LiDAR Acquisition Report
Bell-McLennan Area of Interest, TX

Prepared for:
Texas Water Development Board

Contract # CCG-GIS-2008-001-3
Purchase Order: 580-11-1213

Photo Science Project # 7553-005

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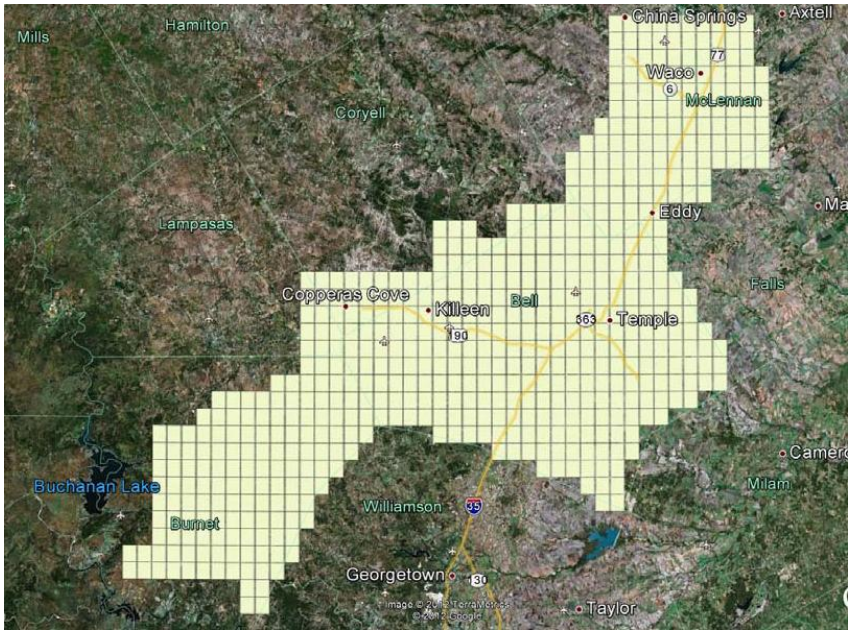
Section 1: Project Plan & Overview

The following is a Light Detection and Ranging (LiDAR) Acquisition Report detailing the technical procedures associated with the Bell-McLennan Area of Interest (Purchase Order 580-11-0547). This project was issued to Photo Science by the Texas Water Development Board (contact # CCG-GIS-2008-001-3) on January 27, 2011. The purpose of this task assignment was to provide LiDAR collection and processing services in adherence to HPIDS RFO: LiDAR Delivery and Quality Control Statement of Work. Reference is made to Photo Science's proposed Project Plan submitted to the TWDB on January 7, 2011 (ref: Photo_Science_Proposal_580111213_LM.pdf).

Note that the original project plan included a total of 378 DO3Q. The actual project tasking was expanded along the southwestern portion of the AOI for an actual project size of 515 Flood Soils DO3Q. Although the proposed technical specifications documented in the Project Plan remained constant, the preliminary flight diagrams were modified to encompass the expanded AOI footprint.

Photo Science provided professional LiDAR acquisition services necessary to collect a pulse density (nominal) of ≥1.0 point per square meter in the AOI. Specifications called for a defined 25cm vertical accuracy requirement in the flood / soils area. The total Bell-McLennan AOI area collected was approximately 2,349 square miles. Photo Science was responsible for complete acquisition of this AOI. The Bell-McLennan AOI boundary area is depicted below.



The AOI was covered by 680 flight lines and 62 mission lifts. Of note, undetected sensor failure with Optech sensor (09SEN246) contributed to re-flight requirements totaling 127 flight lines. As this sensor failure impacted schedule, Photo Science provided a copy of Optech's ALTM Repair Report (dated March 27, 2011) for TNRIS' records. All flights for the project were accomplished with customized single-engine Cessna 206 aircraft which provide an ideal, stable aerial base for LiDAR acquisition. This platform has relatively fast cruise speeds that are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which can prove ideal for collection of high-density point spacing.

Photo Science utilized a total of four LiDAR sensors for this project. These sensors included a Leica ALS50-II LiDAR sensor (SN-019), and three Optech Gemini's (SN-240, SN-246, and SN-247). The maximum frequency of the Leica sensor is 150 kHz, while that of the Gemini's are 167 kHz. Both

manufacturer configurations utilize multi-pulse in-the-air option (MPIA). These sensors are equipped with the ability to measure up to 4 returns per outgoing pulse from the laser which comes in the form of 1st, 2nd, 3rd, and last returns. The intensity of the first three returns is also captured during the aerial acquisition.

