UNION COUNTY GPS NETWORK UPDATE: A FRAMEWORK FOR DATUM MODERNIZATION

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ABSTRACT:

This paper seeks to compare different methods for datum transformations for purposes of modernizing a countywide GPS network within Union County, Oregon. It explores certain deficiencies in the establishment of the original GPS network as well as determines a methodology for transforming the network to the more modern 2011 realization of NAD-83. As the National Geodetic Survey plans for the release of the new 2022 datum, it is anticipated that the adoption of the new datum will be used by the CORS network and Online Positioning User Service (OPUS) provided by the NGS. The Oregon Department of Transportation ORGN network is expected to follow. In order to prevent the Union County GPS network from being outdated, and make PLSS corners and other control points relative to the new datum, an established methodology needs to be established to ensure an accurate means of adjustment between datums and different realizations of datums.

INTRODUCTION:

The Union County GPS Network was started in 1991, with the ultimate goal of obtaining Second Order Geodetic coordinates on all Public Land Survey monuments within the county. The purpose has been:

- To maintain a perpetual record of a monuments location, acting as an independent 'accessory' to allow for replacement should a monument and its physical reference monuments be removed
- To allow for more accurate mapping by the State of Oregon's tax assessment department
- Allow for future surveyors to have access to a reliable coordinate position of a monument should that monument be inaccessible, either by physical means, inclement weather, or by landowner refusal for access

Field methods used 1-2 hour long static GPS observations on monuments, establishing baselines from a minimum of three first or second order horizontal control points. This program has been continued annually, with between 10 and 30 monuments added per year, with the ultimate goal of having second order geodetic coordinates on all public land survey monuments within the county that are suitable for GPS observation.

THE PROBLEM;

As there are improvements in technology, geodetic positioning, and continued observations, the National Geodetic Survey has continually updated the definition of the NAD-83 datum. Coupled with movements of the earth, the need to continually update the datum is necessary, as new realizations of the datum are published every few years.. Though there is funding and expertise at the national level to handle this, tackling this issue at a county level is neither within the budgetary or time constraints of a small rural county. Hence, the current GPS network continues to use the 1991 realization of the NAD-83 datum.

As more surveyors have come to rely on positioning by services such as NGS's OPUS (Online Positioning User Service) and ODOT's ORGN network, the need to maintain consistency between the datums used by these services and the one employed by Union County becomes more necessary. Currently there is approximately 0.2 ft. horizontal difference horizontal between the datum initially utilized (NAD-83(HARN)) and the most current on NAD-83(2011). Failure to update the Union County datum will only lead to potential errors by users and eventually render the entire project irrelevant.

With the announcement of a completely new NAD-22 datum, set to be released in 2025-2026, it has become pressing to establish a reliable method by which the GPS network can be updated and to maintain the ability to transform coordinates between different realizations of datums. The NAD-22 datum is anticipated to account for crustal movements, and will be a dynamic model, including a projected time dependent velocity to coordinate values. Though this makes management of a nationwide datum in the framework of dynamic geophysical forces possible, it puts the local surveyors, whose reliance on static coordinates and monuments to maintain consistency within their work, difficult. In order to build on past collected data, it is necessary to establish a way to utilize old data within the framework of any future datum updates.

OTHER ISSUES:

In addition to the question of datum transformation, there were a couple of issues that arose when examining the previous methods of establishing coordinates:

- The original specifications indicated Orthometric Heights be given in NGVD-29. Instead of computing an orthometric height via a geoid model, and then correcting for the difference between the NAVD-88 and NGVD-29 datum, this correction was applied to the ellipsoid height of the original control position (Blue Mtn CBL 0). This error was inherited from the original surveyor and has continued throughout the life of the program. Though mathematical calculation indicated a minimal effect of this error on the horizontal positioning, the true effect is unknown.
- There have been relatively inconsistent geoid models employed to correct from ellipsoid to orthometric heights. As there have been multiple surveyors that have continued the work on the GPS network, at different times, and as per new datum realizations by the NGS, there too have been updates to Geoid models. These have been inconsistently applied.
- Benchmarks established by NGS, Geological Survey and Department of Transportation tend to be established with a level of care to ensure minimal physical movement and can be situated in areas which are less likely to be disturbed. Establishment of Public Land Survey monuments have neither luxury and therefore may be subject to movement due to disturbance.
- The level of ground movement countywide is unknown. Union County spans an area of 2,039 sq. miles, and the consistency of the velocity of monuments countywide within the framework cannot be accounted for without field observation.

