Article

Rebuilding a resilient land boundary infrastructure following natural disasters

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ABSTRACT: The United States has an aging land survey infrastructure. The effect of natural disasters has been to rapidly destroy land survey evidence. Action taken now to preserve fading evidence will save the expense and uncertainty of lost corner locations in the future. One effective way to preserve land corners is to accurately locate them within the National Spatial Reference System (NSRS), using the Global Navigation Satellite System (GNSS).

KEYWORDS: Public Land Survey, Cadastral Survey, Corner Restoration, Natural Disaster

Introduction

Most rural land survey monuments have been located relative to the surrounding local monuments, and not positionally based on a global reference network. The original surveys monumented corners with stones, referenced by witness trees. When a natural disaster happens, the survey infrastructure is destroyed with no easy way to restore it. Compounding the problem, hurricanes and wildfires are becoming more severe and more frequent.

United States jurisprudence requires that corner monuments found in their original location are correct, regardless of errors made in measurement. When the original monuments cannot be found, corners must be restored by setting a new monument in the same location as the original monument. In the past, coordinates have not been favored by surveyors.

The National Oceanic and Atmospheric Administration (NOAA), Continuously Operating Reference Station (CORS) Network, is called the NOAA CORS Network (NCN). The refinement of Global Navigation Satellite System (GNSS) measurements, has created a reliable method of preserving locations. The best method of preserving a corner today, is to measure the corner’s position in the NCN with a GNSS receiver. The *2009 Bureau of Land Management (BLM) Manual of Surveying Instructions*, now provides for the use of coordinates for corner restoration if the coordinates are repeatable within a known standard of accuracy.

In rural parts of the United States, bearing and witness trees have been a primary method for identifying original corner monuments. Current instructions for surveying land boundaries in the public land system rely on trees to witness and verify the location of corner monuments. Where fire or flood has removed witness trees, posts, and signs, and where an accurate location has not been measured, it will be difficult to locate the remains of the original corners of the land survey in the future.

Fires are getting worse

The California Department of Forestry and Fire Protection (CAL FIRE), reports that twelve of the twenty largest wildfires have occurred since 2018. These large fires burned over seven million acres (CAL FIRE, 2024). CAL FIRE also reports that 13 of the Top 20 Deadliest California Fires, have occurred since 2000. These deadly fires killed 220 people and destroyed over 50,000 structures (CAL FIRE, 2025). According to the National Interagency Fire Center (NIFC), wildfires burn an average of over seven million acres annually in the United States (NIFC, 2024). And wildfires are not the only source of destruction, hurricanes and flooding also destroy land corners and forests (Moore, 2020).

Loss of Survey Marks is not the most tragic loss

The author lived in northern California from 2018 to 2022, and was in Shasta County when the Camp Fire killed 85 people, and the Carr Fire burned right up to the city limits of Redding. The author was also present in Humboldt County when the August Complex fire burned a million acres, and worked for the United States Forest Service during the 2020 fire season, and during the Dixie Fire. Surveyors feel a deference towards the more tragic losses. The most tragic loss is the loss of life and property. Nonetheless, we as surveyors have a duty to mitigate the harm that lies within the realm of our professional practice. We still owe a duty to the public to fix the things within our reach.

The author spent the summer of 2022 marking National Forest boundaries within the burn limits of the Dixie Fire. The Dixie Fire was an enormous wildfire that burned 963,309 acres (CAL FIRE, 2024). It was the largest single (non-complex) fire in California history. About 75 percent of the buildings in the town of Greenville, California, were destroyed (Hernandez, 2021). The Dixie Fire cost 637.4 million dollars to fight, which was the most expensive wildfire fight in history at that time (Alexander, 2022).

As far as survey marks, many monuments survived and some did not. Most bearing and line trees are gone, but many stumps remain for now. Many aluminum posts and signs melted.

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The composite type of posts left stringy glass bands of material which were visible for some time after the fire, but are now mostly covered by vegetation. Unfortunately, the hazard to survey marks is just getting started. Nearly all of the dead and burned witness trees will be removed by salvage logging operations. Dead standing timber is considered a public safety risk, and fallen timber presents a fire risk as excess fuel. If the monuments and posts survive salvage logging, then the future includes being hidden by brush and timber regeneration prior to being dug up or ran over by thinning equipment. In areas where the fire burned really hot, even steel posts melted, everything is gone. In some places the destruction is much less serious.

