Bathymetric Survey of the LEON RIVER

April 2010 Survey

Prepared by:

Texas Water Development Board

September 2010

Texas Water Development Board

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Prepared for:

City of Temple

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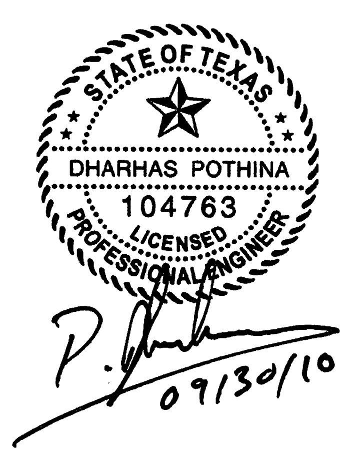

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Introduction

The Hydrographic Survey Program of the Texas Water Development Board (TWDB) was authorized by the 72nd Texas State Legislature in 1991. The Texas Water Code authorizes TWDB to perform surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability.

In April of 2010, the Texas Water Development Board (TWDB) entered into agreement with the City of Temple (TWDB, 2010), to perform a bathymetric survey of the Leon River from Belton Dam to the City of Temple Low Water Dam. Belton Dam is located 3 miles north of the City of Belton, Texas, and both the dam and Leon River study area are located in Bell County. The approximate location of Belton Dam is 97.47ºW 31.12ºN and the approximate location of Temple Low Water Dam is 97.44ºW 31.06ºN. This section of Leon River is approximately 4 miles in length.

This report describes the methods used in conducting the bathymetric survey, including data collection methods and data processing techniques. This report serves as the final contract deliverable from TWDB to the City of Temple, and contains as deliverables: (1) a bottom contour map [Figure 9], and (2) a shaded relief plot of the river bottom [Figure 8].

Bathymetric survey of the Leon River

Datum

The horizontal datum used for this report is North American Datum of 1983 (NAD83), and the horizontal coordinate system is State Plane Texas Central Zone (feet). The vertical datum used during this survey is that used by the United States Geological Survey (USGS) for the stream gage USGS 08102500 Leon Rv nr Belton, TX (USGS, 2009). The datum for this gage is 476.68 feet above mean sea level or National Geodetic Vertical Datum 1929 (NGVD 29). The river boundary is referenced to this gage, while the survey depths were referenced to elevations based on water surface elevations measured by the survey crew using differential global positioning system (DGPS) equipment. DGPS was used to obtain accurate real-time corrected measurements for water surface elevation points throughout the study area. DGPS involves two receivers; one base receiver, which remains stationary, while a second receiver, a rover, is used to take point measurements throughout the study area. The base receiver uses its known position to calculate timing instead of using signal timing to calculate its position. The base receiver determines what the signal timing should be based on this method and calculates a "correction factor". The base receiver then sends the "correction factor" via radio signal to the rover receiver allowing for higher accuracy measurements than if the receiver was relying on satellites alone. (Trimble, 2010).

At the completion of the survey, the global positioning system (GPS) base receiver data was processed using the National Oceanic Atmospheric Administration (NOAA) sponsored Online Positioning User Services (OPUS) website (National Geodetic Survey, 2010b). This website uses National Continuously Operating Reference Stations (CORS) to calculate a real-world correction factor for the GPS base receiver. Three CORS were chosen based on proximity to the GPS base receiver. The GPS base receiver was then triangulated using the CORS to determine the correction factor. The correction factor was applied to the base receiver data as well as the water surface elevations. These corrections were not applied to the GPS on board the boat because this GPS relied on satellites if the corrections sent via radio signal from the base station were interrupted.

The DGPS base station data and water surface elevation measurements were measured in the North American Vertical Datum of 1988 (NAVD88). To convert these measurements to NGVD29, NOAA's VERTCON software was used (National Geodetic Survey, 2010a; National Geodetic Survey, 2010c). All elevations reported here are in feet above mean sea level, NGVD29.

TWDB bathymetric data collection

The bathymetric data was collected using a Specialty Devices, Inc., multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system equipment. Although data was collected using three frequencies, only the 200 kHz frequency was used to identify the current bottom surface of the river bed. Pre-determined survey transects were not used; however, data was collected perpendicular to the channel flow, no more than 100 feet apart. Several lines of data were also collected along the direction of flow, following the channel banks and the channel center line. Bathymetric data collection occurred April 21-23, and April 28, 2010.

Each day prior to beginning the survey, TWDB measured the speed of sound of the water column using a velocity profiler by Valeport Limited. A weighted tape and stadia rod were used to physically verify the depth readings recorded by the depth sounder. During the 2010 survey, team members collected nearly 144,000 data points over cross-sections totaling approximately 39 miles in length.

Data processing

Model boundary

The river boundary was digitized from digital ortho quarter-quadrangle photographs (DOQQs) obtained from the Texas Natural Resources Information System (TNRIS), using Environmental Systems Research Institute's (ESRI) ArcGIS 9.3.1 software (NAIP, 2006, TNRIS, 2009). The DOQQs which cover the Leon River study area are Belton NW and Belton SW. These DOQQs were photographed on September 8, 2004, during which the mean water surface elevation measured by gage height was 5.29 feet, or 481.97 feet above mean sea level. Although the 2004 DOQQs are of 1-meter resolution, due to tree cover, it was impossible to see the true land water interface of the river, therefore, an approximate boundary was digitized and given the elevation of 481.97 feet for modeling purposes (Figure 1). The constant elevation of the boundary does not reflect changes in slope in the river reach surveyed. As a result, the accuracy of the contours and the elevation-area-capacity relationships near the boundary may be affected.

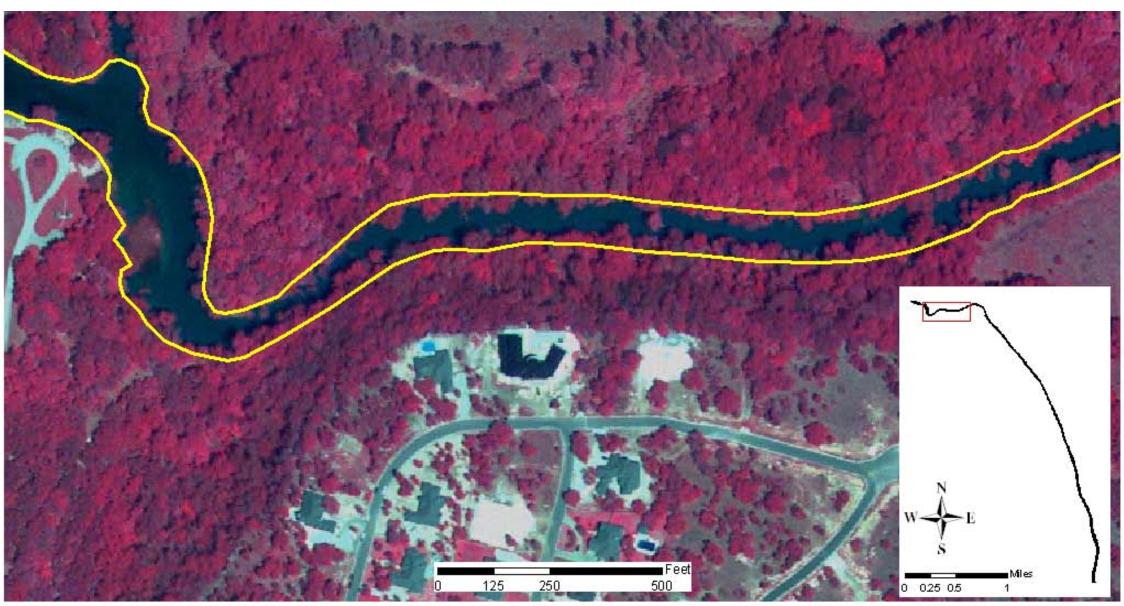

Figure 1. The Leon River boundary, shown in yellow, was digitized from the 2004 DOQQs.

Bathymetric Data Correction

Following completion of data collection, the raw data files were edited using HydroEdit and DepthPic software to remove data anomalies. HydroEdit is used to automate the editing of the 200 kHz frequency signal identifying the bottom surface. DepthPic is used to display, interpret, and manually edit the multi-frequency data. Any manual edits are merged with the automatically edited points using HydroEdit.

The measured water surface elevations at the times of each sounding are used to convert the sounding depths to corresponding river-bottom elevations. As described above in the section titled “Datum,” the TWDB survey crew measured the water surface elevation of the river multiple times each day. Table 1 lists the location where each DGPS reading was taken. Table 2 describes how the water level corrections were applied for each day. Because bathymetric data was not collected precisely when the water surface elevation measurements were taken, the water surface elevations at those times were assumed constant. This assumption was based on the USGS gage data which indicates constant elevation measurements within the same timeframe. The assumed measurements are in the grey boxes. Figure 2 illustrates the relationship between the water surface elevation measurements and the data taken on the corresponding day.