In order to address these issues, the transformation will seek to return the GPS network to true ellipsoid heights based on the GRS-80 ellipsoid. Data will be worked with in ellipsoid heights based on the true GRS-80 ellipsoid without any correction applied.

GENERAL DATUM ISSUES:

Though NAD-83 was the first datum to attempt an earth centered model, as opposed to a surface based model, it still relied on passive benchmarks for its establishment. The forthcoming NAD-22 is anticipated to be an active model, relying on satellite based observation coupled with continuously operating reference stations (CORS). This serves to incorporate the datum used in North America more in line with the International Terrestrial Reference Frame (ITRF). It will include a time dependent component, accounting for plate movement and velocity.

Though this solves the issues of management of a nationwide datum, this constantly iterating coordinate system presents a particular challenge to local users of geodetic coordinates. Data acquired by State and local surveyors becomes a value that is isolated in time, as the reference frame adjusts. Though users of RTK base stations will feel little effect, the increasing reliance on the ORGN network and OPUS solutions for horizontal and vertical positioning makes the importance of being able to confidently adjust between datums more important.

The purpose of this study is not only to perform an actual adjustment between NAD-83(1991) and NAD-83(2011), but to explore how local surveyors can perform such an adjustment in the future as datums evolve in the future, in an efficient and cost effective manner. And will explore options for how to publish the Union County GPS Network data in the future such that it remains relevant with future datum realizations. The NGS has models that can predict the location of datum changes. Future goals for this study will also perform a comparative study between observed adjusted results and results that are done by NGS adjustment models.

METHOD:

The general method is to reestablish geodetic coordinates on known monuments of good stability within the county utilizing updated coordinates on First Order HARN benchmarks as well as utilizing CORS and ORGN data. From this primary network, secondary control can be established on select monuments countywide, paying particular attention to stability and having a large representative sample. From this, coordinates will be converted using a 3d conformal Helmert transformation (Bursa-Wolf method), and remaining coordinates updated. Using a least squares method to establish transformation parameters should allow for examination of outliers and determination if errors are incurred by disturbance of monument, movement of earth, or random error. Following conversion of coordinates, select monuments within the county will be observed to validate the transformation model.

There are a handful of benchmarks within the county that have published adjusted coordinates in NAD-83(2011). These are the two original HARN stations (Blue Mtn Cbl 0 and NGS control point 'Cove' (PID RA0822)), and several located at the La Grande Airport. Furthermore, updated coordinates are established on the ORGN station ELG, managed by Oregon Department of Transportation, as well as P022 at the Ladd Marsh Rest Area, managed by the Plate Boundary Observatory. Outside of the county, NGS maintains CORS stations at Pendleton and at the Baker County Airport.

