	Colorado State-Plane Coordinate System, NAD83, Central Zone 0502
Vertical Datum	NAVD88 & converted to NGVD29 using USACE CorpsCon 6.0.1 software
Units	U.S. Survey Feet
Accuracy	3rd Order Horizontal & Vertical Accuracy per EM 1110-2-1003

7.3.3 Analysis of 2016 Sediment Range Cross Section Data

Cross sectional plots are shown in Appendix A. Analysis of the changes in the sediment range cross sections are as follows.

7.3.3.1 Sediment Ranges CC-01, CC-02, CC-03, & CC-04

These four ranges are mostly underwater when they cross Cherry Creek Lake when the pool is at the top of the Multipurpose Pool (elevation 5,548.7 feet, NGVD29). All four ranges show both deposition and erosion between 1950 and 2016, though this depends on the location on each of the sediment ranges. The following summarizes the approximated changes along these range lines:

- Range line CC-01: 5 to 17.5 feet of deposition across the bottom of the lake.
- Range line CC-02: 4.5 feet of deposition across the bottom of the lake.
- Range line CC-03: 4.5 feet of deposition across the bottom of the lake (corresponding to the original Cherry Creek channel) and 5 feet of erosion outside of the original Cherry Creek channel.
- Range line CC-04: 5 feet of erosion across the bottom of the lake. The original Cherry Creek channel remains generally visible along each of these four range lines.

7.3.3.2 Sediment Ranges CC-05, CC-06, CC-07, CC-08, CC-09, CC-10, CC-11, & CC-13

These sediment ranges have 0.5 to 5 feet of erosion across the original channel between 1950 and 2016.

7.3.3.3 Sediment Ranges CC-12

This sediment range has approximately 3 feet of deposition across the original channel between 1950 and 2016.

7.3.4 2016 High Density Survey Bathymetry

Both HDSB and HDMB bathymetry were collected. For the HDSB, the first survey line at Cherry Creek was established 25 feet parallel from where the water's edge meets the embankment of the dam. Additional upstream survey lines were spaced parallel to the first, approximately 100 feet apart as shown in Figure 7-4. Data was collected in areas where navigation by boat was possible, usually at depths three feet or greater. One survey line circled the perimeter of the shoreline at ± 50 feet. No wading was attempted because of personal safety concerns.

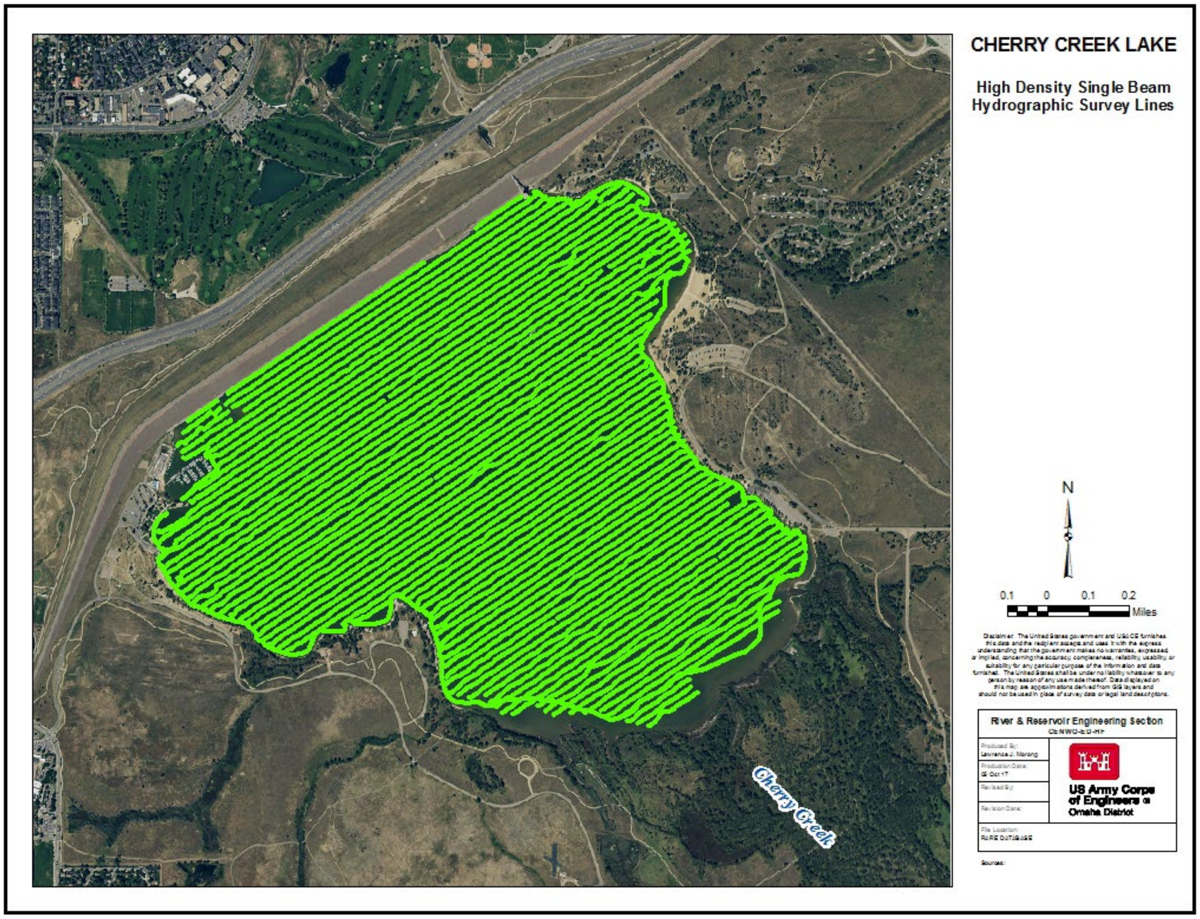

Figure 7-4. Cherry Creek Lake – HDSB Survey Location Map

7.3.5 2016 Reservoir Contour Map from LiDAR & HDSB Bathymetric DEM Surface

A product of the GIS method of the combined 2016 LiDAR/high density DEM surface is reservoir contours. Figure 7-5 shows the shaded contours in 5-foot increments for Cherry Creek Lake created from the HDSB surface. There is no earlier contour data to make surface area or volume comparisons.

