Bathymetric and Sediment Survey of Cheney Reservoir, Reno-Kingman-Sedgwick Counties, Kansas

Kansas Biological Survey

Applied Science and Technology for Reservoir Assessment (ASTRA) Program

Report 2011-01 (August 2012)

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SUMMARY

In July-August 2010, the Kansas Biological Survey (KBS) performed a bathymetric survey of Cheney Reservoir in Kingman-Sedgwick-Reno Counties, Kansas. The survey was carried out using acoustic echosounding apparatus linked to a global positioning system. The 2010 bathymetric survey by KBS indicated that the area of the conservation pool at 1420.7 ft was 9937 acres with a capacity of 167,000 acre-feet. Data from a previous survey conducted by the US Geological Survey in 1998 indicated that the area of the conservation pool at 1420.7 ft in 1998 was 9882 acres with a capacity of 163,306 acre-feet.

Twenty-eight sediment cores were extracted from the lake to determine accumulated sediment thickness at locations distributed across the reservoir. Sediment samples were taken from the top six inches of each core and analyzed for particle size distributions. Three cores were sliced in 5-cm increments and analyzed for texture, total nitrogen, and total phosphorus.

Summary Data:

Bathymetric Survey:		
	Dates of survey:	July 12, 2010 July 13, 2010 July 14, 2010 August 2, 2010 August 3, 2010 August 4, 2010
	Water elevation on date(s) of survey:	(see text)
Reservoir Statistics:		
	Elevation of pool on reference date (NAIP photography, 2006)	1420.7 ft.
	Area at 1420.7 conservation pool:	9937 acres
	Volume at 1420.7 conservation pool:	167,000 acre-feet
	Maximum depth at 1420.7 conservation pool:	41 ft.
	Year constructed (gates closed):	1981
Datums		
	UTM Zone:	14N
	UTM datum:	NAD83
	Vertical datum, all data:	NGVD29
Sediment Survey:		
	Date of sediment survey:	August 5, 2011

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History and Development:

The following was summarized from the US Bureau of Reclamation information on the Wichita Project and the Cheney Dam and Reservoir (http://www.usbr.gov/projects/Project.jsp?proj_Name=Wichita Project)

Figure 1. Cheney Reservoir dam, view from north end of reservoir (Photo by USBR).

Public Law 86-787 authorized the Cheney Division on September 14, 1960, by act of Congress, (74 Stat. 1026). Construction of Cheney Dam began in 1962, and was completed in 1965.

Cheney Dam is on the North Fork of the Ninnescah River about 6 miles north of Cheney and 24 miles west of Wichita, Kansas. The site is at the common intersection of the boundaries of Kingman, Reno, and Sedgwick Counties, with portions of the dam lying in all three. The city of Wichita constructed and operates a 93-cubic-foot-per-second pumping plant at the dam which conveys municipal water through a 5-foot-diameter pipeline to the water treatment plant in the city.

The project provides storage and delivery of a supplemental municipal and industrial water supply to the city of Wichita, Kansas. Cheney Dam and Reservoir provide storage and regulation of available surface waters of the North Fork of Ninnescah River. A pumping plant located at the dam and a 5-foot-diameter pipeline were constructed by the city of Wichita for conveying the regulated flows from Cheney Dam to the water treatment facilities.

Storage began at Cheney Dam with closure of the river outlet works gates on November 5, 1964. Delivery of municipal and industrial water to the city of Wichita began in the summer of 1965. Operation and maintenance of Government constructed project facilities by the city of Wichita began October 1, 1965. The conservation storage in Cheney Reservoir gradually increased until it was filled in October 1968.

Reno-Kingman-Sedgwick Counties, Kansas

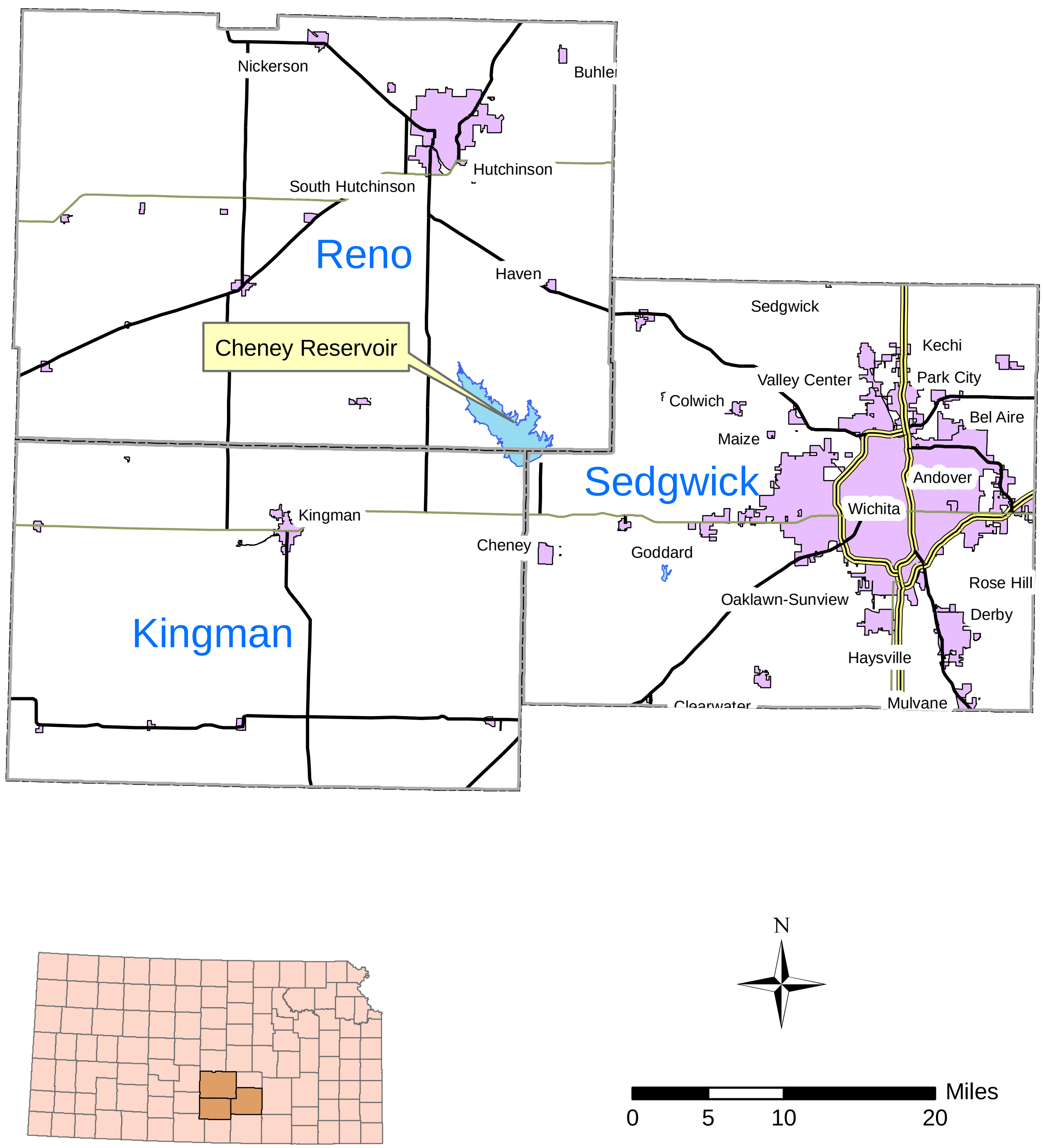

Figure 2. Location of Cheney Reservoir in Reno-Kingman-Sedgwick Counties, Kansas

Reservoir Bathymetric (Depth) Surveying Procedures

KBS operates a Biosonics DT-X echosounding system (www.biosonicsinc.com) with a 200 kHz split-beam transducer and a 38-kHz single-beam transducer. Latitude-longitude information is provided by a global positioning system (GPS) that interfaces with the Biosonics system. ESRI's ArcGIS is used for on-lake navigation and positioning, with GPS data feeds provided by the Biosonics unit through a serial cable. Power is provided to the echosounding unit, command/navigation computer, and auxiliary monitor by means of a inverter and battery backup device that in turn draw power from the 12-volt boat battery.

Pre-survey preparation:
Geospatial reference data: Prior to conducting the survey, geospatial data of the target lake is acquired, including georeferenced National Agricultural Imagery Project (NAIP) photography. The lake boundary is digitized as a polygon shapefile from the FSA NAIP georeferenced aerial photography obtained online from the Data Access and Service Center (DASC). Prior to the lake survey, a series of transect lines are created as a shapefile in ArcGIS for guiding the boat during the survey. A transect spacing of 100 meters was used for the main body of the reservoir, narrowing this distance as needed in smaller coves and inlets.

Survey procedures:
Calibration (Temperature and ball check): After boat launch and initialization of the Biosonics system and command computer, system parameters are set in the Biosonics Visual Acquisition software. The temperature of the lake at 1-2 meters is taken with a research-grade metric electronic thermometer. This temperature, in degrees Celsius, is input to the Biosonics Visual Acquisition software to calculate the speed of sound in water at the given temperature at the given depth. Start range, end range, ping duration, and ping interval are also set at this time. A ball check is performed using a tungsten-carbide sphere supplied by Biosonics for this purpose. The ball is lowered to a known distance (1.0 meter) below the transducer faces. The position of the ball in the water column (distance from the transducer face to the ball) is clearly visible on the echogram. The echogram distance is compared to the known distance to assure that parameters are properly set and the system is operating correctly.
On-lake survey procedures: Using the GPS Extension of ArcGIS, the GPS data feed from the GPS receiver via the Biosonics echosounder, and the pre-planned transect pattern, the location of the boat on the lake in real-time is shown on the command/navigation computer screen. Transducer face depth on all dates is 0.25 meters below the water surface. A perimeter run is initially performed to set the immediate off-shore water depth, with this survey track typically placed 50 meters from shore, modified as necessary during the survey if shallow water or other obstructions are encountered. Following the perimeter run, the cross-lake transects are then acquired. The transect pattern is maintained except when modified by obstructions in the lake (e.g., partially submerged trees) or shallow water and mudflats. Data are automatically logged in new files every half-hour (approximately 9000-ping files) by the Biosonics system.

Establishment Of Lake Level On Survey Dates:

Reservoir shoreline perimeters were digitized off 2006 NAIP aerial photography and the elevation of the reservoir on the date of aerial photography was used as the water surface elevation in all interpolations from point data to raster data. The water elevation on July 13, 2006 was 1420.72 feet AMSL, NGVD29.

Lake levels on the survey dates were obtained from the US Army Corps of Engineers web site (http://www.swt-wc.usace.army.mil/CHENcharts.html)

Water levels on all six survey dates in July and August 2010 were dropping slightly throughout each day (Table 1). A regression equation for each day of data was developed based on the water elevations at 8:00 AM and midnight to predict water elevation as a function of time. Since the Biosonics echosounder includes a time value with each depth measurement, we could then apply the regression equation to the Biosonics data to produce a predicted lake elevation value for each processed depth measurement.

Table 1
Water surface elevations and regression equations, July-August 2010 survey dates

Month	Day	Water surface elevation, 8:00 AM	Water surface elevation, 12:00 AM	Change in water surface (ft)	Change in water surface (in.)	Regression Equation†
July	12	1427.19	1427.10	-0.09	-1.08	y = -0.135x + 1427.24
July	13	1427.05	1426.94	-0.11	-1.32	y = -0.165x + 1427.11
July	14	1426.89	1426.76	-0.13	-1.56	y = -0.195x + 1426.96
August	2	1422.70	1422.52	-0.18	-2.16	y = -0.27 x + 1422.79
August	3	1422.42	1422.24	-0.18	-2.16	y = -0.27 x + 1422.51
August	4	1422.15	1421.98	-0.17	-2.04	y = -0.255 x + 1422.24

† *x= time since 0800 hours in minutes; y = water surface elevation, in feet.*

Water surface elevations for each date of survey were used to convert relative water depths on each date to absolute measures of reservoir bottom depth at each point.

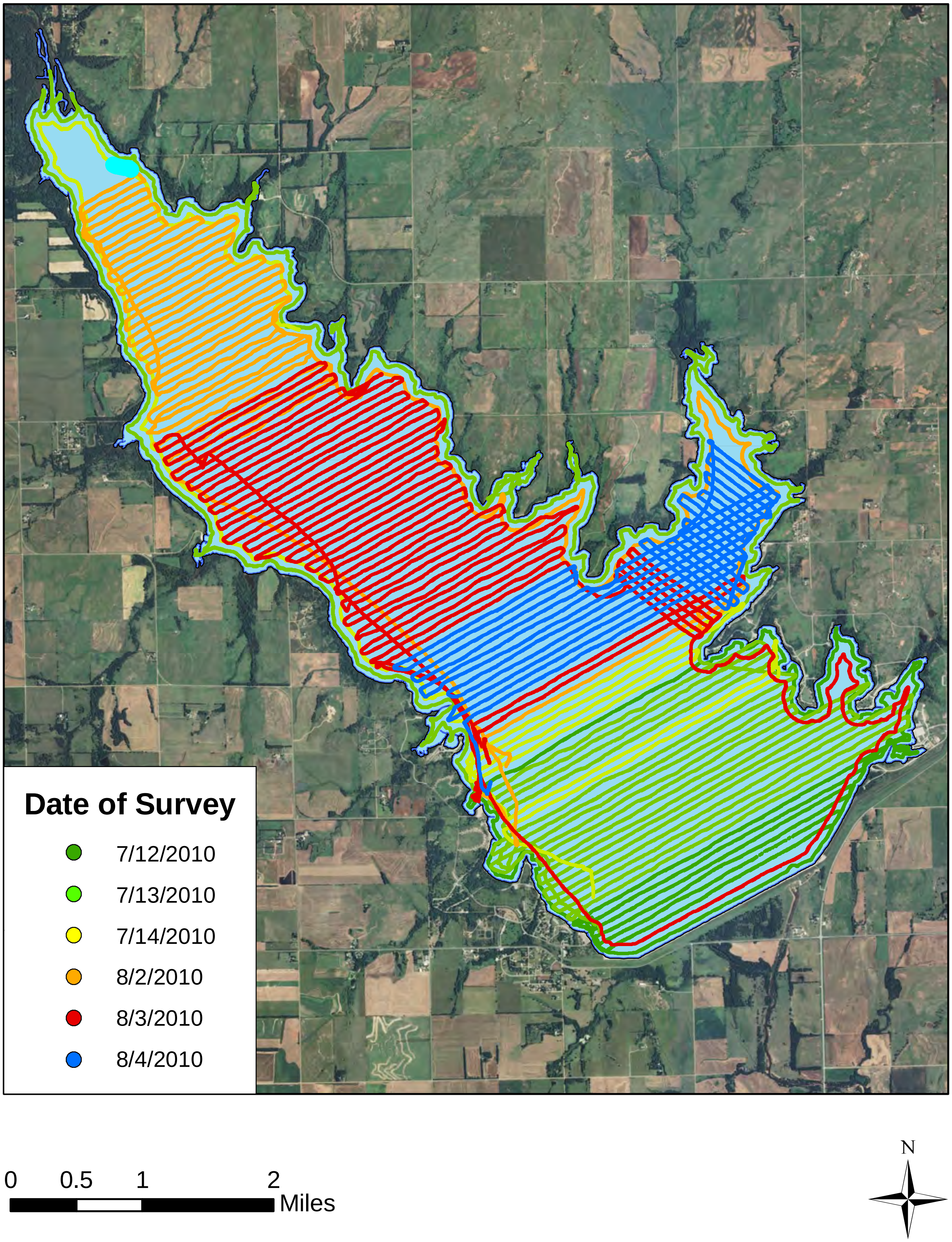

Figure 3. Bathymetric survey transects

<u>Post-processing</u> *(Visual Bottom Typer)*

The Biosonics DT-X system produces data files in a proprietary DT4 file format containing acoustic and GPS data. To extract the bottom position from the acoustic data, each DT4 file is processed through the Biosonics Visual Bottom Typer (VBT) software. The processing algorithm is described as follows:

> *"The BioSonics, Inc. bottom tracker is an "end_up" algorithm, in that it begins searching for the bottom echo portion of a ping from the last sample toward the first sample. The bottom tracker tracks the bottom echo by isolating the region(s) where the data exceeds a peak threshold for N consecutive samples, then drops below a surface threshold for M samples. Once a bottom echo has been identified , a bottom sampling window is used to find the next echo. The bottom echo is first isolated by user_defined threshold values that indicate (1) the lowest energy to include in the bottom echo (bottom detection threshold) and (2) the lowest energy to start looking for a bottom peak (peak threshold). The bottom detection threshold allows the user to filter out noise caused by a low data acquisition threshold. The peak threshold prevents the algorithm from identifying the small energy echoes (due to fish, sediment or plant life) as a bottom echo."* (Biosonics Visual Bottom Typer User's Manual, Version 1.10, p. 70).

Data is output as a comma-delimited (*.csv) text file. A set number of qualifying pings are averaged to produce a single report (for example, the output for ping 31 {when pings per report is 20} is the average of all values for pings 12-31). Standard analysis procedure for all 2008 and later data is to use the average of 5 pings to produce one output value. All raw *.csv files are merged into one master *.csv file using the shareware program File Append and Split Tool (FAST) by Boxer Software (Ver. 1.0, 2006).

<u>Post-processing</u> (*Excel*)

The master *.csv file created by the FAST utility is imported into Microsoft Excel. Excess header lines are deleted (each input CSV file has its own header), and the header file is edited to change the column headers "#Ping" to "Ping" and "E1' " to "E11", characters that are not ingestable by ArcGIS. Entries with depth values of zero (0) are deleted, as are any entries with depth values less than the start range of the data acquisition parameter (0.49 meters or less) (indicating areas where the water was too shallow to record a depth reading).

In Excel, depth adjustments are made. A new field – Adj_Depth – is created. The value for AdjDepth is calculated as AdjDepth = Depth + (Transducer Face Depth), where the Transducer Face Depth represents the depth of the transducer face below water level in meters (Typically, this value is 0.2 meters; however, if changes were made in the field, the correct level is taken from field notes and applied to the data). Depth in feet is also calculated as DepthFt = Adj_Depth * 3.28084.

These water depths are RELATIVE water depths that can vary from day-to-day based on the elevation of the water surface. In order to normalize all depth measurements to an absolute reference, water depths must be subtracted from an established value for the elevation of the water surface at the time of the bathymetric survey. Determination of water surface elevation has been described in an earlier section on establishment of lake levels.

To set depths relative to lake elevation, two additional fields are added to the attribute table of the point shapefile: LakeElevM, the reference surface elevation (the elevation of the water surface on the day that the aerial photography from which the lake perimeter polygon was digitized)and Elev_Ft, the elevation of the water surface in feet above sea level (Elev_ft), computed by converting ElevM to elevation in feet (ElevM * 3.28084).

Particularly for multi-day surveys, Adj_Depth and Depth_Ft should **NOT** be used for further analysis or interpolation. If water depth is desired, it should be produced by subtracting Elev_M or Elev_Ft from the reference elevation used for interpolation purposes (for federal reservoirs, the elevation of the water surface on the day that the aerial photography from which the lake perimeter polygon was digitized).

<u>Post-processing</u> *(ArcGIS):*

Ingest to ArcGIS is accomplished by using the Tools – Add XY Data option. The projection information is specified at this time (WGS84). Point files are displayed as Event files, and are then exported as a shapefile (filename convention: ALLPOINTS_WGS84.shp). The pointfile is then reprojected to the UTM coordinate system of the appropriate zone (14 or 15) (filename convention ALLPOINTS_UTM.shp).

The ArcGIS command TopoToRaster was used to create a raster reservoir bottom elevation model from the set of georeferenced lake bottom elevation points, using the 2006 NAIP lake perimeter as both an elevation contour line and as a masking polygon to restrict interpolation solely to the footprint of the reservoir.

Area-elevation-volume tables are derived using an ArcGIS extension custom written for and available from the ASTRA Program. Summarized, the extension calculates the area and volume of the reservoir at 1/10-foot elevation increments from the TIN data for a series of water surfaces beginning at the lowest elevation recorded and progressing upward in 1/10-foot elevation increments to the reference water surface. Cumulative volume is also computed in acre-feet.

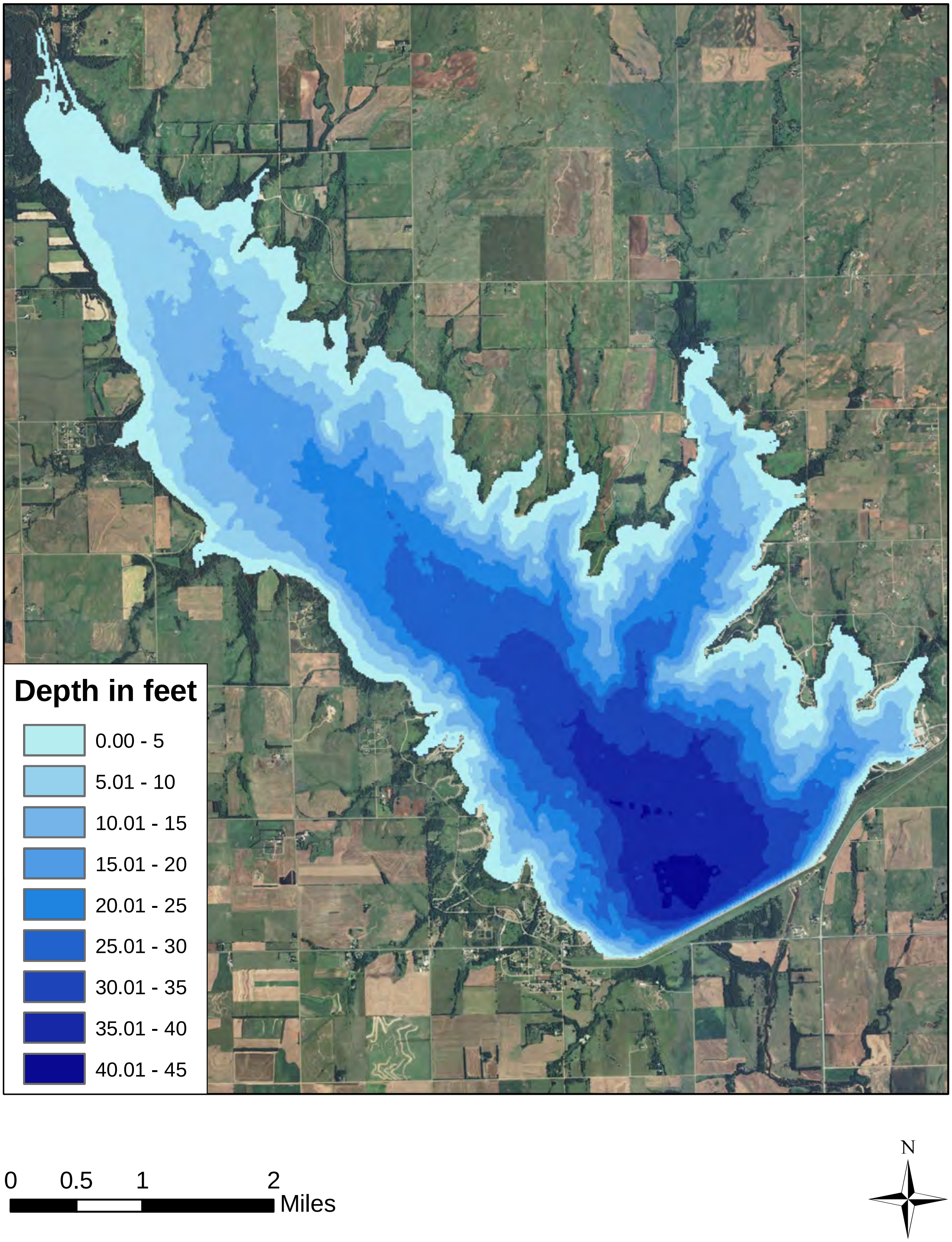

Figure 4. Depth map from 2010 KBS bathymetric survey.
(Depths based on pool elevation 1420.72 ft AMSL NGVD29.