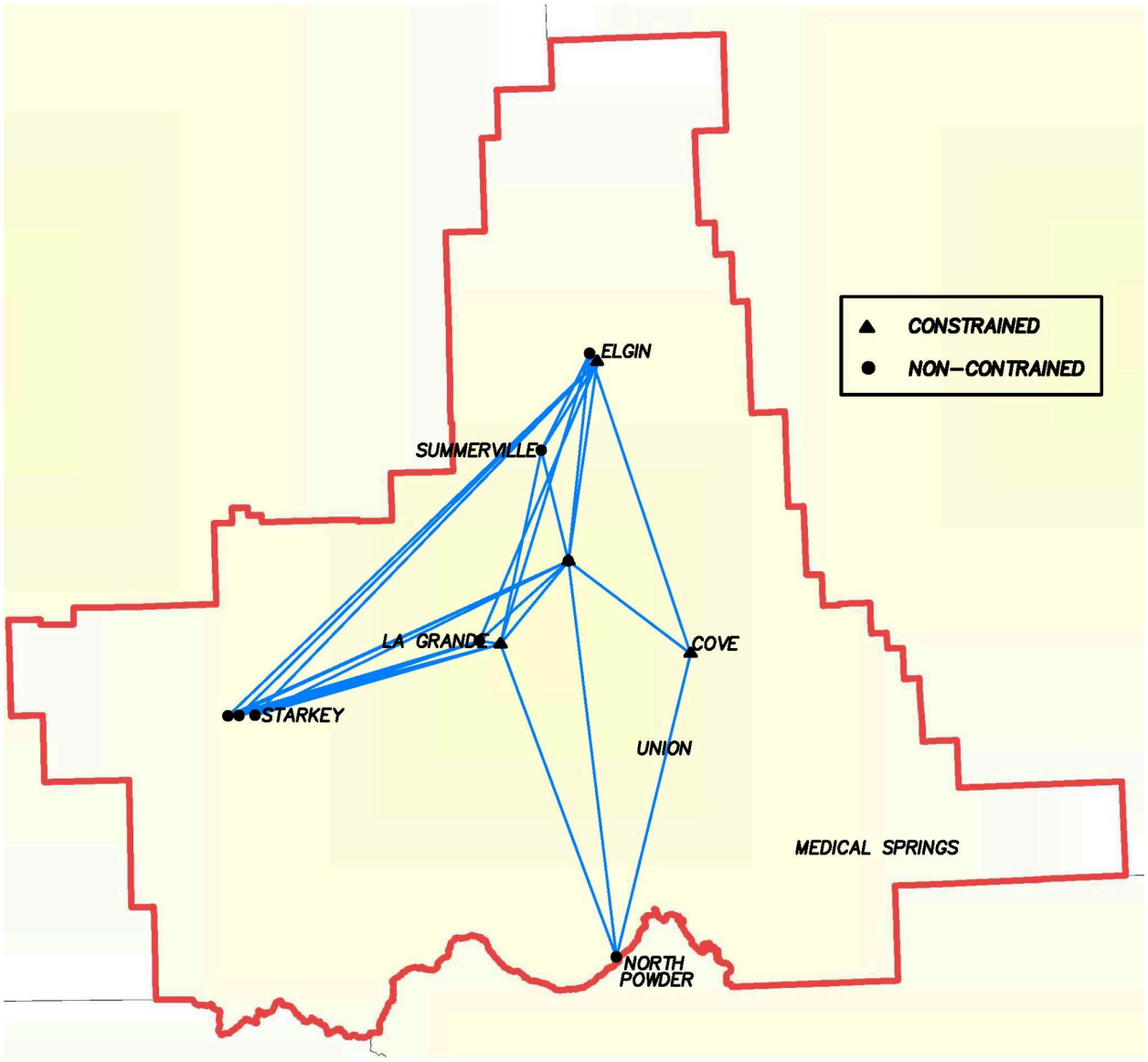
To establish the primary control network, there are several methods that will be explored, and differences between them compared.

1. Establish a seven parameter transformation using active control and passive adjusted benchmarks (Blue Mtn CBL 0 and Cove) utilizing the coordinates of the NGS datasheet for these HARN stations. This will be considered the most robust method of adjustment and the control by which other methods are compared to.
2. Establish a seven parameter transformation using active control only. The passive control established by the NGS are based on adjustment methods and not observation. This method will ignore the published adjusted coordinates of "Blue Mtn Cbl 0" and "Cove" and utilize OPUS corrected coordinates only. This will be to simulate transformation to NAD-22 coordinates, which will have no passive benchmarks to rely upon.
3. Modelensky 3 parameter transformation (3 parameter translation only) - This method seeks to do a comparative study with a simplified method that utilizes only translation factors (no scaling or rotation) and is intended to simulate an independent surveyor correcting a base station position only. This is intended to compare differences to see whether this would be a viable solution for an independent practitioner performing an adjustment with minimal resources.
4. Adjust control using NGS software only. The purpose of this would be to examine if, in fact, the NGS algorithms are sufficient for adjustment of the network, and may further reduce need for fieldwork by the Union County Surveyor.

The results of all the above transformation possibilities will be compared to give possible solutions for future adjustments.

DATA:

The diagram below indicates the control points used and the vectors to observed points. Data was collected over three days and utilized 1-2 hour observations on each point.