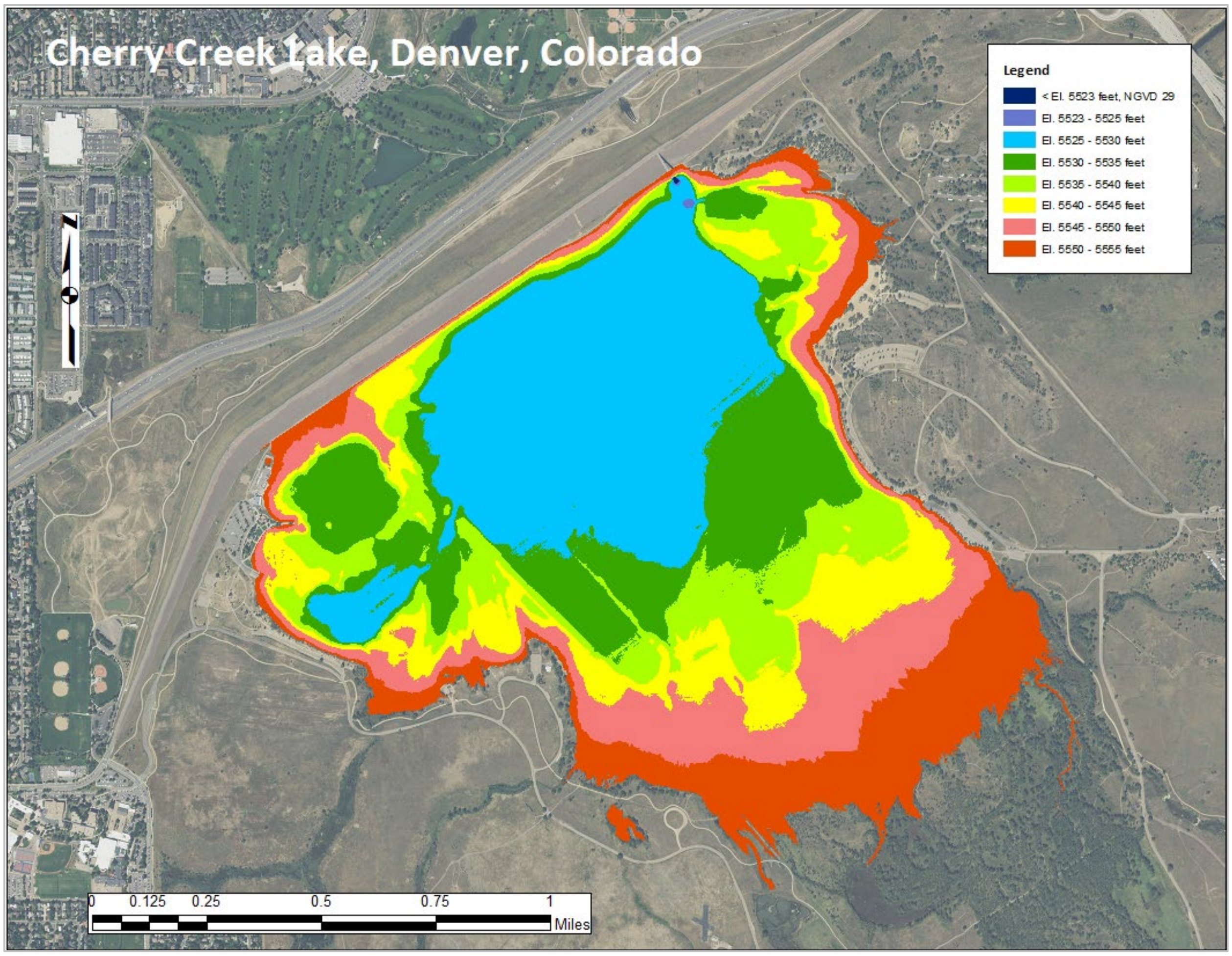

Figure 7-5. Cherry Creek – Lake Contour Map from 2016 HD Multi-beam Surveys (NAVD88 Vertical Datum)

7.4 Cherry Creek Lake – Analysis of Shoreline Erosion

Sediment ranges CC-01 through CC-04 cross Cherry Creek Lake at the Multipurpose Pool elevation of 5,548.7 feet, NGVD29. Cross section analysis of the left and right banks of these four ranges indicate that shoreline erosion has occurred between 1950 and 2016.

- Range line CC-01: 165 to 175 feet of shoreline erosion.
- Range line CC-02: 320 to 350 feet of shoreline erosion.
- Range line CC-03: 120 feet of shoreline erosion.
- Range line CC-04: 10 feet of shoreline erosion.

7.5 Cherry Creek Lake – Analysis of 2016 Bed Material Data

There is only a limited amount of bed material data available for Cherry Creek Lake. Additional bed material data was collected at all sediment ranges during the 2016 USACE cross section surveys. Each sample was graded by mechanical sieve analysis in accordance with ASTM D422 and EM 1110-2-1960. The 2016 Cherry Creek bed material data set (including data tables, Malvern and sieve analysis, and photographs) is tabulated in Appendix B. A location map of where individual samples was collected is shown in Figure 7-6.

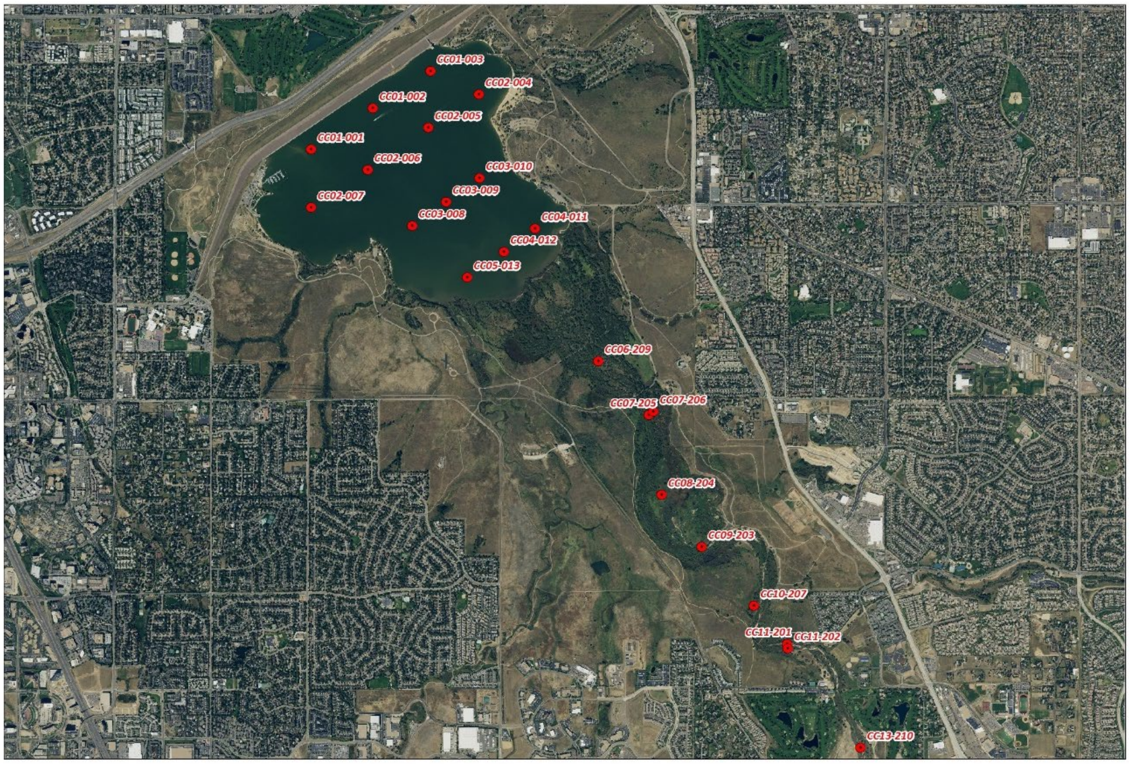

Figure 7-6. Cherry Creek Lake – 2016 Bed Material Sample Locations

7.5.1 1983-84 Core Samples (Cherry Creek Lake)

Dredging was conducted in December 1983 and January 1984 in the vicinity of the Cherry Creek intake structure to remove accumulated sediment. Core samples of the sediment deposited at and near the intake structure were collected in 1982 and 1984. There was no sieve analysis of the samples, however, testing indicated a particle size of < 0.1 mm. The laboratory tests also indicated that the deposited material is generally a fine-grained, silty clay classified as a CH (high compressibility, high liquid limits, highly plastic) soil according to the Unified Soil Classification. Results of the testing is listed in Table 7-5.

Table 7-5. Cherry Creek Lake – Soil Parameters from 1983-84 Core Sample Analysis

Test Parameter	Mean	Median	No. of Samples	Range
Liquid Limit	87	90	6	53 – 109
Plasticity Index	59	68	6	25 – 70
Void Ratio	7.5	3.6	10	2.56 – 48.90
% Water Content	196	170	10	128 – 446
% Material < 0.1 mm	----	----	9	95 – 99
% Material < 0.002 mm	47	46	3	42 – 53
Soil Activity	----	----	3	1.36 – 1.50

7.5.2 Analysis of 2016 Bed Material Samples (Cherry Creek Lake)

The bed material samples were collected from a boat using a USGS BM-54 bed material sampler and then placed in glass jars for transport. The samples collected in the lake reflect predominantly silts with an average D_{50} particle size of about 0.0348 mm (coarse silt). These samples were analyzed using the Malvern Analysis method and their particle sizes are plotted in Figure B-12 in Appendix B.

7.5.3 Analysis of 2016 Bed Material Samples (Upstream Cherry Creek)

The upstream bed material samples in the Cherry Creek channel were collected by hand with a shovel and placed in glass jars for transport. Mechanical analysis of the bed material outside of the Multipurpose Pool indicate an average D_{50} particle size of 1.161 mm (very coarse sand). A sieve analysis plot of the upstream samples can be found in Figure B-13 in Appendix B.

7.5.4 Sediment Removal

Sediment deposition on the face of the intake structure at Cherry Creek Dam has been a recurring problem. An attempt to install emergency gates at the dam in June 1983 resulted in the discovery of approximately 20 feet of sediment accumulation at the bottom of the intake structure. It is believed that the accumulation is brought about by the movement of fine sediments into the structure and the infrequency of reservoir releases. The sediment was removed at that time by dredging.

