A Look at the Impact of the Digital Revolution on Surveying

A Mini-Workshop presented by:

Earl F. Burkholder, PS, PE

(abridged version)

NMSU Dept of Surveying Engineering

Las Cruces, New Mexico 88003

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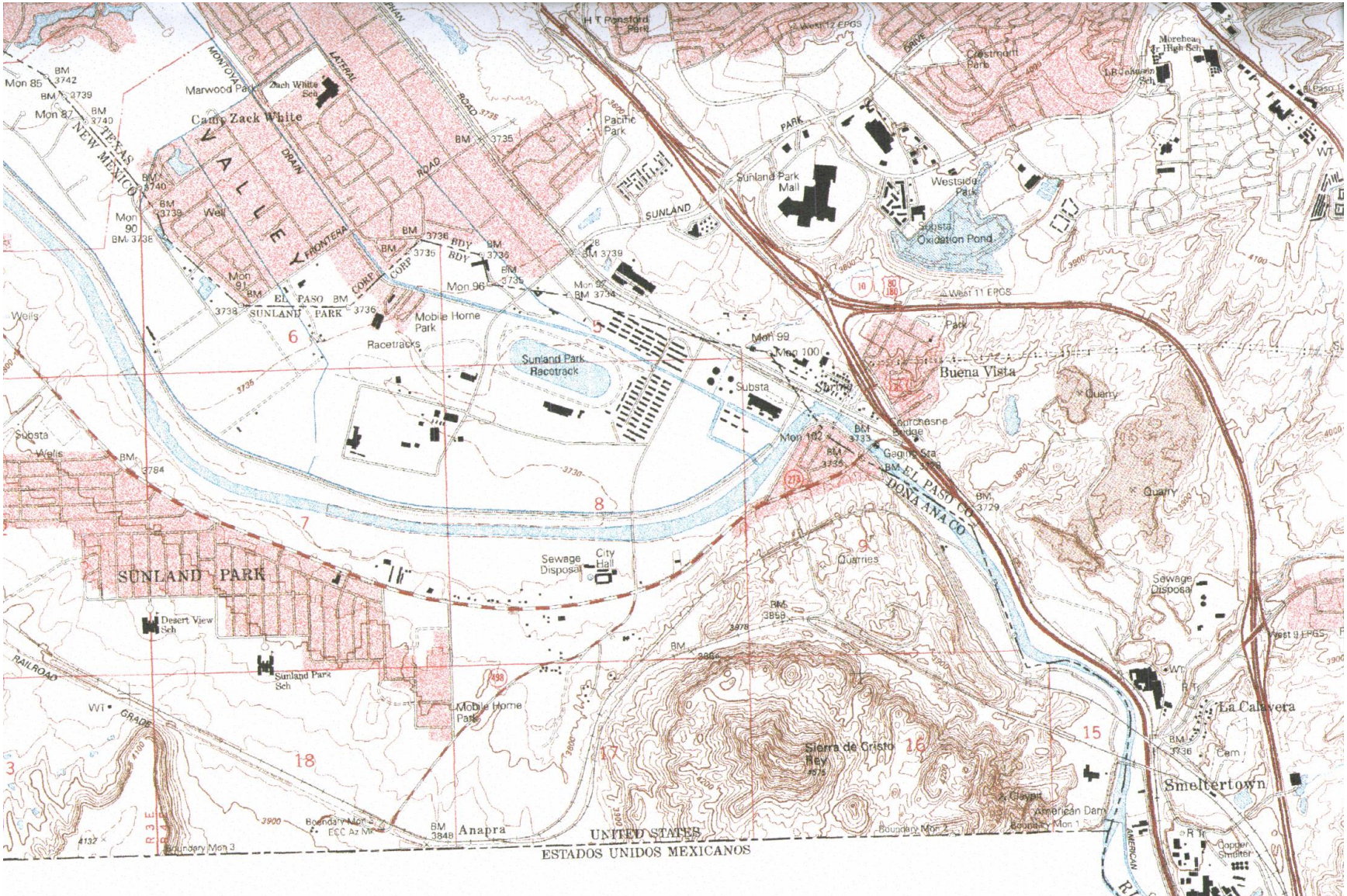
State Boundary Example

- State boundary between NM and Texas follows Rio Grande River for 25 miles.
- River meanders but boundary was “fixed” by U.S. Supreme Court in 1930 on basis of 1929 survey reconstructing 1852 lines.
- 105 monuments set in distance of 25 miles.
- Current project is to GPS the line.
- Horizontal record data are NAD27, Vertical data are NGVD29 (mean sea level).