Table 2
Cumulative area in acres by tenth foot elevation increments

Elevation (ft NGVD29)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
1375	0	0	0	0	0	0	0	0	0	0
1376	0	0	0	0	0	0	0	0	0	0
1377	0	0	0	0	0	0	0	0	0	0
1378	0	0	0	0	0	0	0	0	0	0
1379	0	0	0	0	0	3	6	10	14	19
1380	25	32	38	47	58	70	80	93	104	114
1381	124	138	156	174	196	215	231	246	259	271
1382	282	292	302	312	323	332	340	350	359	369
1383	380	393	409	424	440	456	474	491	510	528
1384	547	564	581	598	615	632	650	665	681	697
1385	713	729	745	763	782	802	823	846	865	884
1386	900	914	928	944	958	971	983	996	1010	1023
1387	1037	1052	1068	1083	1100	1117	1134	1151	1167	1182
1388	1196	1209	1222	1235	1248	1262	1276	1291	1306	1321
1389	1337	1354	1370	1385	1401	1417	1431	1446	1461	1476
1390	1491	1509	1525	1539	1553	1568	1583	1598	1614	1630
1391	1647	1662	1678	1696	1713	1728	1743	1759	1774	1791
1392	1807	1823	1840	1857	1874	1893	1911	1928	1944	1959
1393	1975	1992	2009	2026	2045	2065	2085	2106	2128	2152
1394	2177	2204	2230	2257	2283	2307	2332	2357	2380	2405
1395	2427	2447	2467	2487	2508	2529	2550	2571	2592	2613
1396	2634	2656	2678	2699	2721	2744	2768	2793	2817	2841
1397	2864	2887	2910	2934	2957	2981	3005	3029	3052	3074
1398	3094	3115	3136	3157	3179	3202	3225	3247	3269	3291
1399	3313	3335	3357	3379	3401	3422	3445	3467	3491	3514
1400	3536	3560	3583	3607	3631	3655	3678	3702	3728	3755
1401	3782	3809	3834	3859	3884	3909	3933	3957	3981	4007
1402	4032	4057	4083	4109	4135	4161	4187	4214	4241	4269
1403	4296	4324	4352	4379	4405	4431	4457	4484	4510	4534
1404	4559	4585	4610	4635	4661	4685	4711	4737	4765	4790
1405	4816	4841	4867	4893	4919	4945	4972	5000	5028	5058

Table 2, continued
Cumulative area in acres by tenth foot elevation increments

Elevation (ft NGVD29)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
1406	5087	5118	5148	5179	5210	5240	5270	5299	5328	5357
1407	5387	5418	5446	5474	5503	5531	5559	5587	5615	5643
1408	5673	5703	5732	5762	5792	5822	5852	5883	5913	5944
1409	5975	6004	6033	6062	6092	6122	6153	6183	6213	6244
1410	6275	6305	6336	6368	6400	6432	6464	6496	6529	6561
1411	6592	6624	6657	6691	6725	6758	6791	6825	6858	6892
1412	6925	6959	6992	7025	7058	7090	7123	7156	7189	7223
1413	7257	7291	7324	7357	7389	7422	7455	7488	7522	7557
1414	7592	7627	7662	7696	7730	7764	7798	7832	7866	7900
1415	7935	7970	8005	8040	8075	8110	8146	8184	8222	8261
1416	8299	8338	8376	8415	8453	8491	8531	8570	8609	8647
1417	8686	8725	8764	8802	8841	8880	8919	8959	8999	9037
1418	9075	9113	9149	9185	9221	9256	9290	9324	9357	9389
1419	9420	9451	9482	9512	9542	9572	9602	9632	9662	9691
1420	9720	9750	9779	9808	9838	9870	9902	9937		

Table 3
Cumulative volume in acre-feet by tenth foot elevation increments

Elevation (ft NGVD29)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
1375	0	0	0	0	0	0	0	0	0	0
1376	0	0	0	0	0	0	0	0	0	0
1377	0	0	0	0	0	0	0	0	0	0
1378	0	0	0	0	0	0	0	0	0	0
1379	0	0	0	0	0	0	1	1	2	4
1380	6	9	13	17	22	28	36	44	54	65
1381	77	90	104	121	139	160	182	206	231	258
1382	285	314	344	374	406	439	473	507	542	579
1383	616	655	695	736	780	825	871	919	969	1021
1384	1075	1130	1187	1246	1307	1369	1433	1499	1567	1636
1385	1706	1778	1852	1927	2005	2084	2165	2249	2334	2422
1386	2511	2602	2694	2788	2883	2980	3077	3176	3277	3378
1387	3481	3586	3692	3799	3909	4020	4132	4246	4362	4479
1388	4598	4719	4840	4963	5087	5213	5340	5468	5598	5729
1389	5863	5997	6133	6271	6411	6552	6694	6838	6983	7130
1390	7279	7429	7581	7734	7889	8045	8203	8362	8522	8685
1391	8849	9014	9181	9350	9520	9692	9866	10041	10218	10396
1392	10576	10758	10941	11126	11313	11501	11691	11883	12077	12272
1393	12469	12667	12867	13069	13273	13479	13687	13896	14108	14322
1394	14538	14757	14979	15203	15430	15660	15892	16126	16363	16603
1395	16844	17088	17334	17582	17831	18083	18337	18594	18852	19112
1396	19375	19639	19906	20175	20446	20719	20995	21273	21554	21837
1397	22123	22410	22700	22992	23287	23584	23883	24185	24489	24796
1398	25104	25415	25728	26042	26359	26679	27000	27324	27650	27978
1399	28309	28641	28976	29313	29652	29993	30337	30682	31030	31381
1400	31734	32089	32446	32806	33168	33533	33900	34269	34640	35015
1401	35392	35771	36154	36539	36926	37316	37708	38103	38500	38899
1402	39301	39706	40113	40523	40935	41350	41768	42188	42611	43037
1403	43465	43896	44330	44767	45206	45649	46093	46541	46991	47443
1404	47899	48357	48816	49279	49744	50211	50681	51154	51629	52107
1405	52588	53071	53556	54045	54536	55029	55525	56024	56526	57031

Table 3, continued
Cumulative volume in acre-feet by tenth foot elevation increments

Elevation (ft NGVD29)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
1406	57538	58049	58563	59079	59599	60122	60648	61176	61708	62243
1407	62781	63321	63864	64411	64959	65511	66067	66624	67185	67749
1408	68315	68884	69456	70031	70609	71191	71775	72362	72952	73545
1409	74141	74741	75343	75948	76556	77168	77782	78399	79019	79643
1410	80269	80899	81531	82167	82806	83448	84093	84742	85393	86048
1411	86706	87368	88033	88701	89372	90047	90725	91406	92091	92779
1412	93471	94166	94864	95565	96270	96977	97689	98403	99121	99842
1413	100566	101294	102026	102760	103498	104239	104983	105731	106482	107237
1414	107995	108757	109522	110291	111063	111838	112617	113399	114185	114974
1415	115766	116562	117362	118165	118972	119781	120595	121412	122234	123059
1416	123888	124721	125557	126397	127242	128089	128941	129797	130657	131520
1417	132388	133259	134134	135013	135896	136782	137673	138568	139467	140369
1418	141275	142185	143098	144016	144936	145861	146788	147719	148653	149591
1419	150532	151476	152423	153374	154327	155283	156242	157205	158170	159139
1420	160110	161085	162061	163042	164026	165014	166007	167006		

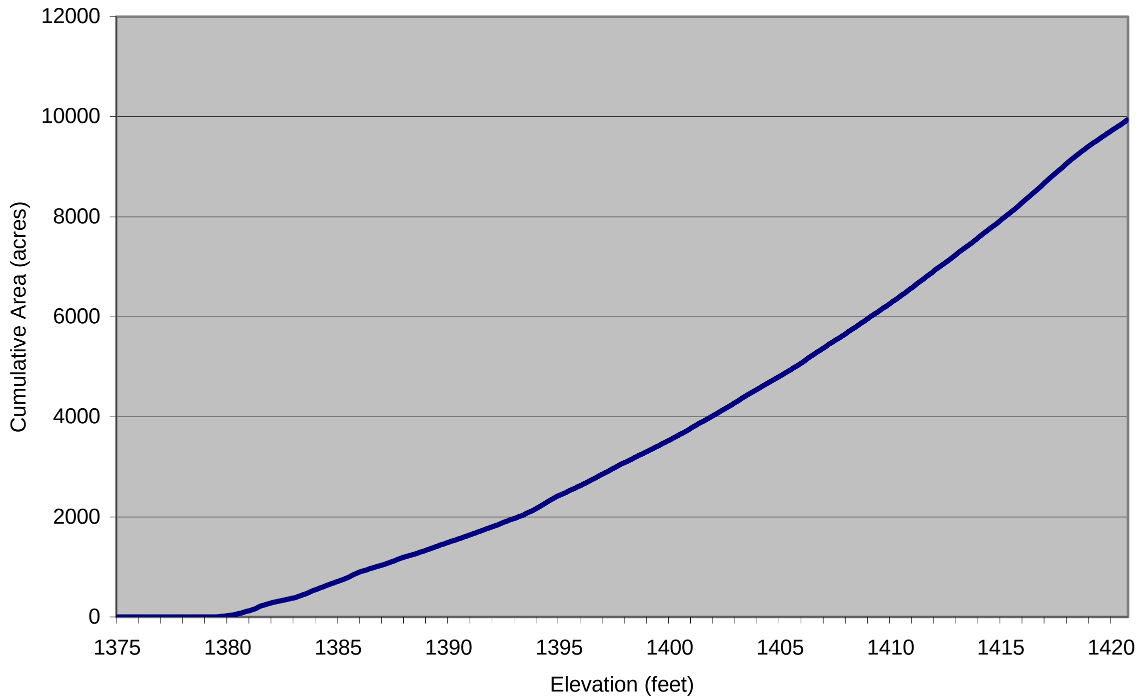

Figure 5. Cumulative area-elevation curve for KBS 2010 bathymetric survey.

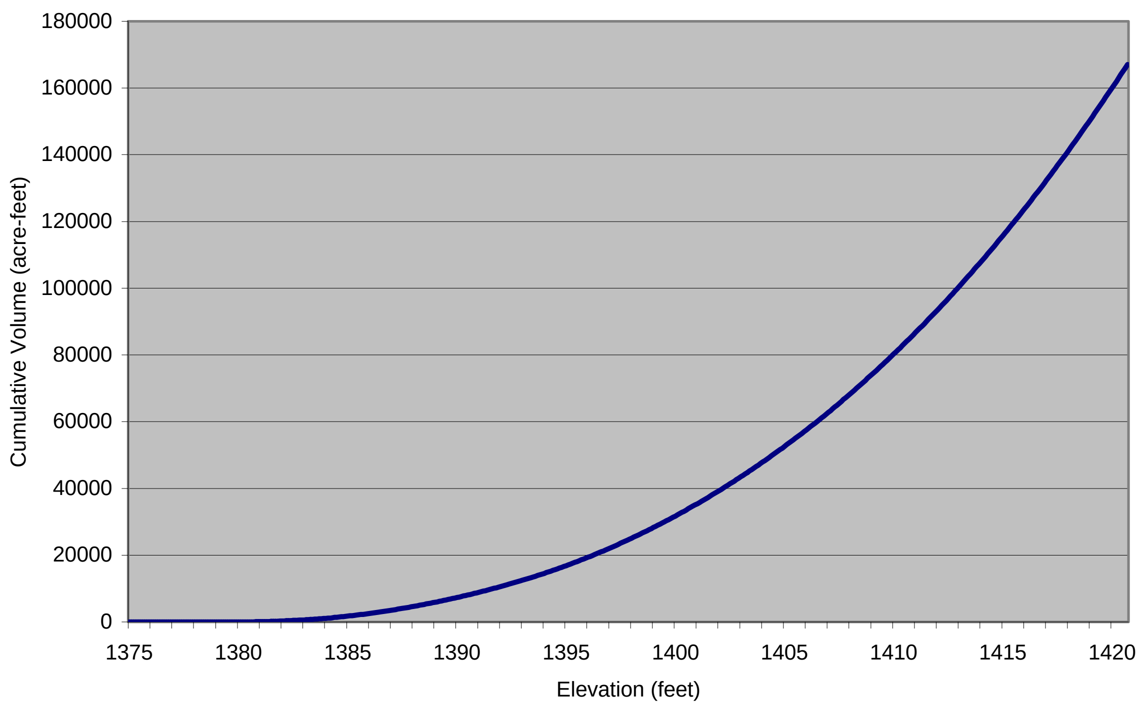

Figure 6. Cumulative volume-elevation curve for KBS 2010 bathymetric survey.

1998 US Geological Survey Bathymetric Survey

A point shapefile of a bathymetric survey conducted in 1998 by the US Geological Survey was obtained from the USGS Kansas office. Specific details of this bathymetric survey are addressed in the 2001 USGS report, "*Sediment Deposition and Trends and Transport of Phosphorous and Other Chemical Constituents, Cheney Reservoir Watershed, South-central Kansas:* U.S. Geological Survey Water-Resources Investigations Report 01-4085, 40 p. The point shapefile contained 6441 lake bottom elevations georeferenced by UTM Zone 14 (NAD27) coordinates (Figure 7). Point data were used to create a reservoir bottom elevation model using the ArcGIS TopoToRaster interpolation, using the 2006 lake perimeter line as a contour at elevation 1420.7 ft AMSL (NGVD29) and the 2006 lake perimeter polygon as bounding polygon (Figure 8).

Area-elevation-volume tables were derived using an ArcGIS extension custom written for and available from the ASTRA Program. Summarized, the extension calculates the area and volume of the reservoir at 1/10-foot elevation increments from the raster data for a series of water surfaces beginning at the lowest elevation recorded and progressing upward in 1/10-foot elevation increments to the reference water surface (Table 4; Figure 9). Cumulative volume is also computed in acre-feet (Table 5; Figure 10).

Caution should be exercised in drawing conclusions based on comparison between two maps of different scales, dates, and production methods.

Changes in lake bottom elevation between 1998 and 2010 were computed by digitally subtracting the 1998 digital elevation model from the 2010 digital elevation model. Negative numbers on the resulting output indicate 2010 elevation *lower* than 1998 elevation (loss of material during the intervening period); positive numbers indicate 2010 lake bottom *higher* than 1998 (accumulated material, or likely siltation) (Figure 11; Figure 12; Figure 13). Apparent lake bottom scouring/change along the face of the dam in Figure 11 is likely attributable to differences in the bathymetric survey transect patterns used by KBS (Figure 3) and USGS (Figure 7) creating differences in the interpolated digital lake bottom models, rather than to actual removal of sediment between the two dates of bathymetric surveys.

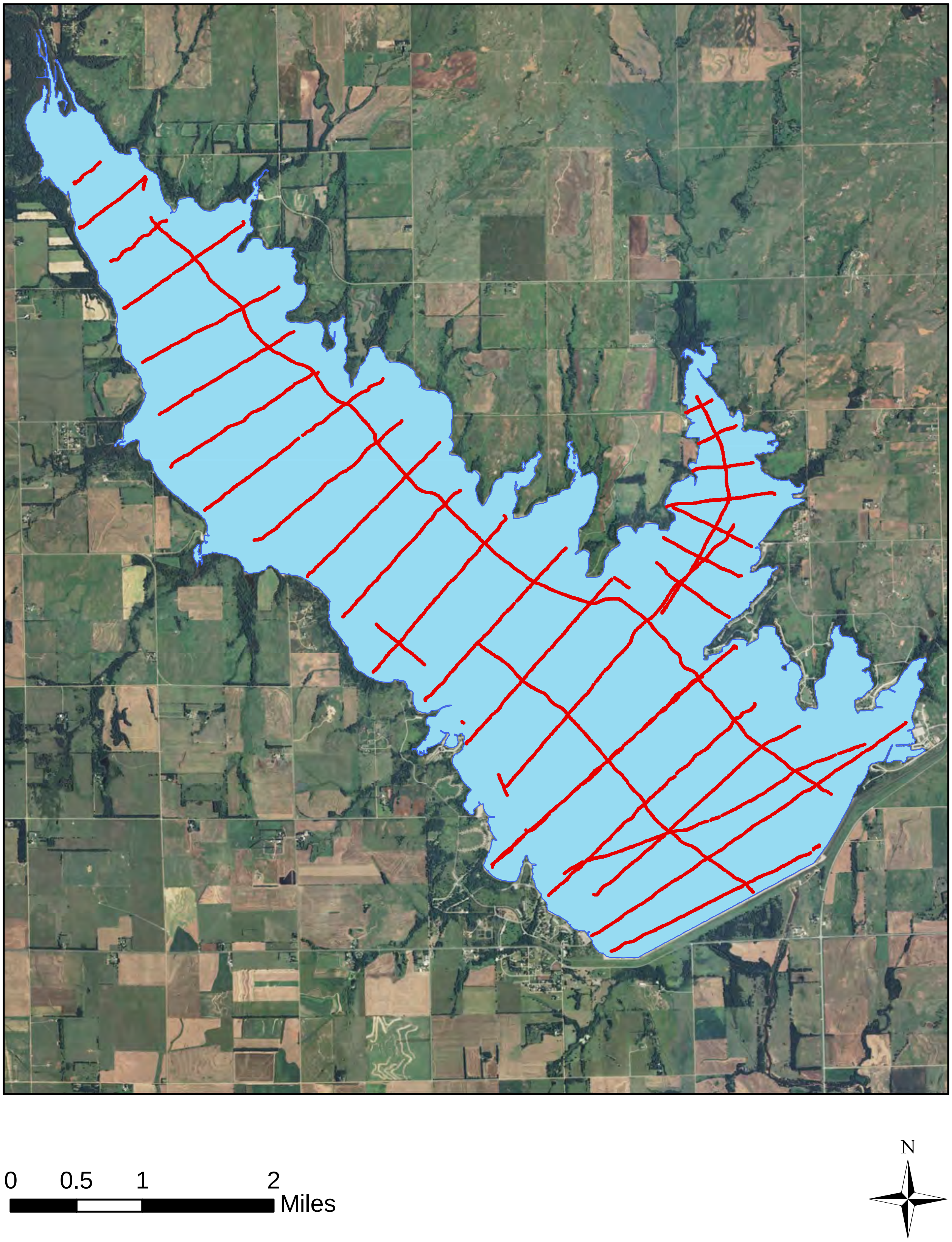

Figure 7. Survey points from 1998 US Geological Survey bathymetric survey.

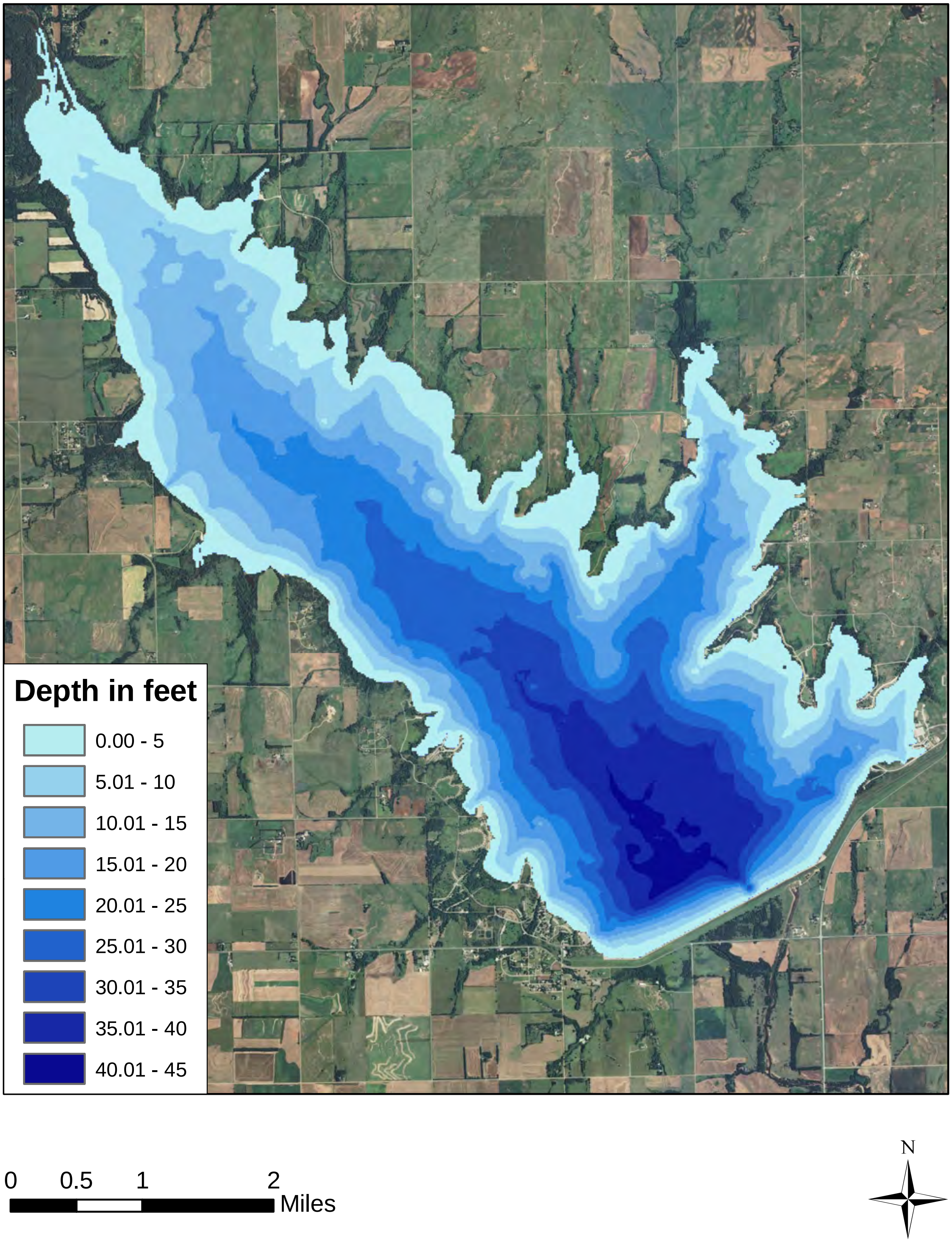

Figure 8. Depth map from 1998 USGS bathymetric survey.
(Depths based on pool elevation 1420.72 ft AMSL NGVD29.