Table 1. DGPS water surface elevation measurements

DGPS Measurement	Date	Time	Easting*	Northing*	Elevation
Corrected dam_wse	4/21/10	01:15:06 pm	3192426.349	10377012.635	482.304
Corrected dam_wse2	4/21/10	01:19:17 pm	3192426.356	10377012.625	482.316
Corrected usbridge_wse4	4/21/10	06:44:35 pm	3197246.606	10374921.453	481.291
Corrected us_wse6	4/22/10	03:43:00 pm	3199915.905	10370580.472	481.830
corrected us_wse6a	4/22/10	03:46:16 pm	3199915.907	10370580.496	481.768
Corrected dsintake_wse5	4/22/10	02:08:38 pm	3201541.440	10363633.915	481.713
Corrected dsintake_wse5b	4/22/10	02:17:33 pm	3201541.530	10363633.831	481.629
Corrected us_wse7	4/23/10	01:40:24 pm	3199911.607	10370585.813	481.577
Corrected us_wse8b	4/23/10	01:44:58 pm	3199911.618	10370585.751	481.666
Corrected dsintake_wse9	4/23/10	04:23:27 pm	3201541.482	10363634.103	481.681
Corrected dsintake_wse9b	4/23/10	04:27:25 pm	3201541.474	10363634.183	481.756
Corrected dam_wse11	4/28/10	11:04:02 am	3192406.340	10377011.016	483.790
Corrected dam_wse12	4/28/10	01:14:56 pm	3195742.538	10376529.995	483.068
Corrected dam_wse12chk	4/28/10	01:17:24 pm	3195742.556	10376529.987	483.137
Corrected dam_wsedswe15	4/28/10	03:50:11 pm	3197202.669	10374984.796	482.761
Corrected dam_wsedswe15chk	4/28/10	03:55:23 pm	3197202.676	10374984.803	482.883

*Coordinates in feet, North American Datum 1983, State Plane Texas Central Zone

Table 2. TWDB DGPS water level measurements used to convert data

	Data collection	DGPS measurements	DGPS WSE (feet above msl[a])	Notes
04/21/2010				
Start Time	2:36 PM	1:15 PM	482.304	Data was collected within DGPS measurements times
		1:19 PM	482.316	
End Time	5:54 PM	6:44 PM	481.291	
04/22/2010				
Start Time	1:35 PM	2:08 PM	481.713	Last DGPS measurement on 4/21/2010 and first water surface elevation measurement on 4/22/2010 close enough to allow linear interpolation of tides to cover 4/22 data collected before first DGPS reading
		2:17 PM	481.629	
		3:43 PM	481.830	
End Time	4:17 PM	3:46 PM	481.768	
04/23/2010				
Start Time	2:31 PM	1:40 PM	481.577	First DGPS measurement before data collection begun, based on constant USGS gage reading, water surface elevation kept constant between final DGPS reading and end of data collection for the day.
		1:44 PM	481.666	
		4:23 PM	481.681	
End Time	5:42 PM	4:27 PM	481.756	
		5:45 PM	481.756	
04/28/2010				
Start Time	12:29 PM	11:04 AM	483.790	First DGPS measurement before data collection begun, based on constant USGS gage reading, water surface elevation kept constant between final DGPS reading and end of data collection for the day.
		1:14 PM	483.068	
		1:17 PM	483.137	
		3:50 PM	482.761	
End Time	5:32 PM	3:55 PM	482.883	
		6:00 PM	482.883	

[a]msl – mean sea level

As discussed above, it was impossible to digitize an accurate boundary from the aerial photographs due to dense tree cover. This tree cover also prevented the GPS on board the survey boat from continuously receiving satellite signal and tracking the boat. Figure 3 illustrates this phenomenon. One line of data is highlighted to illustrate how in some areas data is shifted but in others, tracking was completely lost. To correct this, TWDB developed a computer algorithm using Python to create lines representing boat paths based on sequential data points. These lines were then edited to approximate smooth boat paths. A second algorithm was written to relocate any data point not on the estimated boat path to the line. The points were moved sequentially and spaced equidistant between points that did not need to be moved. In areas where data was shifted, all the shifted points were manually moved to retain boat speed and boat path characteristics. Figure 4 illustrates this process. Figure 5 shows all the data collected within the study area, after correction.

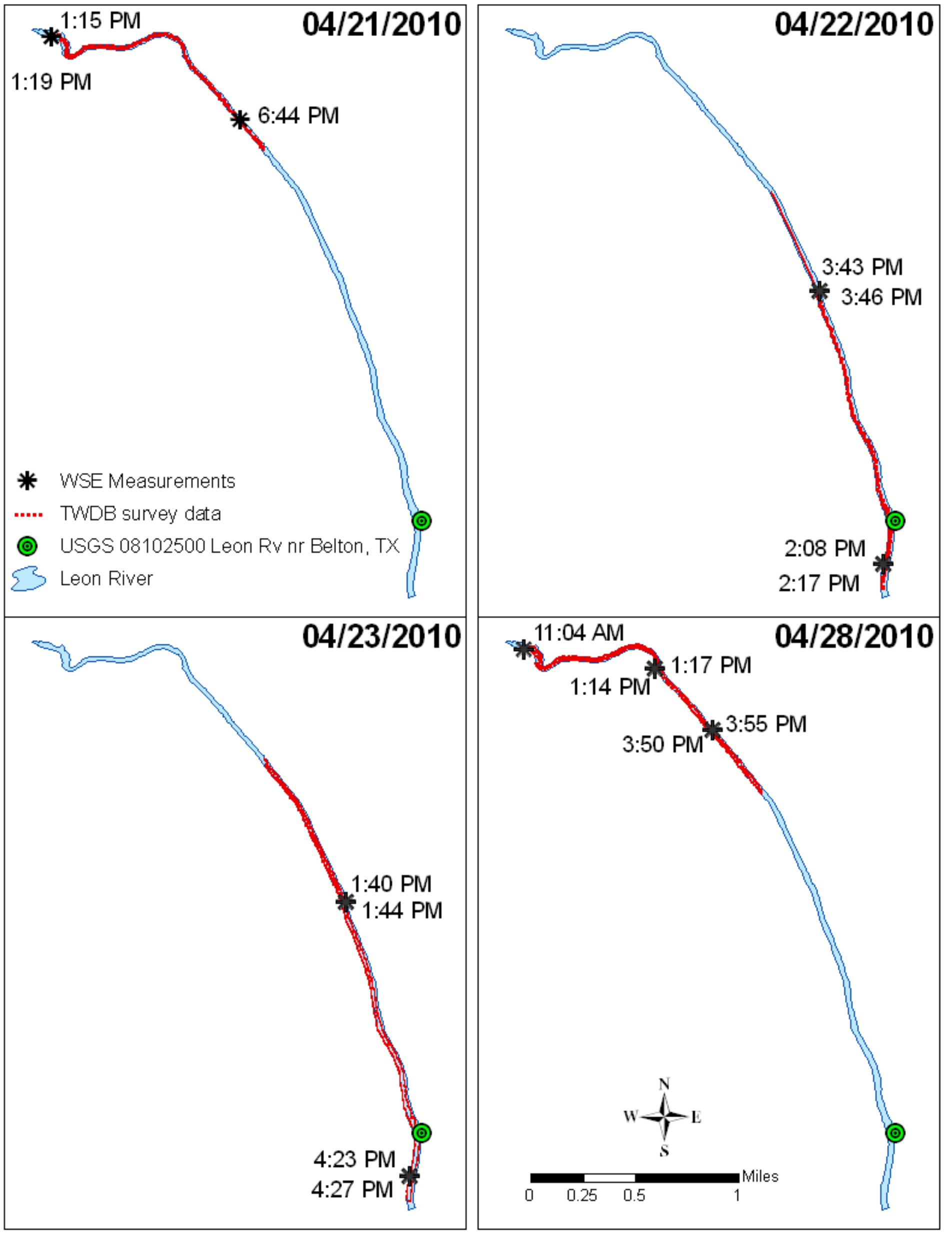

Figure 2. **Illustration of where the water surface elevation measurements were taken in relation to the survey data.**