GPS used were a combination of Leica GS14, 15, 16 and 18 receivers utilizing GPS and GLONASS data. GNSS static data was processed in Leica Infinity software. Baseline reports and Point quality data can be found at [Index of /surveyor/UNIONCO_DATUMADJUSTMENT/BASELINEREPORT]

Below is a comparison of the coordinates, both in the 1991 realization of NAD-83 and the coordinates as observed in the 2011 realization of NAD-83.

	NAD-83(1991) GEOCENTRIC			NAD-83(2011) GEOCENTRIC		
POINT	X	Y	Z	X	Y	Z
99CASE	-6906485.249	-13003675.320	14822926.080	-6906486.210	-13003677.160	14822928.460
99POWDER	-6940118.632	-13092144.520	14730431.860	-6940119.648	-13092146.280	14730434.340
9213*	-6882238.390	-13042272.540	14800556.410	-6882239.505	-13042274.590	14800559.030
9220*	-6936069.074	-13009487.720	14804130.430	-6936070.079	-13009489.600	14804132.920
200704	-6900979.586	-12976671.550	14848900.820	-6900980.587	-12976673.540	14848903.290
ELGINA	-6875370.162	-12964803.910	14871067.790	-6875371.246	-12964805.820	14871070.310
201430	-7020443.438	-12981976.990	14789602.490	-7020444.394	-12981978.880	14789604.880
201502	-7015741.659	-12984471.190	14789513.740	-7015742.629	-12984473.020	14789516.090
2020040	-7023728.958	-12980242.710	14789622.070	-7023729.961	-12980244.560	14789624.530
GOOSE	-6941814.848	-13005530.940	14805016.710	-6941815.851	-13005532.800	14805019.120
9335	-6876800.584	-13049702.651	14797115.054	-6902818.033	-13059014.483	14776308.431

*POINTS IN NAD-83(2011) ARE BASED ON OPUS RESULTS.

POINT SHOWN AS 9220 IS THE NGS STATION 'BLUE MTN CBL 0' - GEOCENTRIC COORDINATES AS PER NGS DATASHEET ARE:
X = -6,936,070.089 Y = -13,009,489.662 and Z = 14,804,132.991
POINT SHOWN AS 9213 IS THE NGS STATION 'COVE' - GEOCENTRIC COORDINATES AS PER NGS DATASHEET ARE:
X = -6,882,239.418, Y = -13,042,274.538 and Z = 14,800,558.984

METHOD 1 RESULTS:

Below are results of the 7 parameter transformation, holding Adjusted NGS NAD-83(2011) coordinates for BlueMtnCbl0 and Cove.

SCALE(ppm)=	-0.300012963
X-ROT(dd.mmss)=	-0.°00′00.01353370″
Y-ROT(dd.mmss)=	0.°00′00.16939786″
Z-ROT(dd.mmss)=	0.°00′00.13140778″
Tx=	17.35554721
Ty=	-9.237491402
Tz=	13.45542182

Below is a table summarizing the residuals:

RESIDUALS				
POINT	**X**	**Y**	**Z**	**TOTAL**
99POWDER	-0.015	0.095	0.003	0.096
9213	0.016	-0.087	0.067	0.110
9220	-0.005	0.017	0.026	0.031
200704	0.035	-0.068	-0.012	0.077
ELGINA	-0.030	0.033	0.023	0.050
201502	-0.012	0.013	-0.055	0.057
201430	-0.001	-0.049	-0.011	0.051
GOOSE	0.003	0.025	-0.049	0.055

9935	-0.008	-0.032	0.044	0.055
99CASE	0.069	0.069	-0.103	0.142
2020040	-0.050	-0.011	0.062	0.080
ROOT MEAN SQUARED =		**0.079**		

Results are very favorable, the main outlier being 99 CASE and 9213 with residuals being 0.14 ft and 0.11 ft respectively. 99CASE is the reference monument for NGS monument "ALICEL RESET", itself a monument that was disturbed in the construction of an irrigation system. Though not apparent, 99CASE sets in an agricultural field with soft, loamy soil, and being adjacent to said newly constructed well, may have suffered disturbance in the process.

9213 is one of the two HARN stations in Union County, as its value is based on the NGS adjusted coordinate. An examination of not utilizing it in the adjustment will be done in Method 2 below.