A jetting process was used in June 1983 to remove sediment beneath the stoplogs. A manifold was attached to the bottom of a stoplog with a compressed air line attached and lowered into the slots. The intent was to disperse the consolidated sediments allowing the stoplog to settle to the concrete base at the bottom of the intake. Jetting resulted in discrete holes in the sediment but little displacement.

Dredging was conducted in December 1983 and January 1984 in the vicinity of the intake to remove the sediment. Divers removed the sediment using hand tools and cut a vertical 1:2 horizontal approach slope of the base of the trash racks in front of the intake.

Sediment was found to have re-deposited to a depth of four to five feet by 1986. A number of alternatives were explored to prevent a recurrence of sediment accumulation within the structure, which could prevent the emergency gates from being lowered in an emergency including structural solutions, dredging, and operational strategies. Because operational strategies were deemed to be the least costly and disruptive, sediment flushing operations occurring at a 300 cfs discharge were carried out and evaluated in June 1985 and April 1986. While the 1985 test was inconclusive, the 1986 test proved that flushing operations could effectively remove sediment in the intake tunnel near the emergency gates. Annual flushing operations have been carried out intermittently since the 1986 test.

Figure 7-7 shows the downstream channel below Cherry Creek Dam at 1,250 cfs during the May 20218 flushing event.

Table 7-6. Cherry Creek Lake – History of Sediment Removal

Date	Removal Method	Discharge (cfs)	Date	Removal Method	Discharge (cfs)
June 1983	Jetting		May 2007	Flush	1,300
December 1983	Dredging		May 2008	Flush	250
January 1984	Dredging		May 2009	Flush	1,300
June 1985	Flush	300	April 2010	Flush	250
April 1986	Flush	300	May 2012	Flush	1,300
February 1987	Flush	800	May 2013	Flush	250
July 1990	Flush	----	May 2014	Flush	1,300
May 1991	Flush	600	May 2015	Flush	250
May 1993	Flush	1,000	June 2016	Flush	1,300
May 1994	Flush	250	May 2017	Flush	250
May 1995	Flush	----	May 2018	Flush	1,300

Figure 7-7. Cherry Creek Downstream during 2018 Flush

7.6 Cherry Creek Lake – Reservoir Hydraulic Elements

Reservoir hydraulics elements are a tool for the analysis of five channel geometry parameters relative to a reference plan elevation. Parameters analyzed include the active channel width, cross sectional area, average channel depth, average bed elevation, and thalweg elevation data was used in this report. These factors are calculated from cross section data sets for each sediment range for selected survey years during the reservoir surface area and storage capacity analysis process. The reference plane elevation chosen for Cherry Creek Lake was 5,596.7 feet, NGVD29, which is the top of the Flood Control Pool. Cross-sections CC-10 through CC-13 have thalweg elevations, which are above the Flood Control Pool, so average depth and average bed calculations cannot be performed on these range lines.

Hydraulic element calculations, generated by the OUP, have been compiled from the 1950, 1961, 1965, 1974, 1988, 2009, and 2016 surveys.

7.6.1 Analysis of Cross Section Average Depth Profiles

Cross section average depth data for Cherry Creek are tabulated in Table 7-7, and plotted profiles are shown in Figure 7-8. The average depth at the Cherry Creek tributary channel decreased < 5.5 feet for the sediment ranges from 1950 to 2016. During this period, the average depth decreased 5.3 feet at sediment range CC-01 suggesting aggradation has occurred near the dam.

Table 7-7. Cherry Creek Lake – Changes in Cross Section Average Depth Profiles (Feet)

Tributary Stream	Sediment Range	Survey Year							
		1950	1961	1965	1974	1988	2009	2016	1950 – 2016
Cherry Creek Channel	CC-01	-57.7	-56.4	-54.7	-53.6	-53.0	-52.7	-52.5	**+5.3**
	CC-02	-58.0	-58.1	-57.3	-56.2	-55.8	-55.5	-55.1	**+2.9**
	CC-03	-40.7	-40.2	-40.1	-39.6	-39.2	-39.0	-39.1	**+1.6**
	CC-04	-42.1	-41.4	-41.3	-41.1	-40.9	-40.8	-40.6	**+1.5**
	CC-05	-33.1	-32.5	-31.6	-31.4	-31.0	-30.8	-30.8	**+2.3**
	CC-06	-26.7	-26.5	-25.0	-24.8	-24.6	-24.7	-25.1	**+1.6**
	CC-07	-17.7	-13.5	-16.9	-16.3	-16.1	-16.1	-16.0	**+1.7**
	CC-08	-8.9	-8.7	-8.7	-8.4		-8.0	-8.3	**+0.6**
	CC-09	-5.9	-5.9	-8.2	-5.9	-3.0	-2.6	-3.2	**+2.7**
	CC-10								
	CC-11								
	CC-12								
	CC-13								

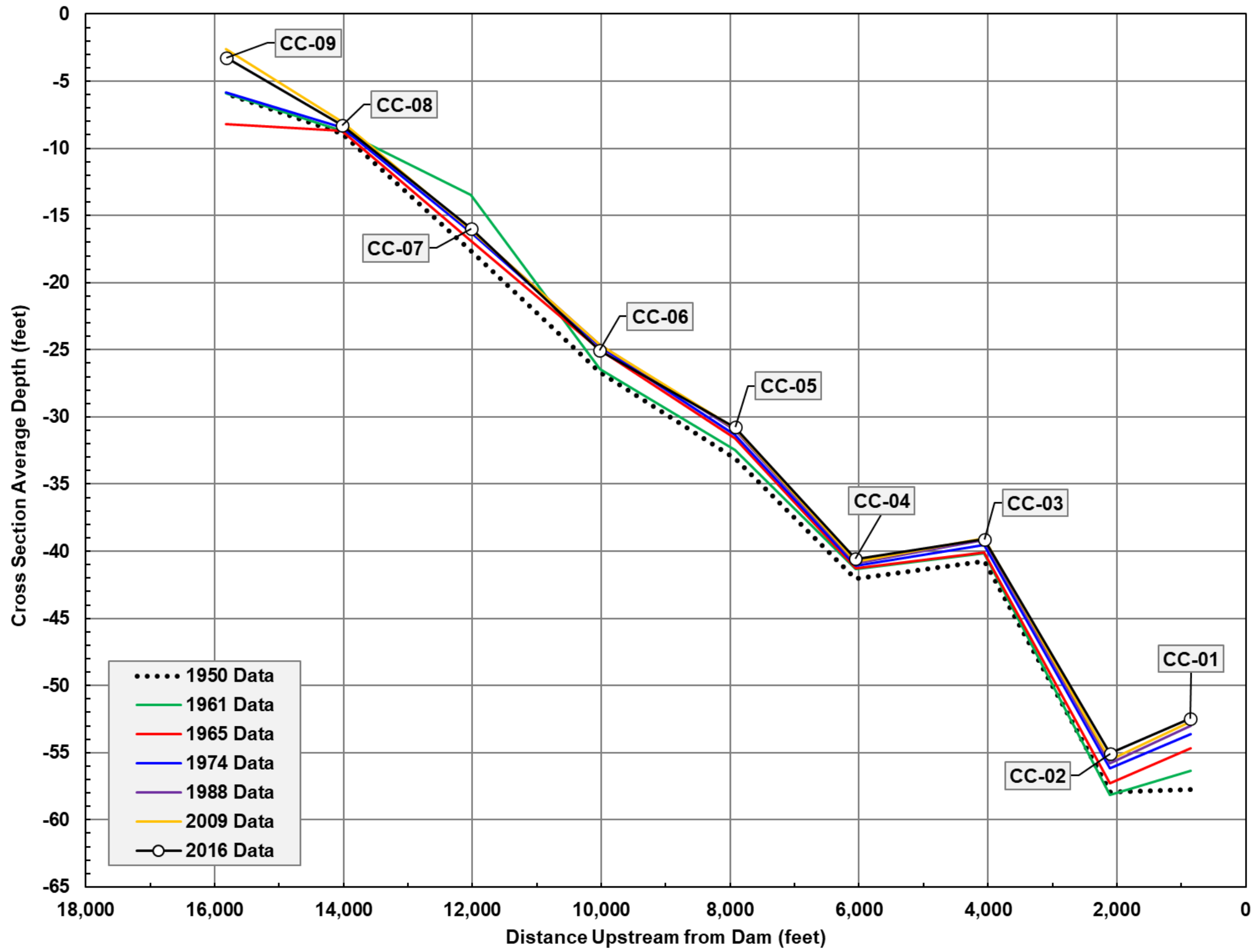

Figure 7-8. Cherry Creek – Changes in Cross Section Average Depth Profiles

7.6.2 Analysis of Cross Section Average Bed Elevation Profiles

Cross section average bed elevation data for Cherry Creek are tabulated in Table 7-8, and plotted profiles are shown in Figure 7-9. The average bed elevation increased < 5.3 feet for the sediment ranges from 1950 to 2016. During this period, the average bed elevation across the entire project increased on average 2.2 feet indicating that aggradation is occurring throughout the reservoir. The largest increase was 5.3 feet at sediment range CC-01 nearest the dam.