Table 4
Cumulative area in acres by tenth foot elevation increments

Elevation (ft NGVD29)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
1375	0	0	0	0	0	0	0	0	0	0
1376	0	0	0	0	0	0	0	0	0	0
1377	0	0	0	0	0	0	0	0	2	5
1378	7	10	13	16	21	25	28	32	36	40
1379	44	48	52	56	61	66	72	78	84	92
1380	99	106	114	123	134	145	156	167	179	192
1381	205	219	231	243	255	266	278	288	299	310
1382	320	331	343	355	368	382	397	413	429	445
1383	462	479	496	514	533	550	566	581	596	610
1384	625	640	654	667	681	695	709	723	736	750
1385	764	778	790	802	814	827	839	851	863	875
1386	887	899	912	924	937	949	962	975	990	1003
1387	1016	1028	1041	1053	1064	1076	1088	1100	1112	1124
1388	1136	1148	1159	1171	1184	1197	1209	1221	1233	1245
1389	1257	1268	1281	1293	1304	1316	1328	1341	1353	1366
1390	1379	1392	1406	1421	1435	1450	1465	1482	1500	1519
1391	1541	1562	1582	1602	1621	1640	1658	1677	1695	1713
1392	1732	1749	1768	1787	1807	1825	1844	1862	1881	1900
1393	1919	1937	1955	1973	1990	2008	2025	2043	2062	2080
1394	2099	2118	2137	2157	2177	2196	2216	2236	2256	2276
1395	2297	2318	2339	2358	2378	2399	2419	2439	2458	2479
1396	2499	2520	2542	2564	2587	2610	2632	2655	2679	2703
1397	2727	2750	2774	2798	2823	2846	2870	2893	2916	2939
1398	2962	2985	3009	3032	3056	3079	3103	3126	3150	3174
1399	3197	3221	3245	3270	3294	3319	3345	3371	3396	3422
1400	3448	3475	3501	3528	3556	3583	3610	3638	3665	3694
1401	3721	3748	3775	3802	3828	3854	3881	3908	3935	3961
1402	3986	4012	4037	4062	4087	4113	4138	4163	4189	4215
1403	4241	4266	4292	4317	4341	4366	4391	4417	4442	4468
1404	4495	4522	4548	4574	4599	4625	4650	4675	4701	4727
1405	4753	4778	4804	4830	4856	4883	4910	4937	4964	4991

Table 4, continued
Cumulative area in acres by tenth foot elevation increments

Elevation (ft NGVD29)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
1406	5019	5047	5076	5106	5136	5166	5197	5229	5260	5292
1407	5322	5352	5382	5411	5442	5472	5501	5531	5560	5589
1408	5618	5648	5677	5706	5735	5764	5793	5821	5849	5878
1409	5909	5939	5971	6002	6033	6064	6095	6126	6156	6186
1410	6217	6248	6280	6311	6344	6376	6410	6442	6475	6509
1411	6542	6575	6607	6638	6669	6700	6731	6763	6794	6826
1412	6857	6887	6917	6946	6976	7005	7034	7062	7090	7118
1413	7147	7175	7204	7233	7262	7292	7324	7356	7388	7421
1414	7453	7486	7517	7548	7578	7608	7638	7667	7697	7727
1415	7758	7789	7819	7850	7883	7914	7946	7978	8009	8041
1416	8072	8103	8134	8165	8195	8225	8256	8286	8316	8346
1417	8377	8407	8437	8467	8497	8528	8558	8589	8619	8650
1418	8681	8713	8744	8776	8808	8841	8874	8908	8942	8976
1419	9012	9047	9083	9120	9158	9197	9237	9278	9320	9364
1420	9409	9457	9508	9563	9623	9691	9770	9882		

Table 5
Cumulative volume in acre-feet by tenth foot elevation increments

Elevation (ft NGVD29)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
1375	0	0	0	0	0	0	0	0	0	0
1376	0	0	0	0	0	0	0	0	0	0
1377	0	0	0	0	0	0	0	0	0	0
1378	1	2	3	4	6	8	11	14	17	21
1379	25	30	35	40	46	52	59	66	74	83
1380	93	103	114	125	138	152	167	183	201	219
1381	239	260	283	306	331	357	385	413	442	473
1382	504	537	570	605	641	679	718	758	801	844
1383	890	937	986	1036	1089	1143	1199	1256	1315	1376
1384	1437	1501	1565	1631	1699	1768	1838	1910	1983	2057
1385	2132	2210	2288	2368	2449	2531	2614	2698	2784	2871
1386	2959	3048	3139	3231	3324	3418	3514	3611	3709	3809
1387	3910	4012	4116	4221	4327	4434	4542	4651	4762	4874
1388	4987	5101	5217	5334	5451	5570	5691	5812	5935	6059
1389	6184	6311	6438	6567	6697	6828	6960	7094	7229	7365
1390	7502	7641	7781	7922	8065	8210	8355	8503	8652	8803
1391	8956	9111	9268	9428	9589	9752	9917	10084	10253	10423
1392	10596	10770	10946	11124	11303	11485	11669	11854	12041	12231
1393	12422	12614	12809	13005	13204	13404	13605	13809	14014	14222
1394	14431	14642	14854	15069	15286	15505	15726	15948	16173	16399
1395	16628	16859	17092	17327	17564	17803	18044	18287	18532	18779
1396	19028	19279	19532	19788	20046	20306	20568	20832	21099	21368
1397	21640	21914	22191	22469	22751	23034	23320	23608	23899	24192
1398	24487	24784	25085	25387	25691	25998	26307	26619	26933	27250
1399	27569	27890	28213	28539	28867	29198	29532	29868	30206	30547
1400	30891	31237	31587	31938	32293	32650	33010	33372	33738	34106
1401	34477	34851	35227	35606	35988	36372	36759	37149	37541	37936
1402	38334	38734	39137	39542	39949	40359	40772	41188	41605	42026
1403	42449	42875	43303	43733	44167	44602	45040	45481	45924	46370
1404	46818	47269	47723	48180	48639	49100	49564	50031	50500	50972
1405	51446	51923	52402	52884	53369	53856	54346	54838	55334	55832

Table 5, continued
Cumulative volume in acre-feet by tenth foot elevation increments

Elevation (ft NGVD29)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
1406	56333	56837	57343	57853	58365	58881	59400	59921	60446	60974
1407	61505	62039	62576	63116	63659	64205	64754	65306	65861	66419
1408	66980	67544	68111	68680	69253	69828	70406	70987	71571	72158
1409	72748	73340	73936	74535	75138	75743	76351	76963	77577	78195
1410	78815	79439	80066	80696	81329	81966	82605	83248	83895	84544
1411	85197	85853	86513	87176	87841	88511	89183	89858	90536	91217
1412	91902	92590	93280	93974	94671	95370	96073	96778	97486	98197
1413	98911	99627	100347	101069	101795	102523	103254	103988	104726	105467
1414	106211	106959	107709	108463	109220	109980	110743	111509	112277	113049
1415	113824	114602	115382	116167	116954	117745	118538	119335	120135	120938
1416	121744	122554	123367	124182	125001	125822	126647	127474	128305	129139
1417	129976	130816	131659	132504	133353	134205	135060	135918	136779	137643
1418	138510	139380	140254	141131	142011	142895	143781	144671	145564	146461
1419	147361	148264	149171	150082	150997	151916	152839	153765	154696	155631
1420	156570	157515	158464	159419	160379	161346	162320	163306		

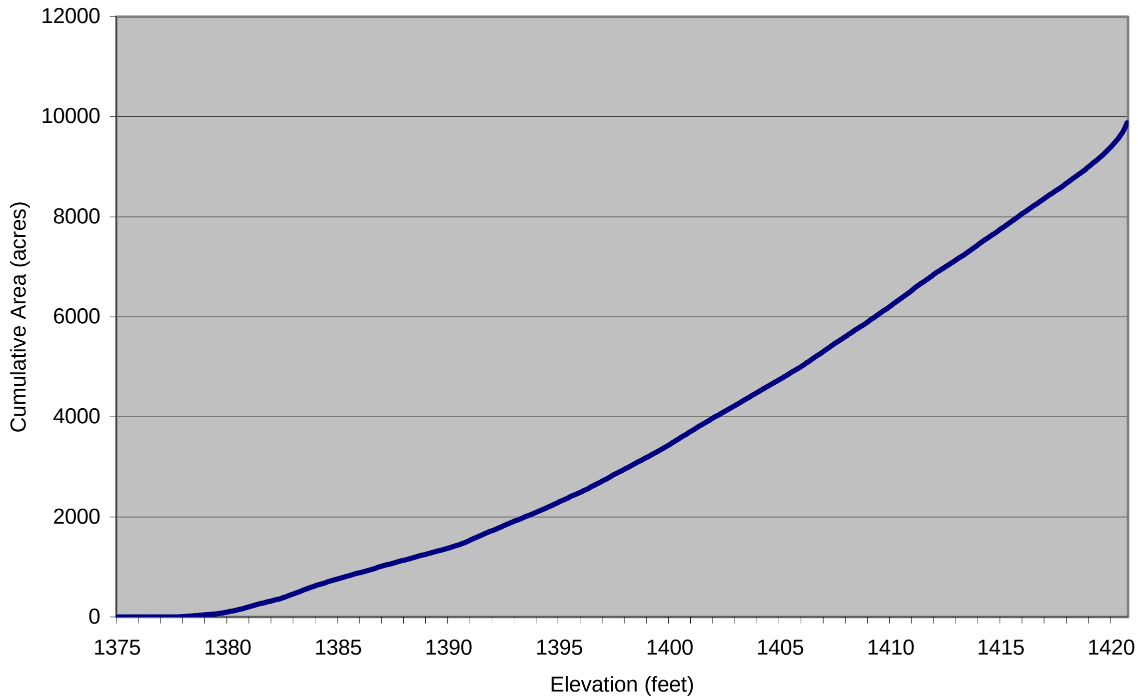

Figure 9. Cumulative area-elevation curve for USGS 1998 bathymetric survey.

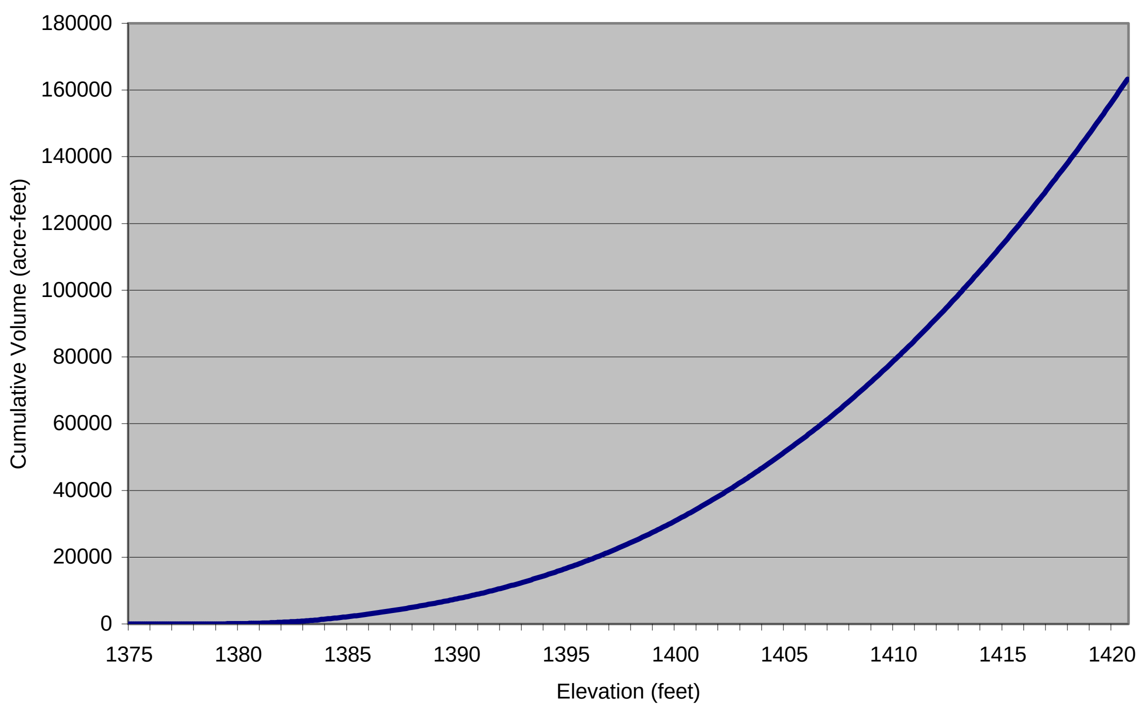

Figure 10. Cumulative volume-elevation curve for USGS 1998 bathymetric survey.

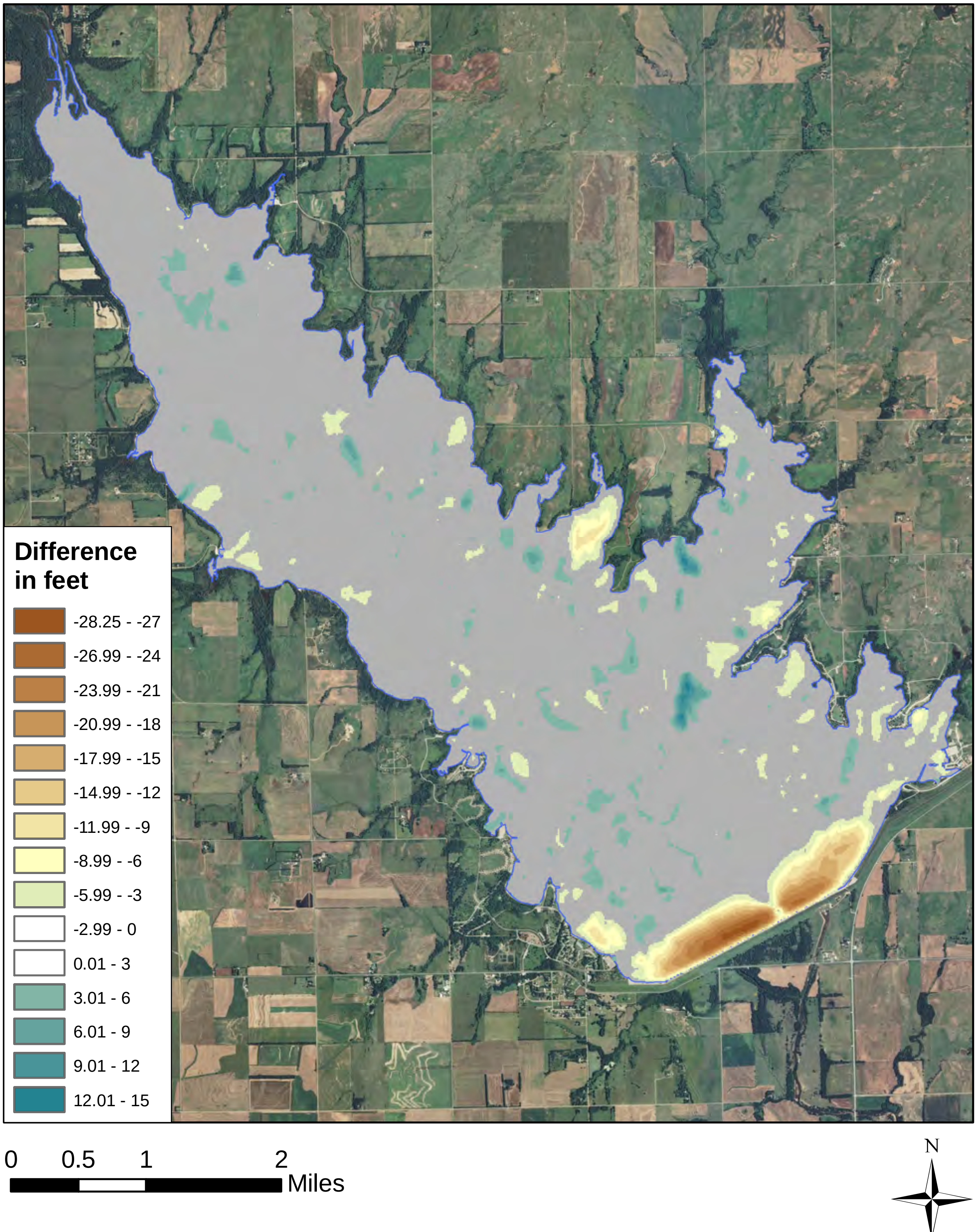

Figure 11. Difference map between 2010 KBS bathymetric survey and 1998 U.S. Geological Survey bathymetric survey. Positive values indicate increase in lake bottom elevation between surveys (sedimentation); negative values indicate lowering of lake bottom elevation (scouring or removal) between 2004 and 2010.

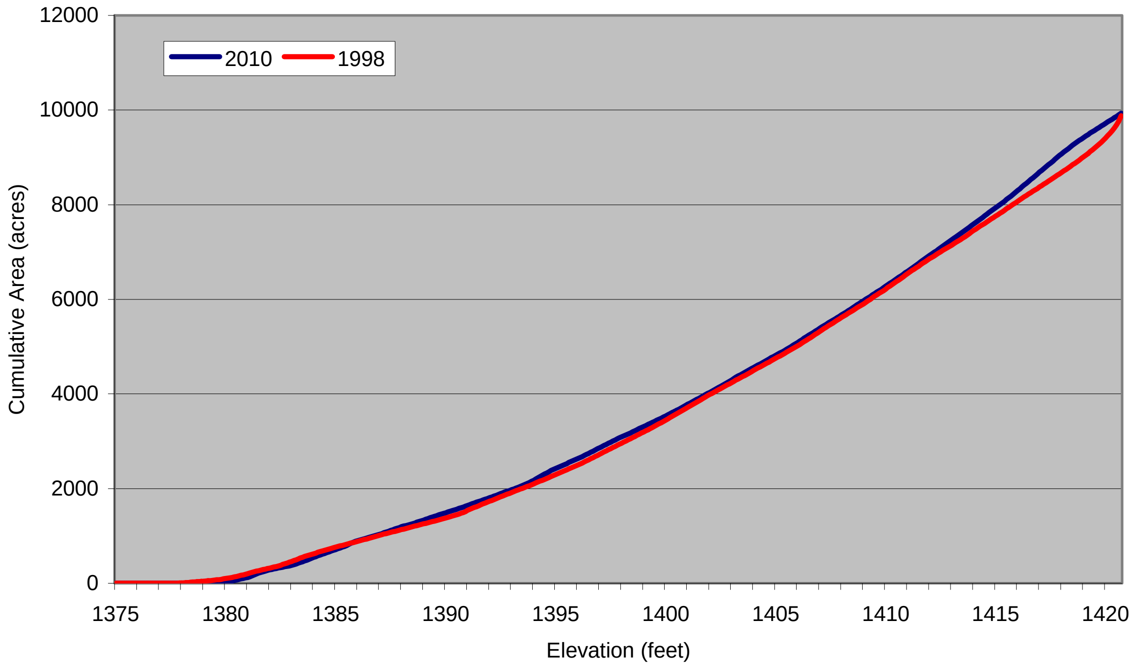

Figure 12. Lake areas, 1998 USGS survey and 2010 KBS survey.

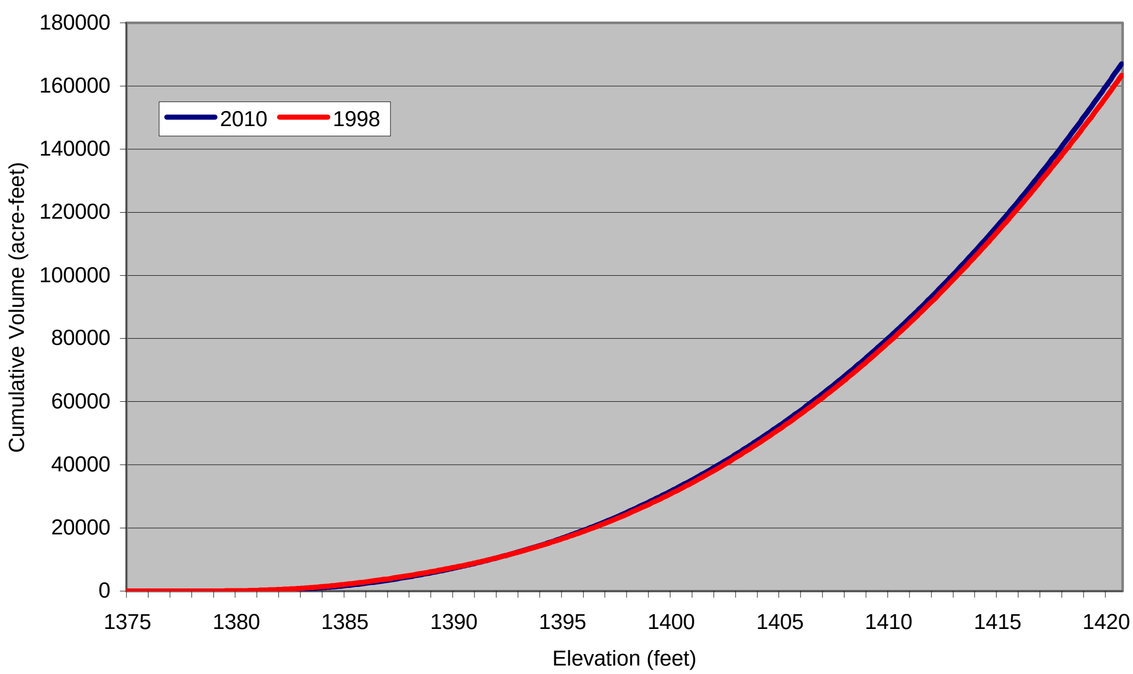

Figure 13. Lake volumes, 1998 USGS survey and 2010 KBS survey.