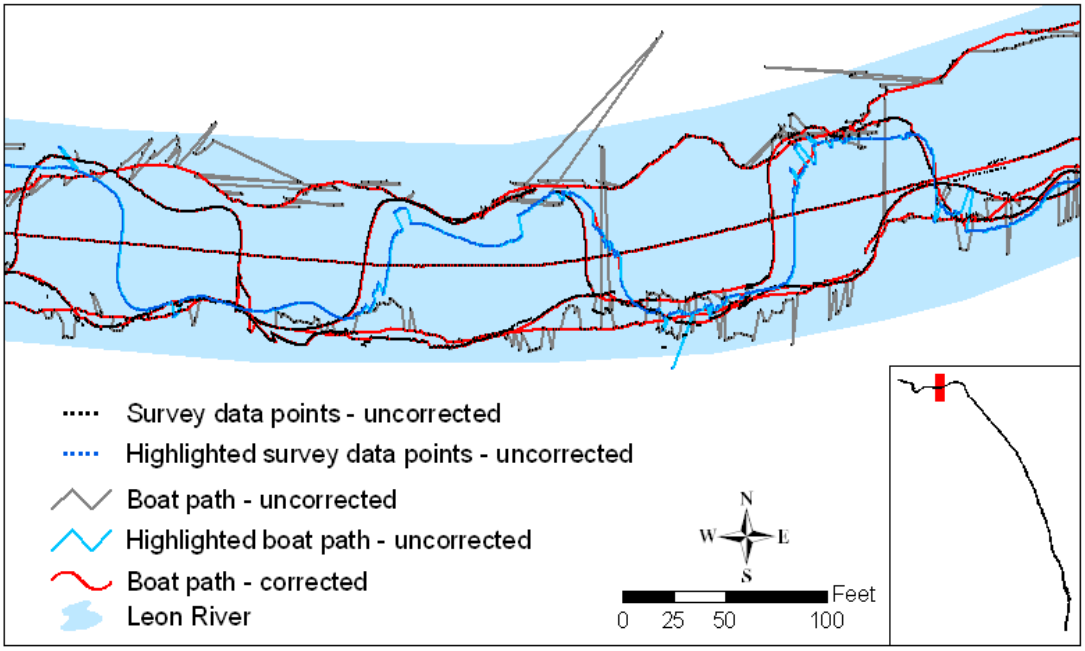

Figure 3. **Illustration of how DGPS signal loss affects the data.**

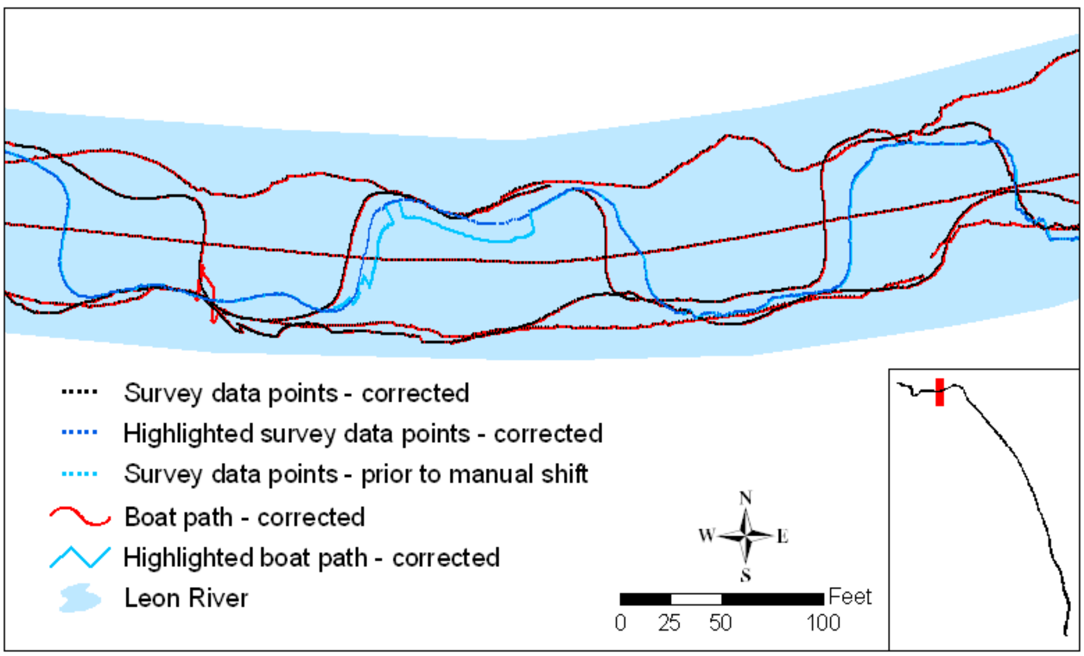

Figure 4. **Illustration of how survey data were corrected using an estimated boat path and manually moving other sections of data.**


Figure 5
Leon River
Bathymetric Survey Data Map
USGS 08102500 Leon Rv nr Belton, TX
Survey data points - corrected
Leon River study area
WSE = 481.97 feet above msl
Background - 2004 DOQQs
Miles
0
0.25
0.5
1

The flow rate was held constant at approximately 1080 cfs for the majority of the survey (April 21 to 23). However, due to unexpected releases, the remainder of the survey was conducted on April 28. Data collected on April 28 covered mainly the upper half of the river reach. During this portion of the survey the flow rate was significantly higher at 2020 cfs. Additional analysis was performed on data to ensure that the change in flow rate did not impact the survey results. This analysis revealed the data for the upper half of the river reach (i.e. April 21 and 28 data, Figure 6) appeared less precise than data from the lower half of the river.

Additionally, below in Figure 7, water surface elevations measured on April 21, 2010 appear approximately 0.7 feet lower when compared to April 28, 2010 water surface elevation measurements taken at the same locations. Note, the relative elevations in Figure 7 have been normalized to the USGS gage height for comparison purposes. The water surface elevation measured 1 mile from Belton Dam (straight line distance) is approximately 0.5 feet below the USGS gage height measured near the downstream dam location. After review of the water surface elevations, no obvious reasons exist for the water surface elevation discrepancies. These discrepancies are mentioned in the report for completeness, but on detailed analysis were found not to affect the contour maps of the river channel measurably.

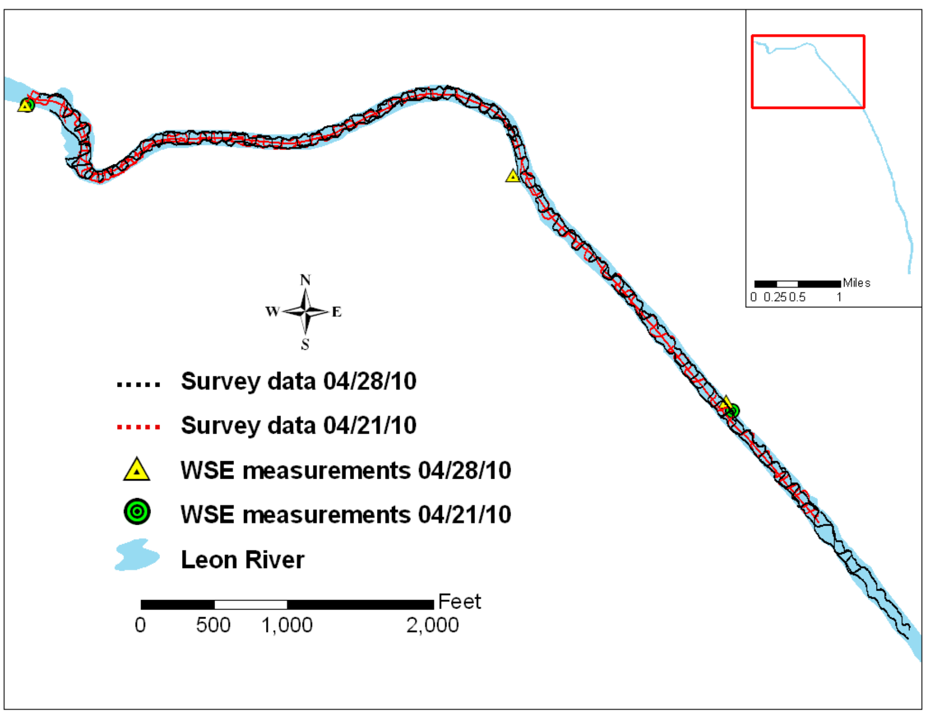

Figure 6. **Comparison of data collected on April 21st and April 28th.**

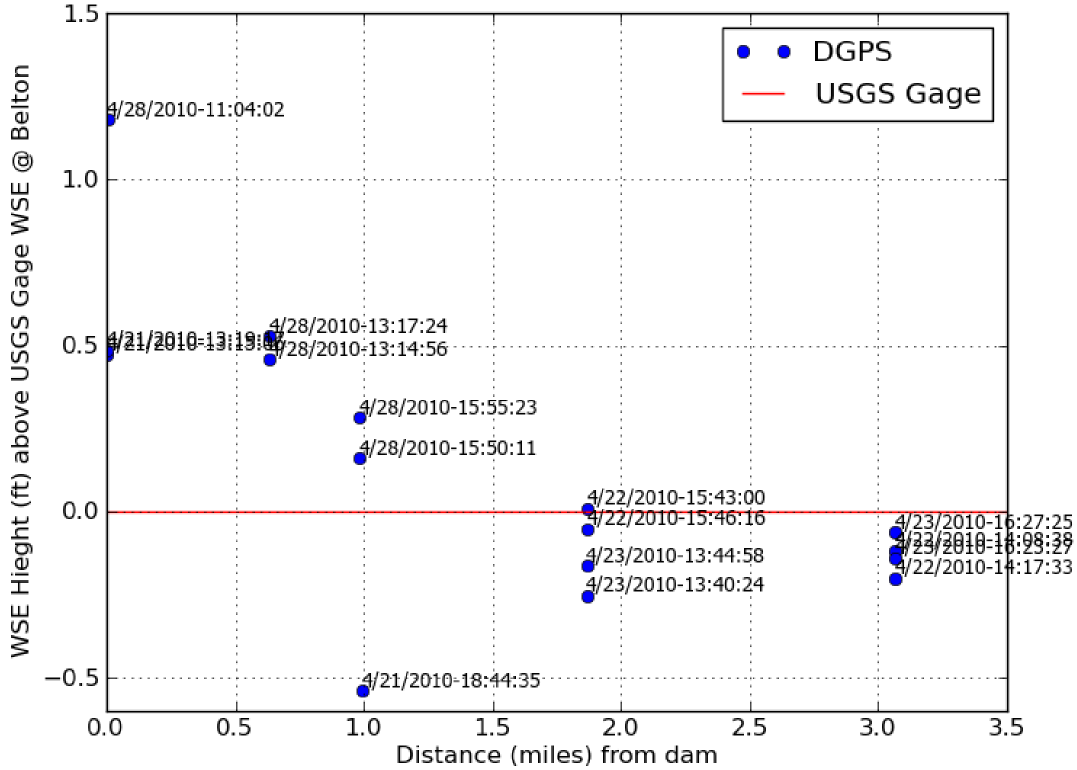

Figure 7. **Water surface elevations relative to the gage water surface elevation.**

River Model

Following completion of the data editing, the files are exported in X,Y,Z format. These points were interpolated using the self-similar interpolation technique (described in the next section titled "Self-similar interpolation"). Both the sounding data and the interpolated points were used in conjunction with the boundary file to create a Triangulated Irregular Network (TIN) model with the 3D Analyst Extension of ArcGIS. The 3D Analyst algorithms use Delaunay's criteria for triangulation to place a triangle between three non-uniformly spaced points, including the boundary vertices (ESRI, 1995).

Using ArcInfo software, volumes and areas were calculated from the bathymetric TIN model for this section of the river at 0.1 feet intervals, from elevation 456.9 feet to elevation 482.0 feet. The elevation-capacity table and elevation-area table, for 2010, are presented in Appendices A and B, respectively. The area-capacity curves are presented in Appendix C. The methodology used to calculate the elevation-area-capacity relationships is based on an assumption of a constant elevation river boundary. The slope of the river, or any changes in the elevation of the river boundary along the river reach, are not reflected in these calculations.

Six cross-sections were extracted from the TIN model in two areas of interest to the City of Temple, near the water intake structure and near Belton Dam, and are presented in Appendix D. The endpoint coordinates for each cross-section are defined in Table 3.

The TIN model was then converted to a raster representation using a cell size of 1 foot by 1 foot. The raster data was used to produce the shaded relief map (Figure 8), representing the topography of the reservoir bottom, and a 2-foot contour map (Figure 9 - attached).

