Cherry Creek Basin Water Quality Authority
8390 East Crescent Parkway, Suite 500
Greenwood Village, Colorado 80111
(P) 303.779.4525
(F) 303.773.2050

Memorandum

To: Rick Goncalves, TAC Chairman

Cc: Chuck Reid, Manager

From: William P. Ruzzo, P.E., Craig Wolf, GEI

Date: January 22, 2014, Amended February 27, 2014

Re: Cherry Creek Reservoir Area-Capacity Data, Amended

The Cherry Creek Basin Water Quality Authority (Authority) has retained Hydros Consulting Inc[1] to develop a reservoir water quality model. Important input data for the model includes the reservoir surface area at regular intervals below the reservoir surface. To develop this data, the Authority also retained Absolute Natural Resources, LLC[2] (ANR) to prepare a bathymetric survey, which determines the depth from the water surface to the reservoir bottom.

ANR conducted the survey in November 2013, processed the data to develop one foot depth contours, and provided the Authority an AutoCAD file with the depth contours in the reservoir. This file was then used by the Authority to calculate surface area and storage volume of the reservoir. The methodology and approach used to prepare the area and volume calculations are described herein and the results presented in tabular and graphic formats.

Based on the ANR 2013 survey, the volume of the reservoir below the normal pool elevations (multipurpose storage pool) was determined to be 13,522 acre feet (ac ft) and presented in Local Project Datum. The surface area at the multipurpose storage pool elevation of 5,550 feet (ft) was determined to be 875 acres (ac).

This memorandum, which replaces the previous memorandum dated January 22, 2014, was amended to include an investigation to determine the appropriate vertical datum for the bathymetric survey and to further compare area and storage volume results to values recently published by the U.S. Army Corps of Engineers (USACE July 2011). The amendment was necessary because it is important for the bathymetric results to be consistent with the elevation information reported by the USACE on their website which is also used by the Colorado Division of Water Resources to manage water rights in Cherry Creek. In addition, the

[1] Agreement dated December 5, 2013

[2] Agreement dated November 13, 2013.

multipurpose storage pool elevation of 5,550 ft is used by the Authority to establish protection elevations for shoreline stabilization projects, such as the Mountain and Lake Loop project completed in 2013.

METHODOLOGY

ANR conducted a sub-foot mapping survey using a professional grade GPS (differential and RTK) hydro-acoustic (sonar) and GIS technology to collect 298,925 data points (i.e.: x, y, and z coordinates). The survey was performed between November 18 and November 27, 2013 by mounting the instrument on a small motorized boat. These spatial data points were used to develop water-depth contours at one-foot intervals and create a contour map of the reservoir using proprietary software (Figure 1 – Cherry Creek Reservoir). ANR provided multiple files to the Authority that included AutoCAD and GIS shape files, laminated maps, and a Google Earth® file with reservoir water depth contours at 1-foot intervals beginning with the "zero" depth at the normal pool elevation of 5,550 ft (Local Project Datum).

The AutoCad file was modified by the Authority to facilitate calculation of surface area at each water depth as follows:

1. Each 1-foot depth contour (39-each) was placed in a separate CAD layer.

2. The contour information, which typically consisted of multiple data blocks, was then "exploded" to create individual polylines. Because there were often multiple individual contour lines for each elevation, depth specific contour lines were "chained" together, where possible, to create one continuous polyline for each depth contour. Contour lines in the area of the outlet tower were found to stop at the outlet tower limits. To facilitate area calculation, the contours surrounding the outlet tower were connected to create complete polylines.

3. The area of each depth specific contour was then calculated using a CAD routine and recorded in an Excel spreadsheet. The volume between each depth layer was then calculated using the equation:

$$V = \frac{D}{3} * (A1 + (A1 * A2)^{0.5} + A2)$$

Where V = Volume
D = Depth between contours (1-foot)
A1, A2 = Area at upper and lower contour.

Calculations for cumulative volume were then added to the Excel spreadsheet to determine the volume of the multipurpose pool below 5,550 ft.

DATUM DIFFERENCES

During the Authority's review of the results published in the original memorandum, it was discovered that the stated vertical datum on the work products was not consistent, with notations contained in electronic files that the datum used was the NGVD29 or NAVD88 datum. The Authority recalled the original memorandum and began investigating the datum discrepancy, the findings which are discussed below.

ANR based their survey on elevations reported on the NOAA website (http://water.weather.gov/ahps2/hydrograph.php?wfo=bou&gage=egdc2) and confirmed that the NOAA data was obtained from the USACE gaging site at the Reservoir[3] by contacting personnel at NOAA.

Elevations reported by the USACE on their website are based on Local Project Datum, not NGVD29[4] or NAVD88 datum. The Local Project Datum, used by the USACE in reports for Cherry Creek, is approximately 1.27 ft[5] above elevations based on NGVD29 datum. The relationship between NGVD29, Local Project, and NAVD88 datum is provided in the Appendix 2. Whereas the datum differences are shown to a precision of 0.01 ft, discussions with the USACE suggest that the precision is overstated and has varied over time.

For the Mountain and Lake Loop Shoreline Stabilization project, which first discovered the datum differences[6], NGVD29 elevations were found to be 0.97 ft lower than elevations shown on the USACE website[7]. The difference of 0.97 ft does not agree with the reported USACE difference of 1.27 ft. The 2011 USACE report does discuss that the staff gage has settled ~0.2-ft but they have confirmed via personal communication that the staff gage is not used to monitor pool elevation, so this offset is not the basis for the discrepancy between the two elevation comparisons either.

REASONABLENESS CHECK

To check the reasonableness of the area and multipurpose pool volume calculations, as based on the ANR analysis, results were compared to recent data published by the USACE and independent calculations by Leonard Rice Engineers (LRE). A comparison of all three sources is presented in the table below:

Data Source	Surface Area (acres)	Storage Volume (acre feet)
ANR 2013	876	13,522
USACE 2011	840	12,558
LRE 2013	n/a	13,504

[3] Email from Wes Friesen (ANR) dated 1/28/2014 Subject: "Cherry Creek Elevations" (see appendix to this memo).
[4] Email from Craig Wolf (GEI) dated January 30, 2014 Subject: "Action items from conference call" (see appendix to this memo).
[5] USACE July 2011. *Tri-Lakes Sedimentation Studies Area-Capacity Report.* Page 2-7. (see appendix to this memo)
[6] Email from Melanie Chenard (Muller Engineering) dated June 30, 2010. "RE: Survey benchmark issues for shoreline project @ Chery Creek Reservoir".
[7] Elevation data were downloaded from the NOAA, USACE, and the Colorado Division of Water Resources websites by GEI, compared, and found to be within 0.01-feet. (see appendix to this memo for comparison table and website links)

USACE Tri-Lakes Sediment Report. The USACE performed cross-section surveys collecting elevation data in 2006, 2007, and 2009 to determine the change in reservoir volume resulting from sedimentation. The results are presented in their 2011 report in which elevation data are reported based on Local Project Datum. The USACE compared cross section data to the original project elevations to determine changes in area, and therefore volume, at each cross section. A copy of the USACE results in tabular form for surface area and for capacity at one-foot intervals is provided in the Appendix 2 to this memorandum and is reproduced in Table 2. The USACE calculated the volume to be 12,558 ac ft, a difference of 964 ac ft or 7.1% when compared to results based on the ANR survey. Similarly, the surface area was calculated by the USACE to be 840 ac, a difference of 36 ac or 4.1%.

LRE Calculations. A copy of the modified ANR GIS shape files were provided to LRE who performed an independent calculation of the reservoir volume (multipurpose storage pool) using GIS software rather than computational formulas in Excel. LRE calculated the volume to be 13,504 ac ft, a difference of 18 ac ft or 0.13% when compared to Excel results based on the ANR survey. LRE calculations are provided in Appendix 1 to this memorandum.

RESULTS

Results of the survey and analysis are presented as tables and figures attached to this memorandum and discussed below. All elevation information presented in these results are based on the Local Project Datum (Local Project Datum = NGVD29 + 1.27 feet).

Table 1 presents the results of the 2013 ANR survey and subsequent calculations by the Authority of the surface area and accumulative volume at each contour (i.e.: from elevation 5,512 ft to elevation 5,550 ft, the multi-purpose storage pool[8]). Figure 2 is a plot of the storage area as a function of elevation (i.e., stage) and Figure 3 is a plot of the surface area at each contour. Between elevation 5,512 ft and 5,523 ft, the area and volume are very small compared to the area and volume at the multipurpose storage pool elevation of 5,550 ft. This is due to sediment accumulation at the downstream end near the Outlet Tower which is frequently flushed out by the USACE and resulted in a deep hole at the outlet structure.

Table 2 provides a comparison between the Authority's calculations based on the ANR survey and the USACE calculations for each elevation[9]. Figure 4 is a plot comparing the storage volumes and Figure 5 is a plot of the surface area for both the ANR and the USACE surveys. As shown in Table 2, the surface area calculations differ from as little as 1 ac up to 99 ac. The storage volume at each elevation differs from 1 ac ft up to 964 ac ft at the normal pool[10].

FINDINGS AND CONCLUSIONS

The USACE determined the storage volume at 5,550 ft to be 12,558 ac ft, which is 964-ac ft (7%) less than the 2013 ANR survey (13,522 ac ft). The USACE surface area at elevation 5,550

[8] In USACE 2011, they report normal pool to be from 5504 to 5550. The difference with the ANR survey could be sediment accumulation and/or precision of side-scan radar.
[9] USACE 2011. p. D-8, (see appendix to this memo)
[10] It is interesting to note that if the elevations for the USACE data are shifted by only 1-foot, the curves for the ANR and USACE storage volume are graphically aligned suggesting that vertical datum differences may account for the volume differences.

is 840 ac which is 36 ac (4%) less than the 2013 ANR survey (876 ac). Possible explanations for these differences are discussed below.