Final acquisition planning included the design of five subsections generally centered on a similar number of base station locations. Primary base stations locations consisted of existing monuments referenced as ILE, PWG, T27_A, T74, and TPL. Secondary base stations were also established as alternative control locations in the subsections of TPL and BMQ.

The Bell-McLennan AOI encompassed flood /soils areas. The basis of planning included key factors such as: accuracies; type of development; amount and type of vegetation within the project area; the required data posting; and potential altitude restrictions for flights in the general area. These collection parameters resulted in a swath width of 1,326 meters and an average point distribution of 1.5 points per square meter. The following documents the parameter and sensor values established for the AOI.

Terrain and Aircraft		
Flying Height AGL	1981	m
Recommended Ground Speed (GS)	100	kts
Scanner		
Field of View (FOV)	37	degrees
Maximum Scan Rate	38.79	Hz
Scan Rate Setting used (SR)	38.4	Hz
Laser		
Maximum Laser Pulse Rate	116800	Hz
Laser Pulse Rate used	116800	Hz
Multi Pulse in Air Mode	Enabled	
Gain Values (Up/Down)	12 / 3	
Range Intensity mode	5	
Recommended Laser Current	76	%
Coverage		
Full Swath Width	1325.67	m
Point Spacing and Density		
Maximum Point Spacing Across Track	1.34	m
Maximum Point Spacing Along Track	1.34	m
Across Track/Along Track Ratio	1	
Average Point Density	1.71	pts / m^2
Average Point Area	0.58	m^2
Average Point Spacing	0.76	m
Nadir Point Density	1.12	pts / m^2
Accuracy		
Estimated Across Track Accuracy	0.23 - 0.26	m
Estimated Along Track Accuracy	0.23 - 0.25	m
Estimated Height Accuracy	0.12 - 0.14	m

Photo Science received authorization to proceed on this project area on January 27, 2011. Acquisition commenced on March 11, 2011 and was finalized on June 9, 2011 (including all re-flights).

Data Anomalies & Corrective Action

In December of 2010, Photo Science took delivery of three new Optech Gemini sensors. These sensors were deployed in March of 2011 to the Bell-McLennan AOI for acquisition purposes. Operating within Optech's published sensor parameters; Photo Science designed an acquisition strategy to gain performance efficiencies from the new sensors. In this regard, the sensors were configured to pulse at 125 kHz. During action, one Gemini sensor did malfunction, was repaired under warranty service, and a portion of the AOI in which this sensor had collected data, was re-flown. Beyond this event, no addition anomalies were detected in the dataset as part of Photo Science's initial post-processing quality control.

However, after large blocks of data where post-processed and the pilot dataset was developed, excessive "noise" was observed in the dataset. This noise was consistent throughout all areas acquired

by the Optech sensors. Additionally, during joint pilot dataset review with TNRIS, it was further observed that the intensity values of the pilot data were significantly lower than previous task order deliveries. These lower intensity values were also not consistent with Photo Science's experience with Optech sensors on previous projects, acquired at a reduced scanning rate. No anomalies of a similar nature were observed in the Leica acquisition areas.

After an extensive internal quality review process, Photo Science reached out to Optech for technical assistance and support. Photo Science delivered a sample TNRIS project dataset to Optech for their analysis. As a result of this action, it was determined that Optech had provided limitedly-distributed acknowledgement of a Pulse Rate Frequency (PRF) issue, consistent with that observed in the dataset. Although the maximum sensor pulse rate specification is 167 kHz, as the PRF is increased the intensity, or the amount of energy applied to each pulse, is decreased. Based on the fundamental design of the Gemini, there is a fixed amount of power being used by the sensor to fire the laser. Therefore, as the PRF increases, that amount of power has to be spread across more pulses.

In order to decrease the amount of noise present in the data set, Optech provided Photo Science with an application referred to as the Dark Surface Elevation Noise Smoother (DSENS). The DSENS is a filter that is added to the settings inside of Dashmap to smooth the data during the creation of the LAS strips from the raw LAS data. Optech provided a document that contained the recommended workflow process, as well as the optimal settings recommended to adjust the TNRIS data set.

Visually, the DSENS application appeared to completely resolve the excessive noise issue; however, Photo Science felt that an independent accuracy assessment was necessary to confirm the dataset was meeting specifications. In this regard, Photo Science randomly identified two areas to validate the accuracy of the DSENS solution. These areas were additionally selected based on their low reflectivity characters. Although accuracy and reflectivity were regarded as exclusive factors, Photo Science did want to confirm that expectation.