Including all points also may indicate a weighting towards monuments within Starkey, as there were three points of close proximity to that area that were utilized. To minimize the effect of any geographic weighting, two of those points (201430 and 2020040) were removed and the calculation run again. 99CASE, due to the possibility of disturbance was removed as well. Below are the results.

SCALE(ppm)=	-0.369487862
X-ROT(dd.mmss)=	-0.°00'00.01036135''
Y-ROT(dd.mmss)=	0.°00'00.27416533''
Z-ROT(dd.mmss)=	0.°00'00.22979147''
Tx=	30.59991325
Ty=	-13.68225418
Tz=	17.8161072

And a summary of the residuals

RESIDUALS				
POINT	**X**	**Y**	**Z**	**TOTAL**
99POWDER	-0.015	0.093	-0.011	0.095
9213	0.032	-0.058	0.029	0.073
9220	-0.007	-0.050	0.088	0.101
200704	0.043	-0.045	-0.035	0.071
ELGINA	-0.014	0.069	-0.011	0.072
201502	-0.039	-0.018	-0.024	0.049
GOOSE	0.000	0.027	-0.056	0.062
9935	0.002	-0.014	0.015	0.021
ROOT MEAN SQUARED =		**0.072**		

METHOD 2 RESULTS:

In this method, the NGS adjusted coordinated for Blue Mtn Cbl 0 (9220 in Union County GPS network) and 'Cove' (9213 in Union County GPS network) were ignored and OPUS solutions for both utilized instead. Below are the resulting coordinates:

	NAD-83(1991)			NAD-83(2011)		
POINT	X1	Y1	Z1	X2	Y2	Z2
99POWDER	-6940118.632	-13092144.52	14730431.86	-6940119.663	-13092146.27	14730434.33
9213	-6882238.39	-13042272.54	14800556.41	-6882239.505	-13042274.59	14800559.03
9220	-6936069.074	-13009487.72	14804130.43	-6936070.079	-13009489.6	14804132.92
200704	-6900979.586	-12976671.55	14848900.82	-6900980.603	-12976673.54	14848903.28
ELGINA	-6875370.162	-12964803.91	14871067.79	-6875371.249	-12964805.82	14871070.31
201502	-7015741.659	-12984471.19	14789513.74	-7015742.635	-12984473.03	14789516.09
GOOSE	-6941814.848	-13005530.94	14805016.71	-6941815.857	-13005532.84	14805019.16
9935	-6902816.996	-13059012.56	14776305.89	-6902818.032	-13059014.49	14776308.43

And the resulting transformation parameters:

SCALE(PPM)	-0.432518284
ROT X (“)	0.008967397
ROT Y (“)	0.306442037
ROT Z (“)	0.27742535
TRANS X (ft)	35.47052235
TRANS Y (ft)	-17.4929585
TRANS Z (ft)	18.61297692

And the residuals

	RESIDUALS			
POINT	**X**	**Y**	**Z**	**TOTAL**
99POWDER	-0.010	0.103	-0.028	0.107

9213	-0.032	-0.098	0.066	0.123
9220	0.016	0.013	0.019	0.029
200704	0.042	-0.034	-0.038	0.066
ELGINA	0.000	0.081	-0.012	0.082
201502	-0.045	-0.040	-0.007	0.061
GOOSE	0.006	-0.010	-0.016	0.019
9935	0.025	-0.012	0.010	0.029
ROOT MEAN SQUARE =			**0.074**	

COMPARISON OF METHOD 1 AND 2

Results between the two methods are very close with a comparison of the residuals between Methods 1 and 2 (after removing 99CASE and monuments in the Starkey area) are within 0.02 ft. in 3D residuals. In comparing adjusted coordinates, there appears to be only minor differences. Within the areas of the adjustment, the differences in coordinates between any of the adjustment methods amounts to approximately 0.01 ft. However, outside of the area where monuments were reobserved are more apparent. The difference between the two adjustment methods in the North extents of Union County appears to have a difference of up to 0.04 ft, primarily in latitude. Along the Eastern extents of Union County, the differences between Method 1 and Method 2 are up to 0.03 ft., primarily in longitude. The differences in the East end of the County are relatively unconcerning, as this area falls deep within a wilderness area. However, the differences along the North end of the County should be addressed in future adjustments, with more observations being taken in Palmer Junction/Lookingglass area.