Table 7-8. Cherry Creek Lake – Changes in Cross Section Average Bed Elevation (Feet, NGVD29)

Tributary Stream	Sediment Range	Survey Year							
		1950	1961	1965	1974	1988	2009	2016	1950 – 2016
Cherry Creek Channel	CC-01	5,539.0	5,540.3	5,542.0	5,543.1	5,543.7	5,544.0	5,544.2	**+5.3**
	CC-02	5,538.7	5,538.6	5,539.5	5,540.5	5,540.9	5,541.2	5,541.6	**+2.9**
	CC-03	5,556.0	5,556.5	5,556.6	5,557.1	5,557.5	5,557.7	5,557.6	**+1.5**
	CC-04	5,554.6	5,555.3	5,555.4	5,555.6	5,555.8	5,555.9	5,556.1	**+1.5**
	CC-05	5,563.6	5,564.2	5,565.1	5,565.4	5,565.7	5,565.9	5,565.9	**+2.3**
	CC-06	5,570.1	5,570.2	5,571.7	5,571.9	5,572.1	5,575.0	5,571.7	**+1.6**
	CC-07	5,579.0	5,579.2	5,579.8	5,580.4	5,580.6	5,580.6	5,580.7	**+1.7**
	CC-08	5,587.8	5,588.1	5,588.0	5,588.3		5,588.7	5,588.4	**+0.6**
	CC-09	5,590.8	5,590.8	5,588.5	5,590.8	5,593.7	5,594.1	5,593.5	**+2.7**
	CC-10								
	CC-11								
	CC-12								
	CC-13								

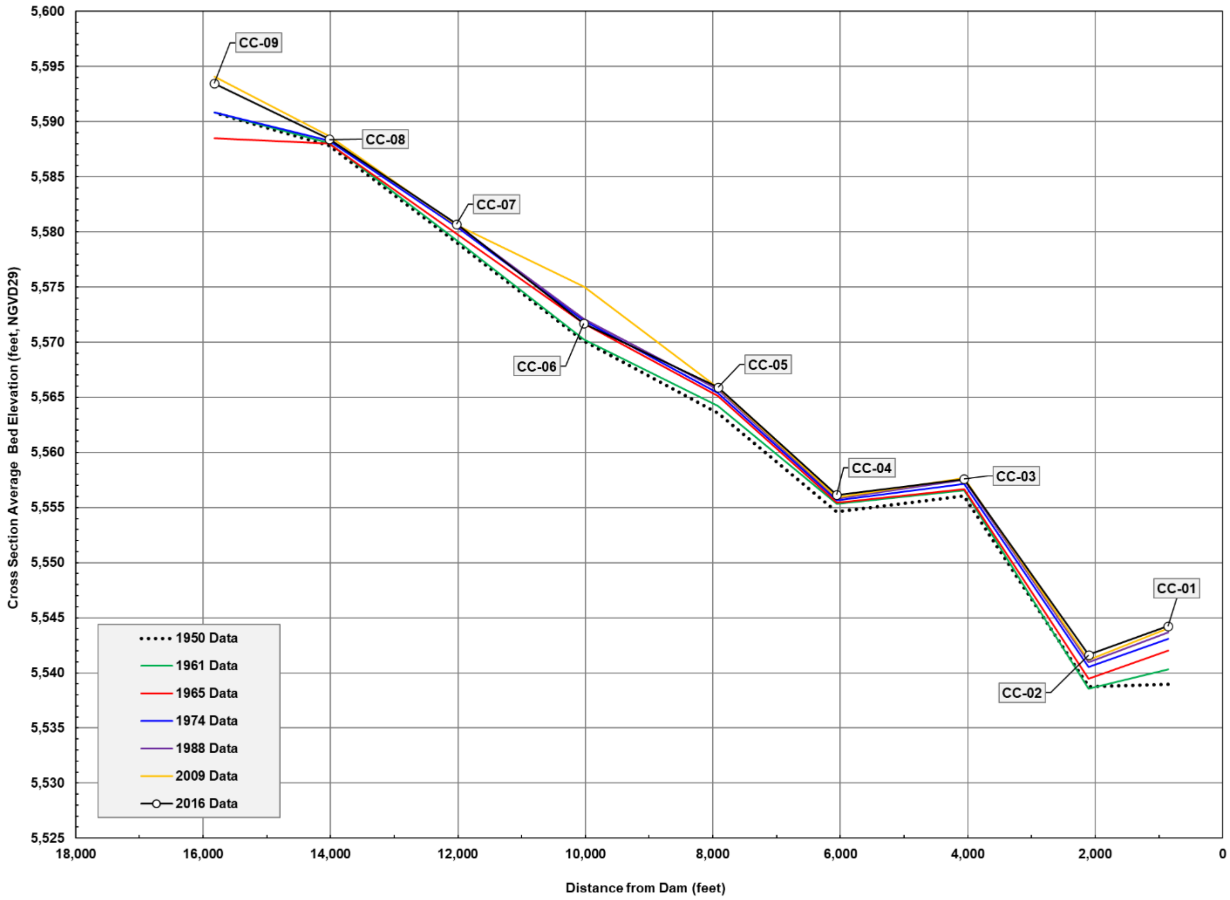

Figure 7-9. Cherry Creek – Changes in Cross Section Average Bed Elevation Profiles

7.6.3 Analysis of Cross Section Thalweg Profiles

Cherry Creek thalweg elevation data is present in Table 7-9. Plotted thalweg profiles for Cherry Creek are shown in Figure 7-10. The thalweg elevation has increased steadily from sediment range CH-07 towards the dam. In the upper portions of the reservoir which exhibit a more riverine environment at normal pools (CH-08 to CH-12), the thalweg has remained fairly even throughout the years except at the most upstream end of the reservoir which exhibited 4.2-foot degradation at sediment range CH-13.

Table 7-9. Cherry Creek Lake – Changes in Cross Section Thalweg Elevations (Feet, NGVD29)

Sediment Range	Survey Year							
	1950	**1961**	**1965**	**1974**	**1988**	**2009**	**2016**	**1950 – 2016**
CC-01	5,504.9	5,513.9	5,520.1	5,522.7	5,523.9	5,524.8	5,525.2	**+20.3**
CC-02	5,509.4	5,515.9	5,518.6	5,523.5	5,524.0	5,525.7	5,525.5	**+16.1**
CC-03	5,519.0	5,520.9	5,521.1	5,525.7	5,526.2	5,529.0	5,527.1	**+8.1**
CC-04	5,532.8	5,536.9	5,539.0	5,540.6	5,541.1	5,541.7	5,541.9	**+9.1**
CC-05	5,543.5	5,544.5	5,544.6	5,544.6	5,550.1	5,549.8	5,549.8	**+6.3**
CC-06	5,557.0	5,557.7	5,560.9	5,561.7	5,561.7	5,561.7	5,561.7	**+4.7**
CC-07	5,567.9	5,568.8	5,567.0	5,567.0	5,567.0	5,567.0	5,572.7	**+4.8**
CC-08	5,578.8	5,578.1	5,577.4	5,579.7		5,580.1	5,578.4	**-0.4**
CC-09	5,588.4	5,588.5	5,585.7	5,587.8	5,590.3	5,587.3	5,590.0	**+1.6**
CC-10	5,604.6	5,604.0	5,603.5	5,604.3	5,605.3	5,605.8	5,605.8	**+1.3**
CC-11	5,616.6	5,617.1	5,615.1	5,616.2		5,614.5	5,615.8	**-0.8**
CC-12	5,623.2	5,622.4	5,622.4		5,623.2	5,622.5	5,622.5	**-0.7**
CC-13	5,628.0	5,627.9	5,627.9		5,628.6	5,629.2	5,623.8	**-4.2**