Although outside of the TNRIS project scope, Photo Science collected an additional 101 control points, at our expense, to validate the accuracy of the DSENS. Two Photo Science GPS Technicians were mobilized to Waco, Texas, on August 27, 2011. The GPS technicians utilized RTK surveying techniques and were equipped with dual frequency Trimble R7 GNSS and R8 GNSS GPS receivers. NGS monuments J 900 and M 1302, located near the collection sites, serve as the basis of Horizontal and Vertical positioning.

With the R7 GNSS receiver serving as the base-station and occupying the NGS monuments, the R8 GNSS (rover) receiver collected truthing points along Steinbeck Bend Road and South New Road. The technician collected points on the shoulder (hard surface) and a point perpendicular in open, flat terrain areas (bare earth) on both roads. The points were collected for approximately one mile and spaced 200 - 300 feet apart. All points were occupied twice and an averaged position was used as a final position for each point.

The analysis of the RMSE revealed the dataset was in vertical specification compliance, and the excessive noise had been removed. Referenced in Attachment A are results of the Ground Control GPS accuracy assessment, conducted for this purpose.

Section II: GNSS-IMU Trajectory Information

Equipment

Photo Science owns and operates all the equipment utilized for the collection and post-processing effort. Photo Science deployed sensor platforms consisting of one Leica ALS50-II and three Optech Gemini sensors configured our Cessna 206 aircraft (tail #'s N9471R, N7320G, & N2448G, and N7266Z). Systems configurations included NovAtel 12-channel, L1/L2 dual frequency GNSS antennas collecting at 2 Hz. Photo Science's Leica ALS50-II MPiA serial number 019 is equipped with an Applanix POS A/V v4 positioning and orientation system which utilizes an Inertial Measurement Unit (IMU) operating at 200Hz data sampling rate. Photo Science's Gemini's are also equipped with Applanix positioning and attitude systems which also utilizes a 200Hz IMU configuration.

Primary Base Stations utilized for the project are referenced as separate files. These include the following:

- ILE Base Station Monument.pdf
- PWG Base Station Location.pdf
- T27_A Base Station Monument.pdf
- T74 Base Station Location.pdf
- TPL Base Station Monument.pdf.

General descriptions of primary GPS base stations utilized during the acquisition phase of this AOI are as follows:

1. BMQ (T27 A) – Burnet Municipal Kate Croddock Field Airport
2. ILE – Killeen Municipal Airport
3. PWG – McGregor Municipal Airport
4. T74 – Taylor Municipal Airport
5. TPL – Draughon-Miller Municipal Airport

Data Processing

Airborne GNSS and IMU data was post-processed and quality control using one of two software suites, depending of the configuration of the sensor. The Leica uses an Applanix POS A/V system so it is processed using Applanix POS MMS v5.1 software. The Optech Gemini's are processed with DashMap software. Both software suites utilize ground GPS base station data to differentially correct the aircrafts' position in space, then utilize the IMU data to determine the roll, pitch, and heading to generate either a smoothed best estimate of trajectory ('SBET', Applanix data) necessary for the point cloud post processor to develop the appropriate swath projections from the LiDAR missions.

Note: a copy of printout documenting Photo Science delivery of the GPS & SBET data to TNRIS on August 5, 2011 is referenced in file 580111213_7553-005__Bell-Mclennan_GPS_SBET.pdf

Section III LiDAR Systems Configurations

The LiDAR data was acquired Leica ALS50-II 150kHz and Optech Gemini (multi-pulse enabled) LiDAR systems, on board Cessna 206 Aircraft. The ALS50-II LiDAR system, developed by Leica Geosystems of Heerbrugg, Switzerland, includes the simultaneous first, intermediate and last pulse data capture module, the extended altitude range module, and the target signal intensity capture module. The Gemini's were manufactured by Optech Incorporated of Vaughan ON, Canada. The Gemini's utilize the DASHMap LiDAR processing software. System specifications for both sensor types are included on the following pages.