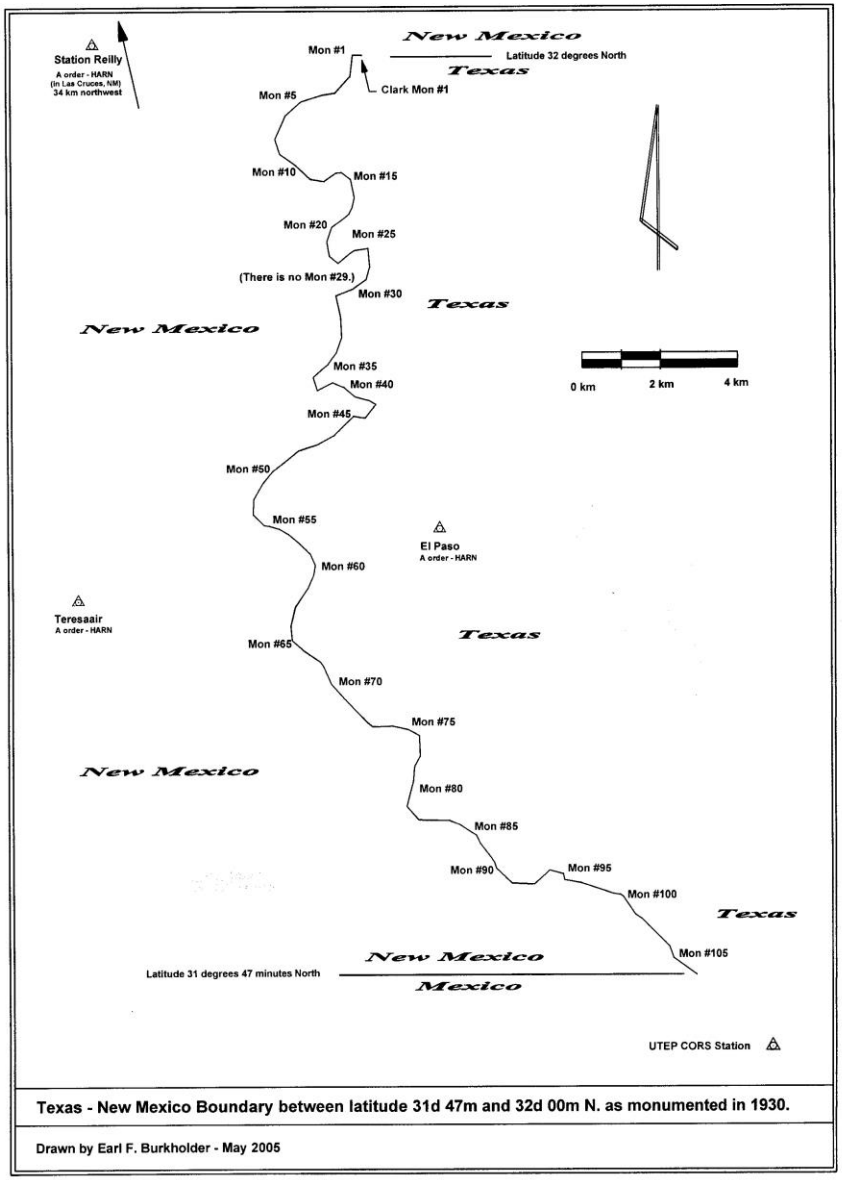
Rio Grande River Boundary Area

Map of Boundary Area - Part



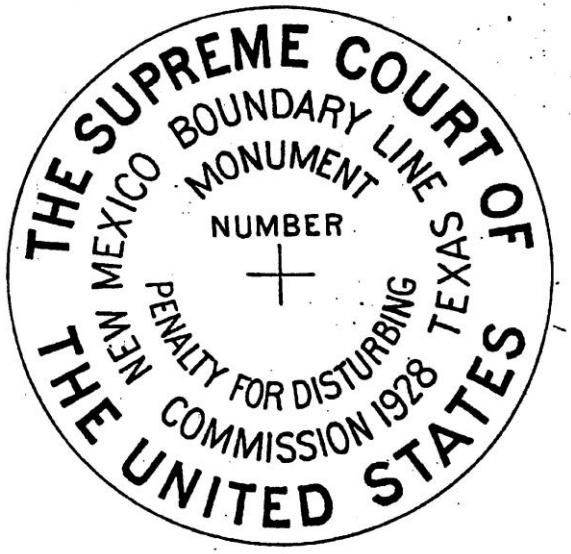
State Boundary Example

- CORPSCON used to convert:
  - NAD27 latitude/longitude to NAD83(HPGN)
  - NGVD29 to NAVD88 – meters.
- GEOID03 used to find geoid heights.
- Ellipsoid heights = elevation + geoid heights.
- Latitude/longitude/height converted to geocentric X/Y/Z coordinates.
- $\Delta X/\Delta Y/\Delta Z$ directly comparable to GPS data.



Texas - New Mexico Boundary between latitude 31d 47m and 32d 00m N. as monumented in 1930.

Drawn by Earl F. Burkholder - May 2005



BRONZE TABLET IMBEDDED IN TOP OF EACH
BOUNDARY LINE MONUMENT

DESCRIPTIONS AND GEOGRAPHIC POSITIONS ON 1927 NORTH AMERICAN DATUM OF BOUNDARY LINE MONUMENTS AND REFERENCE MONUMENTS ALONG OR ADJACENT TO THE NEW MEXICO-TEXAS BOUNDARY LINE IN THE RIO GRANDE VALLEY FROM THE PARALLEL OF 32 DEGREES SOUTHWARD TO THE PARALLEL OF 31 DEGREES 47 MINUTES

Monuments

All monuments, unless otherwise described, consist of a concrete base 24 by 24 by 24 inches set in the ground with top flush with the surface. A galvanized metal form 3 feet long, 14 inches in diameter at base, 8 inches in diameter at top, filled with concrete is embedded 6 inches in the concrete base, 30 inches showing above ground. The weight of each monument exceeds half a ton.

In center of top of the form a bronze tablet with inscription shown facing page 20 is cemented for boundary line monuments and a similar tablet with inscription shown facing page 54 is cemented for reference points or marks. The mean sea-level elevation given, as well as the geographic position, is in each instance that of the cross mark on the tablet cemented in top of the monument form.