The storage volume derived from the 2013 ANR survey was based on the average end-area method using horizontal sections (i.e.: contours) at 1-foot intervals. The storage volume calculated by the USACE used the average end-area method based on vertical cross sections that were hundreds of feet apart. The closer transect spacing used by ANR (e.g. 50 ft) to achieve their sub-foot measurements is believed to result in a more accurate estimate of the storage volume.

According to the USACE sediment report, the accumulation of sediment in the reservoir has decreased from a peak of 161 af/yr in 1965 to ~12 af/yr in 2009 (p.5-4). Therefore, additional sediment accumulation accounts for less than 5%[11] of the difference and is not believed to be the reason for the difference in storage volume.

The USACE also used an alternate approach to surveying using LiDAR techniques[12] that resulted in a storage volume of 13,926 ac ft at 5,550 ft, which is 3% greater than the 2013 ANR survey. Because the storage volume based on the 2013 ANR survey lies between the two estimates calculated by the USACE, the 2013 ANR survey results are believed to be consistent with USACE calculations.

Using GIS routines, LRE independently calculated the storage volume at the multipurpose pool elevation to be 13, 504 ac ft, which is less than 0.5% different from the average end-area methodology presented in this memorandum. Therefore, we believe the Authority's volume calculations are consistent with other estimates.

RECOMMENDATIONS

Based on the investigations and findings described in this memorandum, the following recommendations are presented for the bathymetric results and future shoreline stabilization projects.

1. The Authority's depth specific surface area and volume calculations, based on the 2013 ANR survey (Table 1) are recommended for input to the Reservoir model. Using the Local Project Datum will allow correlation between the reported water surface elevations on the USACE, NOAA, or DWR websites and the model results.

2. When preparing design plans for PRF's in the Park, the USACE requires the work to be done in either NGVD29 or NAVD88 datum and to include an equation comparing the two. Because management of the storage levels in the reservoir are based on the Local Project Datum, it is recommended the Authority use the Local Project Datum and elevation 5,550 ft to identify vertical stabilization limits for shoreline stabilization projects, which can be easily checked daily using the available websites. The 2011 USACE report shows that the annual maximum and minimum water surface elevation in the reservoir typically vary around elevation 5,550 ft Local Project Datum[13].

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[11] (4-years x 12-af/yr = 48-af; 48/964 = 0.05)
[12] USACE 2011. p. G-3. (see appendix to this memo)
[13] USACE 2011. p. F-7. (see appendix to this memo)

List of Tables and Figures

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

Table 1 - Reservoir Volume and Surface Area

Normal Pool El = 5550.0

Depth	Contour Elevation	Area (acres)	Volume Acre Feet	
			Vol.	Cumulative
-38	5512	0.0	n/a	0
-37	5513	0.0	0.0	0
-36	5514	0.0	0.0	0
-35	5515	0.0	0.0	0
-34	5516	0.0	0.0	0
-33	5517	0.0	0.0	0
-32	5518	0.0	0.0	0
-31	5519	0.0	0.0	0
-30	5520	0.1	0.1	0
-29	5521	0.1	0.1	0
-28	5522	0.2	0.1	0
-27	5523	0.5	0.4	1
-26	5524	1.9	1.1	2
-25	5525	25.8	11.6	13
-24	5526	165.1	85.4	99
-23	5527	239.7	201.3	300
-22	5528	279.8	259.5	560
-21	5529	315.0	297.2	857
-20	5530	344.7	329.7	1187
-19	5531	387.3	365.8	1552
-18	5532	416.6	401.9	1954
-17	5533	440.2	428.3	2383
-16	5534	467.6	453.9	2836
-15	5535	490.6	479.1	3315
-14	5536	514.5	502.5	3818
-13	5537	546.2	530.3	4348
-12	5538	563.9	555.0	4903
-11	5539	590.2	577.0	5480
-10	5540	613.8	602.0	6082
-9	5541	635.1	624.4	6707
-8	5542	656.8	645.9	7353
-7	5543	683.1	669.9	8022
-6	5544	711.6	697.3	8720
-5	5545	742.0	726.7	9446
-4	5546	772.2	757.1	10204
-3	5547	804.2	788.1	10992
-2	5548	833.5	818.8	11810
-1	5549	857.0	845.2	12656
0	5550	875.5	866.2	13522

NOTE: Based on survey by Absolute Natural Resources performed November 18-27, 2013
Elevations are based on Local Project Datum. NGVD29 = Project Datum - 1.27'

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

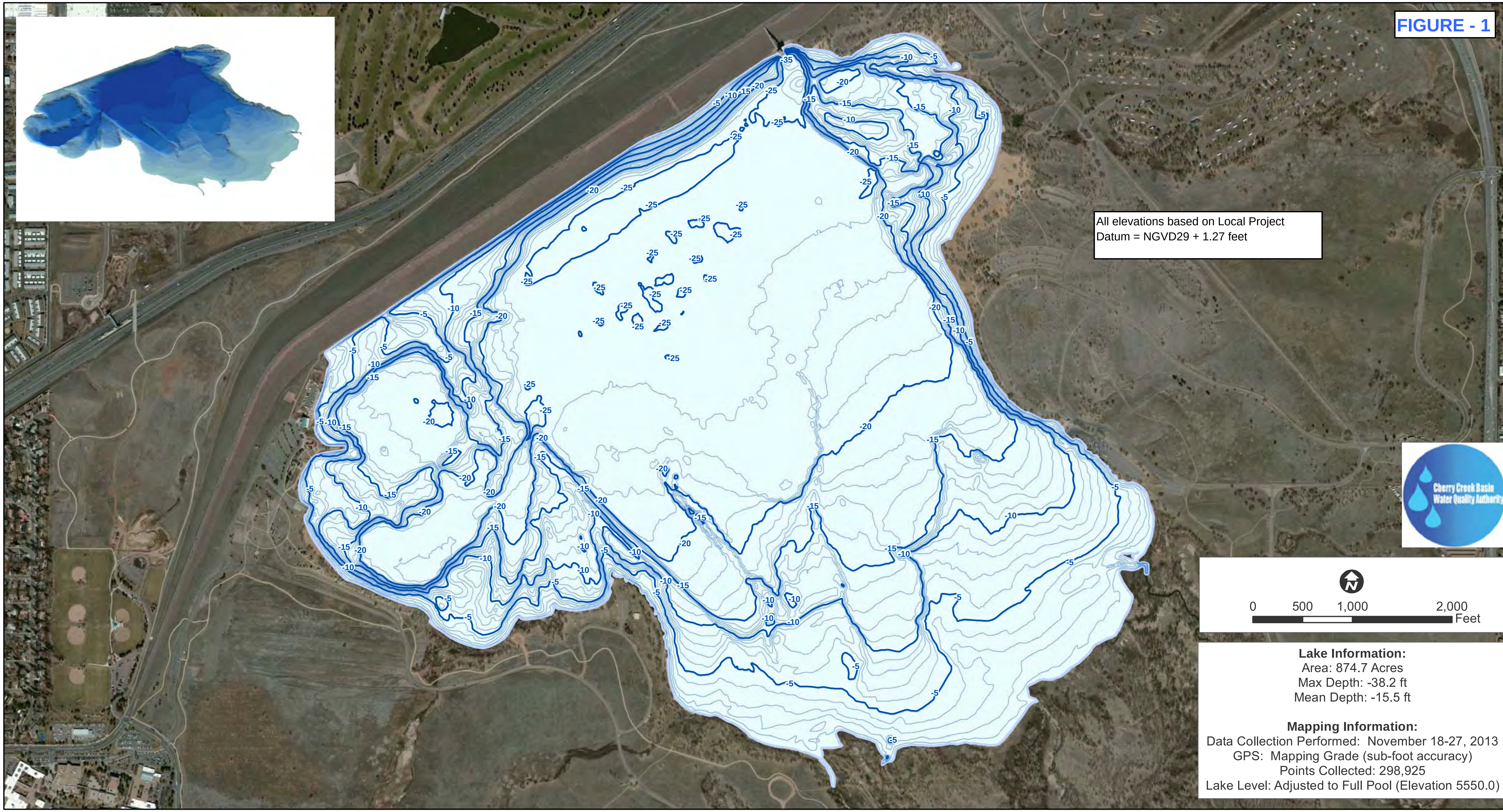
Table 2 - Reservoir Volume and Surface Area - Comparison w/USACE

