THE American Surveyor
A Foot In The Past... An Eye To The Future
May 2006

Island Network

GPS, GIS & the GLO
Exposing old errors in Wisconsin

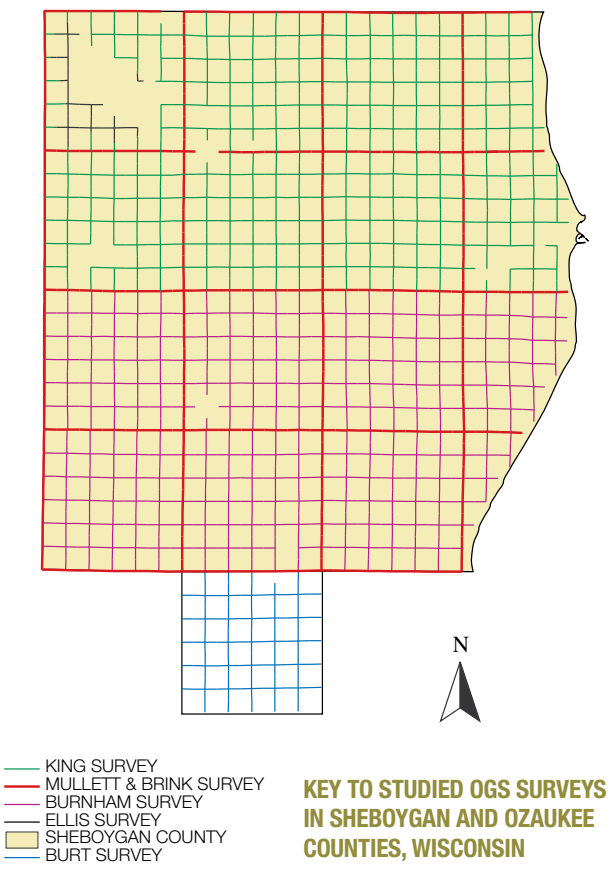
Nantucket's Compass Stones
Unlocking mysteries of the Meridian Stones

Quality Control & Assurance
Analyzing your business from the ground up

$4.95

An Analysis of GLO Surveys using GPS and GIS

Figure 1



KEY TO STUDIED OGS SURVEYS IN SHEBOYGAN AND OZAUKEE COUNTIES, WISCONSIN

Sheboygan County Wisconsin includes twelve complete survey townships. Four additional survey townships along the county's east border are made fractional by Lake Michigan. Excepting the missing parts of the fractional townships, the county is four townships by four townships square.

The original government survey (OGS) was executed by four private contractors (**Figure 1**). The township exteriors were run in 1834 by John Mullett and John Brink. One year later the township interiors were run. The two southerly tiers of townships were run by Hiram Burnham, and the northerly two tiers were run by Nehemiah King. King left most of one township unsurveyed. He meandered a large lake which he said occupied the unsurveyed area. In 1850, another contractor, Albert Ellis, was employed to survey the omitted area. It was actually occupied by a marsh.

The Ellis survey is bounded by the King survey on all sides. That is, the Ellis survey filled a hole in the King survey. Ellis was often unable to find King's corners. He sometimes found himself in heavily wooded areas in which King had reported no trees for bearings only fifteen years earlier. Modern surveyors find that the lengths of King's last half-miles, which close onto the north or west township exteriors, sometimes vary from his recorded lengths by hundreds of feet. Under both the Burnham and King contracts, closing corners were set along the north town lines. The falling east or west from the standard corner, set by Mullett and Brink, was noted in each case. Beginning in 1835, dependent surveys have shown King's closing corners to have been absent, or other than as reported.

In 1972, Sheboygan County initiated an OGS corner remonumentation program. Corners were restored on an "as

>> By Edgar Harvey, Jr. LS, PE

needed" basis. This "one section at a time" approach gave surveyors little opportunity to develop conclusions about the work that they were retracing. Only by remeasuring many of King's lines, and comparing them to remeasurements of other contemporary surveyors' lines, can it be shown that these errors occur often enough to be indicative of fraud.