Optech Gemini	
Operating Altitude	80 to 4,000 m
Scan Angle	0 to ±25°, in increments of ±1°
Swath Width Variable	0 to 0.93 x altitude (m)
Scan Frequency	100 Hz
Maximum Pulse Rate	33 - 167 kHz
Range Capture	Up to 4 range measurements for each pulse, including last
Elevation Accuracy	5 - 10 cm typical; ±1-sigma
Horizontal Accuracy	1/11,000 x altitude; ±1-sigma*
Number of Returns per Pulse	4 (first, second, third, last)
Number of Intensities	Intensity capture 4 intensity readings
Intensity Digitization	12-bit dynamic range for each measurement
MPia (Multiple Pulses in Air)	Yes
Laser Beam Divergence	0.15/0.25 mrad or nominal (1/e full angle) 0.80 mrad
Laser Classification	Class IV (FDA 21 CFR)
Eye Safe Range	
Roll Stabilization	Roll compensation 5 Hz update rate (Scan angle + roll comp. angle = 30°, e.g., ±20° scan allows ±10°compensation)
Power Requirements	28 VDC, 35 A (maximum)
Operating Temperature	Control rack: +10°C to +35°C (ambient) Sensor head: -10°C to +35°C
Humidity	0 to 95% non-condensing
Supported GNSS Receivers	Any dual frequency receiver with Rinex output

Leica ALS50-II	
Operating Altitude	200 - 6,000 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 90 Hz (variable based on scan angle)
Maximum Pulse Rate	150 kHz
Range Resolution	Better than 1 cm
Elevation Accuracy	8 – 24 cm single shot (one standard deviation)
Horizontal Accuracy	7 – 64 cm (one standard deviation)
Number of Returns per Pulse	4 (first, second, third, last)
Number of Intensities	3 (first, second, third)
Intensity Digitization	8 bit intensity + 8 bit AGC (Automatic Gain Control) level
MPia (Multiple Pulses in Air)	8 bits @ 1nsec interval @ 50kHz
Laser Beam Divergence	0.22 mrad @ $1/e_2$ (~0.15 mrad @ 1/e)
Laser Classification	Class IV laser product (FDA CFR 21)
Eye Safe Range	400m single shot depending on laser repetition rate
Roll Stabilization	±5° at full FOV
Power Requirements	28 VDC @ 25A
Operating Temperature	0-40°C
Humidity	0-95% non-condensing
Supported GNSS Receivers	Ashtech Z12, Trimble 7400, Novatel Millenium

Section IV: LiDAR Accuracy Assessment

The following documents Photo Science Accuracy Assessment for the Bell-McLennan AOI. A total of 30 quality control points were provided by URS for use in this analysis.

Statistical Analysis	
Average Dz	-0.014
Minimum Dz	-0.209
Maximum Dz	0.229
RMSE	0.104
Standard Deviation	0.105

Coordinate System
Horizontal Projection
NAD83 - UTM Zone 19N, Meters
Vertical Datum
NAVD88 - Geoid09, Meters

Point	Easting	Northing	Known Z	LIDAR Z	Dz
BMCS-01	659823.892	3502700.714	184.595	184.59	-0.01
BMCS-03	685129.832	3497656.167	120.986	120.95	-0.04
BMCS-05	679342.320	3491888.883	119.893	119.83	-0.06
BMCS-07	656635.957	3482260.670	195.856	195.75	-0.11
BMCS-09	683916.469	3478599.273	119.052	119.12	0.07
BMCS-11	662024.009	3471863.035	199.684	199.72	0.04
BMCS-13	676729.779	3480697.668	156.581	removed	*
BMCS-15	642241.385	3458997.558	238.465	238.32	-0.15
BMCS-17	625957.027	3458409.767	234.612	234.71	0.10
BMCS-19	597972.958	3447086.485	344.246	344.30	0.05
BMCS-21	614575.568	3443012.975	297.162	297.19	0.03
BMCS-23	650357.891	3448262.933	198.995	199.11	0.12
BMCS-25	664084.166	3445611.006	182.530	182.49	-0.04
BMCS-27	635153.042	3440160.517	218.936	218.90	-0.04
BMCS-29	619089.176	3431977.723	277.749	277.54	-0.21
BMCS-31	668098.212	3438055.048	148.326	148.27	-0.06
BMCS-33	674590.850	3434332.723	138.046	138.18	0.13
BMCS-35	653847.882	3430036.751	153.750	153.71	-0.04
BMCS-37	591827.434	3425877.785	336.289	336.43	0.14
BMCS-39	626091.449	3426020.937	240.835	240.84	0.01
BMCS-41	669181.82	3422900.07	158.75	158.69	-0.06
BMCS-43	646186.50	3414679.52	197.64	197.62	-0.02
BMCS-45	634109.55	3417871.29	223.90	223.96	0.06
BMCS-47	598375.49	3419457.29	338.96	339.19	0.23
BMCS-49	577004.87	3419588.86	424.77	424.68	-0.09
BMCS-51	581324.94	3414820.41	398.68	398.81	0.13
BMCS-53	572824.41	3407367.83	436.42	436.32	-0.10
BMCS-55	581023.04	3402893.87	430.66	430.50	-0.16
BMCS-57	592819.51	3401731.83	358.12	358.14	0.02
BMCS-59	572841.14	3397714.98	357.39	357.23	-0.16
BMCS-61	570776.68	3389602.97	340.36	340.19	-0.17
BMCS-63	589242.34	3390121.15	409.90	409.86	-0.04