Obstacles to accurate control for rural boundaries

The world of the geodetic surveyor has moved forward from passive to active control points, and from monuments to network coordinates. Local land surveyors have been slower to change, but recent developments have improved the ability of local land surveyors to run accurate control under the canopy. The world has changed and the time is now, for the local land surveyor to move forward.

In the past it was difficult for the local land surveyor to appreciate the value of accurate control coordinates because coordinates were not favored relative to monuments, and because establishing state plane coordinates was just an added step. Adding state plane coordinates to a survey required an additional traverse tie to a control station monument that didn’t have anything to do with the survey, and calculating the coordinates was an additional step that didn’t have anything to do with the boundary. Measuring a corner position in the NCN using GNSS happens at the same time that essential boundary measurements are already being made.

According to standard textbooks on land boundaries, coordinates are in last place.

“Thus, the order of importance of conflicting elements that determine a boundary location is the following:

1. An unwritten right.

2. Senior right.

3. Written intentions of parties:

A. Call for a survey.

B. Monuments.

C. Distance.

D. Direction.

E. Area.

F. Coordinates. “

(Brown, 1969)

It is often forgotten that within the same text in Section 4.27, Curtis M. Brown reasoned that, “If a monument is found, and the coordinates of the monument are precisely determined by an acceptable method, and then the monument is later lost, the coordinates so established will probably form the best available means of re-establishing the former position” (Brown, 1969).

Another former obstacle to corner restoration using coordinates was the *1973 BLM Manual of Surveying Instructions*, which did not encourage coordinates in corner restoration. That obstacle has been removed by Section 2-34 of the 2009 revision of the Bureau of Land Management (BLM) Manual. “... any point can be re-established once it’s coordinates have been determined. However, great care must be exercised to ensure that the original coordinate pairs were produced by a process that is repeatable within a quantifiable accuracy standard. Repeatable coordinates may provide collateral evidence of a corner position, may constitute the best available evidence of a corner position, and in some cases, may constitute substantial evidence of the position of an obliterated corner.” (BLM, 2009).

Another part of the problem is that historically, GPS has not worked very well under the canopy. It makes sense that geodetic surveyors have made giant leaps forward using GPS for control, because geodetic surveyors choose control points that are out in the open. GPS has gradually evolved to GNSS. Antennas, firmware and software have evolved to reduce multipath. The NCN has been densified with better receivers that connect to additional satellite networks. And NOAA is updating OPUS to improve multi-GNSS processing. OPUS already works better under the canopy. In most parts of the United States, it is now possible to survey accurately under the canopy using GNSS.

Standards and Guidelines

Existing federal standards and guidelines provide for the use of GNSS receivers and the NCN to establish accurate coordinates for surveys of the public lands. The standards distinguish between local and network accuracy and between project control and corner measurements. The minimally acceptable levels of network accuracy, calculated along the semi-major axis of the 95% ellipse, are less than 0.050 meters for project control, and less than 0.100 meters for corner measurements (BLM, 2019). Canada has published wonderful guidelines, useful to land surveyors in all countries (Donahue et al., 2013). As useful and relevant as these documents are, none are specifically intended for land surveyors working in rough terrain, under the canopy, or in the forest. In fact, most of the guidelines suggest that land surveyors use caution when using GNSS, and particularly RTK, under the canopy. The original Bureau of Land Management-Forest Service guidelines from 2001 contain the following paragraph:

"**Caution**: Operations under a forest canopy using PPK or RTK methods are not recommended… For survey projects in a forest canopy environment with marginal sky visibility, static, or fast static GPS methods or even conventional optical methods should be considered in-lieu of using RTK or PPK."

(USFS/BLM, 2001). It is still true that surveyors need to watch out for bad fixes in real time, and never rely on a single occupation when measuring static.