Normal Pool El = 5550.0

Depth	Contour Elevation	Area (acres)	Volume Acre Feet		USACE 2011 Appendix D Contour Elevation	Area (acres)		Differences USACE - CCBWQA Area (acres)	Volume (acre feet)
			Vol.	Cumulative			Cumulative		
-38	5512	0.0	n/a		5512				
-37	5513	0.0	0.0		5513				
-36	5514	0.0	0.0		5514				
-35	5515	0.0	0.0		5515				
-34	5516	0.0	0.0		5516				
-33	5517	0.0	0.0		5517				
-32	5518	0.0	0.0		5518				
-31	5519	0.0	0.0		5519				
-30	5520	0.1	0.1		5520	0			
-29	5521	0.1	0.1		5521	0			
-28	5522	0.2	0.1		5522	0			
-27	5523	0.5	0.4	0	5523	0			
-26	5524	1.9	1.1	1	5524	0		-2	-1
-25	5525	25.8	11.6	13	5525	61	17	35	4
-24	5526	165.1	85.4	98	5526	120	122	-45	24
-23	5527	239.7	201.3	300	5527	152	258	-88	-42
-22	5528	279.8	259.5	559	5528	184	426	-96	-133
-21	5529	315.0	297.2	856	5529	216	626	-99	-230
-20	5530	344.7	329.7	1186	5530	263	858	-82	-328
-19	5531	387.3	365.8	1552	5531	321	1153	-66	-399
-18	5532	416.6	401.9	1954	5532	369	1500	-48	-454
-17	5533	440.2	428.3	2382	5533	413	1892	-27	-490
-16	5534	467.6	453.9	2836	5534	452	2326	-16	-510
-15	5535	490.6	479.1	3315	5535	486	2796	-5	-519
-14	5536	514.5	502.5	3818	5536	515	3298	1	-520
-13	5537	546.2	530.3	4348	5537	540	3827	-6	-521
-12	5538	563.9	555.0	4903	5538	559	4378	-5	-525
-11	5539	590.2	577.0	5480	5539	574	4946	-16	-534
-10	5540	613.8	602.0	6082	5540	587	5526	-27	-556
-9	5541	635.1	624.4	6706	5541	605	6121	-30	-585
-8	5542	656.8	645.9	7352	5542	627	6737	-30	-615
-7	5543	683.1	669.9	8022	5543	649	7375	-34	-647
-6	5544	711.6	697.3	8719	5544	673	8036	-39	-683
-5	5545	742.0	726.7	9446	5545	698	8721	-44	-725
-4	5546	772.2	757.1	10203	5546	725	9433	-47	-770
-3	5547	804.2	788.1	10991	5547	752	10171	-52	-820
-2	5548	833.5	818.8	11810	5548	780	10937	-53	-873
-1	5549	857.0	845.2	12655	5549	810	11732	-47	-923
0	5550	875.5	866.2	13522	5550	840	12558	-36	-964

NOTE: Based on survey by Absolute Natural Resources performed November 18-27, 2013
All elevations are based on Local Project Datum. NGVD29 = Project Datum - 1.27'

FIGURE - 1



Lake Information:
Area: 874.7 Acres
Max Depth: -38.2 ft
Mean Depth: -15.5 ft

Mapping Information:
Data Collection Performed: November 18-27, 2013
GPS: Mapping Grade (sub-foot accuracy)
Points Collected: 298,925
Lake Level: Adjusted to Full Pool (Elevation 5550.0)

Absolute Natural Resources, LLC
5765 Olde Wadsworth Blvd., Ste. 10
Arvada, Colorado 80002
800-852-4075
www.ANRwildlife.com

Cherry Creek Reservoir

Arapahoe County, Colorado

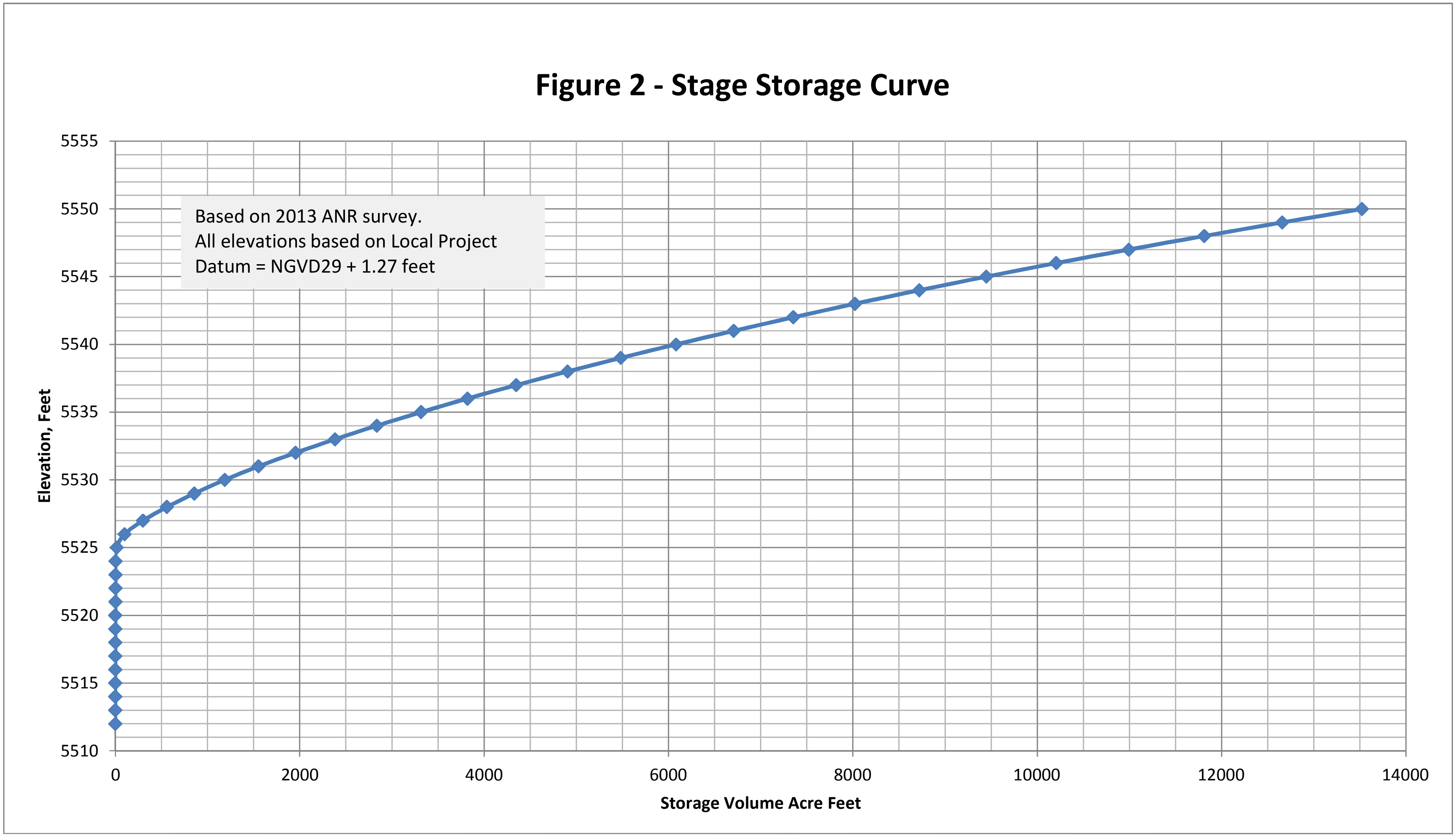


Figure 2 - Stage Storage Curve
Based on 2013 ANR survey.
All elevations based on Local Project
Datum = NGVD29 + 1.27 feet
Elevation, Feet
5555
5550
5545
5540
5535
5530
5525
5520
5515
5510
0
2000
4000
6000
8000
10000
12000
14000
Storage Volume Acre Feet

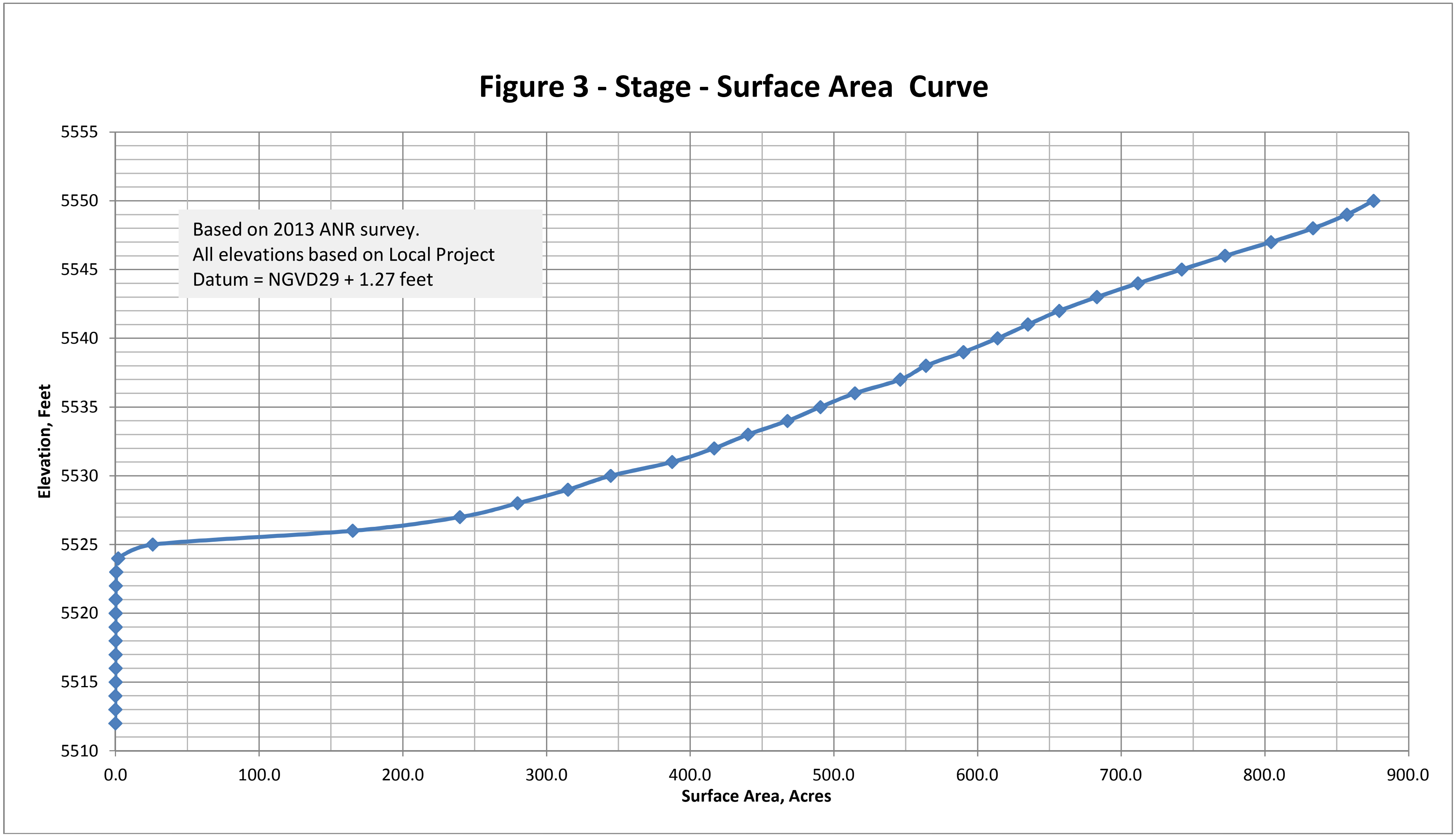


Figure 3 - Stage - Surface Area Curve
Based on 2013 ANR survey.
All elevations based on Local Project
Datum = NGVD29 + 1.27 feet
Elevation, Feet
Surface Area, Acres
5555
5550
5545
5540
5535
5530
5525
5520
5515
5510
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0