Section 5: Flight Log(s)

Flight logs are referenced as attachment files to this document as follows:

- 7553-005_BMQ_Flight_Logs.pdf
- 7553-005_BMQ_Reflights.pdf
- 7553-005_ILE_Flight Logs_A.pdf
- 7553-005_ILE_Flight_Logs_B.pdf
- 7553-005_ILE_Flight_Logs_C.pdf
- 7553-005_PWG_Flight_Logs.pdf
- 7553-005_PWG_Reflights.pdf
- 7553-005_T74_Flight_Logs.pdf
- 7553-005_T74_Reflights.pdf
- 7553-005_TPL_Flight_Logs.pdf
- 7553-005_TPL_Reflights.pdf

Appendix A

The Table below documents Photo Science ground control accuracy assessment undertaken to validate Optech's Dark Surface Elevation Noise Smoother (DSENS) process supported corrective dataset "noise" reduction while maintaining vertical accuracy specifications.

Statistical Analysis	
Average Dz	-0.085
Minimum Dz	-0.25
Maximum Dz	0.09
RMSE	0.107
Standard Deviation	0.066

Coordinate System
Horizontal Projection
NAD83 - UTM Zone 19N, Meters
Vertical Datum
NAVD88 - Geoid09, Meters

Point	Easting	Northing	Known Z	LIDAR Z	Dz
101	671317.252	3498579.879	137.456	137.33	-0.13
102	671383.322	3498586.468	137.282	137.18	-0.10
103	671446.125	3498589.001	137.112	136.99	-0.12
104	671506.850	3498587.687	136.999	136.88	-0.12
105	671574.263	3498583.317	136.718	136.67	-0.05
106	671634.673	3498578.529	136.560	136.44	-0.12
107	671697.116	3498573.464	136.407	136.38	-0.03
108	671759.038	3498568.423	136.423	136.29	-0.13
109	671829.591	3498562.733	136.569	136.45	-0.12
110	671887.097	3498557.771	136.648	136.58	-0.07
111	671942.606	3498553.236	136.688	136.61	-0.08
112	672003.473	3498548.232	136.791	136.68	-0.11
113	672062.902	3498543.470	136.788	136.61	-0.18
114	672125.595	3498538.378	136.852	136.79	-0.06
115	672183.568	3498533.451	136.819	136.73	-0.09
116	672247.985	3498528.308	136.633	136.46	-0.17
117	672309.413	3498523.447	136.417	136.34	-0.08
118	672366.800	3498518.742	136.179	135.99	-0.19
119	672433.346	3498513.188	135.975	135.86	-0.12
120	672491.086	3498508.668	135.725	135.58	-0.15
121	672555.97	3498503.26	135.45	135.40	-0.05
122	672617.18	3498498.38	135.27	135.13	-0.14
123	672677.69	3498493.33	135.07	134.92	-0.15
124	672739.93	3498488.79	135.06	134.86	-0.20
125	672798.25	3498485.42	135.25	135.03	-0.22
126	672864.57	3498480.54	135.46	135.33	-0.13
127	672926.66	3498475.54	135.70	135.52	-0.18
128	672983.59	3498471.03	135.91	135.79	-0.12
129	673040.40	3498465.79	136.22	136.03	-0.19
130	673107.94	3498458.27	136.40	136.27	-0.13
131	673164.79	3498453.58	136.40	136.25	-0.15
201	671315.94	3498591.58	136.68	136.60	-0.08