If King had committed some level of fraud, it had been at a low enough level to allow it to remain undetected for 170 years. While measurement technology improved over the years, challenging terrain proved to be as much of a problem in 1990 as it was in 1835. Comparisons of small numbers of old, questionable measurements to small numbers of new, questionable measurements can only support questionable conclusions. An analysis of King's work versus the other OGS contractors' work might once have had great value to the county remonumentation program. Today, Sheboygan County is within 40 corners of being 100% remonumented. However, a comparison of the measurements of all four OGS surveyors to new much more accurate measurements could be useful to modern surveyors doing retracments in other areas, or to surveyors trying to detect improperly remonumented corners in Sheboygan County.

In 1993, Sheboygan County undertook a countywide survey project to established the coordinate positions of all monumented OGS corners in the county. It was the single largest survey executed in Sheboygan County since the OGS survey. Using a combination of GPS and terrestrial surveying systems, the project was completed through the efforts of five contractors and six contracts.

As coordinate information was received from the respective contractors, it was inserted as nodes into an AutoCAD drawing. Lines were snapped between the nodes. Work progressed over the next eleven years. Software changed. The drawing evolved into an Autodesk Land Development Desk Top (LDD) file. It is the land base for the County's robust GIS. Kept current with additions and corrections, the map is the incarnation of tens of thousands of hours of survey field work – work which began in 1834.

The Project

Using ESRI's ArcView, the values on the modern map were compared to the values on the OGS plats. The magnitude of predictable accumulating errors in the OGS survey were defined. Larger discrepancies which might be attributed to frauds were isolated. The GIS's spatial sorting capabilities were then used to analyze the occurrence of frauds. This process was repeated separately for each of the OGS contractors.

The difference between the magnitude of errors occurring in a properly executed 1830s' chain and compass survey and

OGS SURVEY STATISTICS

BURT

Measurements	119
Total distance reported measured	314,547.42 feet
Actual length of measured distances	316,263.02 feet
Maximum reported overage from actual	6.76 feet
Maximum reported underage from actual	42.05 feet
Average error	4.42 feet less than actual
Standard deviation of errors	8.21 feet
Burt to actual multiplier	1.0055

COE

Measurements	114
Total distance reported measured	302,478.00 feet
Actual length of measured distances	302,869.48 feet
Maximum reported overage from actual	20.75 feet
Maximum reported underage from actual	71.93 feet
Average error	3.43 feet less than actual
Standard deviation of errors	10.93 feet
Coe to actual multiplier	1.0013

COE VS. BURT

Measurements	114
Total distance reported measured	301186.71 feet
Burt's length of same measured distances	302,478.00 feet
Maximum reported overage from Burt	52.80 feet
Maximum reported underage from Burt	46.20 feet
Average error from Burt	11.33 feet less than Burt
Standard deviation of differences	12.28 feet
Coe to Burt multiplier	1.0043

MULLETT & BRINK

Measurements	396
Total distance reported measured	1,046,072.94 feet
Actual length of measured distances	1,048,863.09 feet
Maximum reported overage from actual	80.94 feet
Maximum reported underage from actual	113.78 feet
Average error	7.05 feet less than actual
Standard deviation of errors	15.32 feet
Mullett & Brink to actual multiplier	1.0027

ELLIS

Measurements	39
Total distance reported measured	84,772.38 feet
Actual length of measured distances	84,983.12 feet
Maximum reported overage from actual	53.19 feet
Maximum reported underage from actual	58.39 feet
Average error	5.40 feet less than actual
Standard deviation of errors	24.27 feet
Ellis to actual multiplier	1.0025

OGS SURVEY STATISTICS (CONTINUED)