In the total length of the boundary line, 25.17 miles, 105 monuments were set; the average distance between monuments is 0.24 mile; in addition, 45 reference monuments were set adjacent to the line and 6 triangulation stations were marked so that they can be identified at any time in the future.

Clark Monument No. 1

Clark Monument No. 1 as established by Scott-Cockrell Commission of 1911.

Anthony, N. Mex., 0.6 mile west of, 285 feet north of east-west road in a cultivated field owned by J. W. Bouldin. A concrete monument having a cubical base 28 inches square, with corners to the cardinal points, set 30 inches in the

ground, with a superstructure in the form of the frustrum of a cone encased in galvanized iron 24 inches in diameter at the base, 18 inches at the top and 22 inches high. In the top of the monument there is embedded a circular brass plate 6 inches in diameter, marked "NEW MEXICO" on the north and "TEXAS" on the south of an east-west division line.

Latitude 32° 00′ 02.324″. Longitude 106° 36′ 56.349″. Elevation 3789.768.

Gannett Monument No. 1

Anthony, N. Mex., 0.75 mile west of, 285 feet north of public road and nearly north of a bridge crossing irrigating canal, in cultivated field on land said to belong to J. W. Bouldin. A concrete monument with base 30 inches square and set 30 inches in the ground with a superstructure in the form of a frustrum of a cone encased in galvanized iron 24 inches in diameter at the base, 18 inches at the top, and standing 30 inches high. In the top is placed a bronze tablet 4 inches in diameter stamped "BOUNDARY MONUMENT No. 1. ELEVATION 3790."