Point	Easting	Northing	Known Z	LIDAR Z	Dz
202	671381.89	3498600.74	136.97	136.90	-0.07
203	671446.21	3498606.68	136.83	136.82	-0.01
204	671506.58	3498607.48	136.43	136.37	-0.06
205	671576.77	3498602.34	135.79	135.75	-0.04
206	671636.38	3498595.51	135.24	135.21	-0.03
207	671698.03	3498591.98	135.36	135.30	-0.06
208	671760.12	3498584.61	135.39	135.39	0.00
209	671839.92	3498579.95	136.66	136.66	0.00
210	671886.85	3498574.35	136.51	136.50	-0.01
211	671943.25	3498567.51	136.51	136.54	0.03
212	672004.56	3498561.92	136.52	136.53	0.01
213	672063.17	3498555.60	136.40	136.34	-0.06
214	672125.97	3498551.71	136.40	136.42	0.02
215	672185.15	3498549.62	136.38	136.38	0.00
216	672250.46	3498541.57	136.30	136.26	-0.04
217	672307.67	3498532.78	136.01	135.96	-0.05
218	672374.32	3498526.99	136.05	135.97	-0.08
219	672433.47	3498523.03	135.64	135.64	0.00
220	672490.77	3498516.05	134.47	134.46	-0.01
221	672555.97	3498509.57	134.28	134.19	-0.09
222	672618.48	3498505.96	133.97	133.93	-0.04
223	672677.72	3498506.52	133.22	133.16	-0.06
224	672740.49	3498498.17	133.33	133.25	-0.08
225	672800.01	3498495.52	135.06	134.98	-0.08
226	672865.35	3498491.17	135.76	135.69	-0.07
227	672932.49	3498483.83	135.52	135.39	-0.13
228	672983.66	3498482.28	135.80	135.67	-0.13
229	673039.49	3498480.56	136.14	136.04	-0.10
230	673108.47	3498469.14	136.30	136.20	-0.10
231	673165.05	3498465.83	135.94	135.89	-0.05
301	676188.07	3487476.51	150.67	150.53	-0.14
302	676106.15	3487497.34	151.68	151.57	-0.11
303	676035.90	3487493.63	152.61	152.51	-0.10
304	675940.60	3487473.03	154.05	153.96	-0.09
305	675852.96	3487453.59	154.80	154.70	-0.10
306	675761.57	3487433.22	154.84	154.71	-0.13
307	675672.80	3487413.52	154.56	154.41	-0.15
308	675587.57	3487394.68	154.34	154.26	-0.08
309	675497.04	3487374.56	154.22	154.12	-0.10
310	675388.37	3487350.90	155.77	155.71	-0.06
311	675296.96	3487347.86	157.61	157.54	-0.07
312	675219.05	3487367.71	159.31	159.06	-0.25
313	675140.15	3487415.20	161.51	161.30	-0.21
314	675074.73	3487476.56	162.74	162.62	-0.12
315	675013.94	3487546.43	163.19	163.00	-0.19
316	674952.00	3487605.06	162.61	162.46	-0.15

Point	Easting	Northing	Known Z	LIDAR Z	Dz
317	674882.02	3487671.06	162.28	162.10	-0.18
318	674814.36	3487734.26	162.89	162.72	-0.17
319	674748.95	3487796.44	164.38	164.24	-0.14
320	674692.78	3487849.21	165.89	165.76	-0.13
401	676185.02	3487465.33	150.18	150.18	0.00
402	676102.33	3487484.26	151.12	151.08	-0.04
403	676039.66	3487478.88	151.49	151.49	0.01
404	675945.32	3487457.67	152.57	152.59	0.02
405	675855.43	3487442.40	153.47	153.39	-0.08
406	675763.70	3487419.28	153.96	153.90	-0.06
407	675678.85	3487404.78	154.38	154.31	-0.07
408	675589.76	3487387.57	153.41	153.50	0.09
409	675498.68	3487366.65	152.99	153.07	0.08
410	675391.60	3487345.59	155.56	155.61	0.05
411	675294.99	3487336.54	157.20	157.13	-0.07
412	675212.84	3487353.82	159.61	159.53	-0.08
413	675129.08	3487401.98	161.91	161.82	-0.09
414	675063.13	3487462.71	162.77	162.68	-0.09
415	675021.94	3487554.91	163.18	163.02	-0.16
416	674965.70	3487619.80	162.47	162.53	0.06
417	674893.43	3487680.32	162.09	162.04	-0.05
418	674827.71	3487749.56	162.28	162.18	-0.10
419	674729.76	3487777.12	165.68	165.59	-0.09
420	674676.58	3487835.31	166.65	166.63	-0.02