For the purposes of the datum adjustment from NAD83(1991) to the NAD83(2011) we will utilize Method 1. Though for transformation into the NAD22 datum, as there will no longer be superceded control values on ground based monuments, it is welcome to know that results are nearly identical and reliance on superceded coordinates of static monuments is unnecessary for a proper adjustment.

METHOD 3: THREE PARAMETER MODELENSKY TRANSFORMATION

Below are results of a three parameter translation only based on an average geocentric X, Y and Z translation.

POINT	DELTA X	DELTA Y	DELTA Z	RES X	RES Y	RES Z	DIST
99CASE	0.961	1.840	-2.380	-0.043	-0.043	0.080	0.101
99POWDER	1.016	1.760	-2.480	0.012	-0.123	-0.020	0.125
9213	1.026	1.990	-2.570	0.022	0.107	-0.110	0.155
9220	0.992	1.870	-2.490	-0.012	-0.013	-0.030	0.035
200704	1.001	1.990	-2.470	-0.003	0.107	-0.010	0.108
ELGINA	1.084	1.910	-2.520	0.080	0.027	-0.060	0.103
201430	0.956	1.890	-2.390	-0.048	0.007	0.070	0.085
201502	0.970	1.830	-2.350	-0.034	-0.053	0.110	0.127
2020040	1.003	1.850	-2.460	-0.001	-0.033	0.000	0.033
GOOSE	1.003	1.860	-2.410	-0.001	-0.023	0.050	0.055

9935	1.037	1.920	-2.540	0.033	0.037	-0.080	0.094

And the results of a single point translation on point 9220 (Blue Mountain Cbl 0)

POINT	res x 1	res y 1pt	res z 1pt	
99CASE	0.031	0.030	-0.110	0.118
99POWDER	-0.024	0.110	-0.010	0.113
9213	-0.034	-0.120	0.080	0.148
9220	0.000	0.000	0.000	0.000
200704	-0.009	-0.120	-0.020	0.122
ELGINA	-0.092	-0.040	0.030	0.105
201430	0.036	-0.020	-0.100	0.108
201502	0.022	0.040	-0.140	0.147
2020040	-0.011	0.020	-0.030	0.038
GOOSE	-0.011	0.010	-0.080	0.081

9935	-0.045	-0.050	0.050	0.084

The results of a simple 3 parameter translation, is intended to represent a mathematically simple solution, and though it gives residual values larger than acceptable values on a countywide level, this method, when confined to a small area, would likely show favorable results. It is likely one that may be utilized by an independent surveyor within a smaller area.

ADJUSTMENT BY NGS SOFTWARE

The National Geodetic Survey has developed its own adjustment model for conversion between datums. This is an effort done on a nationwide scale. The NCAT tool was developed to perform this calculation. It was explored whether using this online tool would suffice for purposes of a countywide adjustment. Though technically incorrect, the inputs below utilize ellipsoid heights instead of orthometric heights in an attempt to account for the height issues discussed above. It was determined that this should make little difference in the transformation of the horizontal coordinates. Online tool is available at https://www.ngs.noaa.gov/NCAT/ Below are the results:

To compare horizontal values in feet, a second table is included showing the differences in Northings and Easting based on State Plane coordinate values in Observed coordinates and coordinates established by adjustment with the NCAT tool.

	NCAT CONVERSION					
	LATITUDE (1991)	LONGITUDE (1991)	ELLIPSOID HGT	LATITUDE (2011)	LONGITUDE (2011)	
99POWDER	45.º01'22.19744"	117.º55'40.69117"	3215.690	45.º01'22.20017"	117.º55'40.69003"	3219.314
9213	45.º17'48.36390"	117.º49'12.11042"	2771.719	45.º17'48.36603"	117.º49'12.11005"	2775.351
9220	45.º18'39.41548"	118.º03'52.25915"	2682.694	45.º18'39.41791"	118.º03'52.25871"	2686.247
200704	45.º29'09.25994"	118.º00'14.38540"	2640.304	45.º29'09.26216"	118.º00'14.38514"	2643.901
ELGINA	45.º34'21.00137"	117.º56'14.89832"	2701.661	45.º34'21.00345"	117.º56'14.89807"	2705.325
201502	45.º15'08.20449"	118.º22'59.32090"	3298.562	45.º15'08.20728"	118.º22'59.31977"	3302.234
GOOSE	45.º18'51.08980"	118.º05'29.24375"	2759.548	45.º18'51.09224"	118.º05'29.24333"	2763.114
9935	45.º12'08.66695"	117.º51'37.16311"	2736.555	45.º12'08.66963"	117.º51'37.16178"	2740.144