Latitude 32° 00′ 02.324″. Longitude 106° 37′ 05.056." Elevation 3790.419.

Boundary Monument No. 2

Anthony, N. Mex., 0.8 mile west of, 1,500 feet south of public road in cultivated field owned by S. D. Blair and about 500 feet east of Mr. Blair's house.

Standard concrete monument with bronze tablet stamped "Boundary Monument No. 2. Elev. 3,790."

Latitude 31° 59′ 44.496″. Longitude 106° 37′ 07.482″. Elevation 3790.393.

Boundary Monument No. 3

Anthony, N. Mex., 1 mile west of, 0.6 mile south of main east-west highway, on low, uncultivated, brushy land owned by A. A. Howell. It is 390 feet S. 42° W. (true) from point where line crosses drainage ditch. A standard concrete

Compare Apples with Apples

1. Latitude and longitude published in the Supreme Court Report are on the NAD27.
2. Elevations published in the Supreme Court Report are feet on mean sea level (1929).
3. CORPSCON 5.11.08 was used to convert:
   A. NAD27 to NAD83(HPGN).
   B. NGVD29 to NAVD88 meters.
4. Geoid03 was used to compute the geoid height at each point. The ellipsoid height was computed as h = H+N
5. Record data, latitude/longitude/height converted to NAD83(HPGN) and ellipsoid heights) were used to compute geocentric X/Y/Z for each published position.
6. No standard deviations were assigned to the Supreme Court Report values. But,
   A. Latitude/longitude are published to 0.001 seconds of arc ≈ 0.10 feet or 0.03 m.
   B. Elevations are published to nearest 0.001 feet or 0.0003 meters.
7. GPS vectors are defined in terms of $\Delta X/\Delta Y/\Delta Z$. Local rectangular components are computed from those. Standard deviation of each vector component is provided.
8. BURKORD9 (a free DOS-based, menu-driven 3-D COGO program) was used to compute direction and distance between selected points.
   A. Vectors from Mon #90 to Mon #93 to Mon #94 to Mon #95 are provided herein.
   B. Record components for same courses were computed, making direct comparison (apples with apples?) possible.
9. If time allows, we will input positions for several points (#93 and #94) along with standard deviations acceptable to audience. Then another comparison will be made to attempt to answer the question, "Are the monuments stable or did one or more of them move?"

The GSDM puts tools in the hands of the user to answer such questions:

A. How does one handle the grid/ground distance difference? It doesn't exist. The GSDM inverse provides:
   1. Local tangent plane horizontal distance.
   2. True geodetic azimuth standpoint to forepoint – either way.
B. Did the monument move? Look at the standard deviations (error ellipses) of the record quantities and the observed vectors. Do they overlap?
C. How good is good enough? Only the user knows for sure. But the GSDM provides tools which enable one to make informed judgments.

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Manipulation of Record Values to Facilitate Comparison

Begin with NAD27 positions and mean sea level elevations (as quoted in U.S. Supreme Court Report).

1. Use CORPSCON 5.11.08 to convert:

   a. NAD27 latitude/longitude to NAD83 (HPGN) values.
   b. NGVD29 elevations in feet to NAVD88 meters. H = orthometric height = elevation.

2. Use GEOID03 to compute geoid height (N) at each point and compute ellipsoid height as:

$$\boxed{h = H + N}$$

where: h = ellipsoid height
H = NAVD88 elevation
N = geoid height

3. Compute **WGS84/NAD83** geocentric X/Y/Z coordinates using:

$$\boxed{X = \left(\frac{a}{\sqrt{1 - e^2 \sin^2 \phi}} + h \right) \cos\phi \cos\lambda}$$

$$\boxed{Y = \left(\frac{a}{\sqrt{1 - e^2 \sin^2 \phi}} + h \right) \cos\phi \sin\lambda}$$

$$\boxed{Z = \left(\frac{a(1 - e^2)}{\sqrt{1 - e^2 \sin^2 \phi}} + h \right) \sin\phi}$$

WGS84: $\boxed{a = 6{,}378{,}137.000 \text{ m and } e^2 = 0.00669437999014}$

NAD83: $\boxed{a = 6{,}378{,}137.000 \text{ m and } e^2 = 0.00669438002290}$

Notes:

1. North latitude is positive.
   South latitude is negative.
2. East longitude is positive.
   West longitude is negative.