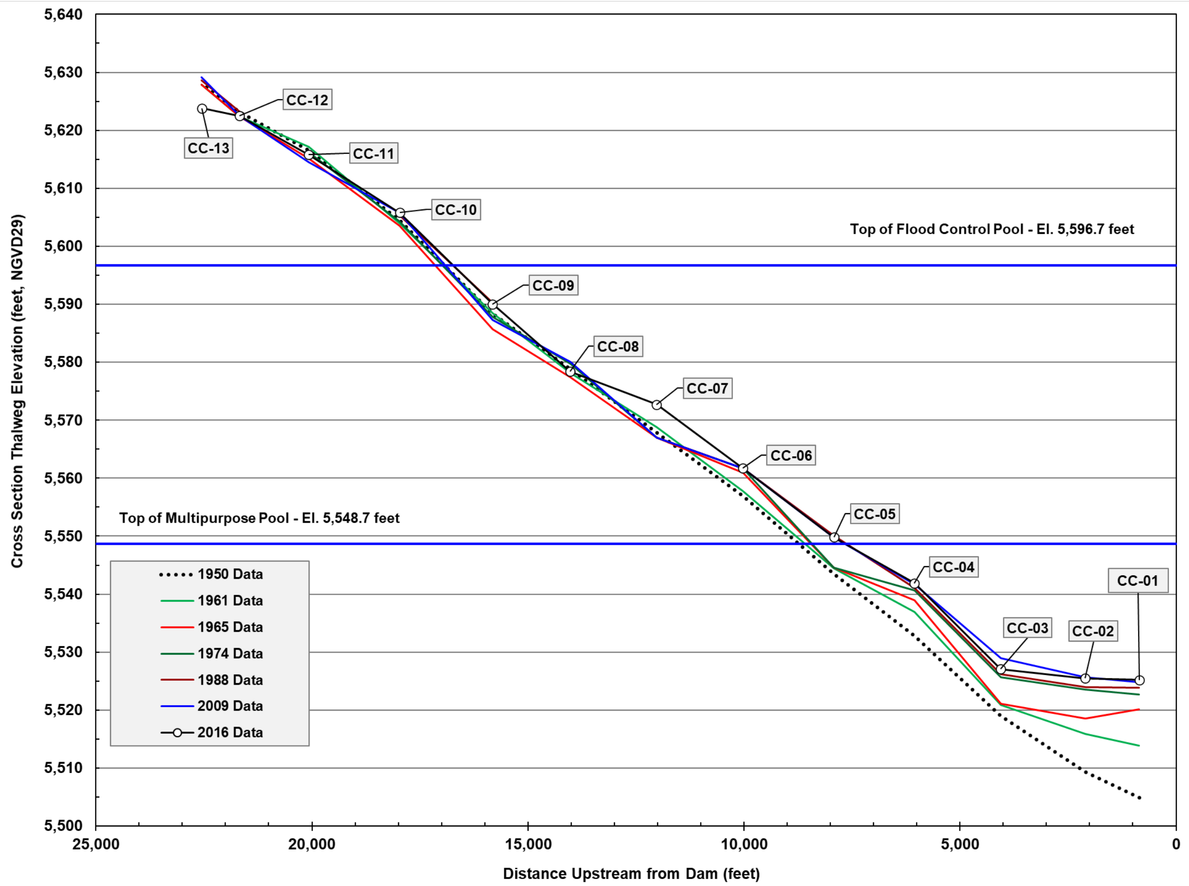

Figure 7-10. Cherry Creek – Changes in Cross Section Thalweg Elevations

7.7 Cherry Creek Lake – Reservoir Surface Area & Storage Capacity

Table 7-10 lists pertinent pool elevation and pool zones for Cherry Creek Lake. In the following sections, 2016 Cherry Creek Lake surface area and capacity data is compared with the surveyed sediment range data using the MAEA method and directly from the 2016 LiDAR/HDMB DEM surface using the GIS method.

Variations between the MAEA method results and the GIS method results may be attributed to variations in the reservoir bed and banks not accounted for during the collection of sediment range data. The variation between the range data (MAEA) and 2016 LiDAR/HDMB DEM surface is the direct result of the increased resolution of the survey data.

Area and capacity tables computed at 0.1-foot increments are located in Appendix D. The capacity tables computed at 0.01-foot increments are available from the USACE Omaha District River and Reservoir Engineering Section.

Table 7-10. Cherry Creek Lake – Pertinent Pool Elevations

Top of Pool	Pool Elevation (Feet, NGVD29)	Pool Zone	Pool Zone Elevations (Feet, NGVD29)
Maximum Pool	5,643.7	Surcharge	5,596.7 – 5,643.7
Flood Control Pool	5,596.7	Flood Control	5,548.7 – 5,596.7
Multipurpose Pool	5,548.7	Multipurpose	5,502.7 – 5,548.7
Inactive Pool	----	Inactive	----
		GROSS STORAGE	**Thalweg El. – 5,643.7**

7.7.1 Analysis of Reservoir Surface Area by Pool Elevation

A comparison of Cherry Creek surface area tables calculated from surveyed sediment range data using the MAEA method are tabulated in Table 7-11. Surface area profiles are plotted in Figure 7-11. Results indicate that surface area between 1950 and 2016 using the surveyed range data has decreased approximately 25 to 46 acres, depending on the pool zone.

Table 7-11 also indicates that between 1950 and 2016, surface area calculated from the 2016 LiDAR/HDMB DEM surface using the GIS method is greater than results generated from the MAEA method. This is likely due to the increased resolution of the DEM surface over the individual cross-section survey. Comparison of 1950 vs. 2016 using the consistent MAEA method shows that there is virtually no change above Flood Control Pool in surface area.

Table 7-11. Cherry Creek Lake – Changes in Reservoir Surface Area (Acres)

Operational Pool	Sediment Range Surveys (MAEA)							2016 GIS (DEM)	1950 – 2016	
	1950	1961	1965	1974	1988	2009	2016		MAEA	GIS
Maximum	4,779	4,762	4,766	4,768	4,770	4,740	4,748	5,196	-31	+417
Flood Control	2,585	2,641	2,636	2,636	2,642	2,638	2,560	2,668	-25	+83
Multipurpose	849	872	856	851	847	840	803	877	-46	+28
Inactive	----	----	----	----	----	----	----	----	----	----