	STATE PLANE COORDINATE COMPARISON						
	NORTHING (OBS)	EASTING (OBS)	NORTHING (ADJ)	EASTING (ADJ)	DELTA NORTHING	DELTA EASTING	DELTA POS
99POWDER	505003.56	8866997.70	505003.53	8866997.88	-0.028	0.174	0.176
9213	605726.10	8891578.91	605726.13	8891578.97	0.033	0.055	0.064
9220	608902.69	8828543.94	608902.70	8828543.98	0.012	0.034	0.036
200704	673135.74	8842135.49	673135.84	8842135.47	0.094	-0.020	0.096
ELGINA	705227.16	8858186.88	705227.17	8858186.96	0.019	0.083	0.085
201502	585210.77	8747168.39	585210.88	8747168.45	0.109	0.062	0.125
GOOSE	609876.69	8821581.35	609876.75	8821581.37	0.055	0.024	0.059
9935	571001.04	8882340.38	571001.08	8882340.49	0.040	0.108	0.115

DISCUSSION ABOUT NCAT TOOL ADJUSTMENT

Exploration of using the NCAT tool solely for adjustment is based on the idea that there would be little need to recreate any adjustment model that a well funded organization like the National Geodetic Survey, employing professionally trained geodesists, has already done. Though adjustment with the NCAT tool indicates favorable results at a fraction of the work, it appears as though the smallest residuals occur within areas immediately around the HARN stations, perhaps unsurprisingly. Monuments, particularly in the outlying areas, exhibit greater differences between adjusted coordinates and observed coordinates. As the scale of the NGS adjustment is on the nationwide scale, it appears that the effort expended in creating a local adjustment model would be worthwhile, in order to preserve the integrity of the Union County GPS network.

CONCLUSION:

This study explores different methods of adjustment between datums, and explores the needs and the methods of establishing the parameters for a countywide datum adjustment. The methodology of reliance on adjusted coordinate values of passive benchmarks or utilizing only CORS adjusted values as an initial base from which datums can be assessed seem to yield acceptable results, an important fact as the use of passive benchmarks is phased out from NGS use.

Furthermore, the use of simplified methods seems to yield results that, even though acceptable for smaller projects by local surveyors, may not be appropriate for a countywide adjustment. The comparative results from these methods and discussion is hopefully useful for smaller practitioners of which a study of this scale would not be feasible and may be adopted for local use.

As the NGS transitions to a the 2022 datum, it is recommended that future studies address the following:

- Instead of relying on Publie Land Survey Corners, that permanent durable monuments, in easy accessible locations, with clear view of the sky be established at key points in the County
- Observation of additional corners in the North end of Union County (Palmer Junction/LookingGlass area) be added to ensure the adjustment parameters are not extrapolating outside of the bounds of where it should be used
- Exploration of the minimum number of permanent monuments that are to be observed annually to ensure that this can be done within the budget constraints of the county surveyor

The study will include an online tool that can be implemented such that coordinate conversions between horizontal datums can be utilized by the public in a user friendly format. As the new datum is rolled out, coordinate transformation parameters will be computed on a biannual basis, so that not only the integrity of the Union County GPS network will be preserved, but also, so that surveyors might make use of coordinate values of points tied in previous datums and datum realizations.

As for the updating of the GPS Observation monumentation sheets, this will likely be phased out. It is anticipated that future reporting of observed and/or adjusted coordinate values will be done via a GIS website, as costs of updating all the datasheets may be prohibitive. Reporting of elevations will likely be done as ellipsoid versus an orthometric height, allowing independent users to utilize their own geoid models.