Table 3. Endpoint coordinates of Leon River cross-sections

Cross-section	X_L	Y_L	X_R	Y_R
LR01	3201827.58851	10364648.192	3201628.11901	10364618.912
LR02	3201742.18872	10364954.4112	3201548.8192	10364895.2413
LR03	3201793.42859	10364775.0716	3201604.32906	10364746.4017
LR04	3192882.45938	10376865.1313	3192664.32058	10376767.113
LR05	3192832.48926	10376942.0084	3192628.76491	10376848.7949
LR06	3192730.62709	10377107.2942	3192639.33552	10376863.2094

XY: NAD83 State Plane Texas Central Zone Coordinates (feet) L=left end point R= right end point

Self-similar interpolation

The 3D Analyst extension utilizes the Delaunay method for triangulation. A limitation of the Delaunay method for triangulation when creating TIN models results in artificially-curved contour lines extending into the river where the river walls are steep and relatively narrow. These curved contours are likely a poor representation of the true bathymetry in these areas. Also, if the surveyed cross sections are not exactly perpendicular to the centerline of the river channel, the TIN model is not likely to represent the true channel bathymetry well.

To ameliorate these problems, a self-similar interpolation routine developed by TWDB was used to interpolate the bathymetry between many survey lines. The self-similar interpolation technique increases the density of points input into the TIN model, and directs the TIN interpolation to better represent the topography between cross sections (Furnans, 2006). In the case of Leon River, the application of self-similar interpolation helped represent the morphology near the banks and improved the representation of the river channel itself (Figure 10). In areas where obvious geomorphic features indicate a high-probability of cross-sectional shape changes (e.g. incoming tributaries, significant

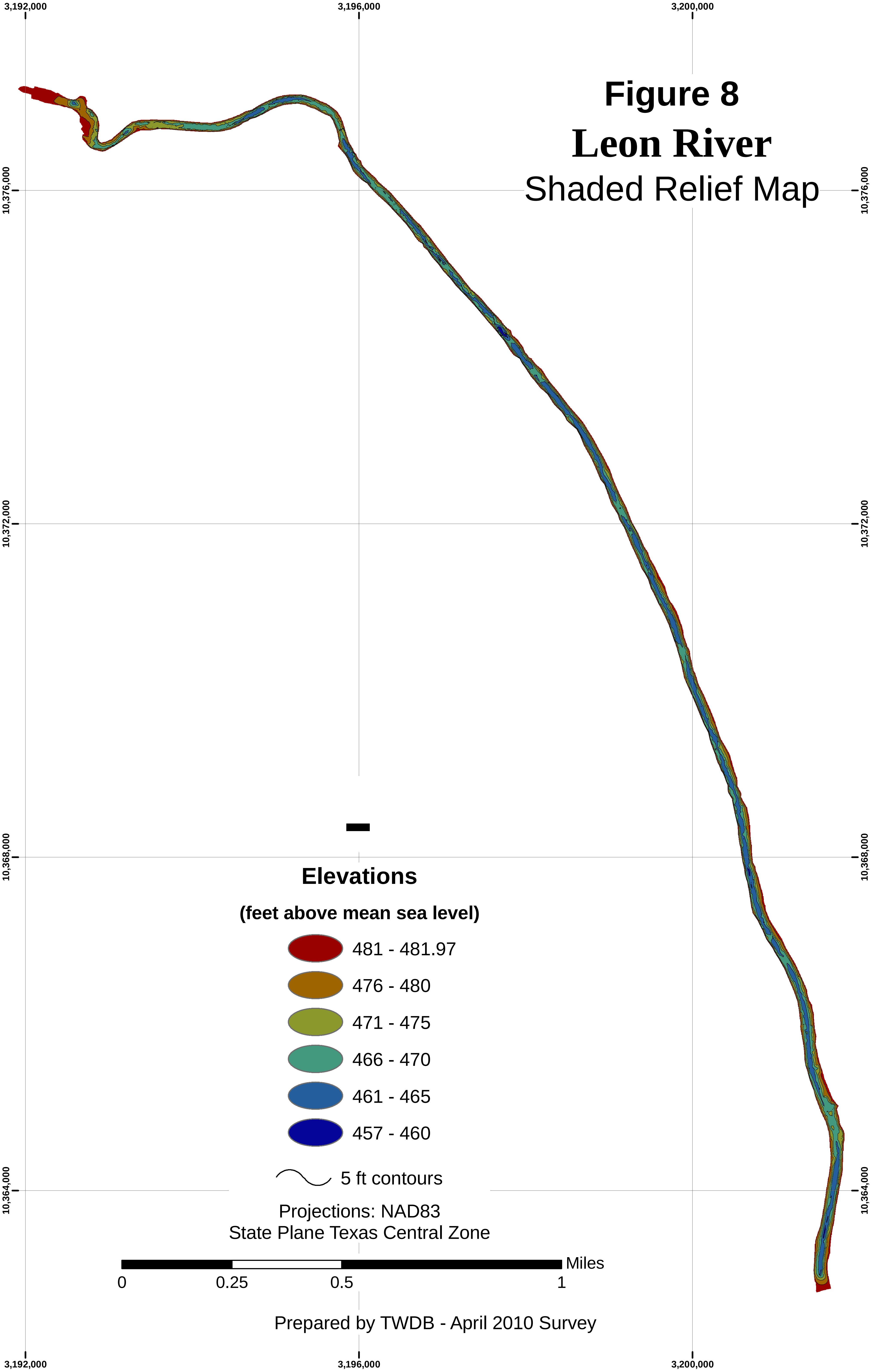
Figure 8
Leon River
Shaded Relief Map
3,192,000
3,196,000
3,200,000
10,376,000
10,372,000
10,368,000
10,364,000
Elevations
(feet above mean sea level)
481 - 481.97
476 - 480
471 - 475
466 - 470
461 - 465
457 - 460
5 ft contours
Projections: NAD83
State Plane Texas Central Zone
Miles
0
0.25
0.5
1
Prepared by TWDB - April 2010 Survey

widening/narrowing of channel, etc.), the assumptions used in applying self-similar interpolation are not likely to be valid. Therefore, interpolation was not used in areas of the Leon River where a high probability of change between cross-sections exists. Figure 10 illustrates typical results from the self-similar interpolation routine for the Leon River. In 10A, contours loop away from the banks. This is an artifact of the TIN generation routine, rather than an accurate representation of the physical bathymetric surface. Inclusion of self-similar points (10B) corrects and smoothes the bathymetric contours.

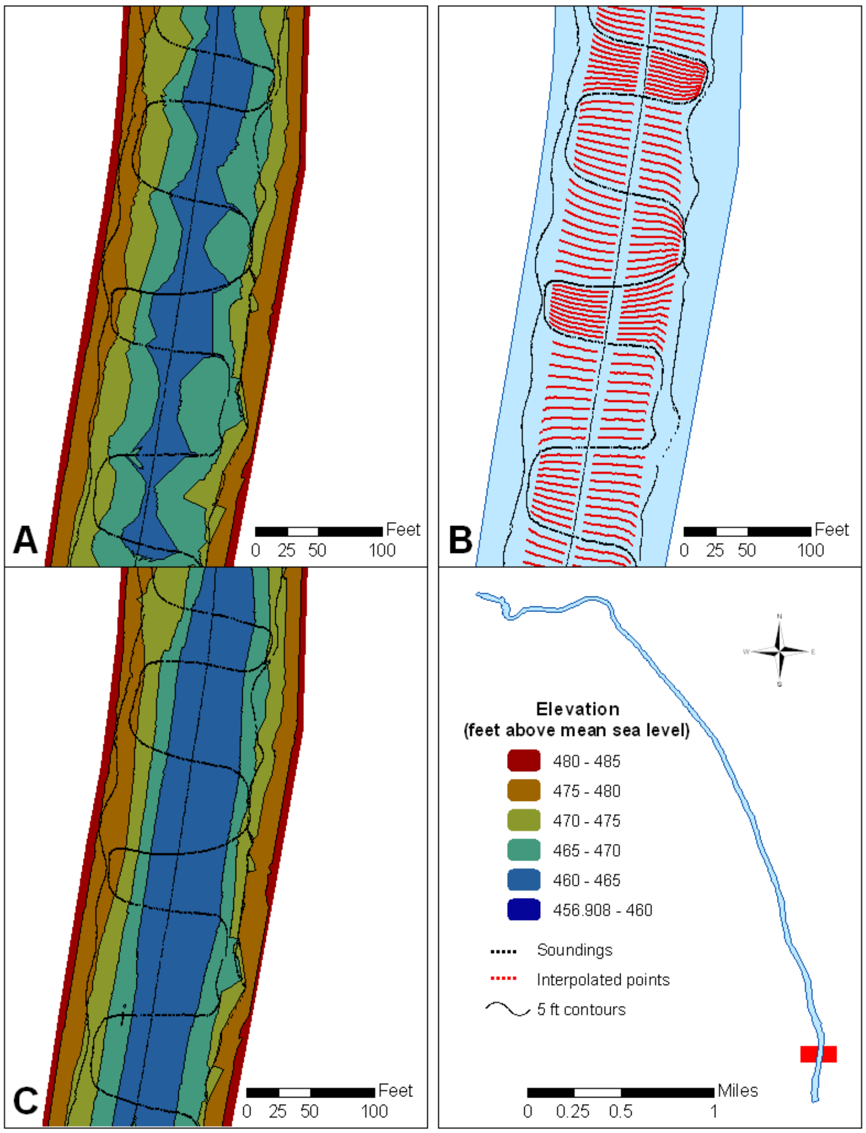

Figure 10. **Application of the self-similar interpolation technique to the Leon River sounding data – A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red) with reservoir boundary shown at elevation 481.97 feet, C) bathymetric contours with the interpolated points.**

TWDB Contact Information

More information about the TWDB Hydrographic Survey Program can be found at: http://www.twdb.state.tx.us/assistance/lakesurveys/volumetricindex.asp