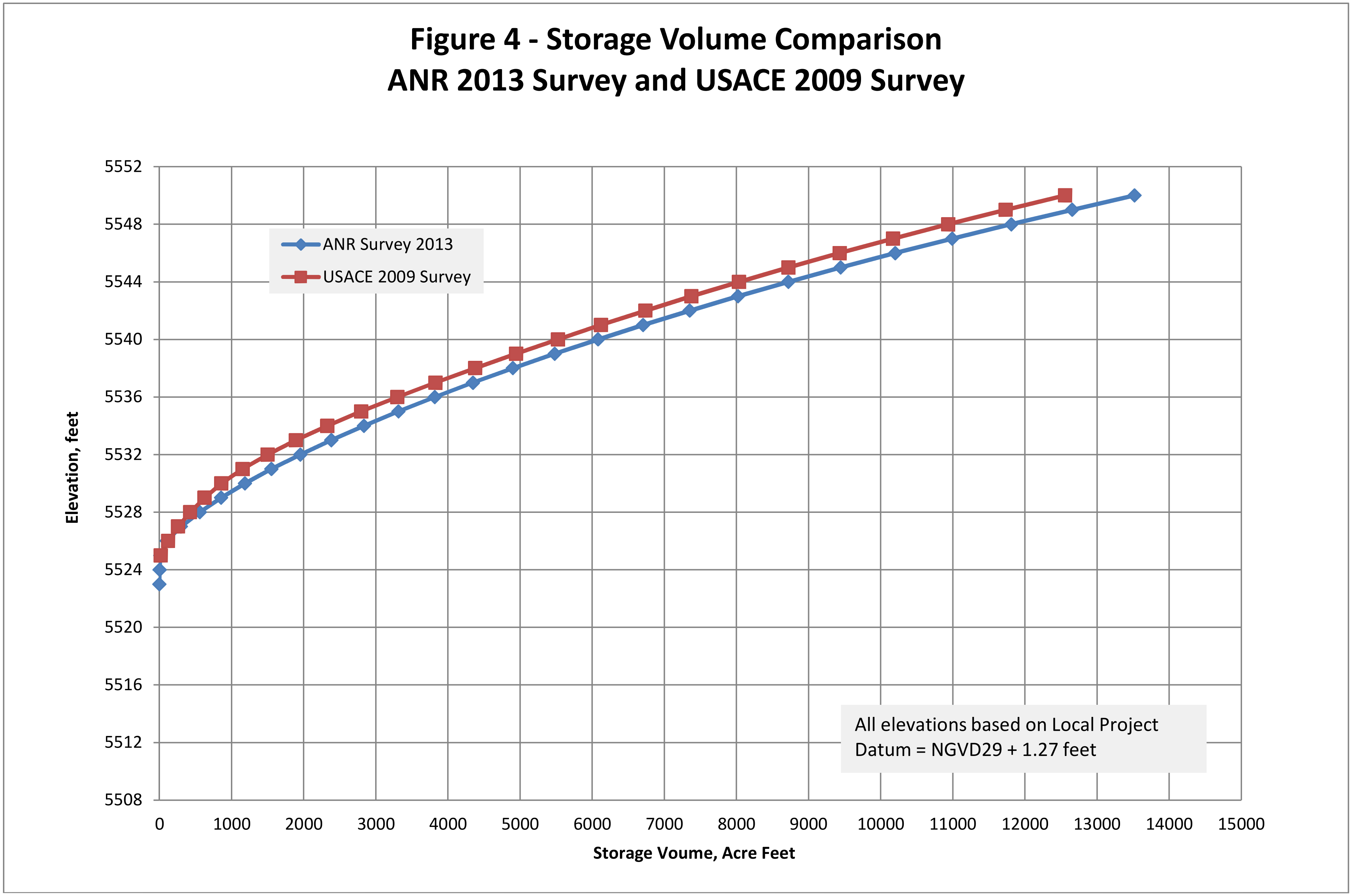
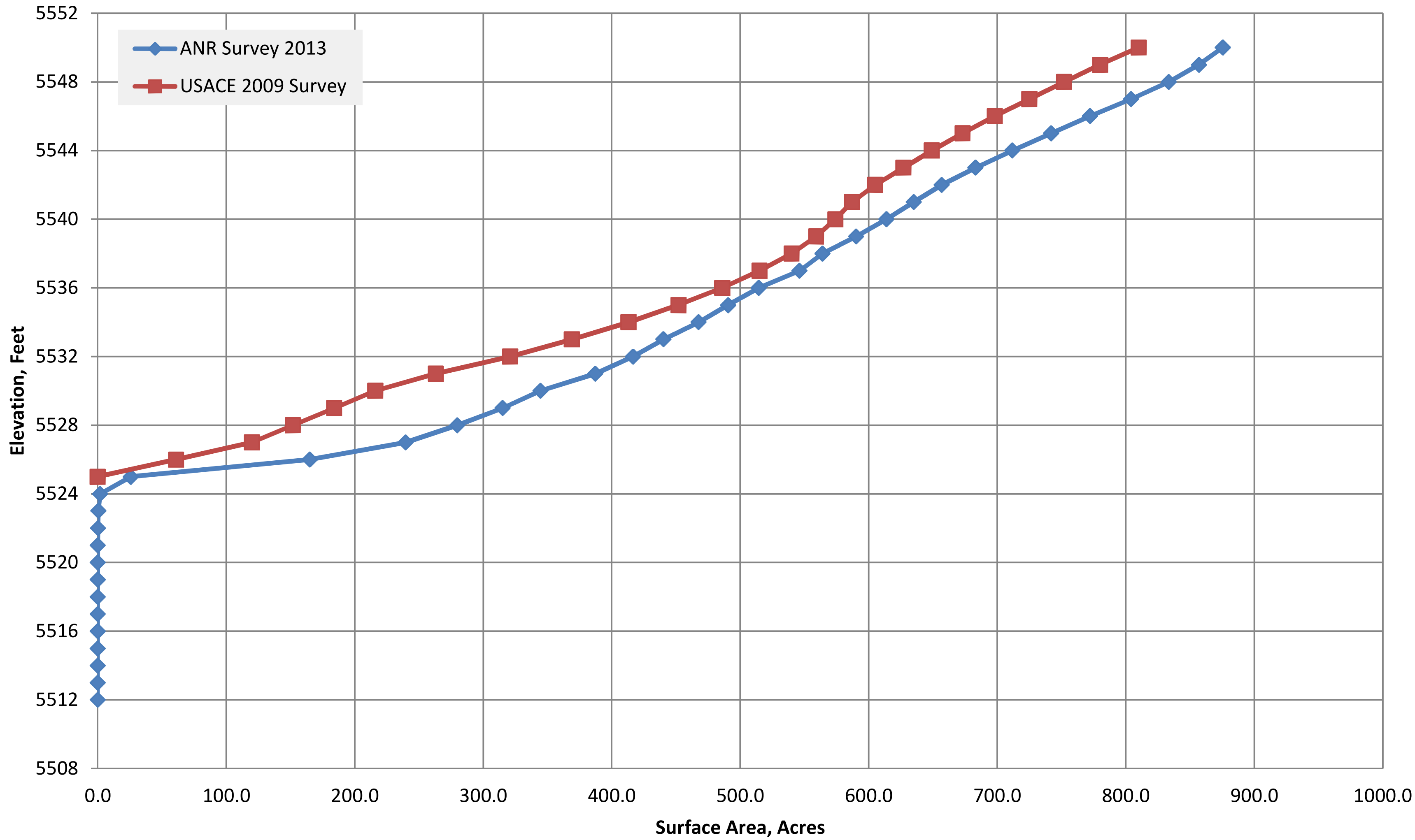


Figure 4 - Storage Volume Comparison
ANR 2013 Survey and USACE 2009 Survey
ANR Survey 2013
USACE 2009 Survey
All elevations based on Local Project Datum = NGVD29 + 1.27 feet
Elevation, feet
Storage Voume, Acre Feet
5552
5548
5544
5540
5536
5532
5528
5524
5520
5516
5512
5508
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000