Reservoir Cross-sections:
Comparison of 2010 KBS data to 1998 USGS data

No coordinates for rangeline endpoints were available from the US Bureau of Reclamation, the US Army Corps of Engineers, or the City of Wichita. A poor-quality scan of a map with rangelines visible (Map 835-514-66, Frames 1-7, from the USBR) was used to approximate and recreate the rangelines as a line shapefile, with the assistance of a USGS Digital Raster Graphic (DRG) file (Figure 14; Figure 15).

Each line in the shapefile was converted into a series of points at 50-foot intervals. The ArcGIS program Extract Values to Points was used to extract the elevation value for each point from the 1998 and 2010 reservoir bottom elevation DEMs previously described. Points were then imported to Excel for plotting as charts (Figure 16a – 16k). No data was extracted for the non-water areas outside the perimeter of the lake digitized from the 2006 NAIP photography; these values were set to 1420.7 ft. AMSL, NGVD29.

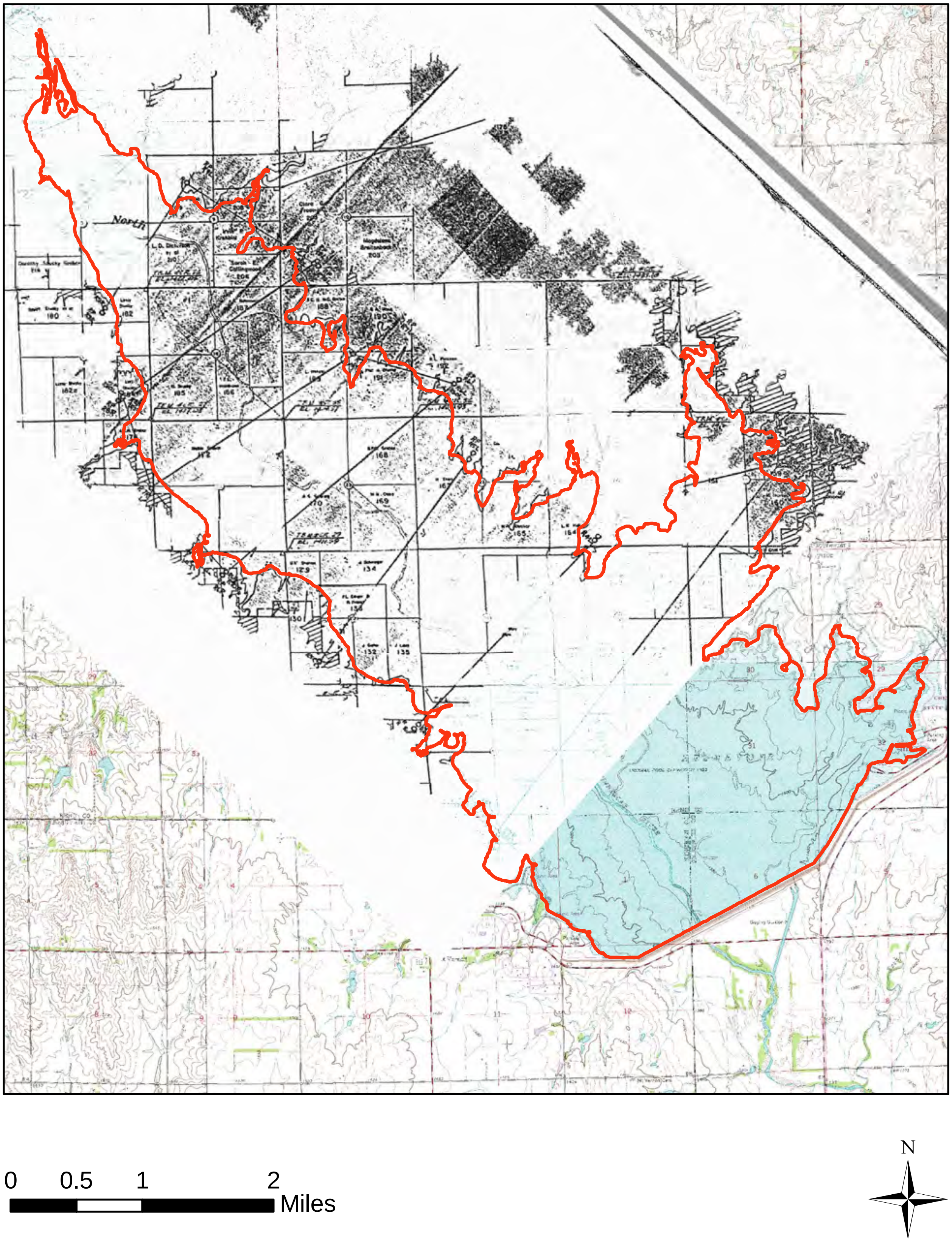

Figure 14. Portion of a scanned, georeferenced range line map for Cheney Reservoir.

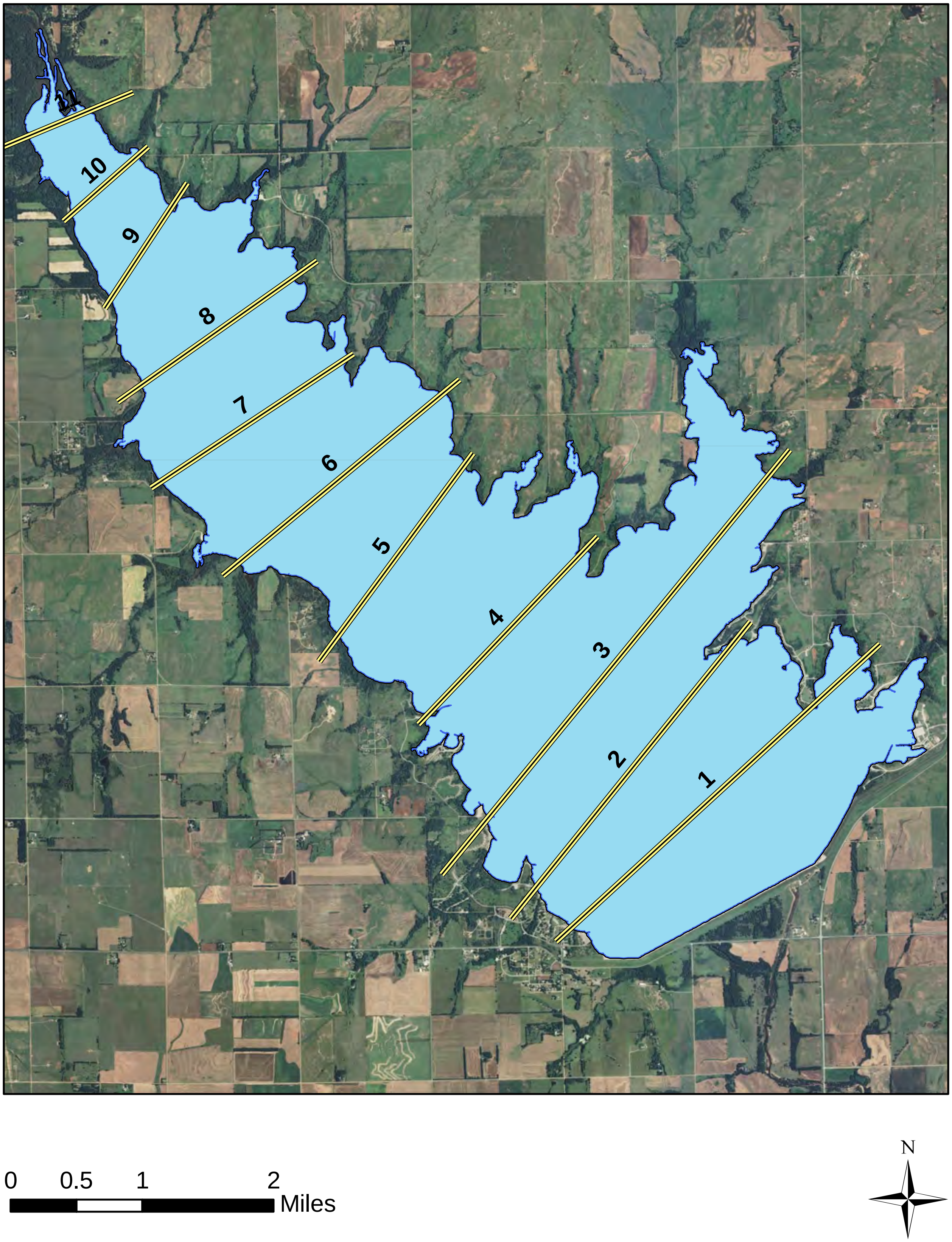

Figure 15. US Army Corps of Engineers / US Bureau of Reclamation range lines.

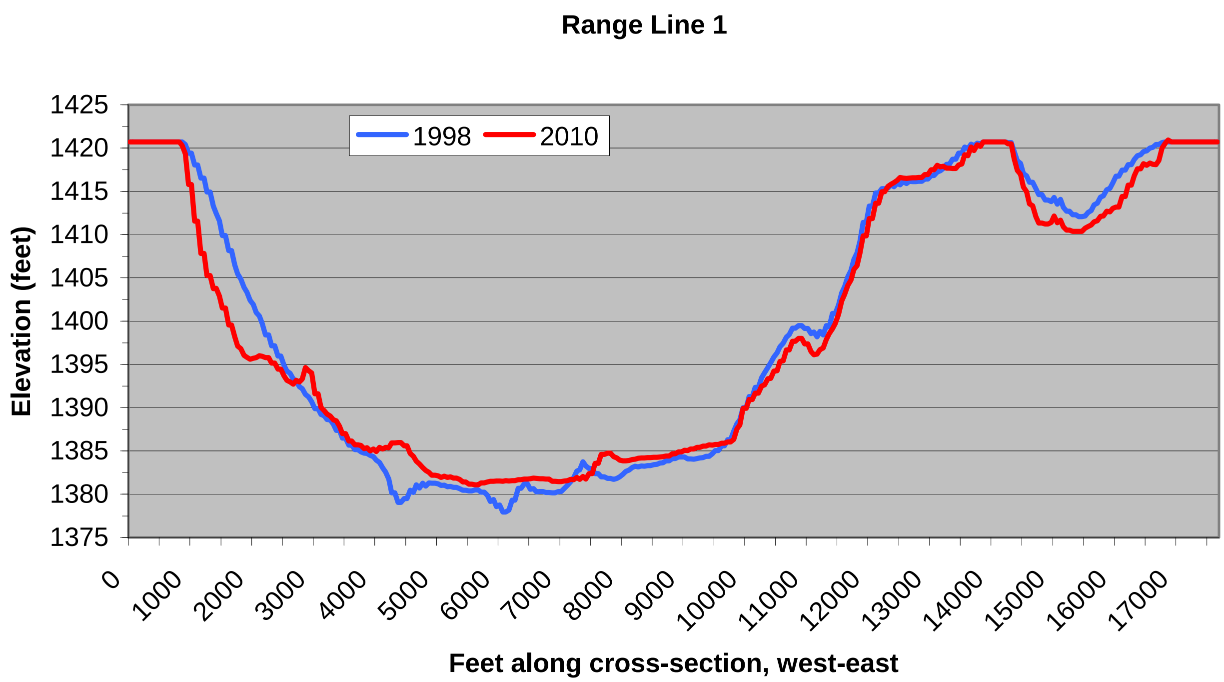

Figure 16a. Cross-section along Rangeline 1. Reservoir reference elevation = 1420.72 ft.

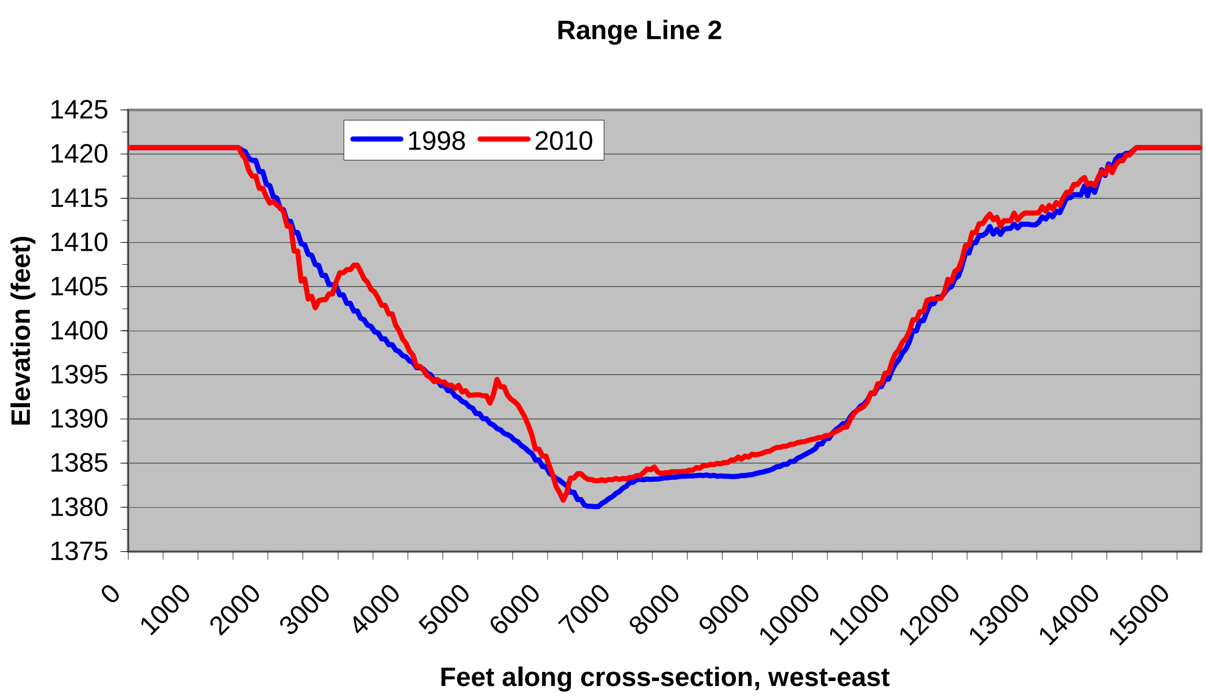

Figure 16b. Cross-section along Rangeline 2. Reservoir reference elevation = 1420.72 ft.

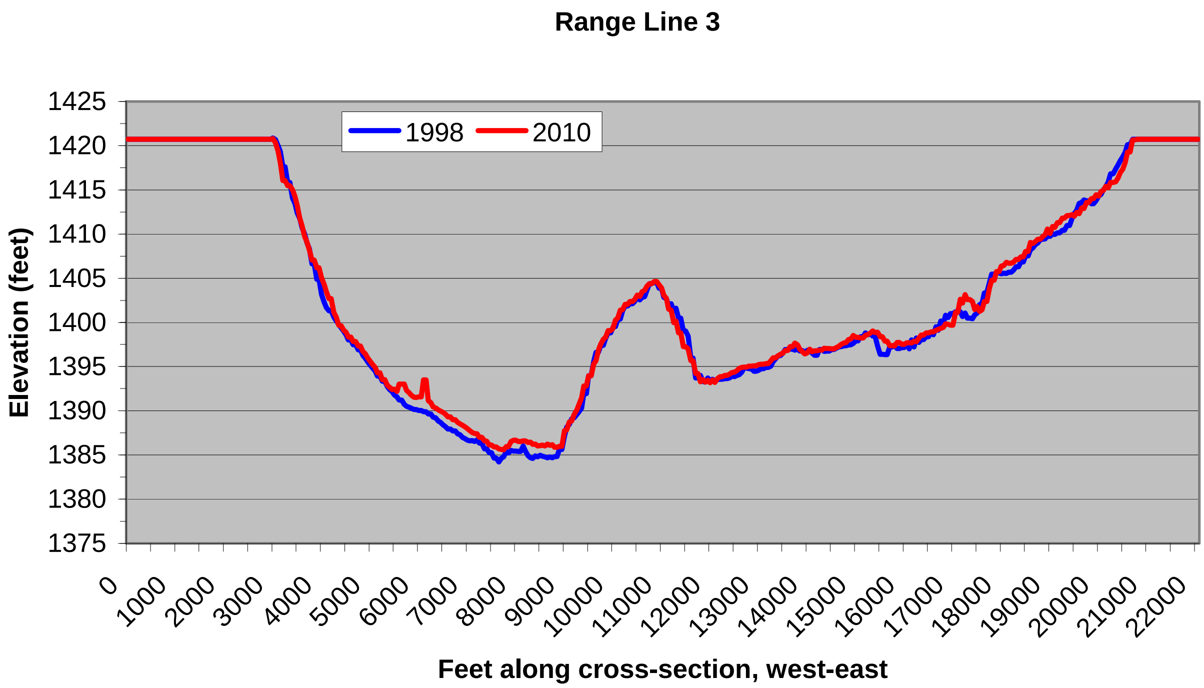

Figure 16c. Cross-section along Rangeline 3. Reservoir reference elevation = 1420.72 ft.

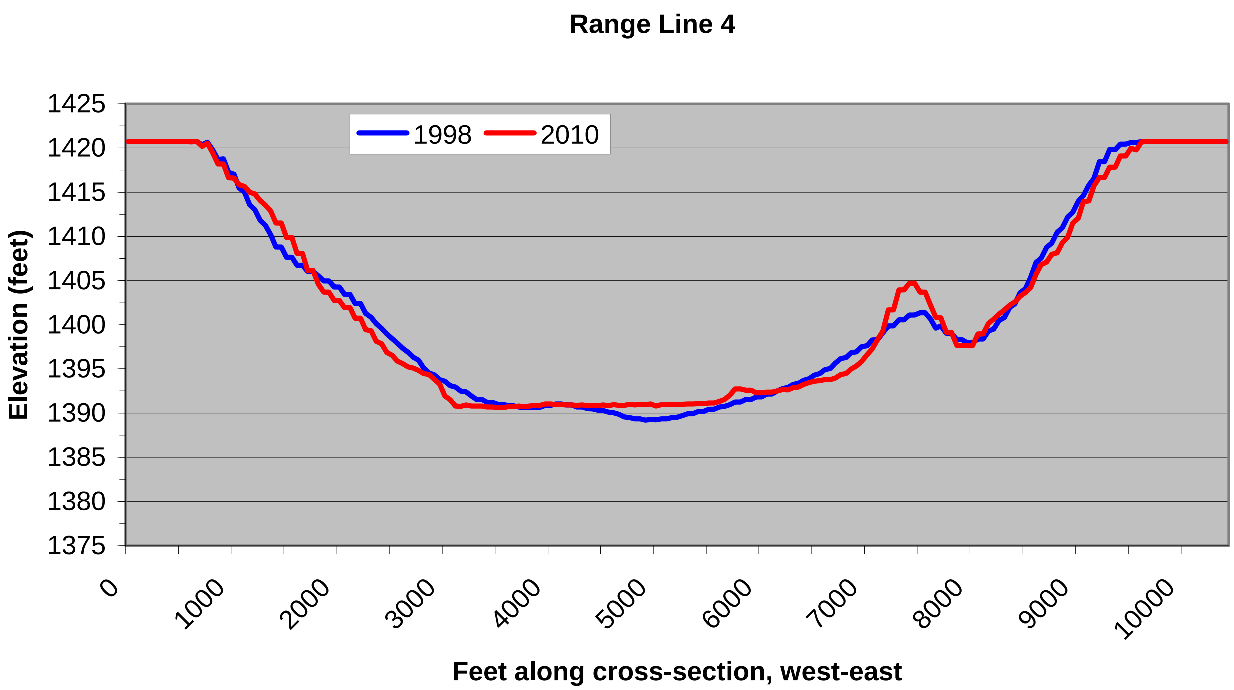

Figure 16d. Cross-section along Rangeline 4. Reservoir reference elevation = 1420.72 ft.

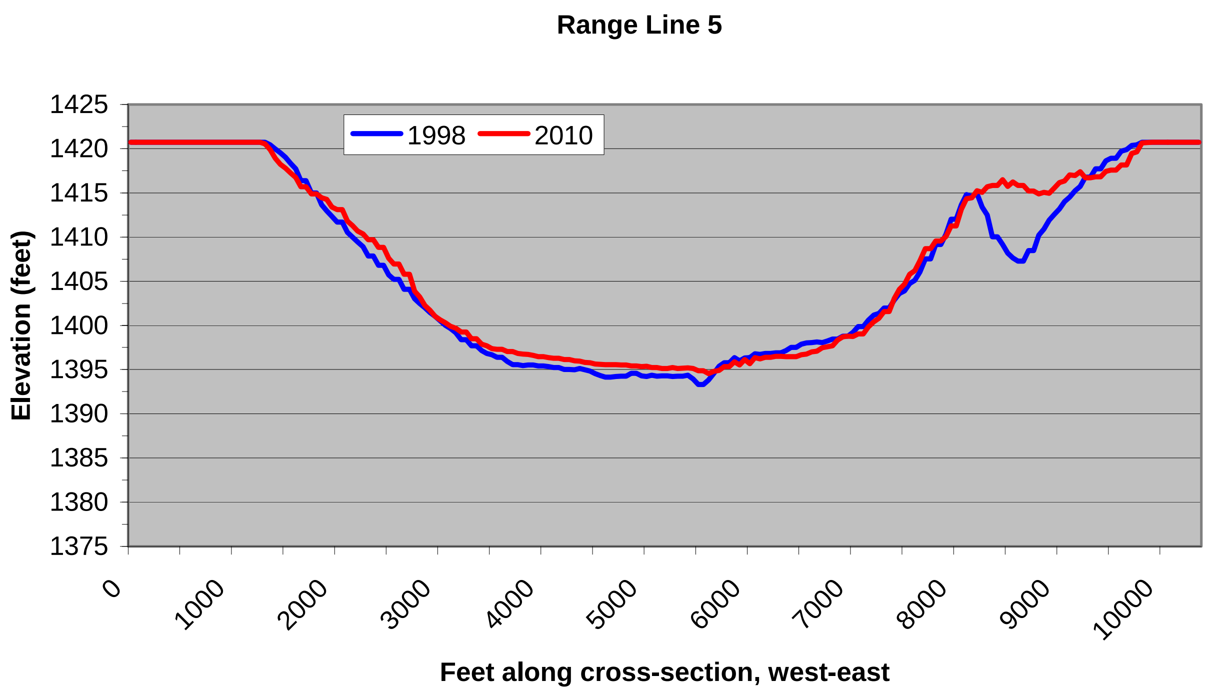

Figure 16e. Cross-section along Rangeline 5. Reservoir reference elevation = 1420.72 ft.