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Appendix A

Leon River

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — April 2010 Survey

CAPACITY IN ACRE-FEET

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
456	0	0	0	0	0	0	0	0	0	0
457	0	0	0	0	0	0	0	0	0	0
458	0	0	0	0	0	0	0	0	0	0
459	0	0	0	0	0	0	0	0	0	0
460	0	0	0	0	0	0	0	0	0	0
461	0	0	1	1	1	1	1	1	1	1
462	1	1	2	2	2	2	2	3	3	3
463	4	4	5	5	6	6	7	7	8	9
464	10	10	11	12	13	14	15	16	17	19
465	20	21	23	24	25	27	28	30	32	33
466	35	37	38	40	42	44	46	48	50	52
467	54	56	58	60	62	65	67	69	72	74
468	76	79	81	84	86	89	91	94	97	99
469	102	105	108	111	113	116	119	122	125	128
470	131	134	137	140	143	147	150	153	156	159
471	163	166	169	173	176	180	183	187	190	194
472	197	201	204	208	212	215	219	223	226	230
473	234	238	242	246	249	253	257	261	265	269
474	273	277	281	286	290	294	298	302	306	311
475	315	319	323	328	332	336	341	345	350	354
476	359	363	368	372	377	381	386	391	395	400
477	405	409	414	419	424	429	433	438	443	448
478	453	458	463	468	473	478	483	488	494	499
479	504	509	514	520	525	530	536	541	546	552
480	557	563	568	574	579	585	591	596	602	608
481	613	619	625	631	636	642	648	654	660	666
482	672									

Appendix B

Leon River

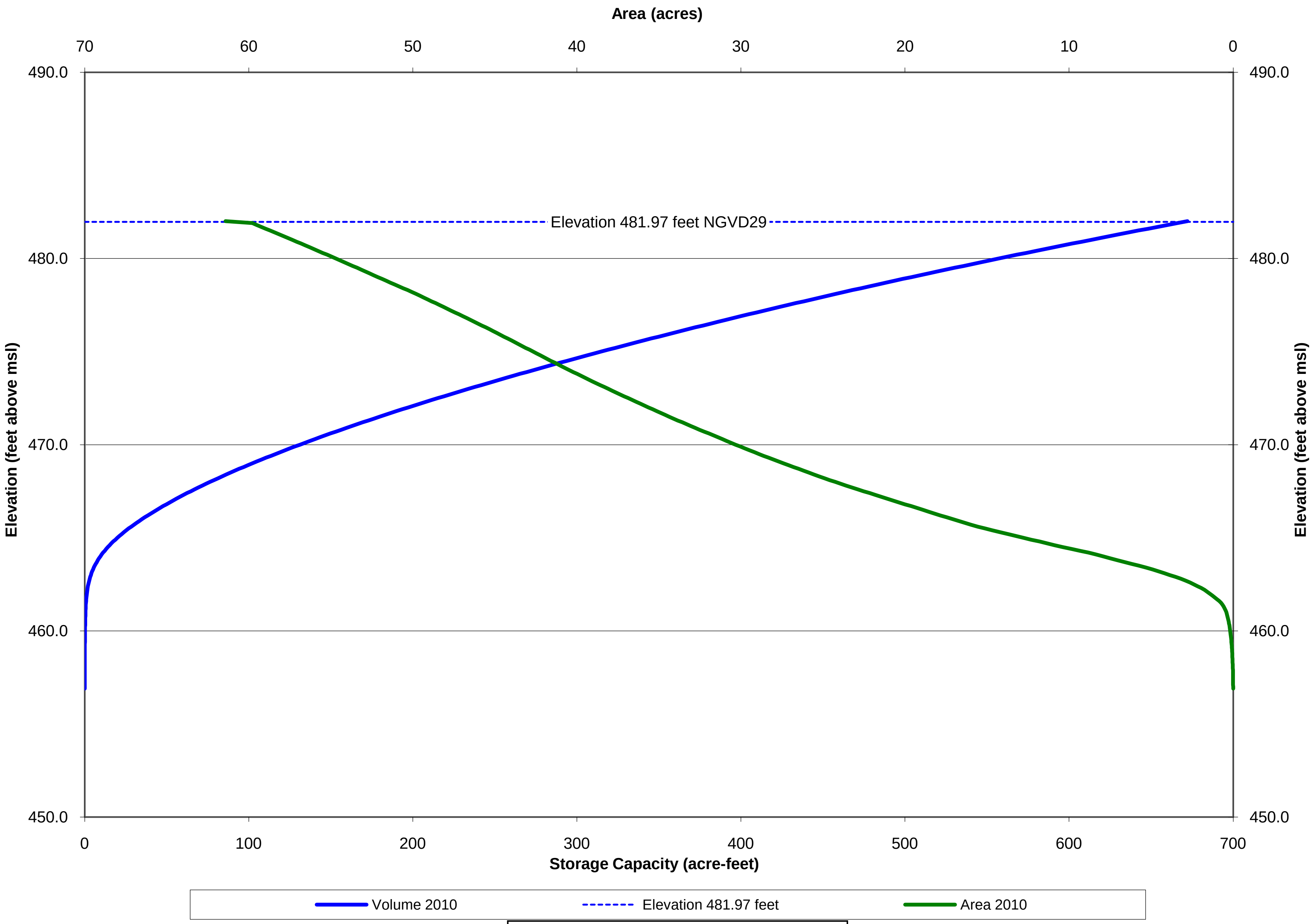
RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — April 2010 Survey

AREA IN ACRES

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
456	0	0	0	0	0	0	0	0	0	0
457	0	0	0	0	0	0	0	0	0	0
458	0	0	0	0	0	0	0	0	0	0
459	0	0	0	0	0	0	0	0	0	0
460	0	0	0	0	0	0	0	0	0	0
461	0	0	1	1	1	1	1	1	1	1
462	1	2	2	2	2	2	3	3	3	4
463	4	4	5	5	5	6	6	7	7	7
464	8	8	9	9	10	10	11	11	12	12
465	13	13	14	14	15	15	16	16	16	17
466	17	17	18	18	19	19	19	20	20	20
467	21	21	21	22	22	23	23	23	24	24
468	24	25	25	25	26	26	26	26	27	27
469	27	28	28	28	29	29	29	29	30	30
470	30	31	31	31	31	32	32	32	33	33
471	33	33	34	34	34	34	35	35	35	35
472	36	36	36	36	37	37	37	37	38	38
473	38	38	39	39	39	39	40	40	40	40
474	40	41	41	41	41	42	42	42	42	42
475	43	43	43	43	44	44	44	44	44	45
476	45	45	45	46	46	46	46	46	47	47
477	47	47	48	48	48	48	49	49	49	49
478	50	50	50	50	51	51	51	51	52	52
479	52	52	53	53	53	53	54	54	54	54
480	55	55	55	55	56	56	56	57	57	57
481	57	58	58	58	58	59	59	59	60	60
482	61									