Figure 5 - Surface Area Comparison
ANR 2013 Survey and USACE 2009 Survey

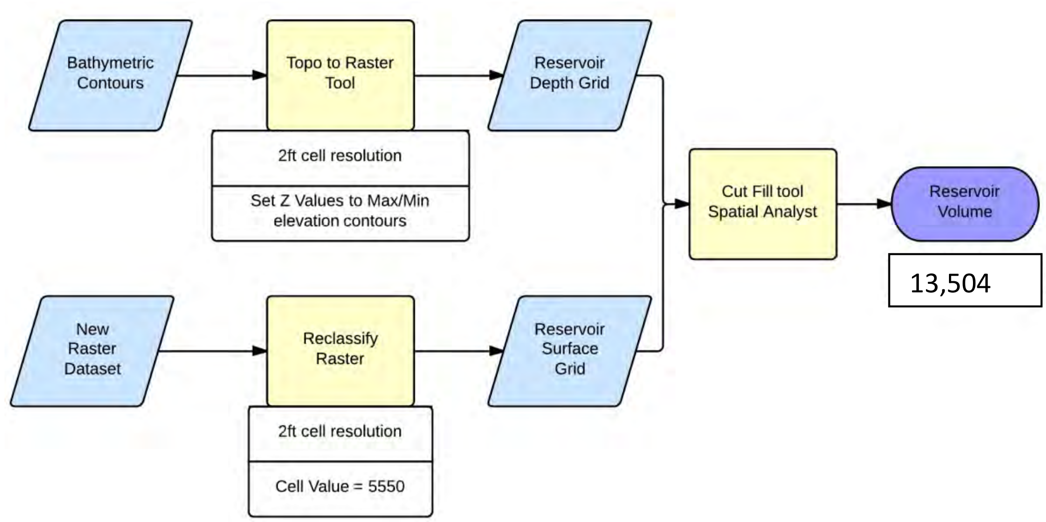


APPENDIX 1

LRE Cherry Creek Reservoir Volume Calculations Using GIS Techniques

Cherry Creek Reservoir Volume Calculation Using GIS Techniques

The following describes how the total volume of water in the Cherry Creek Reservoir was measured using GIS software, and the Cut/Fill tool in ArcGIS 10 starting with a bathymetric contour shapefile. The cut/fill tool measures the amount of gain, or loss between to elevation grids, to measure changes in volume or elevation, thus two raster grids were needed to run the tool: the first, derived from interpolation of the contour shape file showing depth of the reservoir in 2 ft. cell sizes (5514 ft-5549 ft), and another mask grid, containing only the constant surface elevation of the water (5550 ft) at equal 2 ft. cell sizes. After the two grids are obtained, the cut fill tool can be used to create a new grid showing and measuring the changes between the two elevation surfaces. The output measurement is shown by default as cubic units (ft), and then was recalculated in acre feet. The result of this calculation is 13,504 AF.



This represents a reasonable level of accuracy; however there are some sources where error could have occurred:

1) Repairing broken contours (as shown in following figures)

2) Interpolation of the depth Grid

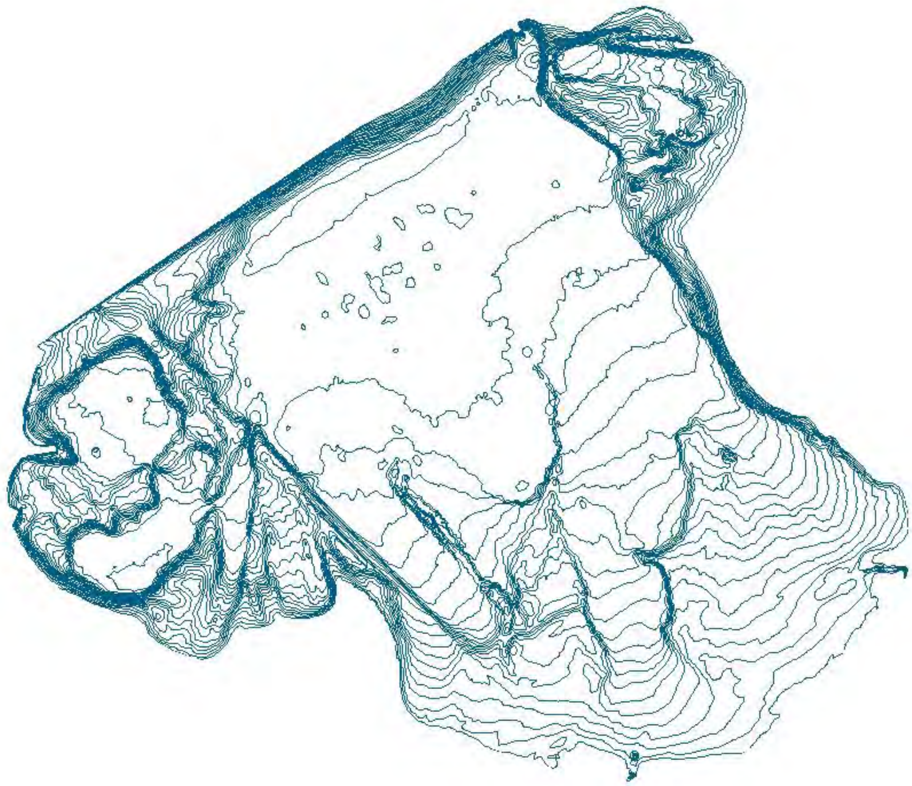
3) Human error

4) Data accuracy

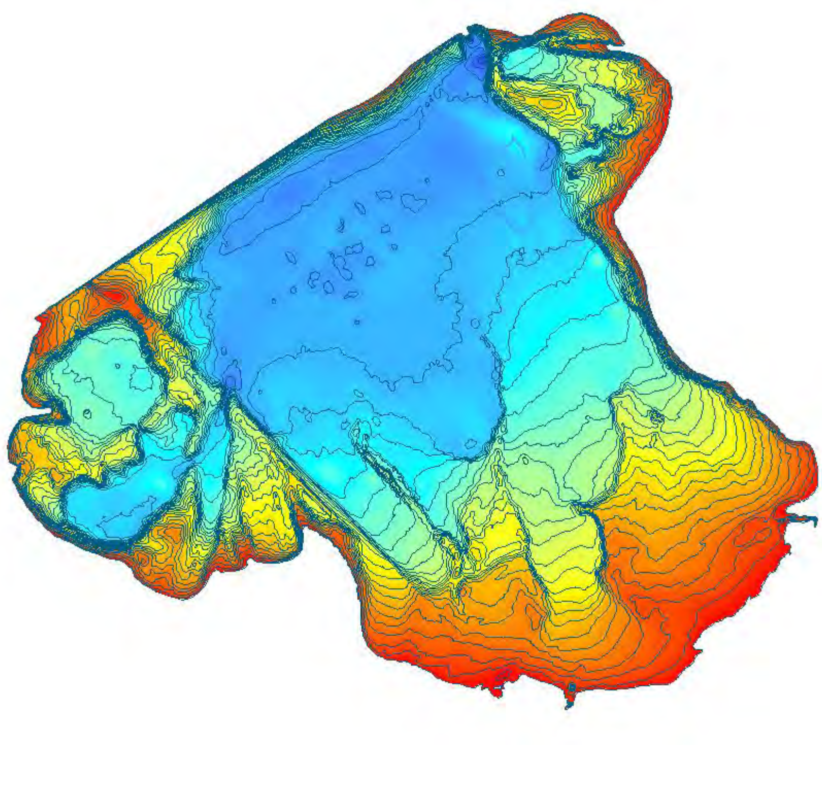
References:

Price, ESRI, Mike. "Deriving Volumes With ArcGIS Spatial Analyst." *ArcUser* (2002) Web, Jan 2014

Original Contours:

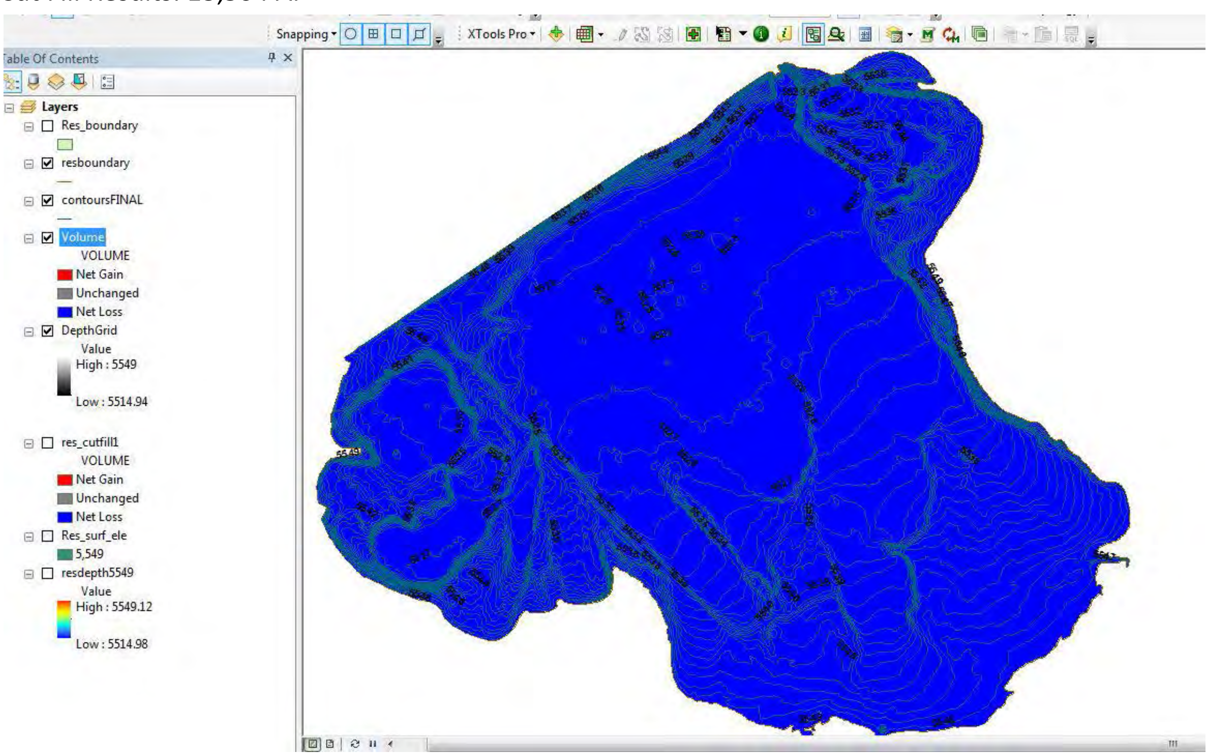


Reservoir Depth Grid:

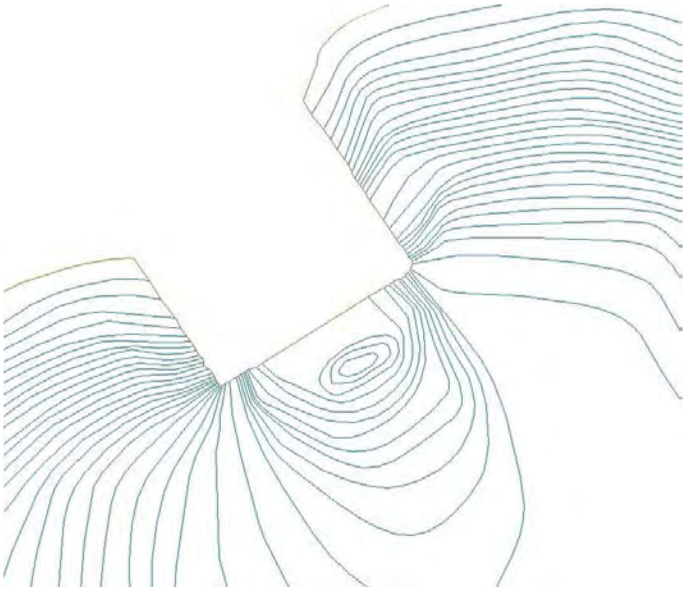


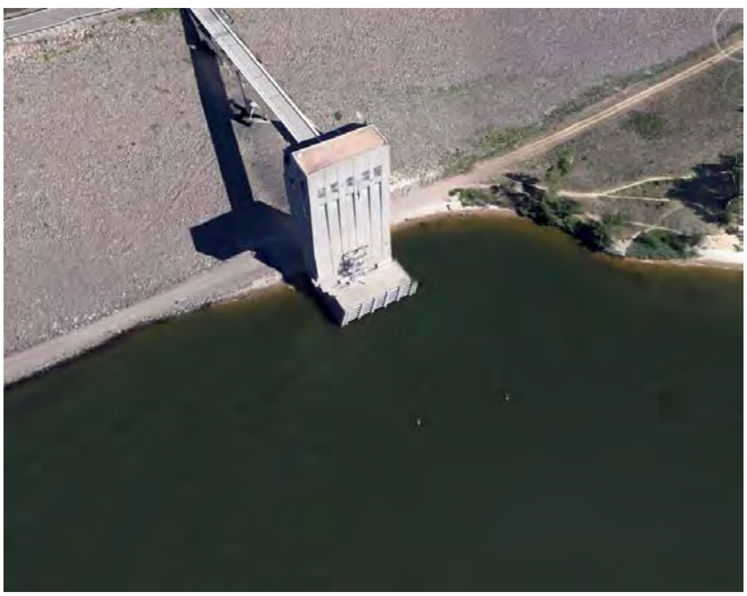
Constant Surface Grid at 5,550 feet:

Cut Fill Results: 13,504 AF



Sources of Error? Broken Contours:





APPENDIX 2

Email communications and extracted pages from USACE Tri-Lakes Sedimentation Studies Area-Capacity Report Revised July 2011.

XFINITY Connect **bill.ruzzo@comcast.net**

+ Font Size -

Cherry Creek Elevations

From : wfriesen@anrwildlife.com Tue, Jan 28, 2014 04:43 PM

Subject : Cherry Creek Elevations 1 attachment

To : bill ruzzo <bill.ruzzo@comcast.net>

Bill,

We attained our elevation datum readings from the NOAA website at http://water.weather.gov/ahps2/hydrograph.php?wfo=bou&gage=eqdc2 . Our data was justified to elevation readings daily at 12:00 noon. All readings were confirmed with NOAA's hydrologist Treste Huse (email : treste.huse@NOAA.gov) and comes directly from the Army Corp of Engineers gauging station at the reservoir. Please let me know if this is enough information.

Thanks,

Wesley Friesen
Project Biologist / Assistant Project Manager

Absolute Natural Resources, LLC
5765 Olde Wadsworth Blvd., Ste. 10
Arvada, CO 80002

Voice: (720) 974-4075
Fax: (720) 974-4830

ANR
ANRwildlife.com

ANR

sigimg1
26 KB

Bill

From: Wolf, Craig <CWolf@geiconsultants.com>
Sent: Thursday, January 30, 2014 3:07 PM
To: Jean Marie Boyer; hawley@hydrosconsulting.com; Taylor Adams; Bill Ruzzo; Christopher Lewis ; Katie Fendel; Max Grimes (maxmgrimes@live.com); Myrna Poticha; Reid, Chuck; Rick Goncalves; Wolf, Craig
Subject: action items from conf call
Attachments: CorpDatumDifferenceExplanation.pdf

Hello everyone,

I spoke with Ben Letak and Katie Seefus from the USACE and they report that USACE elevation data is based on their "local project datum" and ***NOT*** NAVD88 or NGVD29. The attached file summarizes the relationship between the three approaches, but Ben reaffirmed that the differences are not exact and he uses 1.8 and 1.3 for the differences. Katie also mentioned that the staff gage is not used to monitor pool elevation so the 0.2 offset reference in the memo does not apply to CCR elevations.

Because ANR adjusted their elevations to the USACE reported values and the 5,550.0 pool elevation, the ANR data should be in local project datum too....

The other time series flow and WQ data for 2013 calendar year were also transferred to Hydros so both action items have been addressed.

Please contact me if you have any questions.

Cheers!
Craig

Craig F. Wolf
Senior Aquatic Ecologist / Limnologist
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2.4.2.3 *Cherry Creek*

The 2009 survey data presented in this report is a composite of data collected in 2006, 2007, and 2009. Cross sections CC-01 through CC-06 were completed in 2006 by in-house personnel. A contractor surveyed cross sections CC-07 through CC-11 and CC-13 in 2007. The hydrographic surveys completed during the 2006 survey were determined to be inaccurate and these sections, CC-01 to CC-04, were resurveyed in 2009 by in-house personnel. Note the CC-12 cross section was completely destroyed; survey data from 1988 was used for this cross section to run the area-capacity program for the latest survey.

<u>Brief Metadata: Cherry Creek</u>

Survey Date:	Data collected in 2006 (In-House), 2007 (A-E Contract), and 2009 (In-House)
Surveyor:	In-House: USACE Omaha District, Hydrologic Engineering Branch, Sedimentation & Channel Stabilization Section Contract Work: Ayres & Associates, Inc., Fort Collins, Colorado
Horizontal Datum:	Colorado State-Plane Coordinate System NAD83, Zone 0502.
Vertical Datum:	Survey data was collected in the ***<u>Local Project Datum</u>***.
Units:	U.S. Survey Feet
Accuracy:	3rd Order Horizontal & Vertical per EM 1110-2-1003

A detailed Cherry Creek basin survey was performed using LiDAR mapping, flown on 12 February 2009 by Woolpert, Inc., Englewood, Colorado. The LiDAR data was provided to the Sedimentation and Channel Stabilization Section for comparison to the range line surveys. The LiDAR dataset was collected using vertical datum NAVD88.

The Cherry Creek Dam was built using elevations in a Local Project Vertical Datum. Based on a September 2010 survey, conducted by the USACE Omaha District Surveys & Mapping Section, the Local Project Datum 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, see Figure 2-2. Table 2-3 compares range line monument elevations as surveyed using the three datums. Any conversions between datums should be coordinated through the USACE Omaha District Surveys Section to ensure accuracy, these values are approximations. Elevations in this report for Cherry Creek are reported in the Local Project Datum.

The elevations on the Cherry Creek staff gage, which is located on the downstream side of the intake structure, are in Local Project Datum plus approximately 0.20 feet (1.47 feet above NGVD29 datum and 1.56 feet below NAVD88 datum). This 0.20 feet difference corresponds closely to the settlement observed in the upstream end of the conduits at the intake since original construction. If the staff gage is used to monitor pool elevation, subtract 0.20 feet from the elevation to approximate the elevation in Local Project Datum.

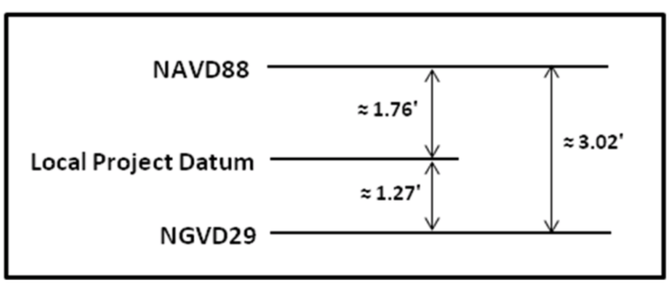

Figure** 2-2. **The Local Project Datum for Cherry Creek Relative to NAVD88 and NGVD29

BK 106

Bill Ruzzo

From: Melanie D. Chenard [mchenard@MULLERENG.COM]
Sent: Wednesday, June 30, 2010 9:03 AM
To: Rios, Alfredo A NWO
Cc: Johnson, Daniel B NWO; Jim T. Wulliman; bill.ruzzo@comcast.net
Subject: RE: Survey benchmark issues for shoreline project @ Cherry Creek Reservoir

Fred,

Thank you for getting back to us so quickly. We will proceed with the design as you have indicated. The answer to item # 2 does potentially impact our design as we look at the expected range of reservoir pool elevations - we need to make sure that we extend our shoreline protection to cover this range, which probably means protecting one foot lower than we had expected to cover the datum difference. We can proceed without an answer, but if you get one, we'd appreciate hearing it.