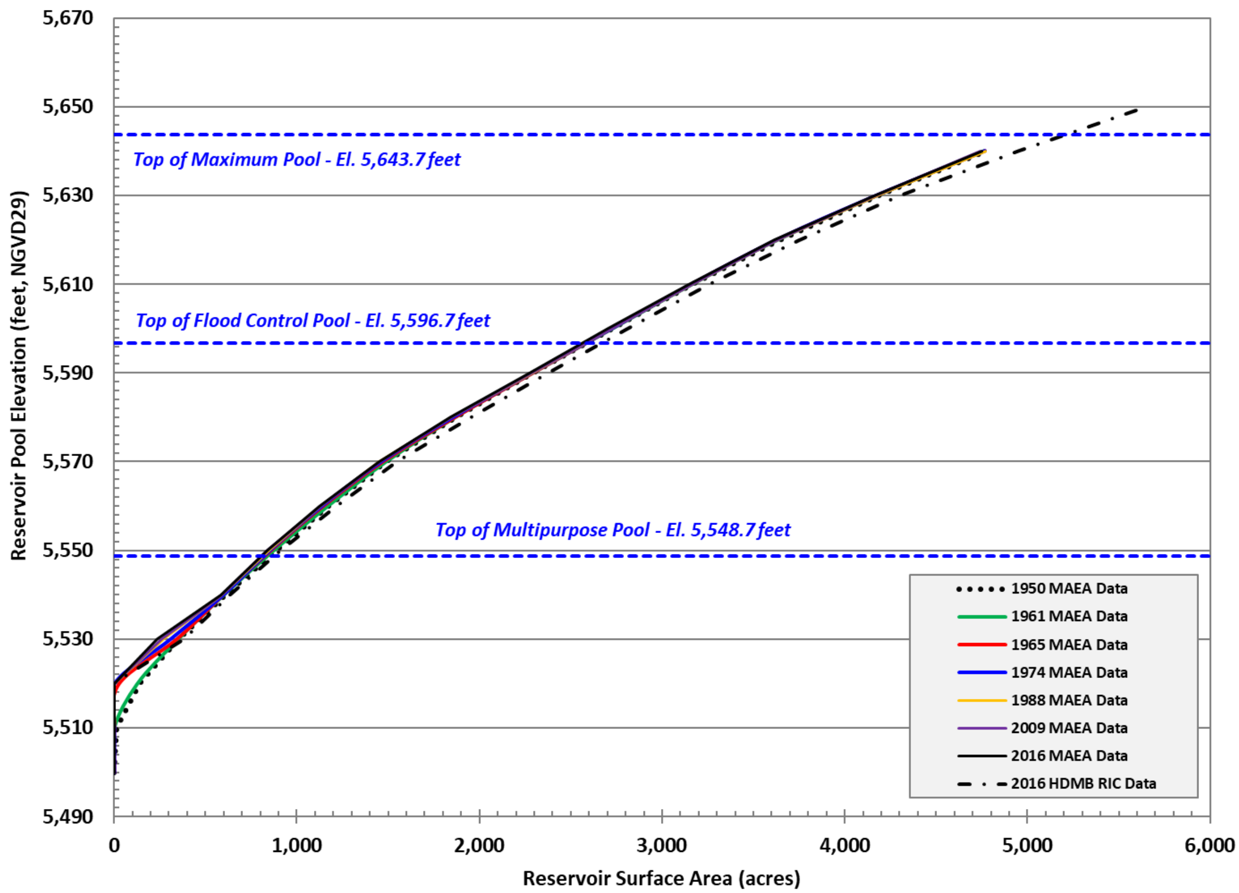

Figure 7-11. Cherry Creek Lake – Reservoir Surface Area Profiles

7.7.2 Analysis of Reservoir Storage Capacity by Pool Elevation

Table 7-12 and Table 7-13 tabulate the historical Cherry Creek Lake storage capacity data. Storage capacity profiles are shown in Figure 7-12. Results indicate that between 1950 and 2016 reservoir capacity has generally decreased between surveys and methodologies at the four operational pool elevations. Using the GIS method, the Maximum Pool increased by 26,151 acre-feet, the Flood Control Pool increased by 2,460 acre-feet, and the Multipurpose Pool decreased by 883 acre-feet between 1950 and 2016.

In summary:

- MAEA method capacity results show a decrease in capacity since 1950.
- GIS method capacity results show a general increase in capacity since 1950.
- Apparent increase in reservoir capacity is largely due to a change in methodology, using the GIS method instead of the MAEA method in order to calculate the reservoir capacity.

Table 7-12. Cherry Creek Lake – Changes in Reservoir Storage Capacity by Pool Elevation (Acre-Feet)

Operational Pool	Sediment Range Surveys (MAEA)				
	1950	1961	1965	1974	1988
Maximum	248,353	247,391	245,992	244,939	244,248
Flood Control	92,433	95,087	93,857	92,796	92,127
Multi-purpose	14,040	14,585	13,941	13,220	12,805
Inactive	----	----	----	----	----

Table 7-13. Cherry Creek Lake – Changes in Reservoir Storage Capacity by Pool Elevation (Acre-Feet)

Operational Pool	Sediment Range Surveys (MAEA)			2016 GIS (DEM)	1950 – 2016	
	1950	2009	2016		MAEA	GIS
Maximum	248,353	243,757	242,679	274,504	-5,674	+26,151
Flood Control	92,433	91,852	87,865	94,893	-4,568	+2,460
Multipurpose	14,040	12,558	11,211	13,157	-2,829	-883
Inactive	----	----	----	----	----	----

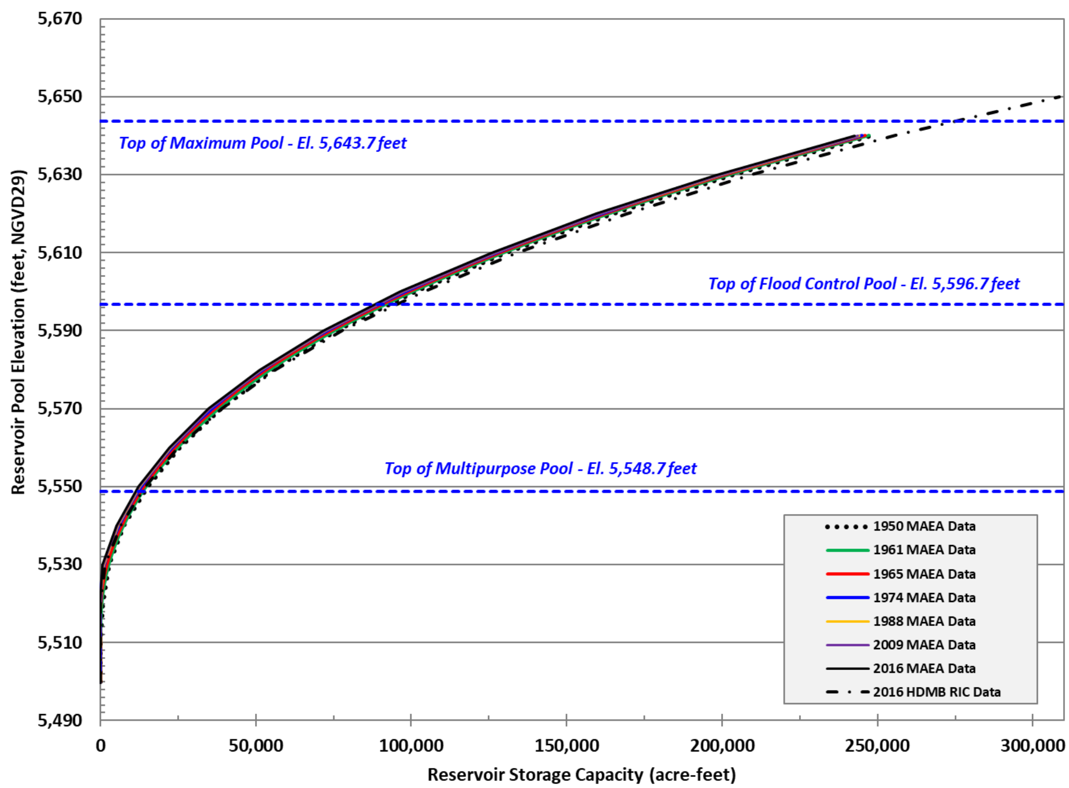

Figure 7-12. Cherry Creek Lake – Reservoir Storage Capacity Profiles

7.7.3 Analysis of Reservoir Storage Capacity by Storage Zone

The changes in reservoir storage capacity for the different pool or storage zones were analyzed to show the effects of sedimentation on a zone-by-zone basis. Table 7-14 presents reservoir capacity by pool zone for each sediment range survey and the 2016 LiDAR/HDMB DEM surface. A comparison of reservoir storage capacity between the 1950 and the 2016 sediment range data shows a steady decline in storage capacity at all pool zones.

Table 7-15 presents the change in storage capacity by pool zone. Figure 7-13 depicts the changes in reservoir storage capacity over time for each pool zone.

- Gross storage (elevation 5,502.7 – 5,643.7 feet, NGVD29) increased 26,151 acre-feet (+10.6%) using the GIS method.
- In the Surcharge Pool (elevation 5,596.7 – 5,643.7 feet, NGVD29), storage increased 23,691 acre-feet (+15.2%) using the GIS method.
- Storage in the Flood Control Pool (elevation 5,548.7– 5,596.7 feet, NGVD29) increased 3,343 acre-feet (+4.3%) using the GIS method.
- Storage in the Multipurpose Pool (elevation 5,502.7 – 5,548.7 feet, NGVD29) decreased 883 acre-feet (-5.2%) using the GIS method.

The variation between the two methods of calculating reservoir storage capacity is the results of the increased resolution at the bottom contours of Cherry Creek Lake of the 2016 LiDAR/HDMB DEM Surface. Also, the lack of a 1950 survey, using the GIS method, does not allow for a direct comparison of storage capacities.