Leon River
April 2010 Survey
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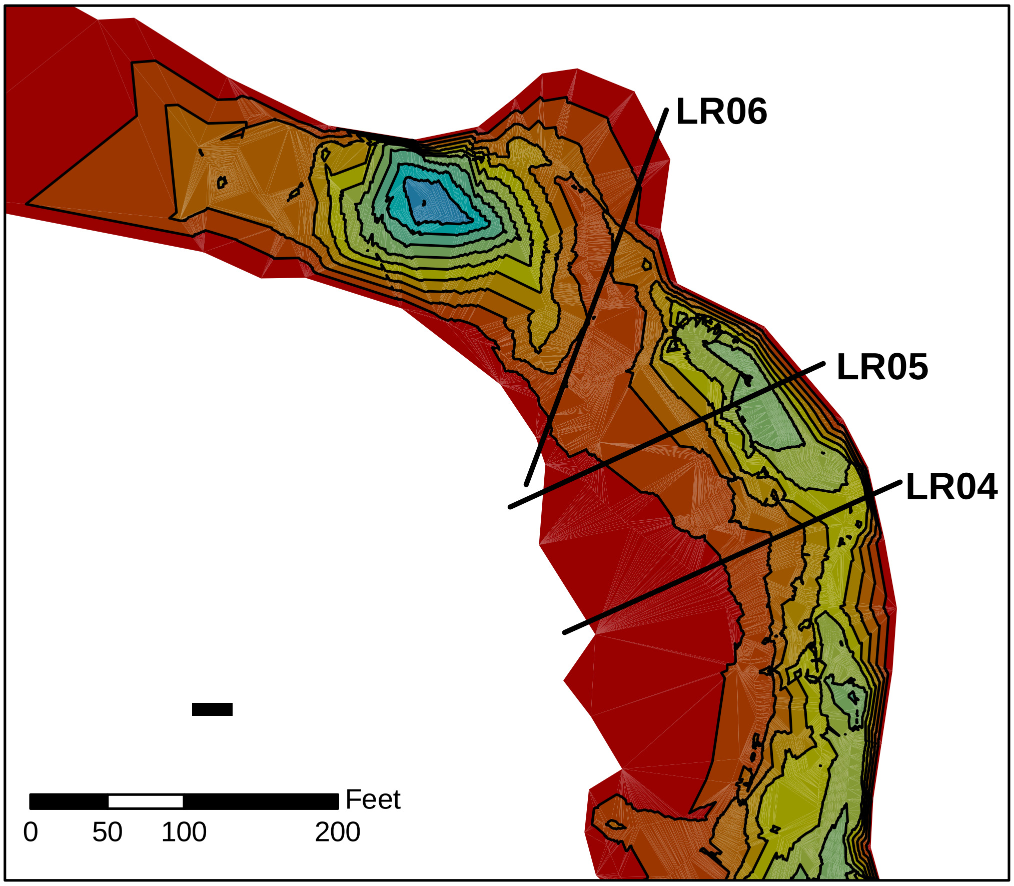
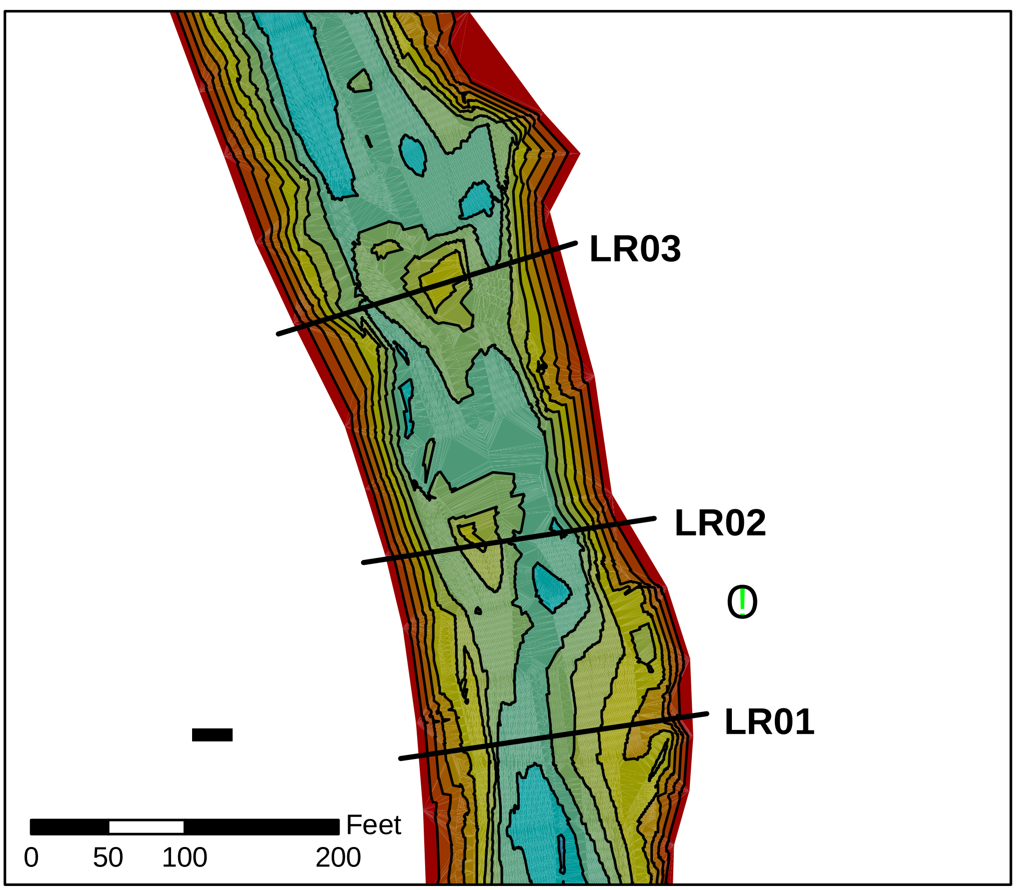
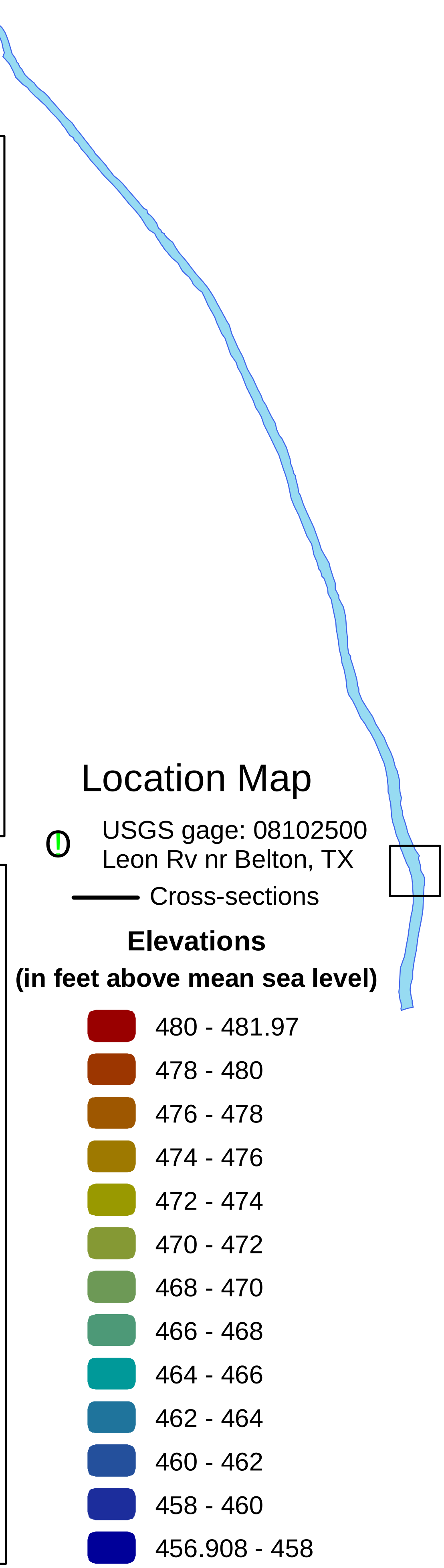
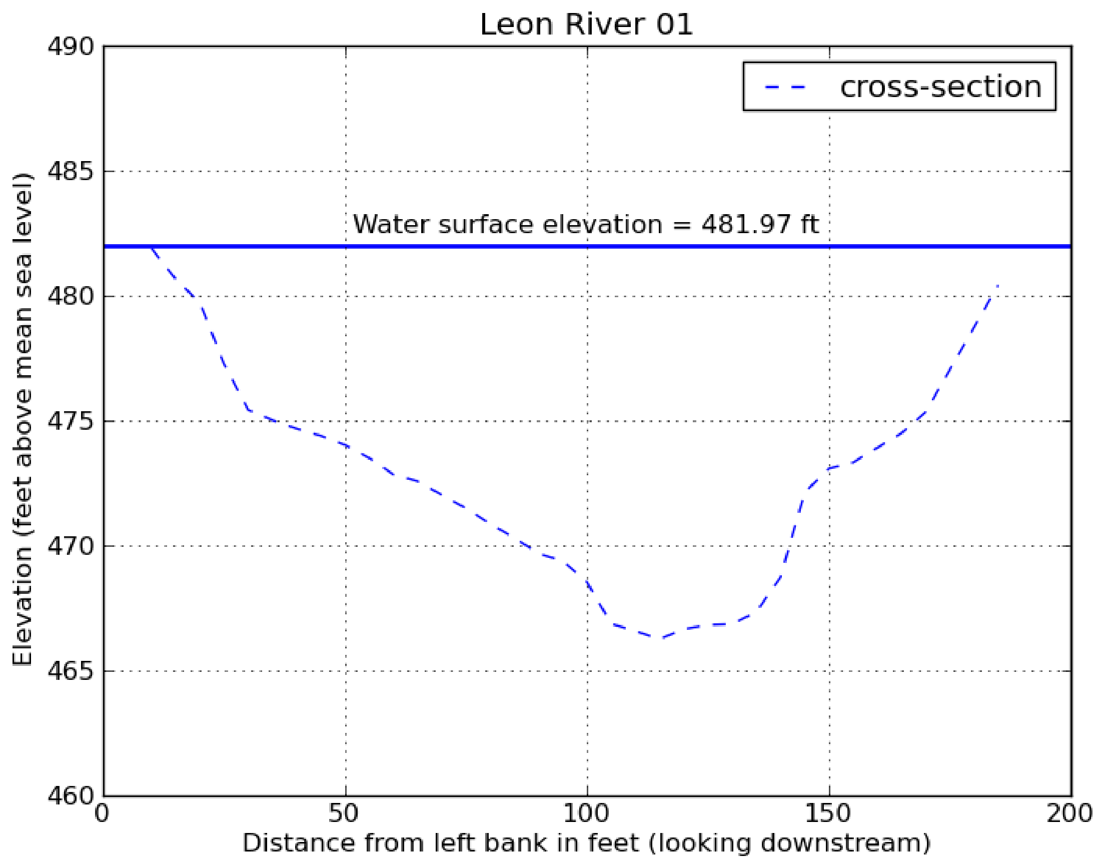
Appendix C: Area and Capacity Curves