BURNHAM

Measurements	814
Total distance reported measured	2,149,664.88 feet
Actual length of measured distances	2,160,909.16 feet
Maximum reported overage from actual	21.28 feet
Maximum reported underage from actual	137.00 feet
Average error	13.81 feet less than actual
Standard deviation of errors	2.88 feet
Burnham to actual multiplier	1.0052

KING

Measurements	789
Total distance reported measured	2,071,367.25 feet
Actual length of measured distances	2,072,633.31 feet
Maximum reported overage from actual	342.46 feet
Maximum reported underage from actual	280.24 feet
Average error	1.60 feet less than actual
Standard deviation of errors	43.47 feet
King to actual multiplier	1.0006

the magnitude of the deviation from actual lengths, which is likely to occur from a fraud, are often large enough to be detected. A listing of the differences between modern measurements and OGS measurements is not really a listing of errors in the OGS survey. Such a list should really be divided into three groups. Some of the discrepancies are frauds in the OGS survey (the line was not measured by the OGS survey, and the reported length was only a guess). Some are discrepancies resulting from remonumentation errors (the two measurements were not actually made between the same two points). The remaining errors are normally occurring errors in 1830s' OGS survey work. The largest errors are likely frauds, if frauds exist in the survey. However, the surveyor did not always guess wildly wrong. If frauds exist in any numbers, some must exist that fall within the normal range of accuracy of the survey. For this reason, the three types of errors cannot be separated from the original set.

"Remonumentation errors dating back to the mid 1800s are more prevalent than might have been anticipated."

Methodology

Each line in the LDD drawing was modified to place it in a layer which was assigned to its OGS surveyor. Most lines ending at a meander corner were removed. Only lines terminating at both ends at a perpetuated, or remonumented, OGS corner were left in the drawing for consideration.

An ESRI SHP file was then exported from Land Development Desktop for each of the original contracts. The attribute tables of the shp files automatically included a populated "length" field. The attribute tables were modified to include an OGS record distance field, and a field populated by the difference between the actual length, and the OGS record length. In the latter field, attention was given to the sign of the difference.

The attribute tables were exported as DBF files, into Microsoft's Excel. To present the data sets in a way which displays the general composition of the individual contracts, graphs were made in Excel. The graphs show ranges of the magnitude of error, on one axis, and the number of occurrences in each range on the other axis. Outliers which are not consistent with the accuracy attained by the particular survey are apparent, and are suspected frauds. When a threshold of error which is likely to identify a fraud was identified, a query was run in ArcView to select and highlight those lines having an OGS error greater than the threshold.

To provide a standard for comparison, the work of two additional surveyors was studied. The Town of Fredonia is situated in the northwest corner of neighboring Ozaukee County. Like Sheboygan County, it was subdivided in 1835. The surveyor was William Austin Burt, inventor of the solar compass, whose work is regarded as representing the highest practicable standard of his time. In 1881, Hervey S. Coe, the Ozaukee County Surveyor, set quarried limestones at all of the corners within the township, and rechained the distances between most of the corners. Ozaukee County has recently completed a countywide section corner control project similar to the Sheboygan County project. The 1881 stones should greatly reduce the occurrence of remonumentation errors. The Town of Fredonia also presents an opportunity to compare measurements of the same lines by two chain and compass surveyors (Burt and Coe). An AutoCAD map of the recent Ozaukee County project was obtained. It was processed in the same manner as the Sheboygan County map.

The sidebar shows statistical information of all of the studied surveys. Together with the accompanying graphs, they are helpful in analyzing the surveys.

The number of measurements compared in the surveys ranged from 39 in the Ellis survey, to 814 in the Burnham survey. The small size of the data set which is available for the Ellis survey makes its value questionable. It has a small average error, but, measurements show no consistency. Its maximum

errors are large, as is the standard deviation of its errors. Ellis's work was probably better than the data show, and probably more affected by remonumentation problems than by frauds. Most of the still unremonumented OGS corners in Sheboygan County lie within the Ellis survey area. Because of the historic low value of real property in the marsh, and because of the difficulty of the terrain in the marsh, remonumentation practices have not been as good as in other parts of the county. Generally, remonumentation has been pushed from the outside of the marsh (the King survey area), towards the center. As remonumentation in the Ellis survey area is completed, the Ellis data will likely be strengthened.