Table 7-14. Cherry Creek Lake – Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Operational Pool Zone	Sediment Range Surveys (MAEA)							2016 GIS (DEM)
	1950	1961	1965	1974	1988	2009	2016	
GROSS STORAGE	**248,353**	**247,391**	**245,992**	**244,939**	**244,248**	**243,757**	**242,679**	**274,504**
Surcharge	155,920	152,304	152,135	152,143	152,121	151,905	154,814	179,611
Flood Control	78,393	80,502	79,916	79,576	79,322	79,294	76,655	81,736
Multipurpose	14,040	14,585	13,941	13,220	12,805	12,558	11,211	13,157
Inactive	----	----	----	----	----	----	----	----

Table 7-15. Cherry Creek Lake – Changes in Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Operational Pool Zone	MAEA		2016 GIS (DEM)	1950 – 2016 MAEA		1950 – 2016 GIS	
	1950	2016		Change	% Rem.	Change	% Rem.
GROSS STORAGE	**248,353**	**242,679**	**274,504**	**-5,674**	**97.7**	**+26,151**	**110.5**
Surcharge	155,920	154,814	179,611	-1,106	99.3	+23,691	115.2
Flood Control	78,393	76,655	81,736	-1,739	97.8	+3,343	104.3
Multipurpose	14,040	11,211	13,157	-2,829	79.8	-883	93.7
Inactive	----	----	----	----	----	----	----

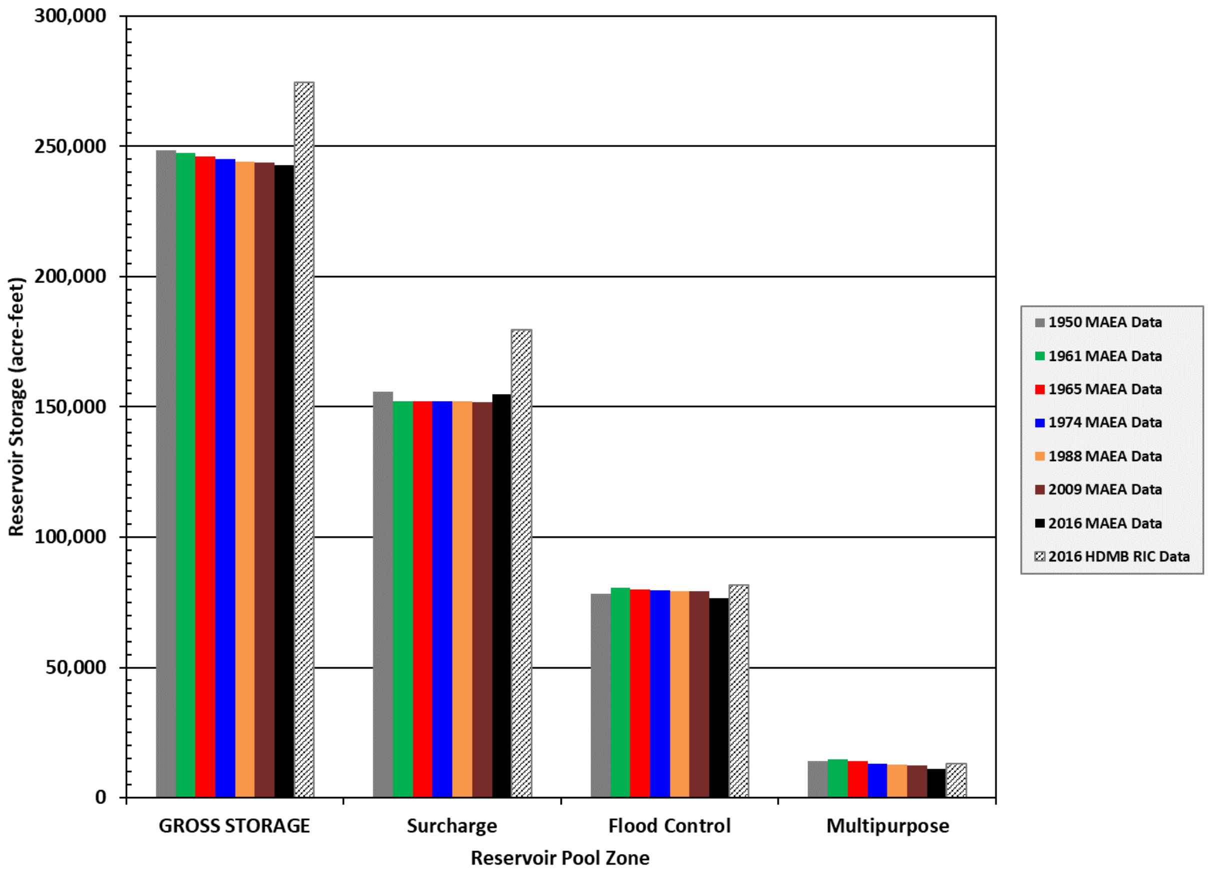

Figure 7-13. Cherry Creek Lake – Changes in Reservoir Storage Capacity by Pool Zone (Acre-Feet)

7.8 Cherry Creek Lake – Reservoir Storage Depletion

The purpose of this report was to evaluate the loss of reservoir storage volume due to sedimentation impacts at Cherry Creek Lake as monitored by the Omaha District. Original sediment yield calculations, historical sediment depletion rates, and future aggradation trends will be evaluated in this section.

7.8.1 Original Sediment Yield Calculations

The original sediment yield calculations for Cherry Creek were first reported in 1950. Cherry Creek Lake was designed to contain a sediment yield for a 74-year period. There is little historical sediment data available for Cherry Creek Lake. The design sediment depletion rate was calculated in the 1944 Definite Project Report (DPR) at 116.3 acre-feet per year based on survey data and calculations from neighboring reservoirs.

The original sediment analysis of Chatfield Lake also considered the sedimentation rates observed at Cherry Creek Lake located in the adjacent drainage basin to the east of the Plum Creek tributary arm and the abnormal sediment runoff from the Plum Creek basin for the period of time it takes for the presently torn and deteriorated channel to naturally heal. The observed rates at the Cherry Creek project included the record runoff contribution from the 16-17 June 1965 flood.

7.8.2 Analysis of Reservoir Sediment Depletion using Volume by Segment Tables

Cherry Creek Lake volume by segment tables were calculated in 10-foot increments for all seven surveys using the MAEA method. Individual segment tables are located in Appendix C. Table 7-16 tabulates reservoir volume by segment changes between 1950 and 2016 from the surveyed sediment ranges, and Figure 7-14 shows the reservoir volume by segment changes between 1950 and 2016 from the surveyed sediment ranges as well.

Data shows that the predominately lake segments (001 through 004), there has been an average decrease of reservoir storage of 749.7 acre-feet (-2.4%). The Cherry Creek segments (005 through 010 and 013 through 014) show an average decrease of reservoir storage of 346.5 acre-feet (-5.9%).

Table 7-16. Cherry Creek Lake – Changes in Reservoir Storage Volume X Segment (Acre-Feet)

Seg. No.	**Bounding Sediment Ranges**	**Sediment Range (MAEA)**							**1950 – 2016**	
		1950	**1961**	**1965**	**1974**	**1988**	**2009**	**2016**	**Change**	**%**
001	DAM – CC-01	14,036	13,964	13,894	13,839	13,800	----	13,711	**-325**	**-2.3**
002	CC-01 – CC-02	31,260	31,126	30,827	30,547	30,400	----	30,111	**-1,149**	**-3.7**
003	CC-02 – CC-03	47,815	47,735	47,529	47,211	47,046	----	46,757	**-1,058**	**-2.2**
004	CC-03 – CC-04	36,612	36,478	36,454	36,395	36,306	----	36,147	**-465**	**-1.3**
005	CC-04 – CC-05	28,082	27,946	27,830	27,783	27,717	----	27,522	**-560**	**-2.0**
006	CC-05 – CC-06	27,364	27,282	26,906	26,833	26,749	----	26,699	**-666**	**-2.4**
007	CC-06 – CC-07	21,073	21,041	20,839	20,754	20,719	----	20,777	**-296**	**-1.4**
008	CC-07 – CC-08	15,263	15,224	15,195	15,124	15,073	----	14,981	**-282**	**-1.9**
009	CC-08 – CC-09	13,362	13,343	13,337	13,289	13,295	----	13,098	**-264**	**-2.0**
010	CC-09 – CC-10	8,216	8,220	8,204	8,183	8,191	----	7,619	**-597**	**-7.3**
011*	CC-10 – CC-11	2,909	2,904	2,849	2,852	2,846	----	3,296	**+387**	**+13.3**
012*	CC-11 – CC-12	1,544	1,522	1,476	1,474	1,480	----	2,384	**+840**	**+54.4**
013	CC-12 – CC-13	513	471	471	471	466	----	474	**-38**	**-7.5**
014	CC-13 – END	304	232	232	232	211	----	234	**-69**	**-22.9**

*Range line CC-11 was re-established for the 2016 survey. Volumes in segments 11 and 12 are based on this new range line adjustment and comparisons with previous years' calculations are not meaningful.