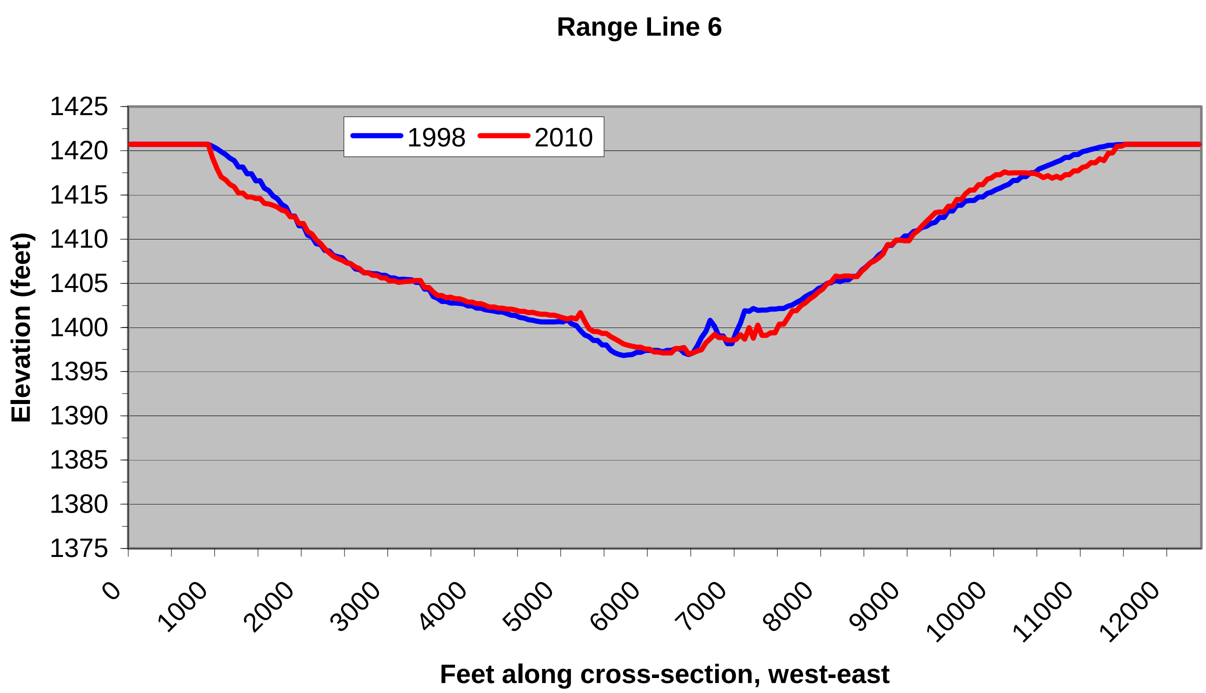

Figure 16f. Cross-section along Rangeline 6. Reservoir reference elevation = 1420.72 ft.

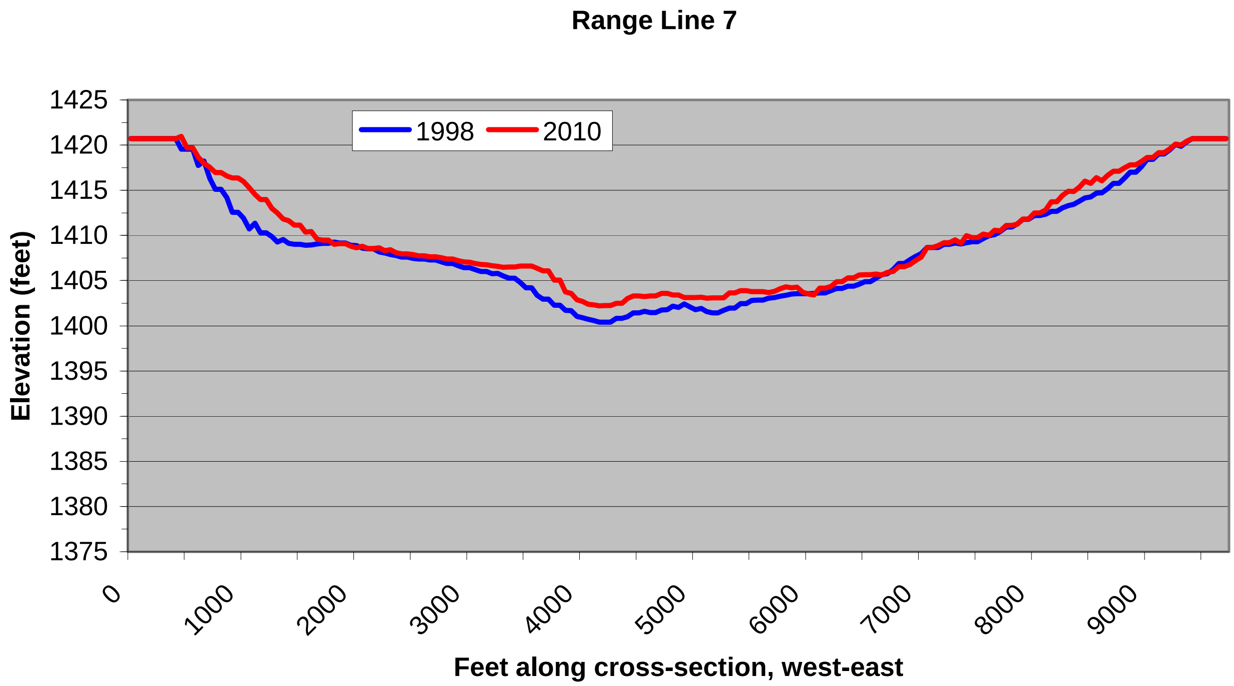

Figure 16g. Cross-section along Rangeline 7. Reservoir reference elevation = 1420.72 ft.

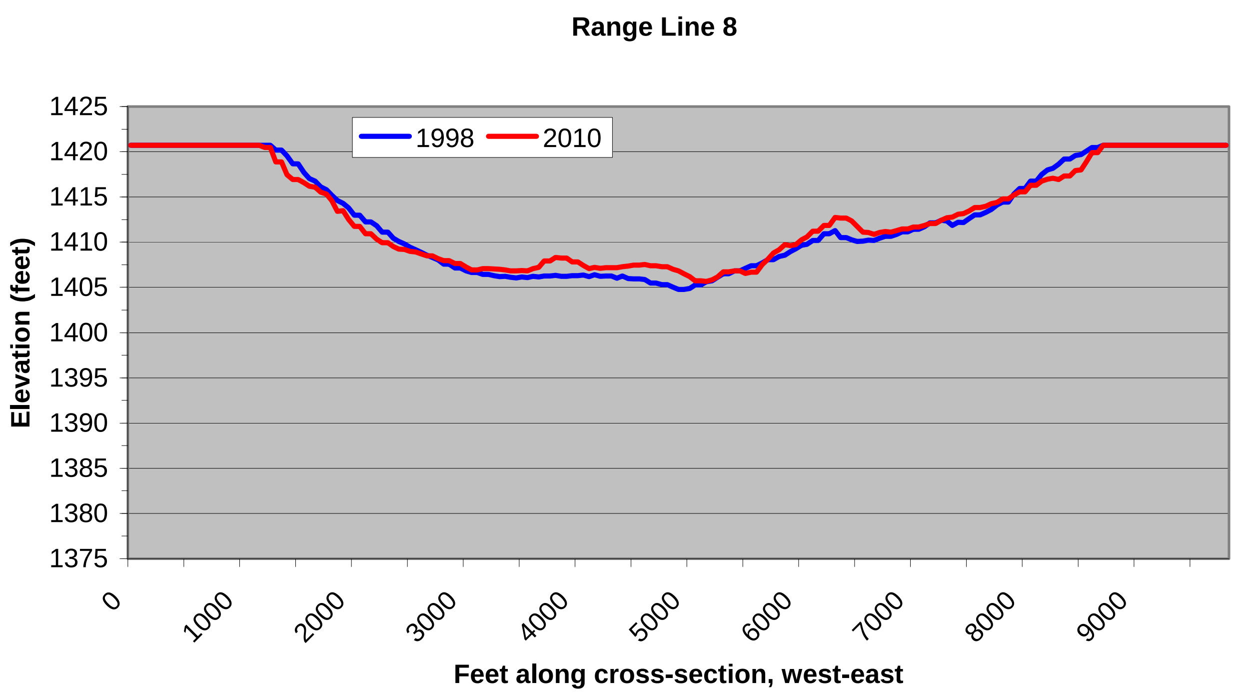

Figure 16h. Cross-section along Rangeline 8. Reservoir reference elevation = 1420.72 ft.

Range Line 9

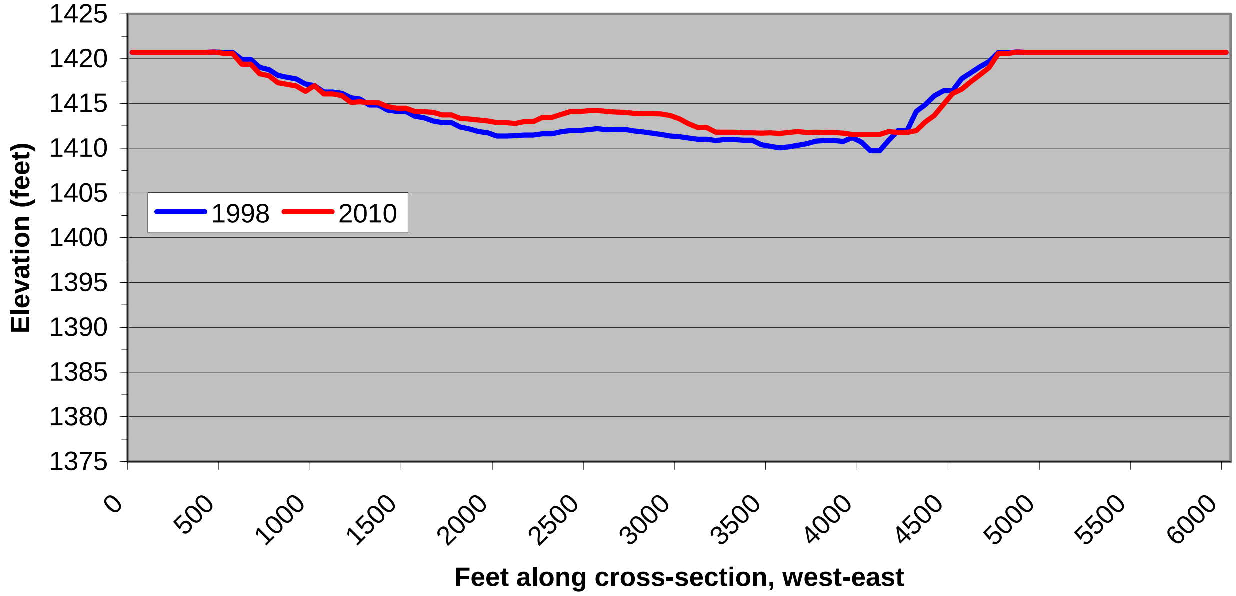

Figure 16i. Cross-section along Rangeline 9. Reservoir reference elevation = 1420.72 ft.

Range Line 10

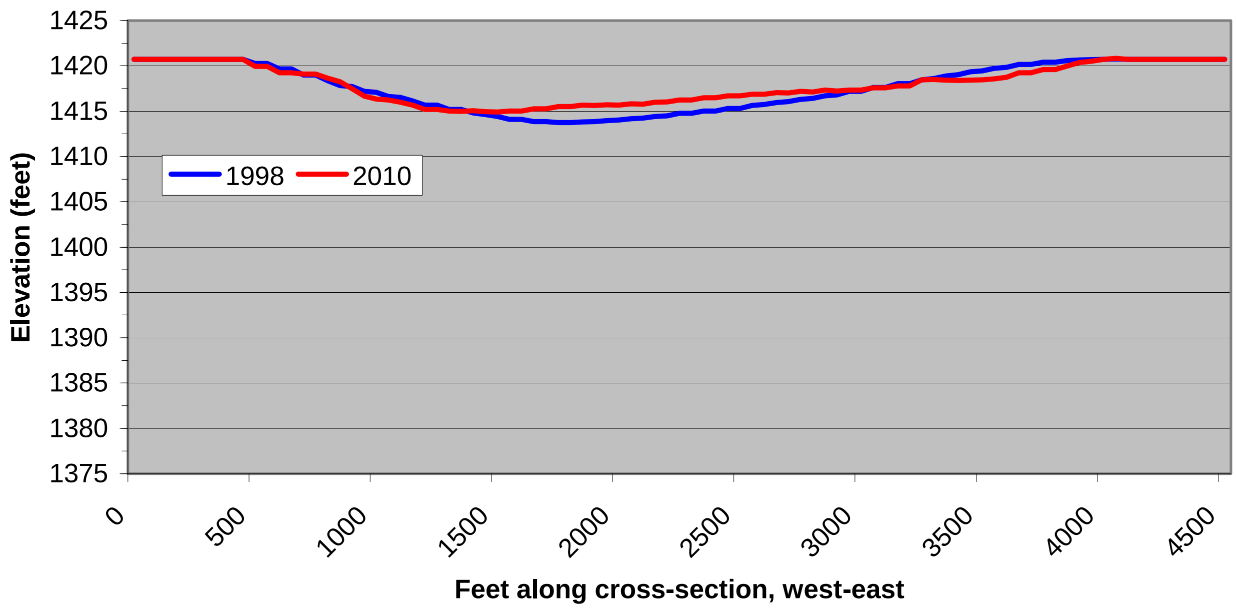

Figure 16j. Cross-section along Rangeline 10. Reservoir reference elevation = 1420.72 ft.

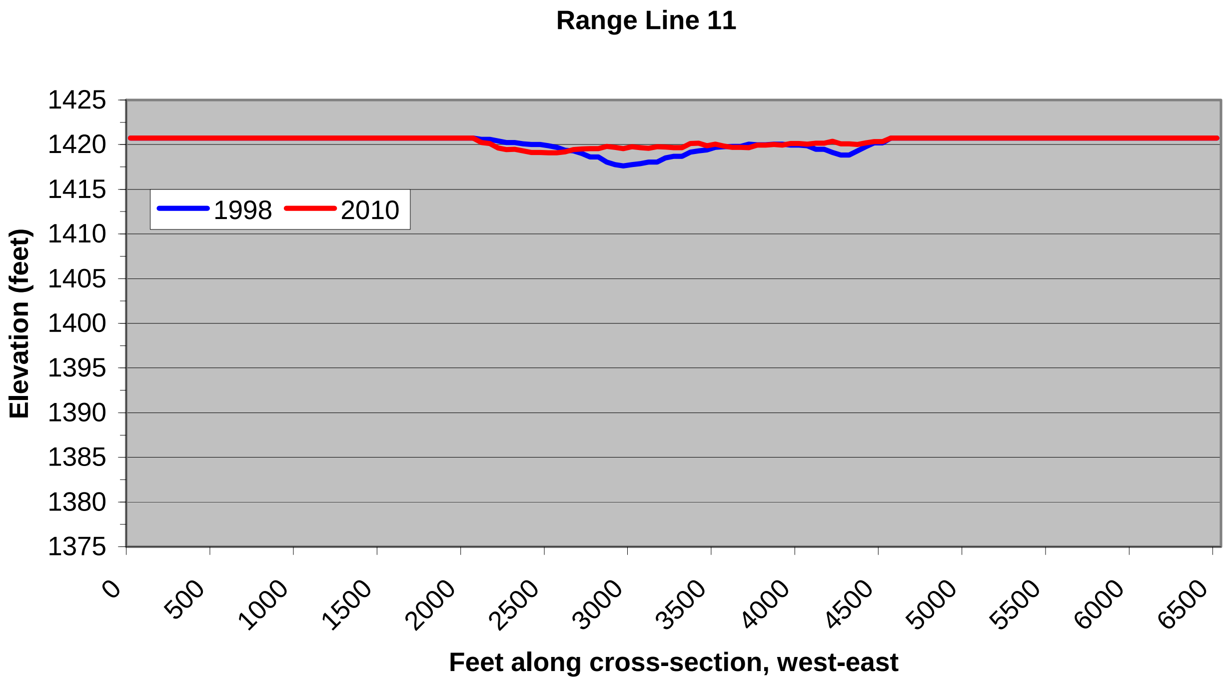

Figure 16k. Cross-section along Rangeline 11. Reservoir reference elevation = 1420.72 ft.

Reservoir Cross-sections:
Comparison of 2010 KBS data to 1964 and 1993 Bureau of Reclamation data

Rangeline surveys for the reservoir were completed in 1964, prior to construction, and a partial bathymetric survey (rangelines 1, 7, 8, 9, and 10) was conducted by the US Bureau of Reclamation on April 5, 1993. No data or information was available on the coordinates of the endpoints of the cross-sections, and two separate maps, also obtained from USBR via the Kansas Water Office, showed slightly different locations for the rangelines. Data for the 1993 and 1964 rangelines was provided by USBR via KWO as flat ASCII files; data for Rangeline 10 is included below as an example of the original format.

```
10 8014289 18014279 100014258 200014249 300014240 400014233
10 500014227 600014212 700014211 800014209 900014207 968014217
10 99001424310000142371036014187
10105001417711000141671150014164120001416613000141591400014164
101500014168160001417117000141701800014155190001415220000014155
102100014160222001416422600141852300014180240001418224500014183
102500014179260001417927000141802800014180290001417829500014183
103350014191375001419838000142013850014207
10 39000142184000014228410001423742000142544300014260
104400014282443301429845000143094525014314
101.000 10 101.000 10 101.000 10 101.000 10 10
```

These files appeared to have the data in a form of distance and depth along a range line, e.g., the value 320013836 is 3200 feet along the range line, with a depth of 1383.6 feet. Data were thus extracted as such to an excel file for each year (1964 and 1993) and each rangeline (1,7,8,9, and 10) for comparison to the 2010 data for the corresponding rangelines (Figrues 17a – 17d).

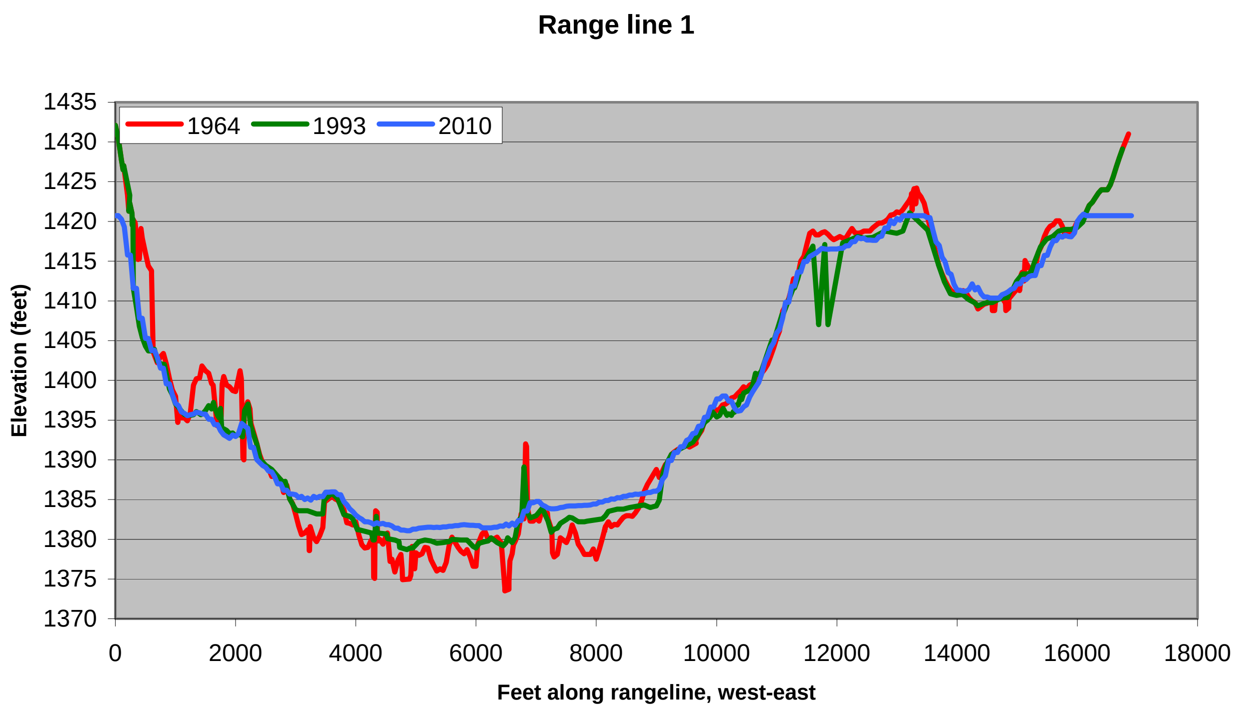

Figure 17a. Cross-section along Rangeline 1. Reservoir reference elevation = 1420.72 ft.