The Burt survey data is enhanced by the Coe survey. When examining the errors, attention should be paid to two types of errors. Accumulating chaining errors will almost always result in posts being set at locations which are short of the reported locations. If we find the "length of his chain," we should be able to predict the actual distances for each reported measurement. This will only work to the extent of the consistency of the surveyor's work, and the influence of other sources of error. The mean, or average error, is the best indicator of the length of his chain. The standard deviation is a good indicator of the consistency of the surveyor's work. Outliers are the best indication of the extent of other sources of errors, including frauds. In Burt's case, the average error is a fairly small (14.42 feet), and the standard deviation is only 8.21 feet. Burt's maximum errors are also small. No real outliers are to be found. It's unlikely that we could have found a better standard for comparison.

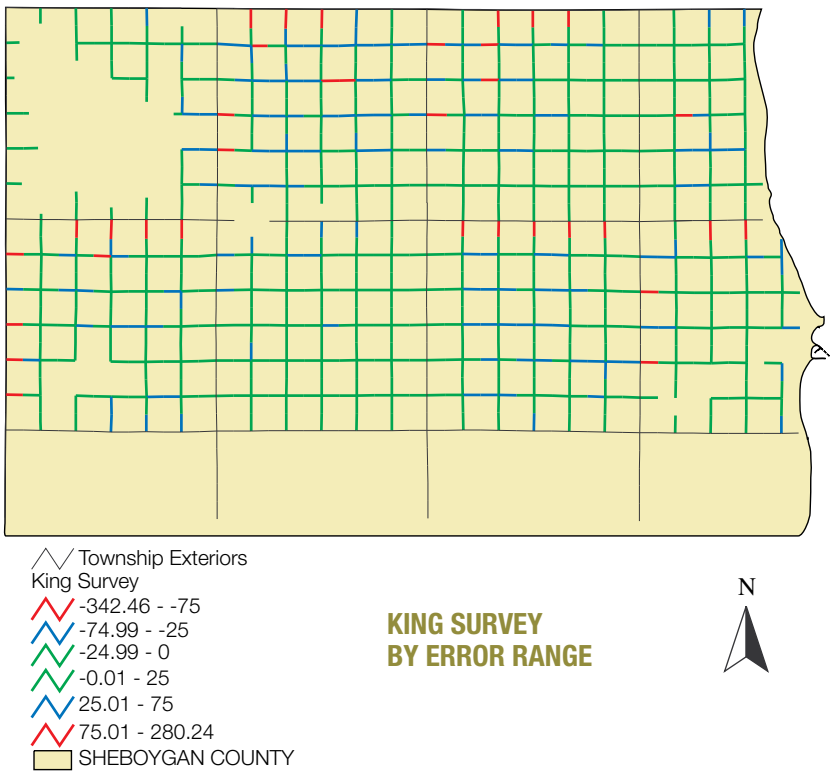
The Coe survey compares much better to actual distances than it does to the Burt survey. This could be due to remonumentation errors which took place between 1835 and 1881. In the Coe survey there are a few identifiable outliers. These were not apparent in the Burt data. The size and number of outliers in some of the other surveys make the Coe outliers seem insignificant. It is only the overall tightness of the Burt and Coe work that makes them troubling.

The township exterior survey of Mullett and Brink is of a similar quality as the Burt survey. It has some significant outliers, however. Some of these outliers appear to be caused by confusion during remonumentation, when only one corner was found where King claimed to have set a second one.