Thanks again,

Melanie D. Chenard, P.E.
Muller Engineering Company, Inc.
303-988-4939
mchenard@mullereng.com

-----Original Message-----
From: Rios, Alfredo A NWO [mailto:Alfredo.A.Rios@usace.army.mil]
Sent: Tuesday, June 29, 2010 8:27 AM
To: Melanie D. Chenard
Cc: Johnson, Daniel B NWO
Subject: RE: Survey benchmark issues for shoreline project @ Cherry Creek Reservoir

Melanie, following is the comments I received from the district office:

-----Original Message-----
From: Behm, Randall L NWO
Sent: Tuesday, June 29, 2010 6:01 AM
To: Rios, Alfredo A NWO; Letak, Ben J NWO
Cc: Schultz, Lloyd H NWO; Kragt, Jon E NWO; Seefus, Kathryn J NWO; Pletka, Angela NWO
Subject: RE: Survey benchmark issues for shoreline project @ Cherry Creek Reservoir

Fred,

With regards to question 5, you are correct, the cut and fill balance is not required for the area below the conservation pool. However, work in this area should be documented.

I understand that the survey datum has become an item of discussion for the reservoir. While that concern will be resolved through future survey efforts it should not impact the level of design or review for any specific projects identified to occur along the shoreline. Each project should be designed using one datum only. The design of the excavation material and the fill material should be based upon only one datum. In essence, each project can be viewed as using a local construction datum, if needed. That way we can perform a review of the cut and fill and not have to worry about a datum shift occurring within the project limits. We want to ensure that the area capacity curve is not adversely impacted by the addition of fill material.

Randy

Randall L. Behm, P.E. CFM
Chief, Flood Risk and Floodplain Management Section
Hydrologic Engineering Branch - Omaha District
Office: (402) 995-2322

Fax: (402) 995-2321
e-mail: randall.l.behm@usace.army.mil
Certified Floodplain Manager

I know this doesn't directly answer question 1 and 2, but it gives you direction on 3,4, and 5. I believe the answers to your questions are as
follows:

1. Correct, based on conversations I have had with district staff.
2. Waiting for an answer to this, but shouldn't impact your design.
3. Use datum used in past, based on 1929 NGVD as you have used on past projects. Noting the datum difference and include a conversion on your design drawings in not necessary?
4. The cut/fill balance should be the datum used in past for other projects.
5. A cut/fill balance below the conservation pool is not necessary, but the area impacts should be document.

Is this response sufficient to allow you to move forward with your design?

Fred Rios
Operations Project Manager
Tri-Lakes Project Office

-----Original Message-----
From: Melanie D. Chenard [mailto:mchenard@MULLERENG.COM]
Sent: Thursday, June 24, 2010 3:36 PM
To: Rios, Alfredo A NWO
Subject: Survey benchmark issues for shoreline project @ Cherry Creek Reservoir

Fred,

As you know, we have been looking into a survey issue that has come to light in our work on the Mountain & Lake Loop Shoreline Stabilization project.
We
have been in contact with various USACE personnel in the Surveys, Mapping & GIS Section of the Omaha District to help define the problem and would like to inform you of our findings and receive direction on how to proceed on this project.

Project Overview

We are currently under contract with the Cherry Creek Basin Water Quality Authority to address erosion and degradation along 2300 linear feet of shoreline at Cherry Creek Reservoir near the Mountain Loop and Lake Loop recreation areas. The proposed work will include riprap and boulder protection along the shoreline along with a series of jetty points intended to deflect erosive currents and provide recreational opportunities. In addition, surface runoff quality will be improved through the reconfiguration of an existing parking lot, construction of infiltration areas, and improvement or elimination of social trails.

Survey Benchmark Issues

A field survey was conducted in October of 2009 to develop project mapping.
The benchmark used for this survey is a local benchmark with a published elevation on the NGVD29 vertical datum, and has been used as the project benchmark for numerous projects within the Cherry Creek Reservoir pool.
The
reservoir water surface elevations measured during the field survey were later compared to the published pool levels on the Colorado Surface Water Conditions website, maintained by the Colorado Division of Water Resources.
It was noted that the surveyed water surface elevations were approximately 0.9' lower than the published elevations for the dates of the field survey.

Because the vertical component of this project is critical both from a design standpoint in the establishment of anticipated reservoir levels and from a review standpoint in the balance of cut and fill material for the preservation of flood storage, we endeavored to resolve this 0.9'
discrepancy
to ensure that the project design and construction would be based on the same datum used by the Corps for management of the Reservoir.

Additional field survey was conducted to compare the project datum to other local benchmarks in the area, and to two USACE control points near the reservoir. The original project datum was confirmed to match published NGVD29 elevations for the local benchmarks and to differ from the USACE control points by 0.97'. Correspondence with the USACE Omaha District - Surveys, Mapping & GIS Section revealed that the Cherry Creek Reservoir "Project Elevations" (Reservoir datum) is only loosely based on NGVD29, and that a 1983 USACE survey identified the Reservoir datum to be 0.954'
higher
than NGVD29. This difference applies only to select USACE control points (CP
1 - CP 6), but does carry through to the published reservoir water surface elevations. (Selected email correspondence is attached.)

We understand that the USACE administers the reservoir based on a conservation pool elevation of 5550.0. What has come to light through this inquiry is that the 5550.0 elevation is based on the Reservoir datum rather than the NGVD29 as commonly believed. This means that the conservation pool elevation translates to 5549.0 on NGVD29. However, it appears that the reservoir is administered with the assumption that the Reservoir datum is the same as NGVD29. This leaves us needing some clarification on how to proceed with our project. We believe it is preferable to all parties to keep the project survey on NGVD29 rather than shift to the Reservoir datum. What is not clear is whether the datum difference should be acknowledged on the design plans and in the calculation of cut/fill balance.

Summary

Our investigation has yielded information and raised questions as follows:

1. The USACE Cherry Creek Reservoir vertical datum is 0.954' higher than NGVD29.

2. It appears that this datum difference is not commonly known, and as a result the USACE and Cherry Creek State Park manage the reservoir according to NGVD29.

3. To keep the project on a common datum, the project survey will remain on NGVD29. Should we note the datum difference and include a conversion on our design drawings?

4. Should our cut/fill balance between the conservation pool and the spillway be based on 5550.0 NGVD29 (5551.0 Reservoir datum) or on 5549.0 NGVD29 (5550.0 Reservoir datum)?

5. As a separate but related item, we would also like to confirm that a cut/fill balance below the conservation pool is not necessary as it does not impact flood storage.

We understand that you will be forwarding this information to the appropriate authorities who can provide us with the clarification and guidance we require to proceed with this important project. We appreciate the time taken by all in helping identify and address this issue. Please feel free to contact me with any questions. We look forward to your response.

Regards,

Elevation Data Sources for Cherry Creek Reservoir

USACE Online Source http://www.nwd-mr.usace.army.mil/rcc/programs/data/CHCR
NOAA Online Source http://water.weather.gov/ahps2/hydrograph_to_xml.php?gage=egdc2&output=tabular
DWR Online Source http://www.dwr.state.co.us/Surfacewater/data/detail_tabular.aspx?ID=CHRRESCO&MTYPE=ELEV

USACE Online Source			NOAA Online Source		DWR Online Source		DWR Online Source	
Hourly Data (Raw vs Ave ??)			Raw vs Hourly Ave ??		Raw Data		Hourly Averages	
----------CHCR----------								
28-Jan-14			Observed Data:					
HR	EL	SG	|Date(UTC)|	|Stage|	Date/Time (raw)	ELEV (ft)	Date/Time (raw)	ELEV (ft)
1	5550.10	12.65	1/28/2014 1:00	5550.11	1/28/2014 1:00	5550.11	1/28/2014 1:00	5550.11
2	5550.11	12.65	1/28/2014 2:00	5550.09	1/28/2014 2:00	5550.10	1/28/2014 2:00	5550.11
3	5550.11	12.65	1/28/2014 3:00	5550.11	1/28/2014 3:00	5550.12	1/28/2014 3:00	5550.11
4	5550.11	12.65	1/28/2014 4:00	5550.12	1/28/2014 4:00	5550.12	1/28/2014 4:00	5550.12
5	5550.11	12.65	1/28/2014 5:00	5550.10	1/28/2014 5:00	5550.10	1/28/2014 5:00	5550.11
6**	5550.11	12.65	1/28/2014 6:00	5550.11	1/28/2014 6:00	5550.11	1/28/2014 6:00	5550.11
7	5550.11	12.65	1/28/2014 7:00	5550.12	1/28/2014 7:00	5550.12	1/28/2014 7:00	5550.11
8	5550.11	12.65	1/28/2014 8:00	5550.11	1/28/2014 8:00	5550.10	1/28/2014 8:00	5550.11
9	5550.11	12.65	1/28/2014 9:00	5550.10	1/28/2014 9:00	5550.10	1/28/2014 9:00	5550.11
10	5550.11	12.65	1/28/2014 10:00	5550.12	1/28/2014 10:00	5550.12	1/28/2014 10:00	5550.11
11	5550.11	12.65	1/28/2014 11:00	5550.12	1/28/2014 11:00	5550.12	1/28/2014 11:00	5550.11
12**	5550.11	12.65	1/28/2014 12:00	5550.10	1/28/2014 12:00	5550.10	1/28/2014 12:00	5550.11
13	5550.11	12.65	1/28/2014 13:00	5550.11	1/28/2014 13:00	5550.11	1/28/2014 13:00	5550.11
14	5550.11	12.65	1/28/2014 14:00	5550.12	1/28/2014 14:00	5550.12	1/28/2014 14:00	5550.12
15	5550.11	12.65	1/28/2014 15:00	5550.10	1/28/2014 15:00	5550.11	1/28/2014 15:00	5550.11
16	5550.11	12.65	1/28/2014 16:00	5550.10	1/28/2014 16:00	5550.10	1/28/2014 16:00	5550.11
17	5550.11	12.65	1/28/2014 17:00	5550.12	1/28/2014 17:00	5550.12	1/28/2014 17:00	5550.12
18**	5550.11	12.65	1/28/2014 18:00	5550.12	1/28/2014 18:00	5550.12	1/28/2014 18:00	5550.11
19	5550.11	12.65	1/28/2014 19:00	5550.10	1/28/2014 19:00	5550.11	1/28/2014 19:00	5550.12
20	5550.12	12.65	1/28/2014 20:00	5550.11	1/28/2014 20:00	5550.11	1/28/2014 20:00	5550.11
21	5550.12	12.65	1/28/2014 21:00	5550.12	1/28/2014 21:00	5550.12	1/28/2014 21:00	5550.12
22	5550.12	12.65	1/28/2014 22:00	5550.11	1/28/2014 22:00	5550.12	1/28/2014 22:00	5550.12
23	5550.12	12.65	1/28/2014 23:00	5550.10	1/28/2014 23:00	5550.12	1/28/2014 23:00	5550.12
24**	5550.12	12.66	1/29/2014 0:00	5550.12	1/29/2014 0:00	5550.12	1/29/2014 0:00	5550.12