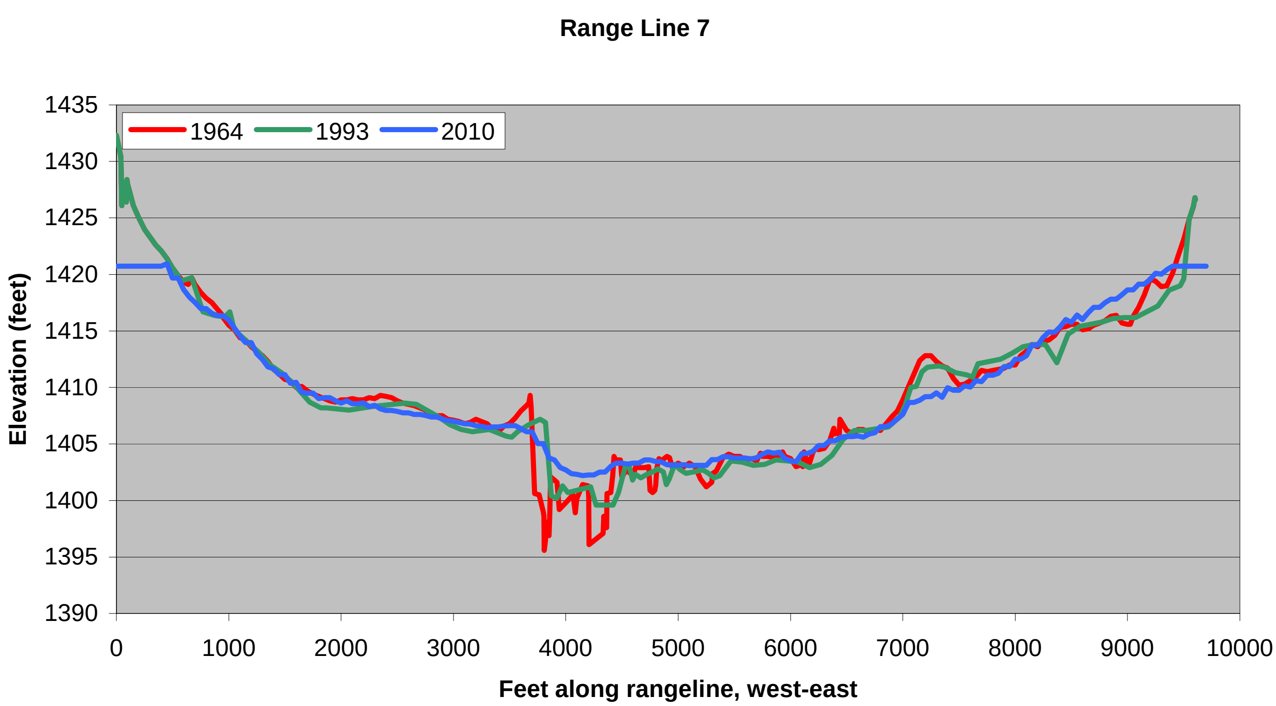

Figure 17b. Cross-section along Rangeline 7. Reservoir reference elevation = 1420.72 ft.

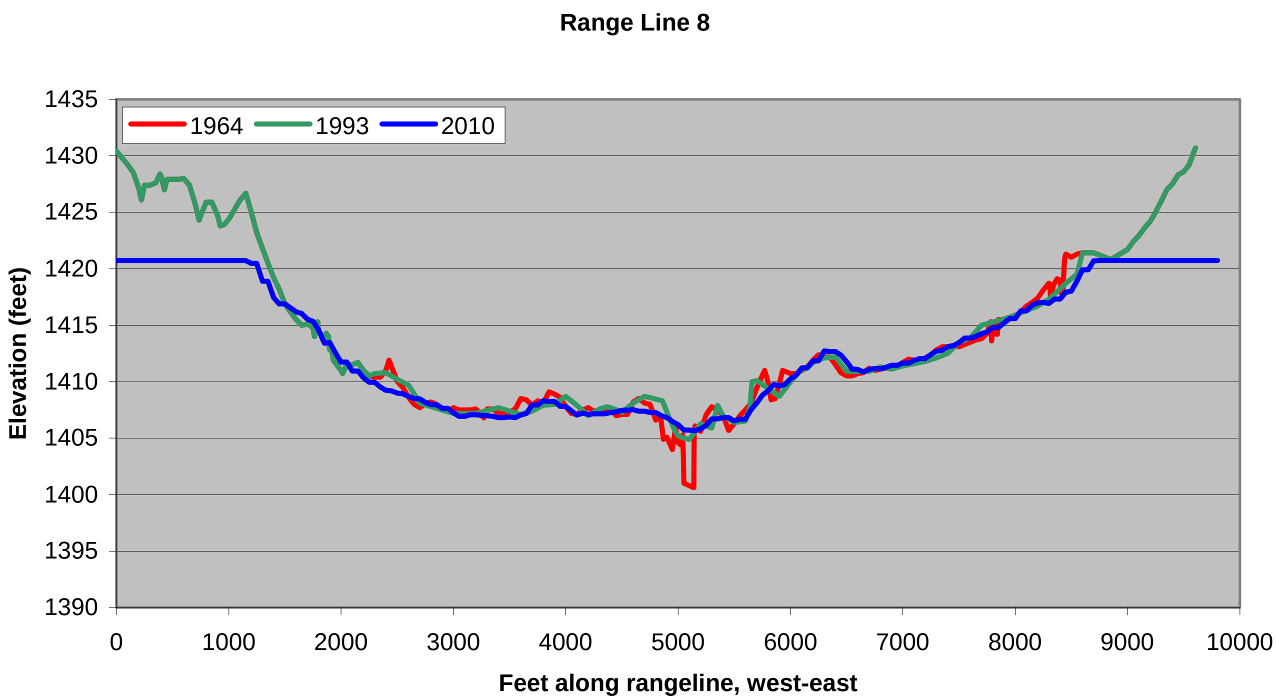

Figure 17c. Cross-section along Rangeline 8. Reservoir reference elevation = 1420.72 ft.

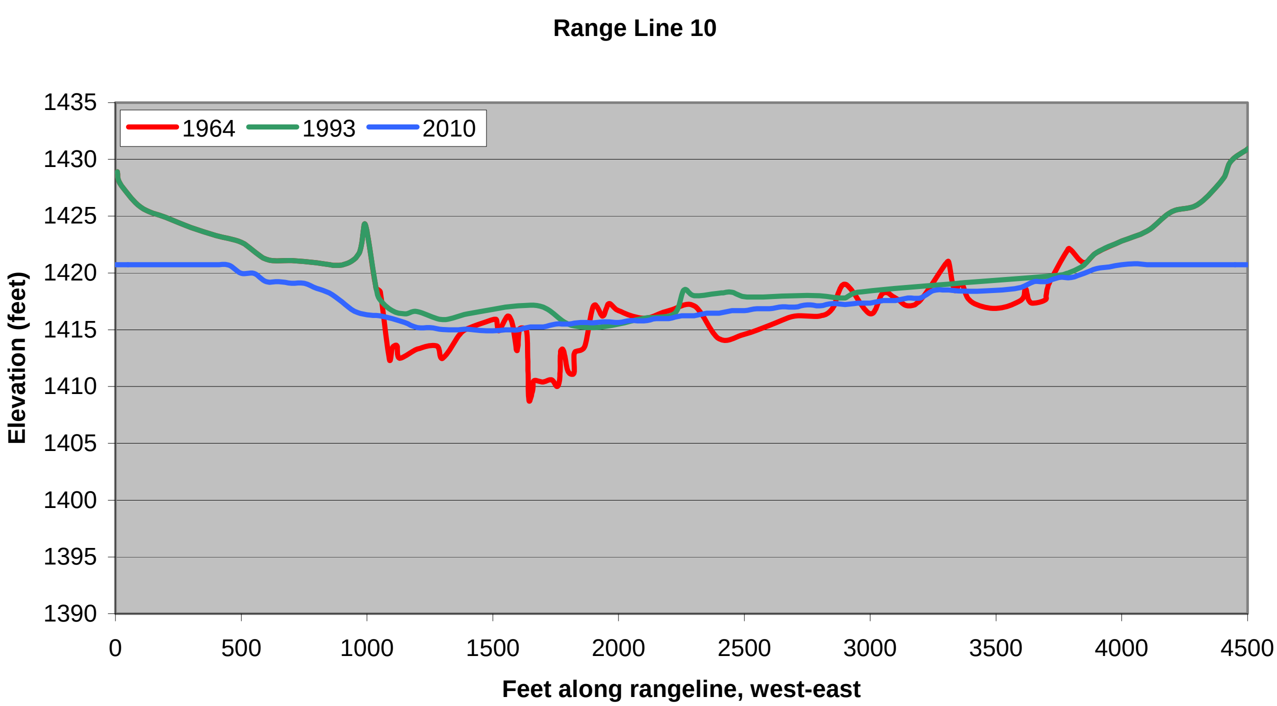

Figure 17d. Cross-section along Rangeline 10. Reservoir reference elevation = 1420.72 ft.

SEDIMENT CORING/SAMPLING PROCEDURES

KBS operates a Specialty Devices Inc. sediment vibracorer mounted on a dedicated 24' pontoon boat. The vibracorer uses 3" diameter aluminum thinwall pipe in user-specified lengths. The system uses an 24-v electric motor with counter-rotating weights in the vibracorer head unit to create a high-frequency vibration in the pipe, allowing the pipe to penetrate sediments and substrate as it is lowered into the lake using a winch. Once the open end of the core pipe has penetrated to the substrate, the unit is turned off and the unit is raised to the surface using the winch. At the surface, the pipe containing the sediment core is disconnected from the vibracore head and the sediment extruded from the pipe and measured.

KBS vibe-core system.

At each site, determined using GPS, the core boat is anchored and the vibracore system used to extract a sediment core down to and including the upper several inches of pre-impoundment soil (substrate). The location of each core site is recorded using a GPS. Cores are carefully extruded from the core pipe, and the interface between sediment and substrate identified. Typically, this identification is relatively easy, with the interface being identifiable by changes in material density and color, and the presence of roots or sticks in the substrate. The top 15 cm of sediment are collected and sealed in a sampling container. The samples are then shipped to the Kansas State University Soil Testing Laboratory (Manhattan, KS), for texture and other analyses.

To assess bulk density, the syringe method described by Hilton et al (1986)[1] was used, employing a cutoff 35-ml syringe inserted into the exposed core to extract a 15-cc sample of the sediment. Where permitted by core length, samples were taken from the lower, midpoint, and upper parts of the core (e.g., 10-cm above sediment-substrate interface; midpoint of core length; 10 cm below sediment top). Shorter cores (30-50 cm) were sampled only at the upper and lower end, and very short (length < 20 cm) were sampled only at the midpoint. Samples were ejected from the syringe using the plunger and sealed in sample canisters. In the lab, samples were weighed, dried at 100°C for 48 hours, and weighed again. At several sites, a bulk density sample was taken from the substrate as well for comparison to sediment bulk density.

[1] J. Hilton, J., Lishman, P., and Millington, A. 1986. A comparison of some rapid techniques for the measurement of density in soft sediments. *Sedimentology* (33):777-781.

Sediment Coring and Sampling Results:

Twenty-eight coring sites were distributed across the reservoir (Figure 18). An effort was made to avoid the original stream channel, which would have likely yielded higher sediment thicknesses not representative of the overall reservoir bottom sediment thickness. Site CHE-10 was pre-selected for coring but low water levels prevented access to this location, hence its omission in the results. Typical for most large Kansas reservoirs, relatively high sediment thicknesses were recorded near the dam at sites CHE-21 (145 cm), CHE-26 (180 cm) and CHE29 (115 cm) (Figure 19; Table 6). No sediment accumulation was recorded for two sites (CHE-XX and CHE-YY) in the large eastern cove of the reservoir, suggesting either that little sediment inflows to this part of the reservoir, or that periodic sediment flushing may be moving material from the eastern arm into the main body of the reservoir.

Sites 1through 13 were selected to be the same as the 13 sites cored in 1997 by the US Geological Survey (Table 7). As previously noted, site CHE-10 was inaccessible due to low water and could not be revisited, and sites CHE-5, CHE-7, and CHE-9 exhibited indefinite interfaces between the sediment and substrate, making determination of sediment thickness difficult. Sediment thickness were all higher in 2011 than 1997; however, different sampling equipment (USGS gravity corer vs KBS vibra-corer), and imprecision of location may account for some of this difference.

Again, typical of large reservoirs sampled in this region, silt predominates in the samples taken from the upper (inflow) end, and clay is slightly dominant in the samples taken from the lower (dam) end (Figure 20; Figure 21). Sand is a significant constituent in several samples, with four sites (CHE-2, CHE-5, CHE-6, and CHE-15) containing greater than 50% sand. Bulk density was highly variable across the reservoir (Table 8). Bulk density for site CHE-2 appears to be anomalously high; however, field notes indicate, "*Coarse sand. Very hard, dense*" accounting for the higher than typical bilk density.

Sediment samples from 19 of the 28 sites were sent to the Kansas State University Soil Testing Laboratory (Manhattan, KS) for analysis of total nitrogen (total N) (Figure 22) and total phosphorus (total P) (Figure 23). Nine sites were not analyzed for nutrients, as these cores were either sliced in 5-cm intervals for detailed nutrient analysis, the sample was retrieved and transported in core tube for later analyses, or the core yielded insufficient material for analysis (Table 6).

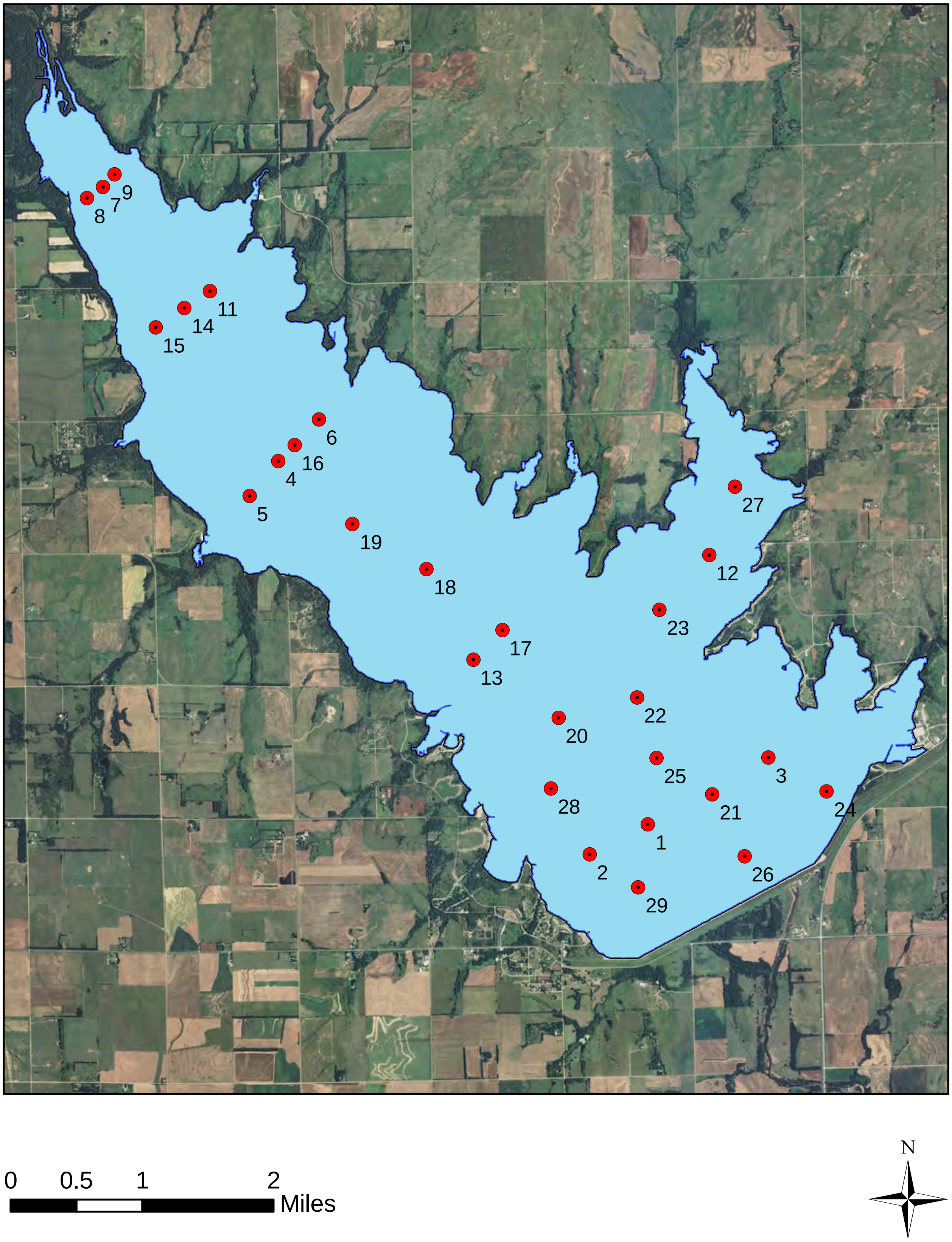

Figure 18. Sediment coring sites (2011 sampling) for Cheney Reservoir.

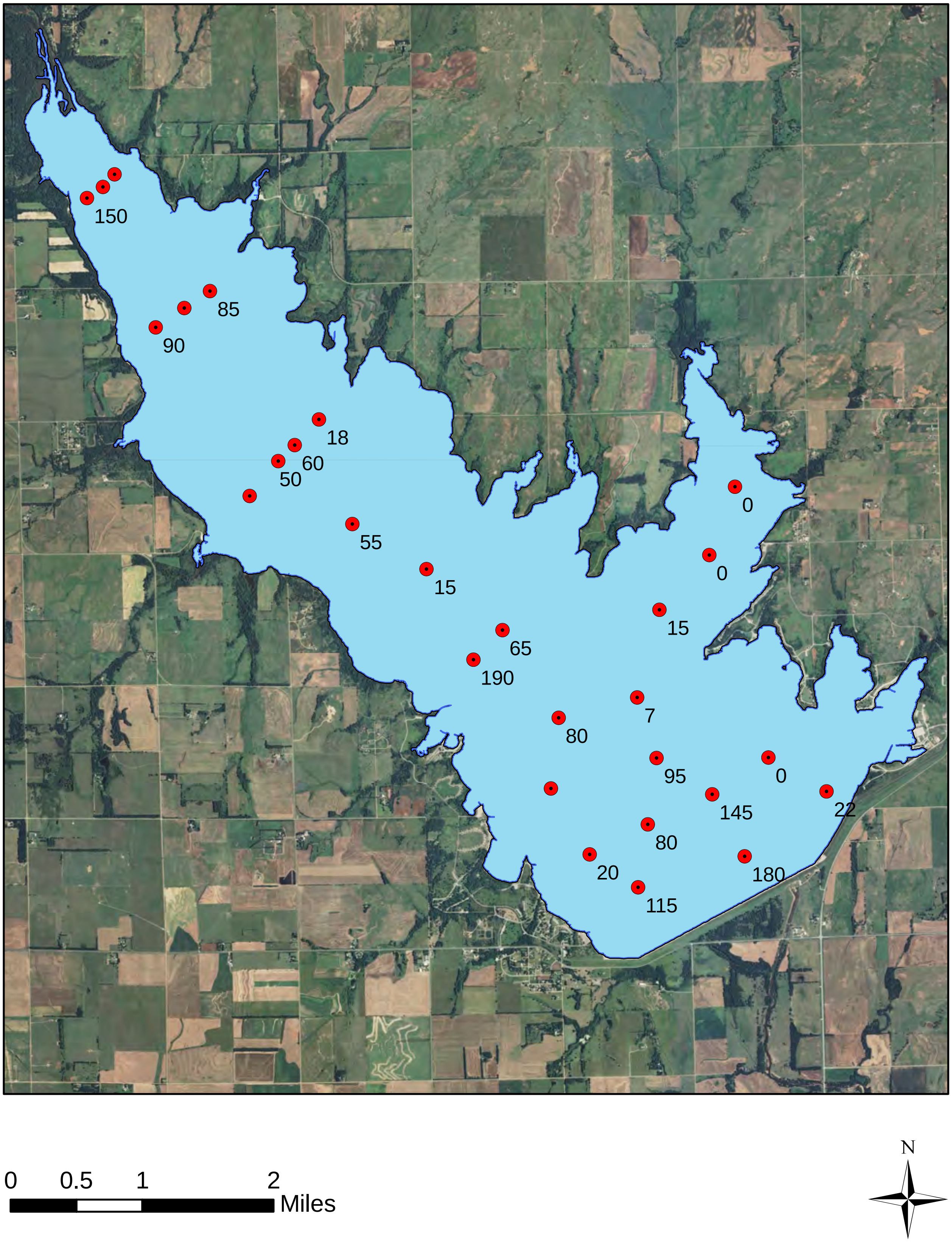

Figure 19. Sediment thickness in centimeters at coring sites

Table 6
Cheney Reservoir Sediment Coring Site Data

Code	UTMX	UTMY	Sediment Thickness (cm)	Mean Bulk Density (g/cm^3)	Sand %	Silt %	Clay %
CHE-1	604544	4176789	80	0.37	4	38	58
CHE-2	603828	4176417	20	1.83	70	16	14
CHE-3	606018	4177606	0	*No sample taken – insufficient material*			
CHE-4	600017	4181232	50	.77	0	64	36
CHE-5	599671	4180803	*Indefinite interface*	*n.d.*	84	10	6
CHE-6	600518	4181739	18	*n.d.*	58	24	18
CHE-7	597871	4184584	*Indefinite interface*				
CHE-8	597675	4184448	150	*Core sample sliced in 5-cm intervals for nutrient analysis*			
CHE-9	598016	4184741	*Indefinite interface*	*Core sample retrieved and transported in core tube for later analyses.*			
CHE-11	599184	4183310	85	0.95	6	78	16
CHE-12	605292	4180081	0	*No sample taken – insufficient material*			
CHE-13	602405	4178801	190	0.49	0	36	64
CHE-14	598870	4183105	*Indefinite interface*	*Core sample sliced in 5-cm intervals for nutrient analysis*			
CHE-15	598517	4182869	90	*n.d.*	72	20	8
CHE-16	600219	4181428	60	0.74	10	62	28
CHE-17	602761	4179164	65	0.43	0	38	62
CHE-18	601834	4179912	15	*n.d.*	32	38	30
CHE-19	600925	4180459	55	0.55	32	38	30
CHE-20	603447	4178092	80	0.38	4	54	42
CHE-21	605328	4177155	145	*Core sample sliced in 5-cm intervals for nutrient analysis*			
CHE-22	604409	4178342	7	*n.d.*	4	40	56
CHE-23	604684	4179412	15	*n.d.*	10	60	30
CHE-24	606727	4177191	22	1.03	10	60	30
CHE-25	604648	4177598	95	0.43	0	40	60
CHE-26	605724	4176396	180	0.55	0	44	56
CHE-27	605605	4180918	0	*No sample taken – insufficient material*			
CHE-28	603354	4177224	*unclear*	*No sample taken*			
CHE-29	604421	4176015	115	0.44	0	32	68

***Note:* UTM coordinates datum NAD83, units meters.**

Table 7
Comparison of sediment thickness measured at 13 sites by USGS in 1997 and KBS in 2011

USGS 1998 Site	KBS 2011 Site	USGS 1998 sediment thickness (cm)	KBS 2011 sediment thickness (cm)
1	1	36	80
2	2	10	20
3	3	0	0
4	4	25	50
5	5	0	*Indefinite interface*
6	6	13	18
7	7	13	*Indefinite interface*
8	8	94	150
9	9	30	*Indefinite interface*
10	10		*Inaccessible*
11	11	51	85
12	12	0	0
13	13	86	190

USGS site locations and sediment thickness from Mau, D.P., 2001. *Sediment deposition and trends and transport of phosphorus and other chemical constituents, Cheney Reservoir watershed, south-central Kansas.* U.S. Geological Survey Water-Resources Investigations Report 01-4085, 40 p.