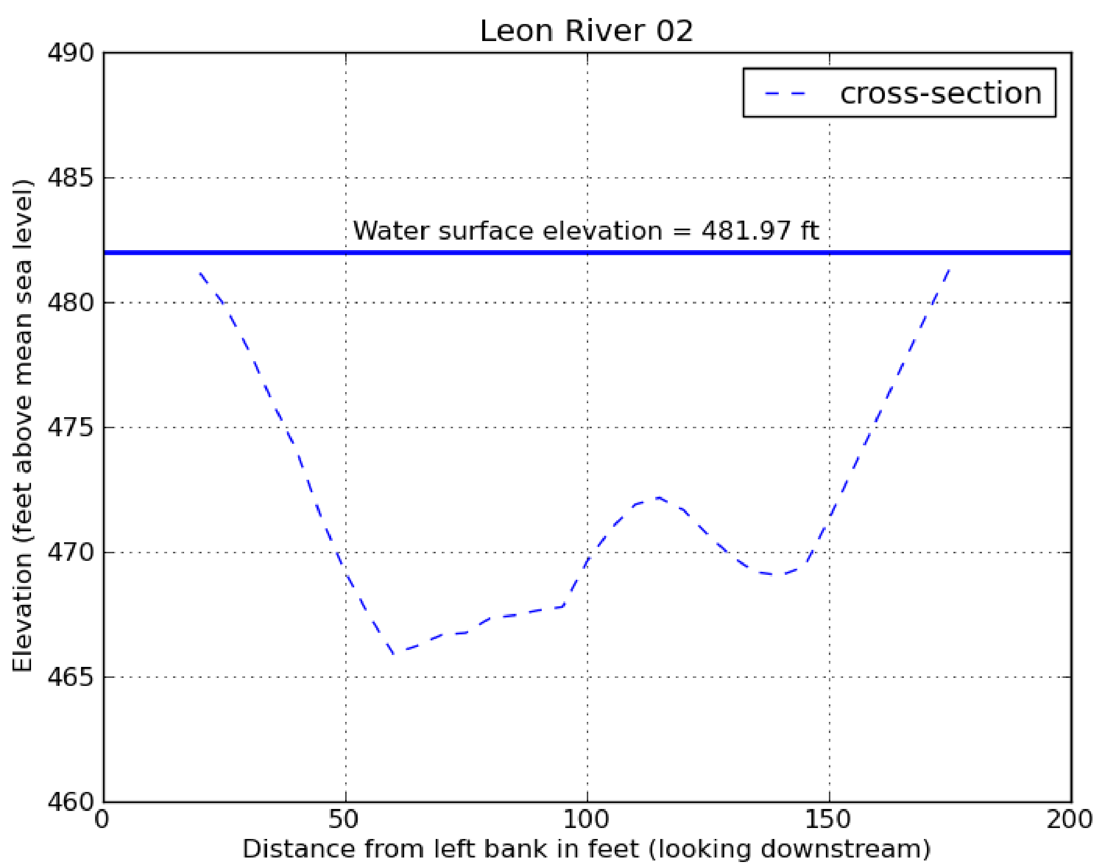
Appendix D
Leon River cross-sections

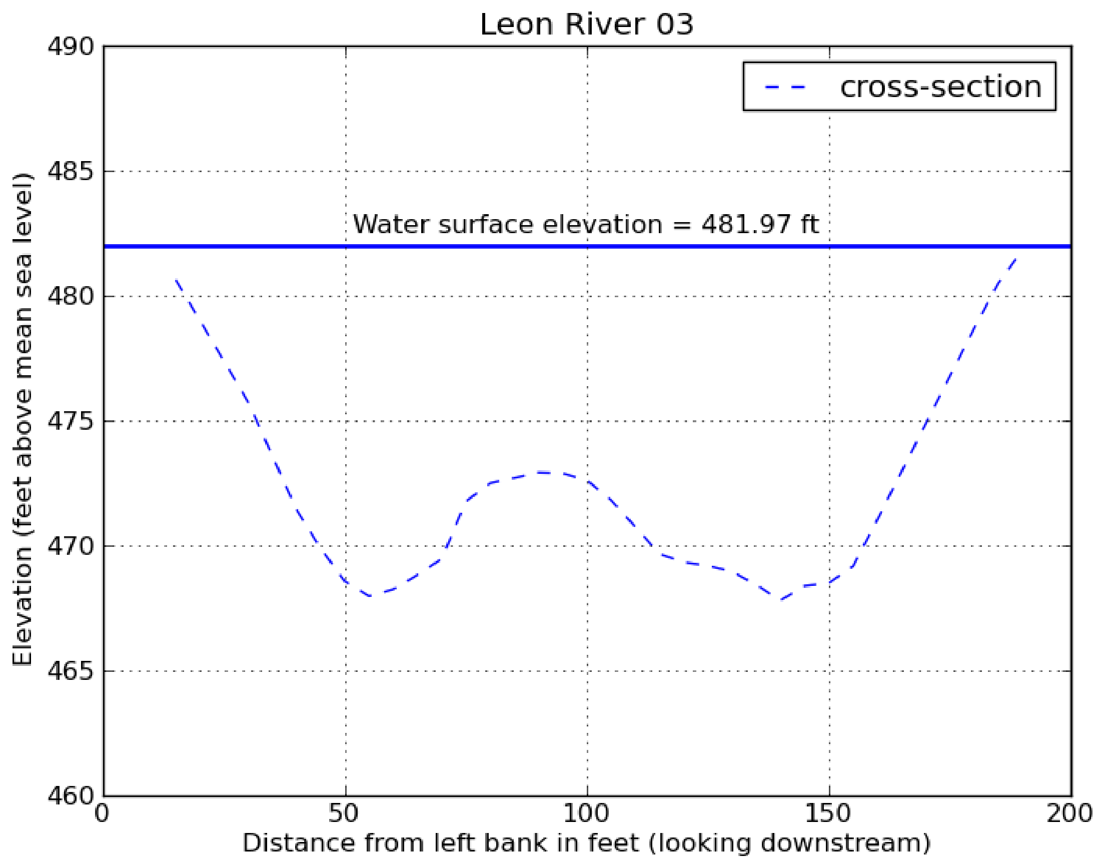


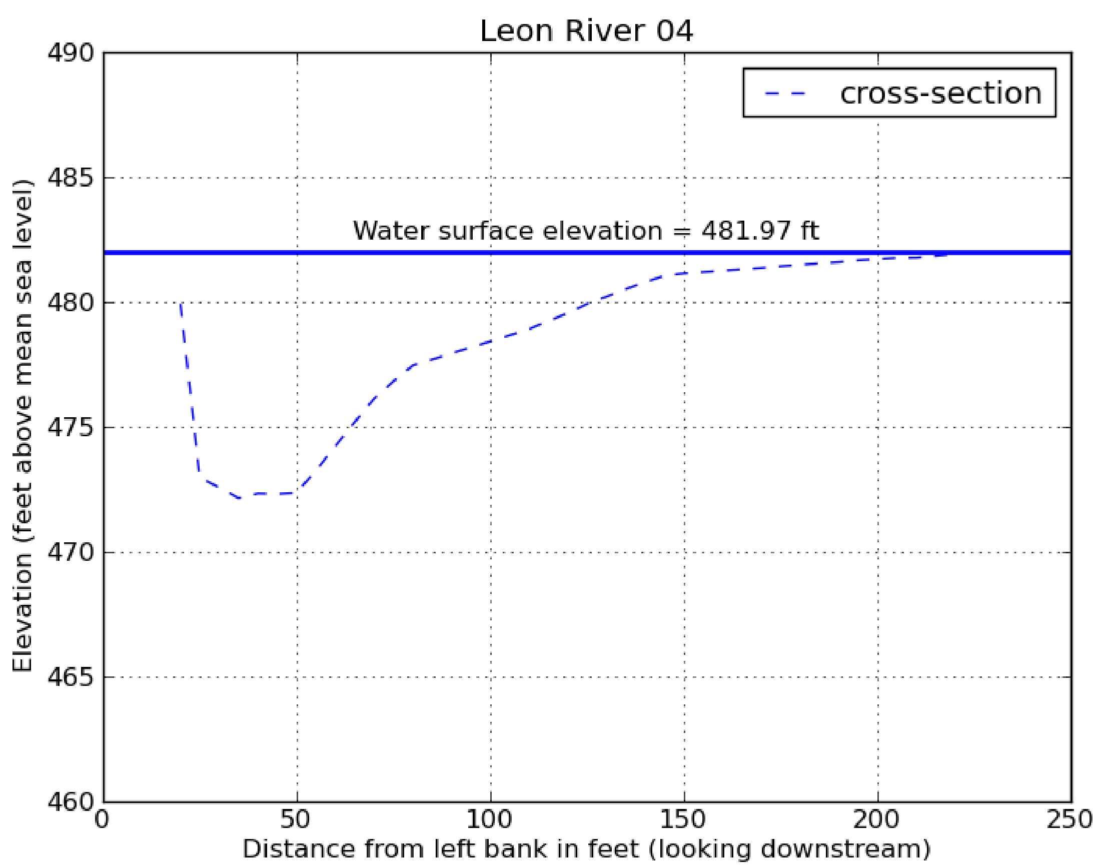


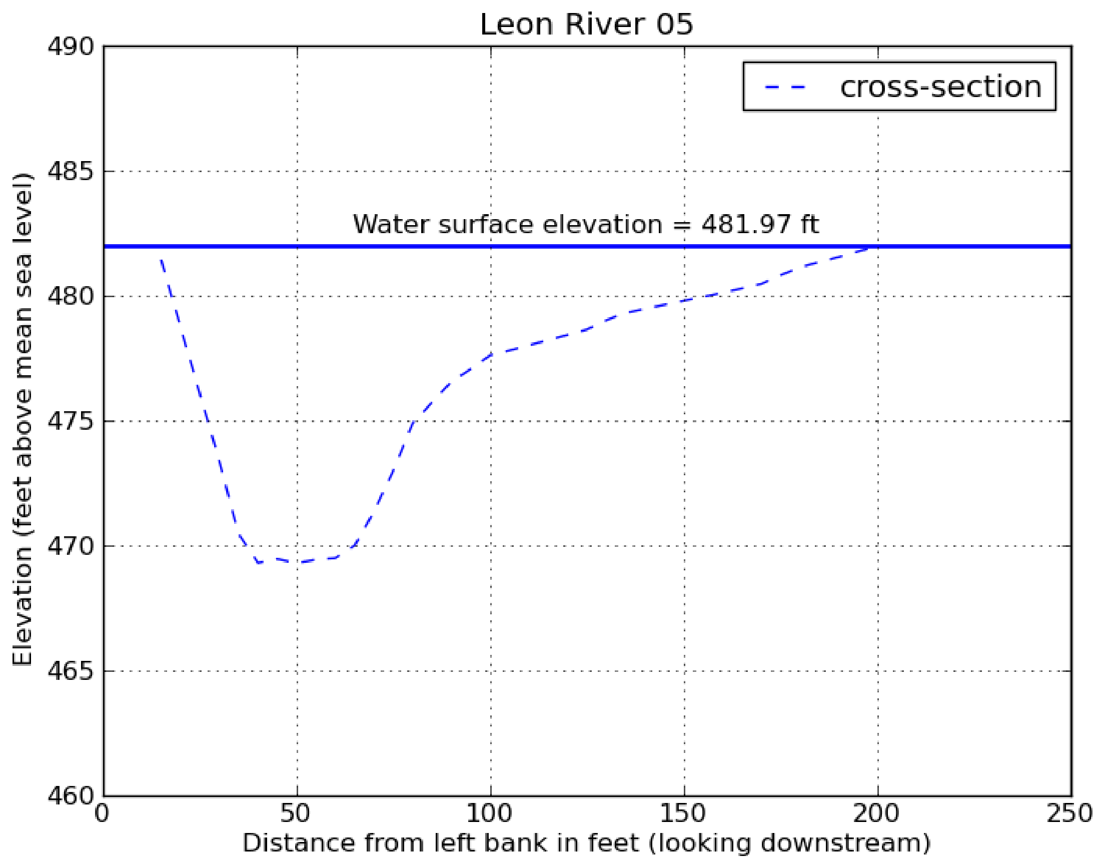



Leon River 01
cross-section
Water surface elevation = 481.97 ft
Elevation (feet above mean sea level)
490
485
480
475
470
465
460
0
50
100
150
200
Distance from left bank in feet (looking downstream)