When testing the Burnham survey, in ArcView, it was noticed that the two largest outliers are of about equal value, but opposite sign. They are adjacent east-west measurements. The full mile measures fine, but the common corner is misplaced by about 130 feet. This is severe enough to be a visible jog on maps. The corner is located in a road intersection, and all occupation conforms to it. If the corner were located 130 feet further west, houses would be in the wrong section. Given that knowledge, we can be fairly certain that houses *are* in the wrong section. Records in the County Surveyor's office show that the corner was probably still at Burnham's location in 1857. It was reset at its current location in 1864.

Overlooking the two big outliers, the Burnham statistics are quite close to the Burt statistics. Looking at the first four surveys (ignoring the Ellis survey), we have put together a pretty consistent picture of what a properly executed chain and compass survey should look like. In doing so, we have eliminated any suspicion of fraud from the surveys of Burt, Mullett and Brink, Ellis, and Burnham.

Figure 2



Fraud or Half-Fraud?

Oddly, the average error in the King survey is the smallest average error of all of the surveys which were examined. However, maximum errors are huge. The standard deviation is three times that of any of the other surveys. There is a pronounced presence of outliers. The graphs of the first four surveys, show a fairly vertical "pile of errors". The King graph shows a long horizontal line of outliers in both directions from the pile, and fillets at the intersection of the vertical error pile and the base line. The fillet areas which are absent, or much less pronounced in the other surveys may be frauds which were better guesses. Or, they may be half-frauds.

When running an east-west section line, a surveyor would run the first half-mile and set a temporary 1/4 post. He was then supposed to run the rest of the line, closing to the already existing post on the other end of the section. He would return the way he came, correcting the 1/4 post. If the surveyor were

prone to frauds, he might choose not to run the second half-mile. He would report both half-miles to be some made up length. Therefore, the first half-mile was actually measured, while the second half-mile was a guess.

If the 1/4 corner then becomes lost, it would properly be re-established by single proportionate measure. The procedure would distribute the error caused by the fraud across both half-miles. These "half lies" would be harder to detect, because they are smaller in magnitude, but there would also be twice as many of them. They would exist nearer the center of the graph, and would commonly fall in the normal range of accuracy of the survey, or in the fillet areas.

This theory is supported by the GIS examination of the errors (**Figure 2**). Errors in the King survey which are larger than 75 feet are nearly always in closing half-miles. Errors between 25 and 75 feet are almost always in interior east-west lines. The occurrence of large errors in the Burnham and Burt surveys is much more random.

Conclusions

The goal of the project was in part to test the work of the various OGS surveyors, and to test the effectiveness of GIS technology in analyzing the old surveys. The process does a good job of identifying potential frauds. It cannot, however, identify an individual fraud with any degree of certainty. That would require a case-by-case examination of the involved corners and their histories.

The project was successful in documenting a common level of accuracy for honestly executed OGS chain and compass surveys in the mid 1830s. The consistency between the work of Burt, Coe, Mullett and Brink, and Burnham, proves in itself, that the work of all four was honestly executed and reported. Comparison of the King survey to the others casts an even dimmer light on his work than had been suspected at the project's onset.

Incorrect remonumentation was a larger issue than anticipated. These errors made the data "noisy," or "cluttered". Incorrect remonumentation is most prevalent in surveys having a high occurrence of fraud. It is almost impossible to remonument a lost corner correctly, if the OGS surveyor lied about where he put it. The practice of proportionate measure distributes errors across two or more measurements, reducing the size of errors due to frauds, and making them harder to detect. Remonumentation errors dating back to the mid 1800s are more prevalent than might have been anticipated.

Perhaps King, nearly alone in the wilderness and far from any other knowledgeable surveyor, surmised he would never be caught; after all, who would ever come to a place so big, so dark, and so remote? Who would ever pay money for land in this place? Like others of his time, he likely could not have comprehended what future technology would reveal. The idea still merits contemplation today – how will surveyors analyze *our* work in 170 years? ⅄

Edgar Harvey is the County Surveyor of Sheboygan County, Wisconsin.