Table 8
Cheney Reservoir Sediment Bulk Density Data

Sample Site	Position	Volume (cc)	Density (g/cc)	Mean density, (g/cm^3) (excluding substrate)
CHE-01	Upper	15	0.37	
CHE-01	Lower	15	0.36	0.37
CHE-02	Middle	15	1.83	
CHE-04	Upper	15	0.84	
CHE-04	Lower	15	0.69	0.77
CHE-11	Upper	15	0.87	
CHE-11	Upper-mid	15	0.84	
CHE-11	Lower-mid	15	0.99	
CHE-11	Bottom	15	1.07	0.95
CHE-13	Upper	15	0.59	
CHE-13	Upper-mid	15	0.50	
CHE-13	Lower-mid	15	0.44	
CHE-13	Bottom	15	0.45	0.49
CHE-16	Middle	15	0.74	
CHE-16	Sub	15	1.68	
CHE-17	Upper	15	0.48	
CHE-17	Lower	15	0.38	0.43
CHE-19	Middle	15	0.55	
CHE-20	Upper	15	0.43	
CHE-20	Lower	15	0.33	0.38
CHE-24	Middle	15	1.03	
CHE-25	Upper	15	0.47	
CHE-25	Lower	15	0.38	0.43
CHE-26	Upper	15	0.55	
CHE-26	Upper-mid	15	0.43	
CHE-26	Middle	15	0.41	
CHE-26	Lower-mid	15	3.03	
CHE-26	Bottom	15	0.35	0.55
CHE-29	Upper	15	0.55	
CHE-29	Middle	15	0.41	
CHE-29	Lower	15	0.35	0.44
CHE-29	Sub	15	2.03	

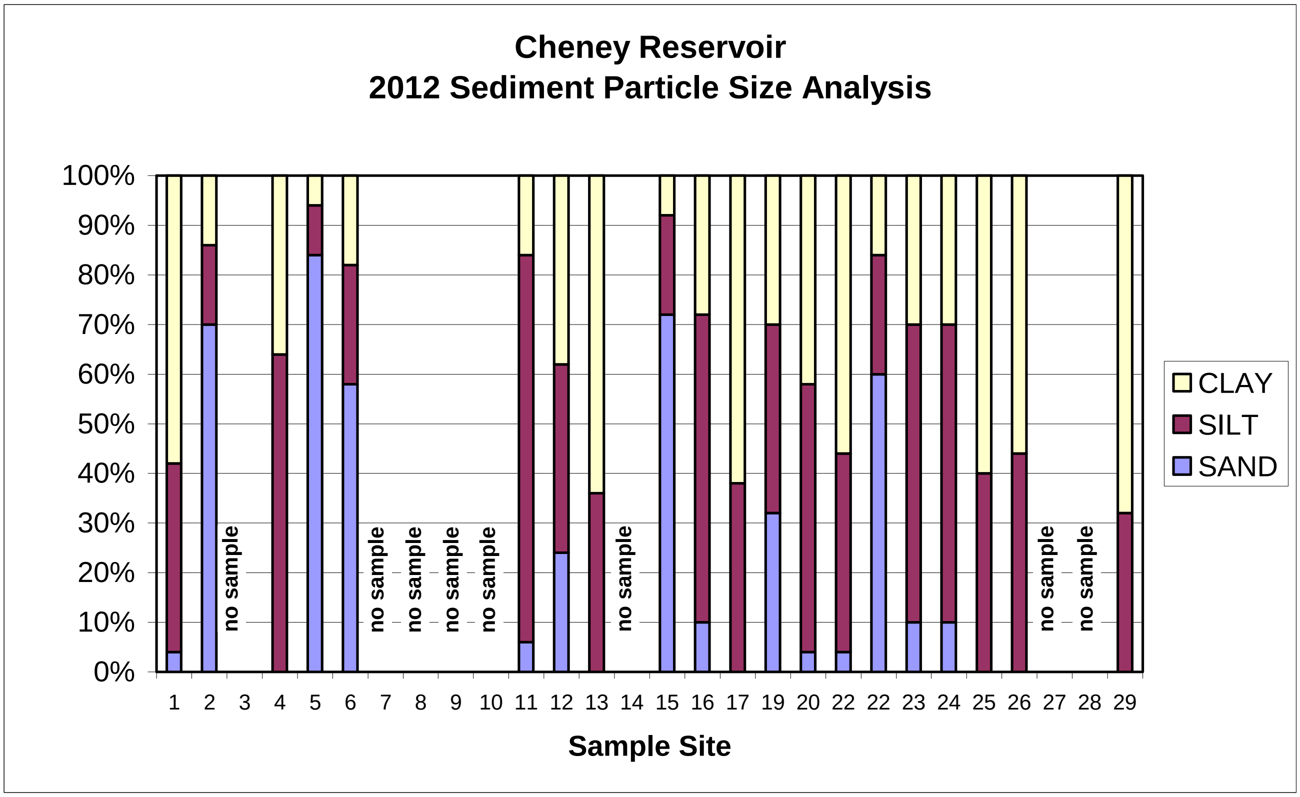

Figure 20. Sediment particle size analysis.

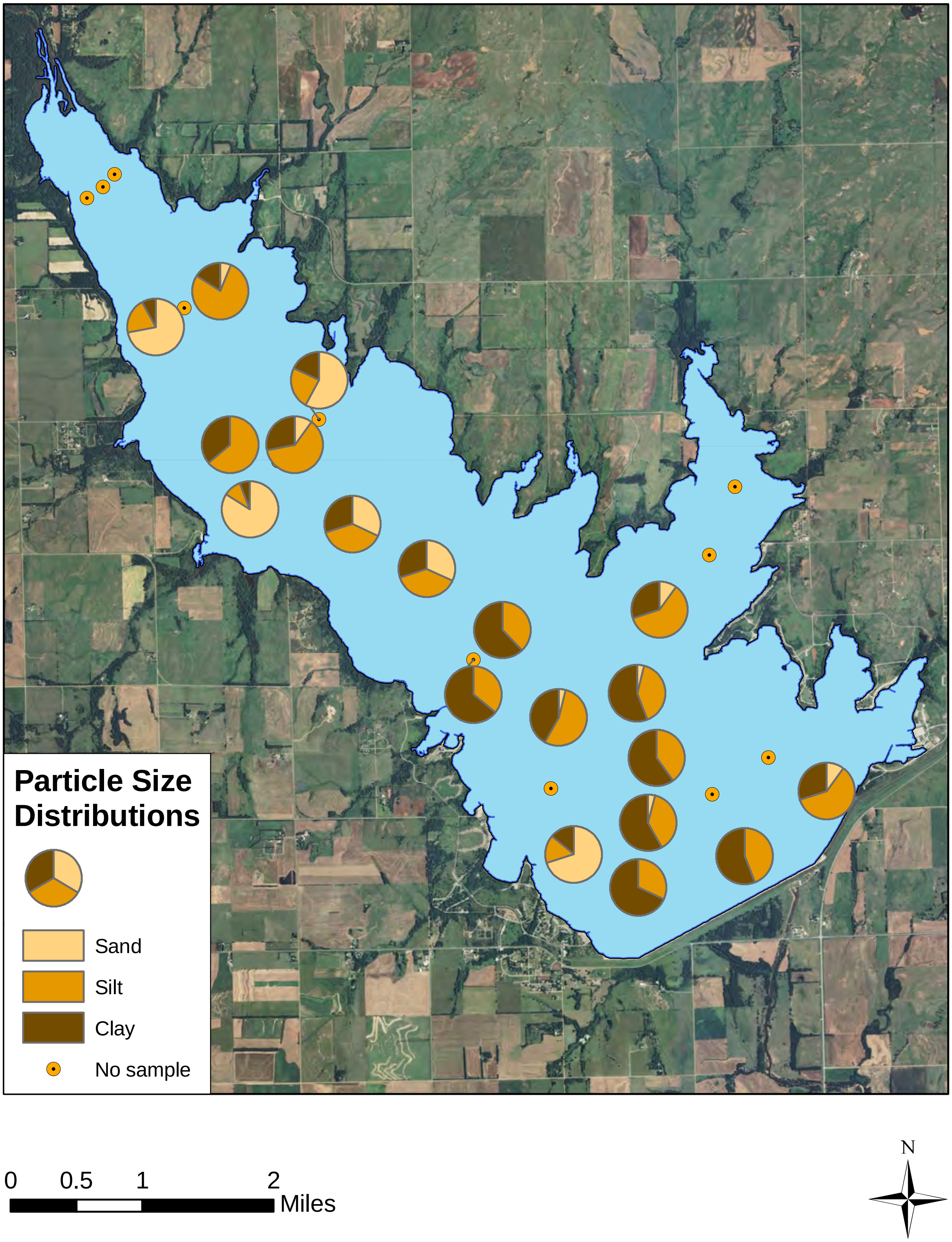

Figure 21. Sediment particle size distributions at coring sites.

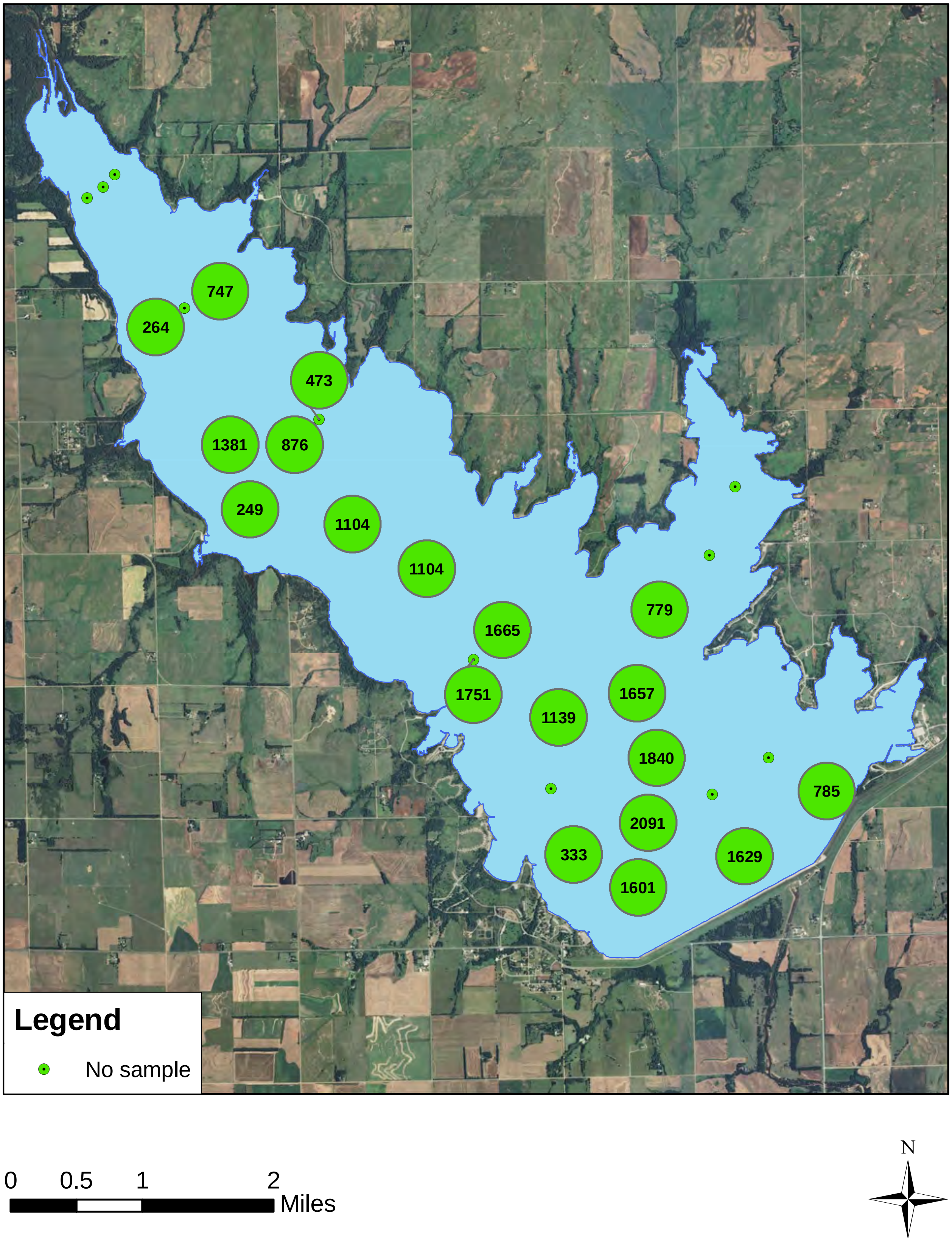

Figure 22. Total nitrogen (parts per million) sediment surface samples at coring sites.

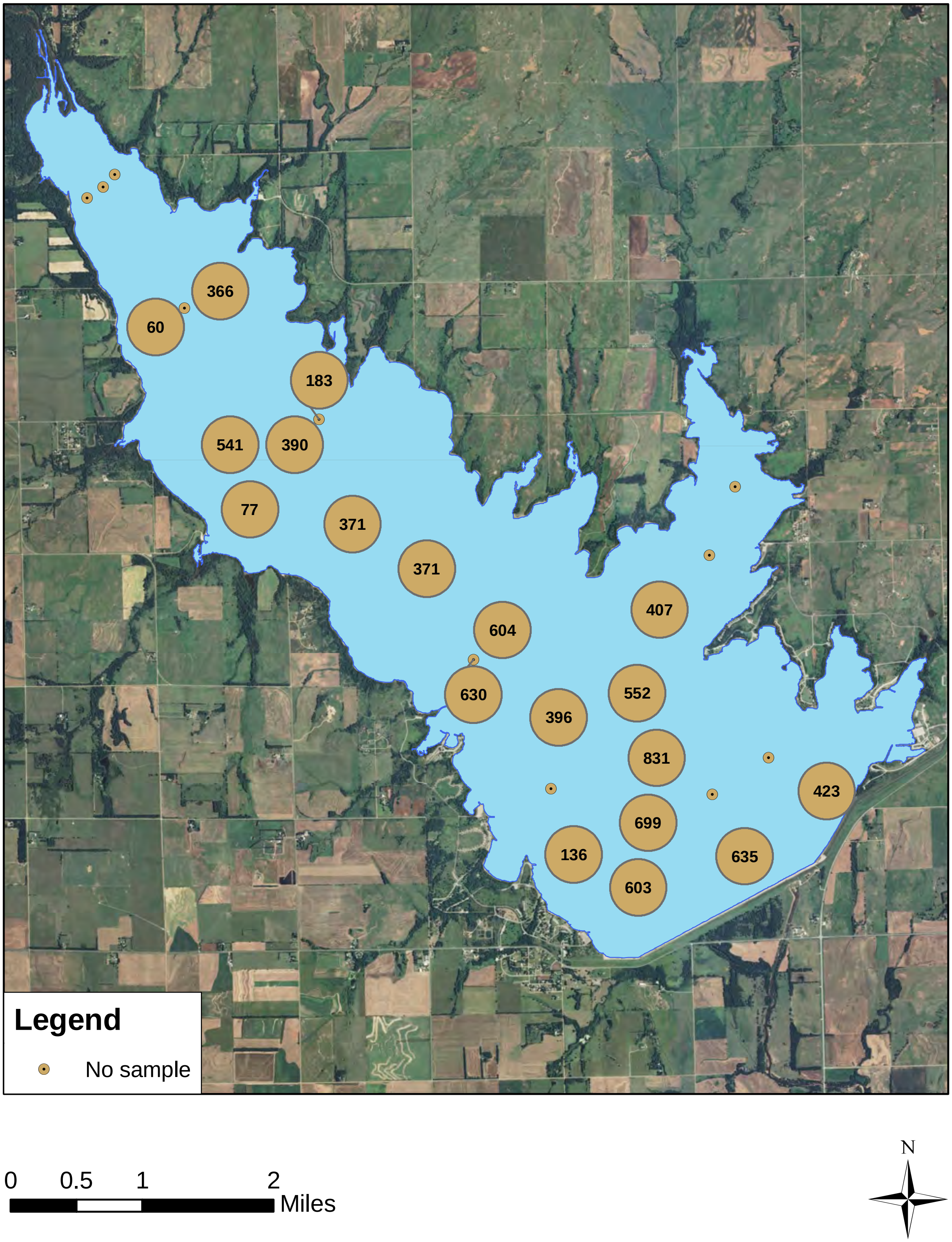

Figure 23. Total phosphorus (parts per million) sediment surface samples at coring sites.

Sediment chronosequence analyses:

Cores from three sites – CHE-8, CHE-14, and CHE-21 – were sliced into 5-cm sequential sections in the field and bagged in whirl-paks (Figure 24). Samples were sent to the Kansas State University Soil Testing Laboratory (Manhattan, KS) for texture analysis (percent sand, silt, and clay) and analysis of total nitrogen (total N) and total phosphorus (total P) to create a chronosequence of texture and nutrient levels in the sediment column.

Results:

Texture: Sediment texture in CHE-8, the site closest to the inflow end of the reservoir, was dominated by silt in nearly every sample in the sequence. A significant sand lens (> 70% sand) occurs at samples 65 and 70 (60 cm to 70 cm from base of core), likely the legacy of a major inflow event. Site CHE-14 was dominated by sand, with samples in the sequence averaging >60% sand per sample. Site CHE-21, the site closest to the dam, was dominated by clay, averaging >69% per sample (Figure 25).

Total nitrogen (ppm): Total nitrogen in parts per million (ppm) was determined for each sample in the sediment sequences. Total N exceeded 3000 ppm in the lower (older) sediments of sample CHE-8, decreasing over time to less than 1000 ppm at the top of the sediment core (most recent sediments). Site CHE-8 exhibited the greatest range of values of total N of all three cores, while sites CHE-14 and CHE-21 exhibited little variation in total N across all samples. Total N for site CHE-14 was generally low, with all samples but one in the sequence under 500 ppm. Total N for site CHE-21 averaged ~1500 ppm (Figure 26).

Total phosphorus (ppm): Total phosphorus in parts per million (ppm) was determined for each sample in the sediment sequences. Patterns of total P were similar to the patterns for total N observed in each sample. Although the highest values of total P were observed in samples from the lower part of core CHE-8 (maximum total P = 764 ppm), site CHE-21 had the highest average total P (average total P = 653 ppm) and CHE-14 had the lowest average total P ($\bar{X}$ = 223 ppm) (Figure 27).

Relationship between total phosphorus and clay: The positive linear relationship between percent clay and total phosphorus for samples from sites CHE-8 and CHE-14 suggests that phosphorus in bottom sediment is sorbed to clay-size particles (Figure 28). Site CHE-21 had little variation in total phosphorus and percent clay for all samples, and data values are clustered accordingly on the scatterplot (Figure 28). Given that phosphorus binds to clay, and the amount of phosphorus in a sample thus increases with an increasing percentage of clay in a sample, the phosphorus data was normalized by dividing the total phosphorus by the percent clay (Juracek and Ziegler, 2007)[1](Figure 29).

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[1] Juracek, K.E., and Ziegler, A.C., 2007, Estimation of sediment sources using selected chemical tracers in the Perry Lake and Lake Wabaunsee Basins, northeast Kansas: U.S. Geological Survey Scientific Investigations Report 2007-5020, 53 p.