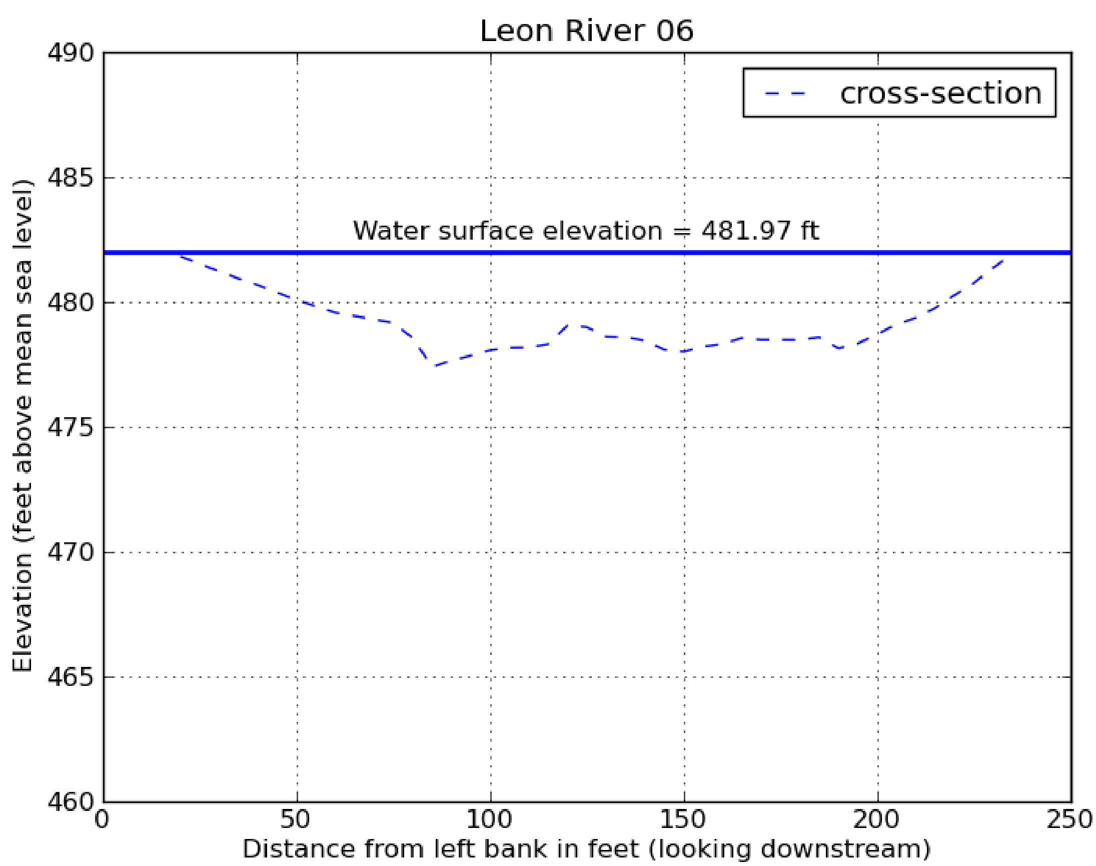

Leon River 02
cross-section
Water surface elevation = 481.97 ft
Elevation (feet above mean sea level)
490
485
480
475
470
465
460
0
50
100
150
200
Distance from left bank in feet (looking downstream)


Leon River 03
cross-section
Water surface elevation = 481.97 ft
Elevation (feet above mean sea level)
490
485
480
475
470
465
460
0
50
100
150
200
Distance from left bank in feet (looking downstream)


Leon River 04
cross-section
Water surface elevation = 481.97 ft
Elevation (feet above mean sea level)
490
485
480
475
470
465
460
0
50
100
150
200
250
Distance from left bank in feet (looking downstream)



Leon River 05
cross-section
Water surface elevation = 481.97 ft
Elevation (feet above mean sea level)
460
465
470
475
480
485
490
0
50
100
150
200
250
Distance from left bank in feet (looking downstream)



Leon River 06
cross-section
Water surface elevation = 481.97 ft
Elevation (feet above mean sea level)
460
465
470
475
480
485
490
0
50
100
150
200
250
Distance from left bank in feet (looking downstream)

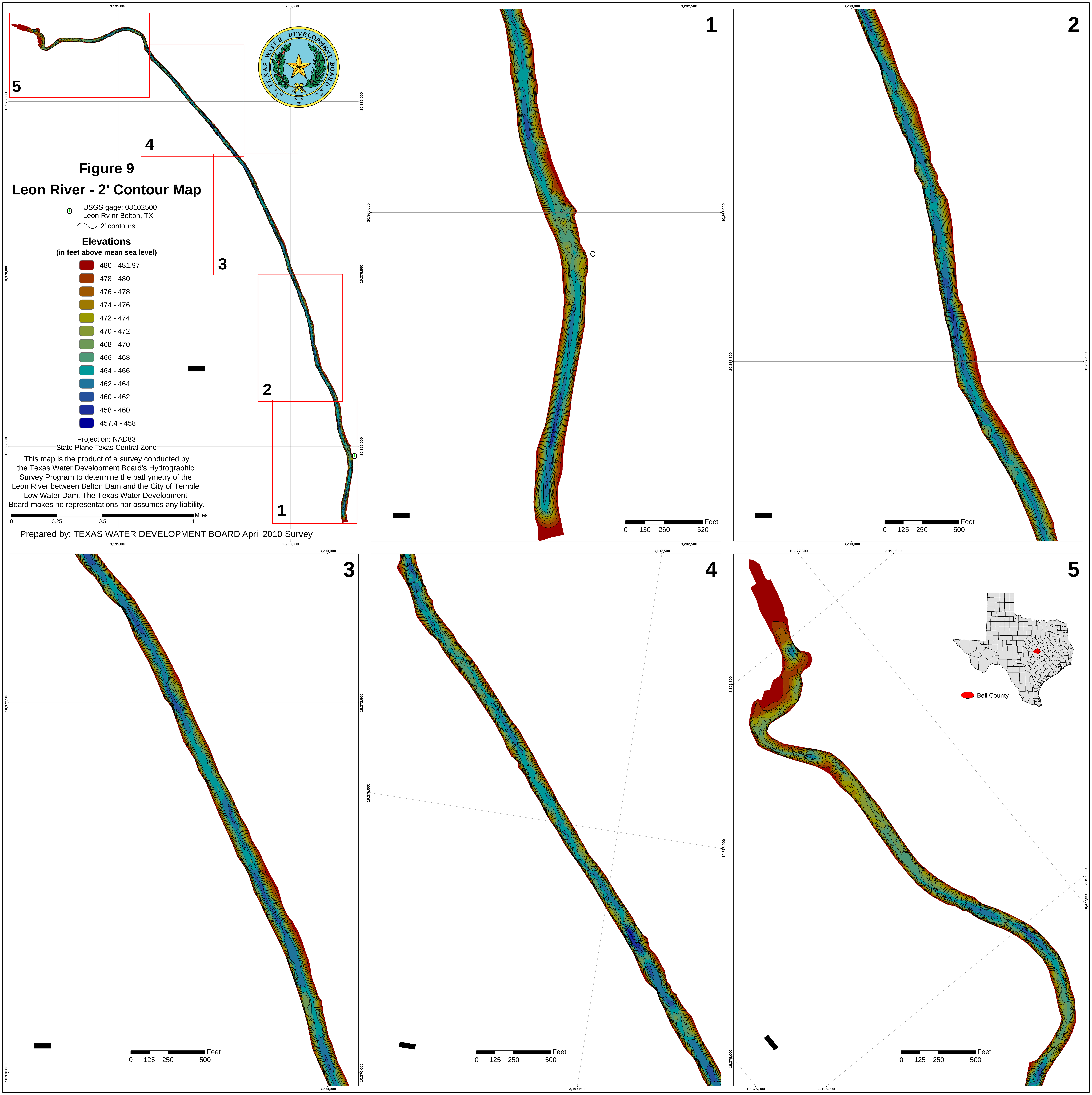


Figure 9
Leon River - 2' Contour Map
USGS gage: 08102500
Leon Rv nr Belton, TX
2' contours
Elevations
(in feet above mean sea level)
480 - 481.97
478 - 480
476 - 478
474 - 476
472 - 474
470 - 472
468 - 470
466 - 468
464 - 466
462 - 464
460 - 462
458 - 460
457.4 - 458
Projection: NAD83
State Plane Texas Central Zone
This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the bathymetry of the Leon River between Belton Dam and the City of Temple Low Water Dam. The Texas Water Development Board makes no representations nor assumes any liability.
0 0.25 0.5 1 Miles
Prepared by: TEXAS WATER DEVELOPMENT BOARD April 2010 Survey
TEXAS WATER DEVELOPMENT BOARD
1
2
3
4
5
0 130 260 520 Feet
0 125 250 500 Feet
Bell County