Working under the canopy requires an all-out effort and the latest equipment. Here is a list of suggestions for improving your results taken from the GNSS Guidelines listed in this articles references;

1) Turn on and use every satellite constellation available to you. For both real time and static methods, shorten your baselines. If you are using RTK, set as many nearby project control points as necessary to create fast initializations and convenient check points. If you are using fast static in a region without many CORS stations, you may need to include your own static stations along with the CORS data and, increase observation time (Javad, 2015), (Londe, 2019).

2) Avoid using broadcast ephemeris data. Use rapid or precise instead. This may require recording raw data while operating in real time in order to post process later. If you are working in real time, use only fixed ambiguity solutions, never floating or DGPS, and always make a check measurement to a previous control point from each new base station setup (Donahue et al., 2013), (Londe, 2019).

3) Always pay attention to the number of satellites that you are viewing. Monitor Positional Dilution of Precision (PDOP) and Signal to Noise Ratio (SNR). Set your elevation mask to 15 degrees or higher, and remember that raising the height of your receiver may help. Clear the sky for your receiver as best as you can by removing trees and brush (Donahue et al., 2013), (USFS/BLM, 2001).

4) All corner positions should be based on two independent observations. If you get one OPUS solution, wait as long as practical, and then do another one. Remember this, do your best, and then do it again (USFS/BLM, 2001).

The Forest Service Handbook 5609.11-2020-1, Chapter 71, requires “All cadastral surveys for both corner positioning and control on public lands using carrier phase Global Navigation Satellite Systems technology shall comply with or exceed the GNSS accuracy standards jointly established and implemented by the Forest Service and BLM.” And once again in Chapter 72.3 under the Boundary Surveys heading, “All cadastral and land surveys using GNSS technology shall comply with BLM/Forest Service Standards for Positional Accuracy Using GNSS Technology.” Finally, under Chapter 73, “In order to place geodetic information in the public record, note the coordinate data on at least two corner positions depicted on filed survey plats. The Forest Service Land Surveyor may also consider providing geodetic data on corner perpetuation forms developed by States for recordation in local jurisdictions.” (USDA, 2020).

A simple way to meet federal standards is to occupy a land corner with a GNSS receiver for at least 35 minutes (longer if necessary). Send your file to OPUS for post processing, and then do it again. When you are done, show the coordinates on your survey plat, and file a corner form with persuasive documentation of your results. Just copy over the text from your two OPUS solutions to page two of your corner form. The idea is to create a public record of repeated reliable coordinates established with a known precision.

Here is an example of rapid static post processing results copied to the back of a state corner form:

SKETCH OF CORNER

OBSERVATION ONE
START: 3/1/2022 11:23:12 PM STOP: 3/1/2022 11:59:28 PM
REF FRAME: NAD83(2011)(EPOCH:2010.0000) ITRF2014 (EPOCH:2022.163)
X: -8295428.271(sf) 0.028(sf) -8295431.592(sf) 0.028(sf)
Y: -13467718.896(sf) 0.048(sf) -13467714.570(sf) 0.048(sf)
Z: 13658397.424(sf) 0.048(sf) 13658397.257(sf) 0.048(sf)

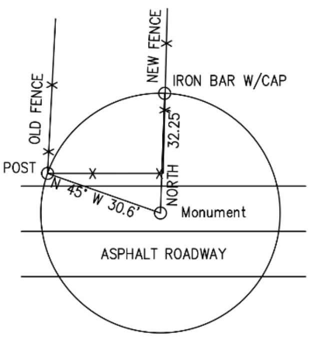
LAT: N 41° 00' 03.60040" 0.035(sf) N 41° 00' 03.61172" 0.035(sf)
E LON: E 238° 22' 08.57335" 0.046(sf) E 238° 22' 08.50692" 0.046(sf)
W LON: W 121° 37' 51.42665" 0.046(sf) W 121° 37' 51.49308" 0.046(sf)
EL HGT: 2904.610(sf) 0.045(sf) 2903.036(sf) 0.045(sf)
ORTHO HGT: 2985.248(sf) 0.045(sf) [NAVD88 (Computed using GEOID18)]

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 10)	SPC (California zone 1)
Northing (Y) [survey fee	14894230.908	2248154.814
Easting (X) [survey feet	2018168.053	6663524.179
Convergence [degrees]	0.90481379	0.24131480
Point Scale	0.99976317	0.99989882
Combined Factor	0.99962435	0.99975998