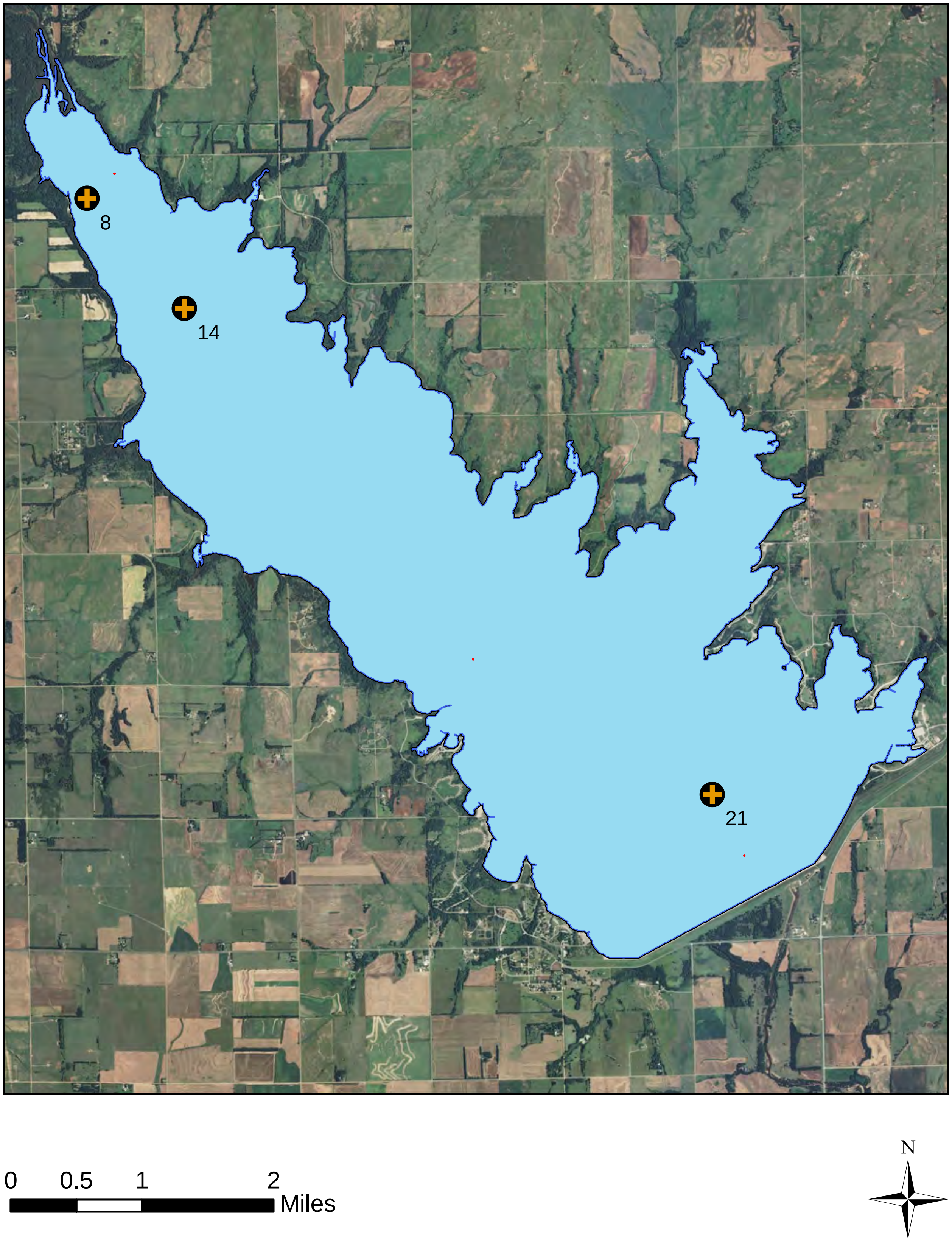

Figure 24. Locations of sediment coring sites (2011 sampling) sliced in 5-cm increments

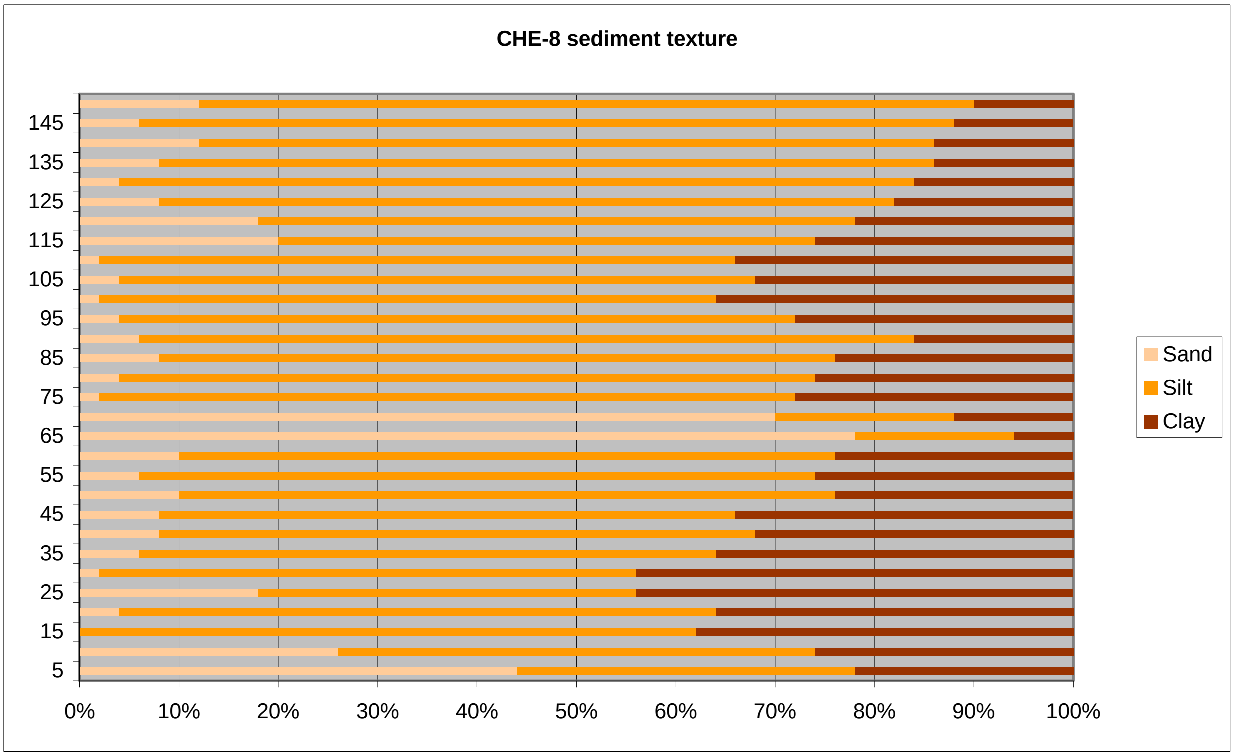

Figure 25a. Texture analysis from sediment chronosequence of core CHE-8.

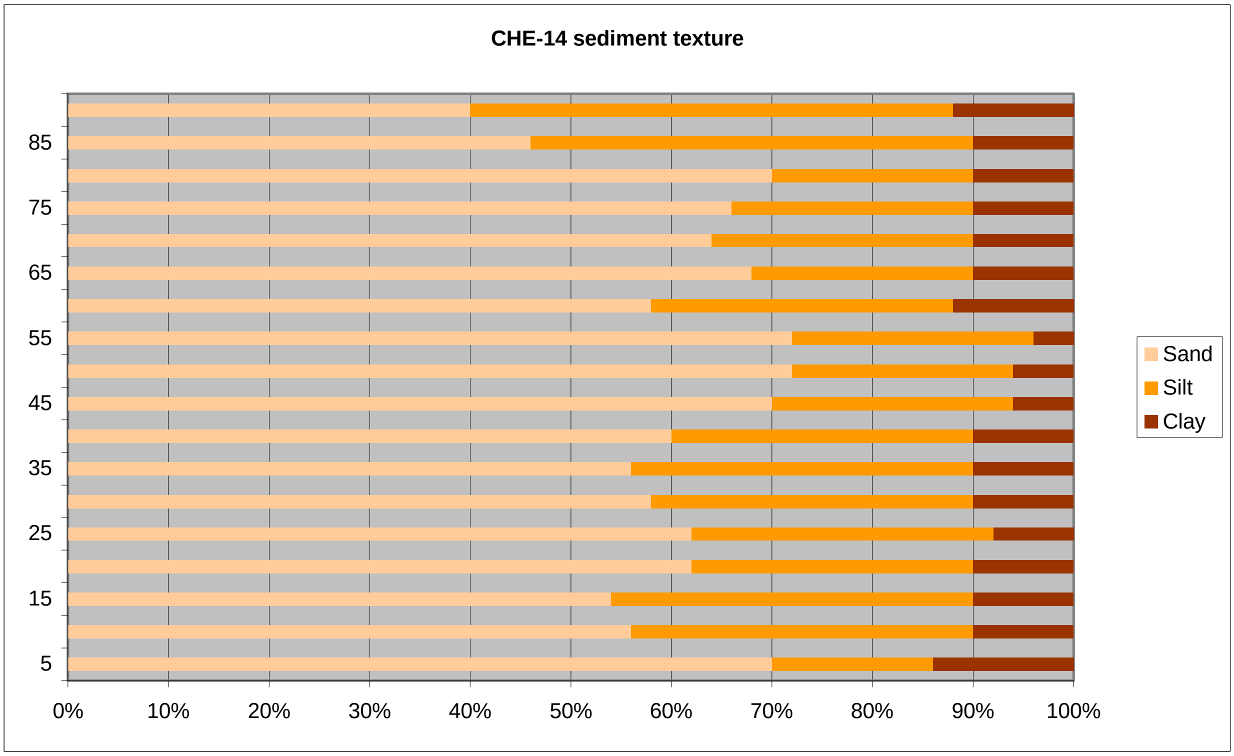

Figure 25b. Texture analysis from sediment chronosequence of core CHE-14.

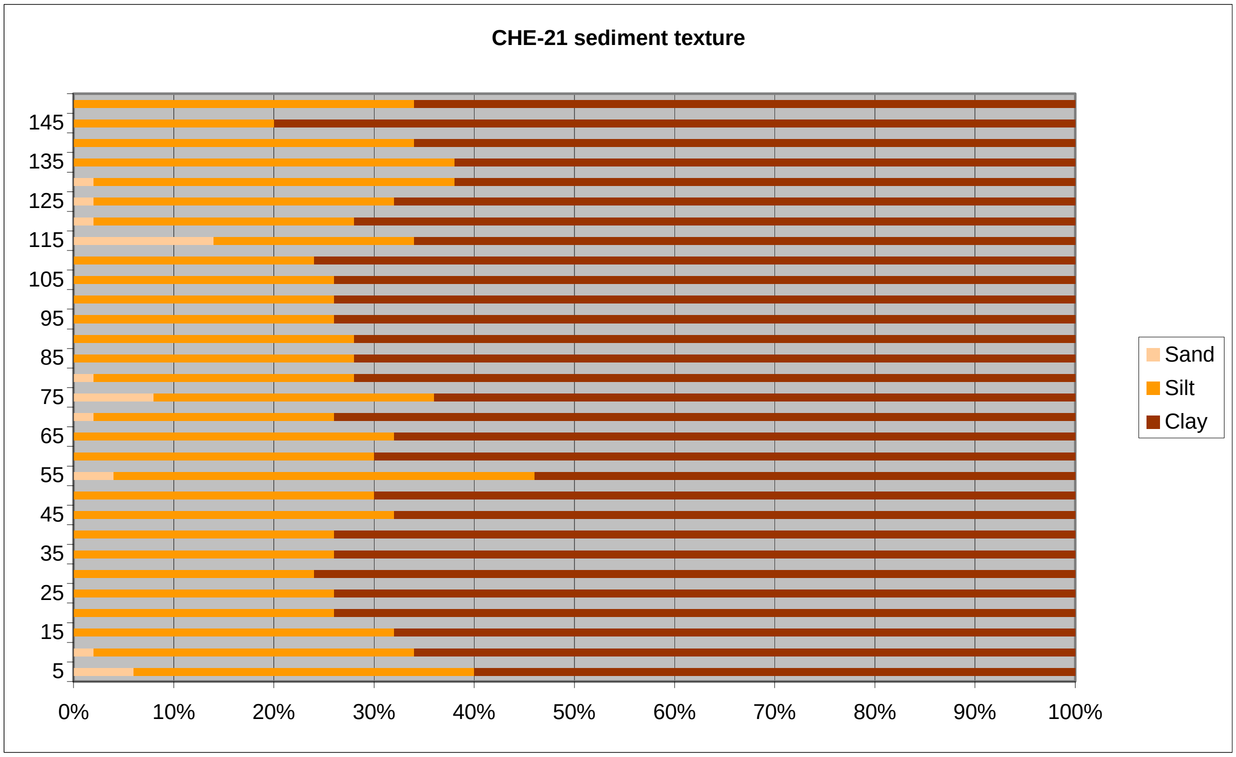

Figure 25c. Texture analysis from sediment chronosequence of core CHE-21.

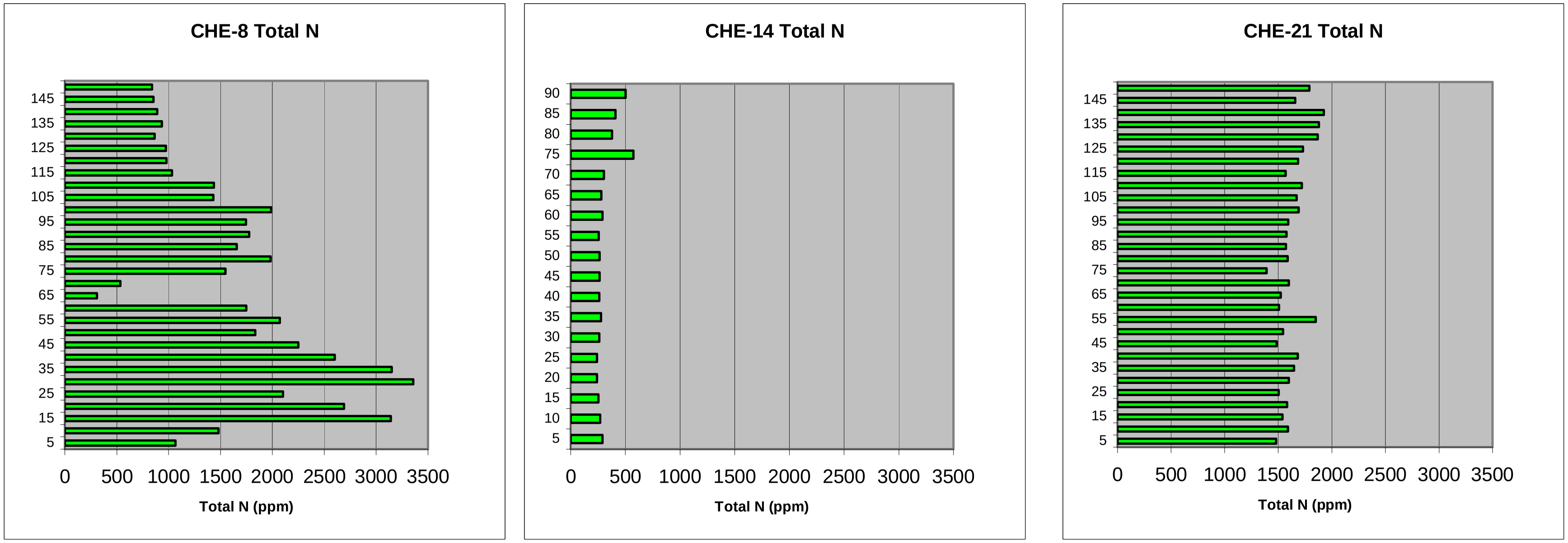

Figure 26. Total nitrogen (ppm) from sediment chronosequences of sediment cores from Cheney Reservoir.

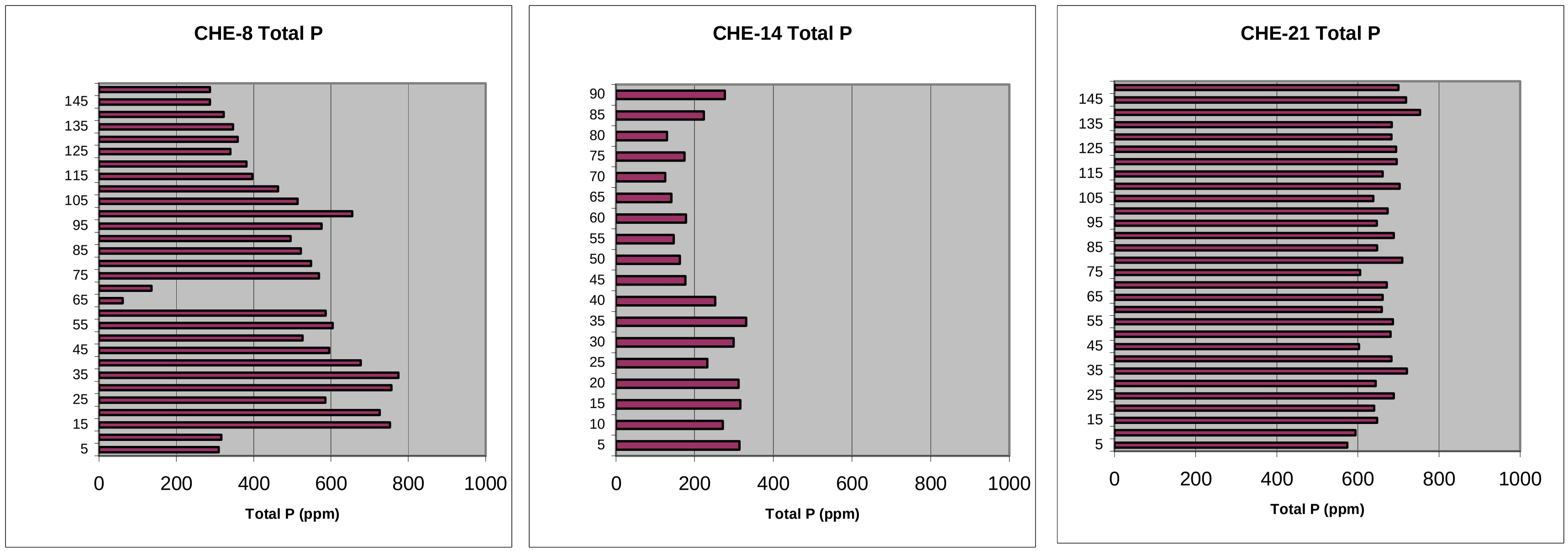

Figure 27. Total phosphorus (ppm) from sediment chronosequences of sediment cores from Cheney Reservoir.

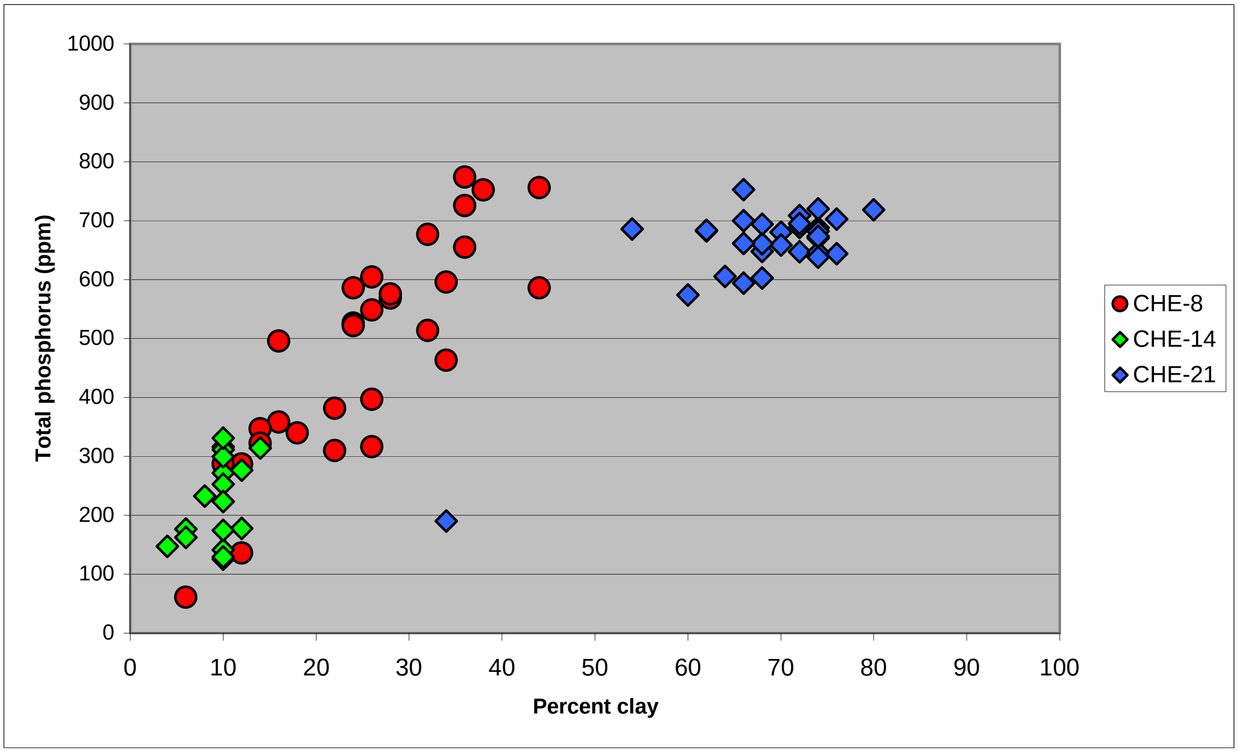

Figure 28. Percent clay versus total phosphorus in sequence samples from three sediment cores.

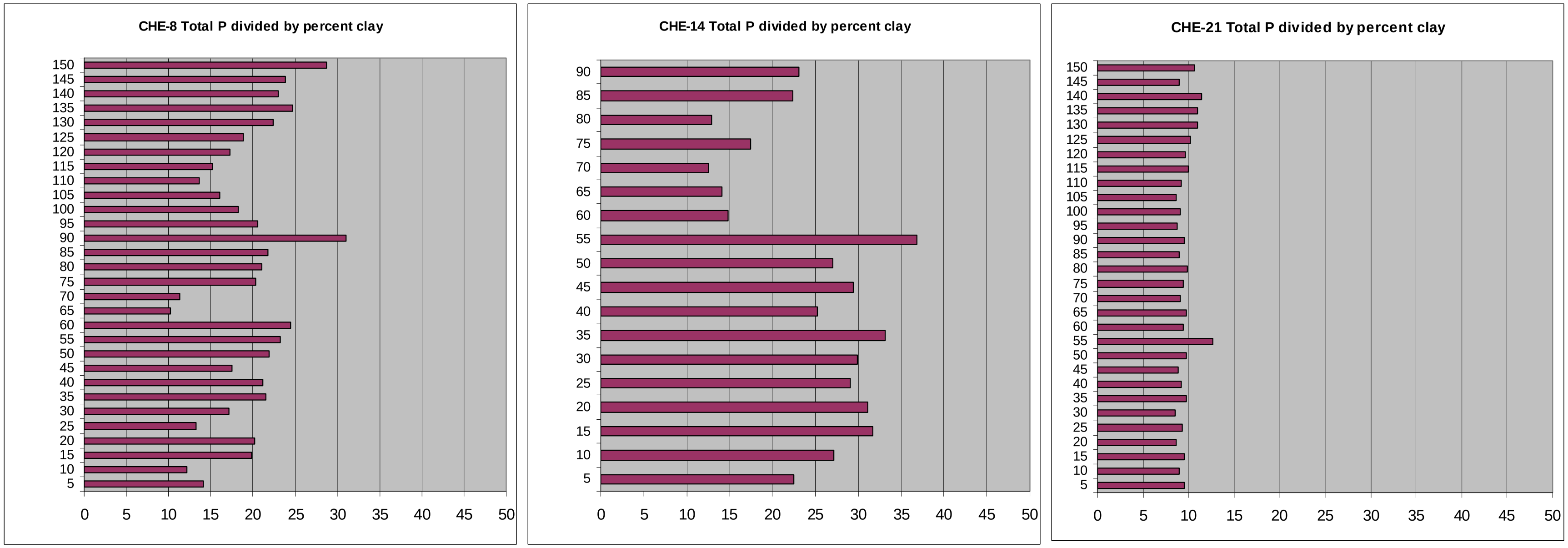

Figure 29. Clay-normalized total phosphorus from sediment chronosequences of sediment cores from Cheney Reservoir.