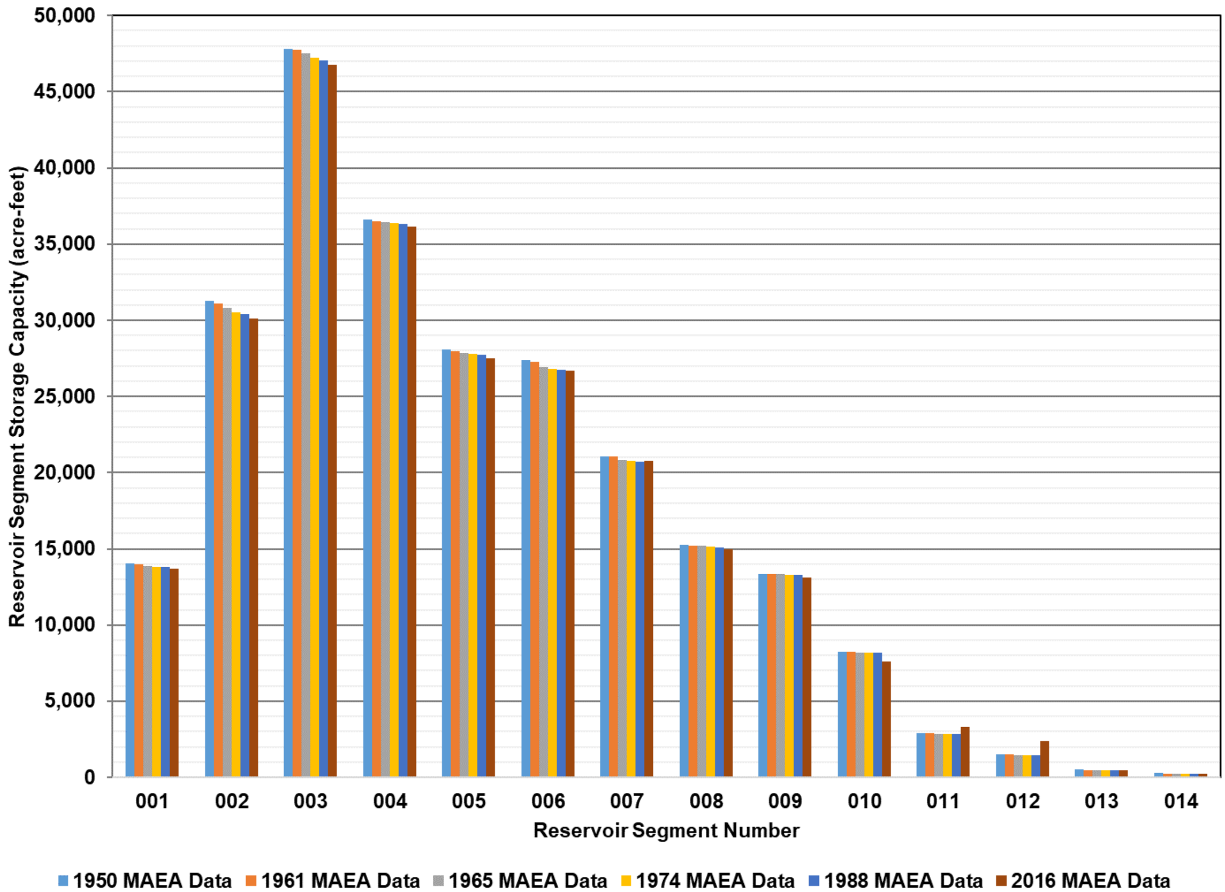

Figure 7-14. Cherry Creek Lake – Changes in Reservoir Storage Volume X Segments

7.8.3 Analysis of Reservoir Storage Depletion Rates

The volume of sediment that entered the reservoir between surveys is represented by the reservoir storage capacity depletion rates as shown in Table 7-17. Gross storage depletion, between 1950 and 2016, at Cherry Creek was a decrease of 86.0 acre-feet per year as generated by the MAEA method and an increase of 396.2 acre-feet per year as generated by the GIS method. The result for the MAEA method was less than, and the result for the GIS method was greater than, the design depletion rate of 116.3 acre-feet per year.

NOTE: The analysis of depletion rates does not include the effects of sediment flushing as previously described in the section on Sediment Removal.

Table 7-17. Cherry Creek Lake – Summary of Reservoir Storage Depletion Rates

(Sediment Range Surveys – MAEA and GIS Calculations)[1]

Period [1950 – 2016] (Years)		**66**	
Drainage Area (mi²)		386	
Design Storage Depletion Rate (AF/YR)		116.3	
		MAEA	GIS
Total Reservoir Storage	% Storage Remaining	97.7	110.5
	% Annual Storage Depletion	-0.035	0.160
	Depletion Rate (AF/YR)	-86.0	396.2
	Normalized Depletion Rate (AF/mi²/YR)	-0.2227	1.0265
Surcharge Storage	% Storage Remaining	99.3	115.2
	% Annual Storage Depletion	-0.011	0.230
	Depletion Rate (AF/YR)	-16.8	359.0
	Normalized Depletion Rate (AF/mi²/YR)	-0.0434	0.9299
Flood Control Storage	% Storage Remaining	97.8	104.3
	% Annual Storage Depletion	-0.034	0.065
	Depletion Rate (AF/YR)	-26.3	50.6
	Normalized Depletion Rate (AF/mi²/YR)	-0.0683	0.1312
Multipurpose Storage	% Storage Remaining	79.8	93.7
	% Annual Storage Depletion	-0.305	-0.095
	Depletion Rate (AF/YR)	-42.9	-13.4
	Normalized Depletion Rate (AF/mi²/YR)	-0.1110	-0.0346
Inactive Storage	% Storage Remaining	----	----
	% Annual Storage Depletion	----	----
	Depletion Rate (AF/YR)	----	----
	Normalized Depletion Rate (AF/mi²/YR)	----	----

1. Depletion rates do not include the effects of sediment flushing.

7.8.4 Analysis of Future Reservoir Storage Depletion

One of the objectives of M.R.B. Sediment Memorandum 23b was to predict future sediment conditions at Chatfield Lake for 50 years into the future (2066). The assessment used area and capacity data and previously calculated depletion rates to estimate the change in reservoir storage capacity that might occur. Table 7-17 above lists the depletion rates, generated by both the MAEA and GIS methods between 1950 and 2016, that were used for this analysis. The results of this analysis can be seen below in Table 7-18.

Table 7-18. Future Cherry Creek Lake – 2066 Reservoir Storage Capacity by Pool Zone (Acre-Feet)

Pool Zone	Elevation Range (Feet, NGVD29)	1950 MAEA	2066 MAEA	Percentage Lost/Gained by 2066 (MAEA)*	2066 GIS	Percentage Lost/Gained by 2066 (GIS)*
Surcharge	5,596.7 – 5,643.7	155,920	153,976	-1.25%	197,559	+26.71%
Flood Control	5,548.7 – 5,596.7	78,393	75,337	-3.90%	84,268	+7.49%
Multipurpose	5,502.7 – 5,548.7	14,040	9,067	-35.42%	12,488	-11.05%
Inactive	----	----	----	----	----	----

*Loss indicated by minus (-) sign, and gain indicated by plus (+) sign.

The 50-year projection shows an apparent increase in capacity for the GIS method. However, the changes since 1950 is well within the noise of the data and the limited accuracy of the capacity estimation methods. It would be foolhardy to predict the reservoir will gain capacity based on these small, measured changes over the last 66 years. Under normal climate conditions, the reservoir will likely not experience a capacity increase, rather it will retain its current capacity for the next 50 years.

7.9 Cherry Creek Lake – Engineering Form 1787 (Reservoir Sediment Data Summary)

Engineering Form 1787, “Reservoir Sedimentation Data Summary” is presented in Appendix G. The purpose of this form is to provide a means for the uniform documentation of pertinent Cherry Creek Lake sedimentation data.

8 References

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