US NATIONAL GRID DESIGNATOR:

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(sf)
NONE	P060	N 40° 59' 51.46286"	W 122° 24' 53.52823"	216418.877
NONE	P347	N 41° 11' 00.02114"	W 120° 56' 54.40776"	199553.843
NONE	P348	N 40° 54' 19.95132"	W 121° 49' 40.75607"	64654.409
NONE	P349	N 40° 43' 51.89429"	W 122° 19' 09.60941"	214325.497
NONE	P671	N 40° 24' 32.89437"	W 121° 25' 41.49484"	222917.710



OBSERVATION TWO
START: 8/10/2021 8:16:53 PM STOP: 8/10/2021 8:49:57 PM
REF FRAME: NAD83(2011)(EPOCH:2010.0000) ITRF2014 (EPOCH:2021.6068)

X: -8295428.327(sf) 0.008(sf) -8295431.615(sf) 0.008(sf)
Y: -13467719.014(sf) 0.012(sf) -13467714.700(sf) 0.012(sf)
Z: 13658397.493(sf) 0.012(sf) 13658397.334(sf) 0.012(sf)

LAT: N 41° 00' 03.60007" 0.009(sf) N 41° 00' 03.61150" 0.009(sf)
E LON: E 238° 22' 08.57354" 0.012(sf) E 238° 22' 08.50755" 0.012(sf)
W LON: W 121° 37' 51.42646" 0.012(sf) W 121° 37' 51.49245" 0.012(sf)
EL HGT: 2904.754(sf) 0.012(sf) 2903.180(sf) 0.012(sf)
ORTHO HGT: 2985.391(sf) 0.012(sf) [NAVD88 (Computed using GEOID18)]

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 10)	SPC (California zone 1)
Northing (Y) [survey fee	14894230.875	2248154.781
Easting (X) [survey feet	2018168.068	6663524.194
Convergence [degrees]	0.90481356	0.24131484
Point Scale	0.99976316	0.99989882
Combined Factor	0.99962434	0.99975997

US NATIONAL GRID DESIGNATOR:

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(sf)
NONE	P060	N 40° 59' 51.46285"	W 122° 24' 53.52823"	216418.893
NONE	P341	N 40° 39' 02.34929"	W 122° 36' 24.78546"	298770.488
NONE	P347	N 41° 11' 00.02116"	W 120° 56' 54.40775"	199553.841
NONE	P349	N 40° 43' 51.89429"	W 122° 19' 09.60940"	214325.495
NONE	P730	N 41° 21' 33.09550"	W 120° 49' 41.64493"	256705.850

SEAL

SIGNATURE	DATE
CORNER INDEX NO.	DOCUMENT NUMBER

SHEET _____ OF _____

There are many GNSS survey methods that can be used to meet the standards, for additional information, study the guidelines and standards in the references section of this article.

Conclusion

There are current standards and guidelines for establishing coordinates using GNSS receivers and the NCN. The BLM manual provides for the use of coordinates for corner preservation and restoration. When the best available evidence for the original location of a land corner is coordinates, it makes sense to use those coordinates to restore that corner. Under the current circumstances, it is also wise to focus corner perpetuation projects on the collection of coordinate data as well. Collecting and publishing accurate coordinates for land corners would be a wise use of resources in landscapes subject to forest devastation by natural disaster. If resources are scarce, target key corners and leverage them using previously made retracement surveys. Where the BLM has done a modern dependent resurvey of a township, locate the township corners, and a few interior corners for a check, then run a least squares calculation based on the record dimensions using *Geographic Measurement Management For Windo*ws (WinGMM). Or leverage other modern retracements in a similar manner, by locating key exterior corners and a few interior corners, then calculating the remainder using least squares.

Some of the serious consequences of natural disasters, can be mitigated by preserving evidence of land corners using the NSRS, while evidence of the original monuments may still be found.

Acronyms

BLM- United States Department of Interior Bureau of Land Management.

CORS- Continuously Operating Reference Stations.

GPS- Global Positioning System.

GNSS- Global Navigation Satellite System.

OPUS- Online Positioning User Service

NSRS- National Spatial Reference System.

USFS- United States Forest Service.

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