Bill

From: Wolf, Craig <CWolf@geiconsultants.com>
Sent: Wednesday, January 29, 2014 11:11 AM
To: Bill Ruzzo
Subject: Emailing: Cherry Creek Reservoir Elevation Sources
Attachments: Cherry Creek Reservoir Elevation Sources.xlsx

Bill,

I downloaded the available CCR elevation data for 28Jan14 from the USACE, NOAA, and DWR websites. NONE of the sites report the same values for each hour of the day... The values are very close (e.g., within 0.01 ft) but I find it ironic that both NOAA and DWR report the values as coming from the USACE, but they do not match. Part of the issue may be related to instantaneous versus hourly averages but the only website that is 100% clear on that issue is the DWR site. USACE calls their data "Hourly Data" and NOAA has a mix of "Observed" versus "Forecast" stages in their tabular data set.

I will ask whether the USACE has an opinion or insight into the differences but I'm not confident I will get much clarification. I'm sure I'll get the provisional data statement too....

Craig

Cherry Creek Project - Effective 09 December 2010 Area in Acres (2009* Survey)										
Elevation	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
5520	0	0	0	0	0	61	120	152	184	216
5530	263	321	369	413	452	486	515	540	559	574
5540	587	605	627	649	673	698	725	752	780	810
5550	840	867	894	920	948	977	1006	1036	1066	1098
5560	1128	1155	1182	1211	1241	1273	1307	1342	1379	1418
5570	1455	1488	1519	1553	1589	1627	1667	1710	1754	1801
5580	1847	1890	1932	1974	2017	2060	2104	2149	2193	2239
5590	2285	2330	2375	2420	2464	2508	2552	2595	2638	2681
5600	2723	2765	2808	2851	2894	2938	2982	3026	3071	3116
5610	3159	3201	3242	3285	3330	3376	3424	3473	3524	3577
5620	3628	3674	3720	3767	3817	3870	3924	3981	4041	4102
5630	4164	4223	4281	4338	4395	4453	4510	4568	4625	4682
5640	4740	0	0	0	0	0	0	0	0	0

*2009 Survey is a composite of data collected in 2006, 2007, and 2009.

Cherry Creek Project - Effective 09 December 2010 Capacity in Acre-Feet (2009* Survey)										
Elevation	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
5520	0	0	0	0	0	17	122	258	426	626
5530	858	1153	1500	1892	2326	2796	3298	3827	4378	4946
5540	5526	6121	6737	7375	8036	8721	9433	10171	10937	11732
5550	12558	13412	14293	15200	16134	17097	18089	19110	20161	21243
5560	22357	23499	24668	25864	27090	28347	29637	30961	32321	33719
5570	35157	36630	38133	39669	41240	42848	44495	46183	47915	49692
5580	51517	53387	55298	57252	59247	61286	63368	65495	67666	69882
5590	72144	74452	76804	79202	81645	84131	86661	89235	91852	94512
5600	97214	99958	102745	105575	108447	111364	114324	117328	120376	123470
5610	126608	129789	133010	136274	139581	142934	146334	149782	153281	156831
5620	160435	164087	167784	171527	175319	179162	183059	187011	191022	195093
5630	199227	203422	207674	211984	216350	220775	225256	229796	234392	239046
5640	243757	0	0	0	0	0	0	0	0	0

*2009 Survey is a composite of data collected in 2006, 2007, and 2009.

In areas where LiDAR has not been collected, it may be more cost effective to send a survey crew up to survey the sediment range lines instead of flying LiDAR. Using the historic method of the average end area to calculate storage capacity curves would have to be done in those situations. However, if there are multiple studies ongoing at the project, LiDAR's capability to acquire ground elevations at a much denser rate may be more beneficial to a greater number of studies and perhaps then a more cost effective method.

Comparing the two methods of InRoads and Average End Area to calculate storage capacity, seems to give us higher capacity in the reservoir especially at lower lake levels. Any time both LiDAR and current storage capacity tables are available, additional comparison of the two methods would aid in a better understanding or further support or oppose the finding for Cherry Creek.

Table G-1. Area Capacity Calculated using the Alternative LiDAR-based InRoads Calculation Method

Cherry Creek Reservoir - LiDAR Based Alternative Calculation Method
Area Capacity in Acre-Feet
(2009-2010 Survey)

NAVD 88 Elevation	0	1	2	3	4	5	6	7	8	9
5520	0		0		1		34	220	405	688
5530	971	1320	1668	2071	2474	2920	3366	3863	4359	4902
5540	5445	6039	6632	7269	7905	8589	9273	10018	10763	11575
5550	12387	13242	14097	14992	15886	16841	17795	18812	19828	20909
5560	21989	23138	24287	25498	26709	27984	29259	30608	31956	33371
5570	34786	36264	37741	39283	40825	42436	44046	45736	47426	49196
5580	50966	52818	54670	56611	58551	60576	62600	64711	66822	69020
5590	71218	73501	75783	78147	80511	82962	85412	87951	90490	93114
5600	95738	98444	101149	103938	106727	109607	112486	115462	118437	121508
5610	124579	127741	130902	134147	137391	140721	144051	147473	150895	154415
5620	157935	161557	165179	168907	172635	176469	180302	184240	188177	192224
5630	196271	200429	204587	208861	213134	217537	221939	226471	231003	235662
5640	240321	245110	249899	254822	259744	264799	269853	275038	280222	285542
5650	290862									

*Blue numbers are estimated using the average of the bordering two values.

To compare the storage capacity for elevation 5550 based on Local Project Datum, use elevation 5551.8 storage value based NAVD88 datum.

NAVD88: Volume at 5551 = 13,242; Volume at 5552 = 14097; then Volume at 5551.8 = 13,926 af

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, CREST ELEVATION										
	110.6-90.6	90.6-80.6	80.6-70.6	70.6-60.6	60.6-50.6	50.6-40.5	40.6-30.6	30.6-20.6	20.6-crest	c - +19.4	19.4+39.4
	PERCENT OF TOTAL SEDIMENT LOCATED WITIN DEPTH DESIGNATION										
5/24/1961	1.9	24.1	8.3	3.6	23.6	6.8	3.6	1.3	2.9	4.6	19.3
8/17/1965	0.8	24.3	12.7	2.3	12.2	13.0	13.0	3.7	1.7	6.1	10.3
7/11/1974	0.5	16.8	29.2	1.6	9.1	11.2	11.1	5.9	3.6	3.8	7.3
6/15/1988	0.4	14.0	31.4	3.6	8.3	10.9	11.6	6.5	3.2	3.5	6.4
6/1/2009	12.8	32.0	2.8	9.4	10.6	9.3	6.0	3.0	2.0	2.0	10.1

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR														
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	-120	-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														
6/1/2009	26.8	30.6	10.5	9.6	3.3	-0.6	0.5	6.3	8.2	4.8	******				

45. RANGE IN RESERVOIR OPERATION

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.
1990	5551.75	5549.98	5,534	2000	5551.05	5549.84	21,024
1991	5551.39	5549.90	4,602	2001	5552.79	5548.89	19,482
1992	5551.48	5548.52	9,182	2002	5550.86	5549.97	8,420
1993	5550.65	5548.95	5,898	2003	5552.42	5548.84	14,253
1994	5550.90	5548.83	7,353	2004	5550.72	5549.58	9,610
1995	5551.00	5548.75	11,484	2005	5551.43	5549.22	20,404
1996	5550.90	5548.80	7,976	2006	5550.30	5548.02	12,193
1997	5550.81	5549.48	7,920	2007	5552.94	5548.20	28,428
1998	5552.16	5549.98	21,080	2008	5550.94	5548.70	19,526
1999	5553.23	5549.98	25,815	2009	5551.40	5548.50	27,126

46. ELEVATION-AREA-CAPACITY DATA

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
5520	0	0	5590	2285	72144			
5530	263	858	5598	2638	91852			
5540	587	5526	5600	2723	97214			
5550	840	12558	5610	3159	126608			
5560	1128	22357	5620	3628	160435			
5570	1455	35157	5630	4164	199227			
5580	1847	51517	5640	4740	243757			

47. REMARKS AND REFERENCES
*Spillway crest has been altered due to spillway side slope sloughing, elevation was originally 5598.0 matching the top of F.C. Pool.
** No conservation or inactive storage ***NCDC Weather Station at Cherry Creek Dam, CO **** 01 Apr is assumed date in 1950
***** 2009 Survey is a composite of data collected in 2006, 2007, and 2009. The 1997 survey data is erroneous and not included.
****** A negative value indicates degradation in the depth or reach designation.

48. AGENCY MAKING SURVEY USACE-Omaha District, CENWO-ED-HF

49. AGENCY SUPPLYING DATA USACE-Omaha District, CENWO-ED-HF

50. DATE 8/1/2011

ENG FORM 1787, NOV 1966