4. Geocentric X/Y/Z coordinates are stored and used for various computations:

   a. Single point - use original latitude/longitude to compute state plane/UTM coordinates. The local component standard deviations (if defined and stored) are readily available.

   b. Point pair - Inverse between points for direction and distance (using rotation matrix).

$$\begin{bmatrix} \Delta e \\ \Delta n \\ \Delta u \end{bmatrix} = \begin{bmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\phi\cos\lambda & -\sin\phi\sin\lambda & \cos\phi \\ \cos\phi\cos\lambda & \cos\phi\sin\lambda & \sin\phi \end{bmatrix} \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \quad \text{where} \quad \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} = \begin{bmatrix} X_2 - X_1 \\ Y_2 - Y_1 \\ Z_2 - Z_1 \end{bmatrix}$$

$$Dist_{1\to 2} = \sqrt{\Delta e^2 + \Delta n^2} \quad \text{and} \quad \tan(azimuth)_{1\to 2} = \frac{\Delta e}{\Delta n}$$

Notes:

1. Standpoint (here) is point 1, Forepoint (there) is point 2.
2. Latitude and longitude are values at Standpoint.
3. Δn and Δe are plane surveying latitude and departure for line "here" to "there."
4. Δu is perpendicular distance from Point 2 to tangent plane through Point 1. (Approximation: Elevation difference is Δu modified by curvature and refraction.)
5. The distance is tangent plane distance from Point 1 to Point 2.
6. The azimuth is the 3-D (geodetic) azimuth from Point 1 to Point 2.

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Comparison of observed vectors with record inverses

Of the various vectors observed so far, the following are included here for comparison:

Mon #90 to Mon #93:

	ΔX m	ΔY m	ΔZ m	Mark to Mark Dist.			
Record	1241.591	-430.521	-95.970	1,317.614 m			
Observed	1241.509	-430.477	-96.031	1,317.527 m			
				Diff = -0.087 m	or	**1:15,144**	
	Δe m	**Δn** m	**Δu** m	Hor Dist.	Geodetic (3-D) Azi.		
Record	1312.820	-112.287	-1.048	1,317.614 m	94	53	19.26
Observed	1312.729	-112.329	-1.096	1,317.526 m	94	53	27.03
		Diff =	0.048	-0.088 m			7.77

Mon #93 to Mon #94:

	ΔX m	ΔY m	ΔZ m	Mark to Mark Dist.			
Record	57.258	11.743	44.772	73.627 m			
Observed	57.096	11.740	44.772	73.501 m			
				Diff = -0.126 m	or	**1:584**	
	Δe m	**Δn** m	**Δu** m	Hor Dist.	Geodetic (3-D) Azi.		
Record	51.533	52.586	0.163	73.627 m	44	25	13.42
Observed	51.379	52.560	0.204	73.501 m	44	20	55.54
		Diff =	0.041	-0.126 m		-4	17.88

Mon #94 to Mon #95:

	ΔX m	ΔY m	ΔZ m	Mark to Mark Dist.			
Record	313.267	-144.019	-78.631	353.639 m			
Observed	313.292	-143.907	-78.485	353.583 m			
				-0.056 m	or	**1:6315**	
	Δe m	**Δn** m	**Δu** m	Hor Dist.	Geodetic (3-D) Azi.		
Record	341.327	-92.500	-0.051	353.639 m	105	9	47.07
Observed	341.319	-92.316	-0.071	353.583 m	105	8	4.29
		Diff =	-0.020	-0.056 m		-1	42.78

Mon #95 to Mon #96: (Trivial vector)

	ΔX m	ΔY m	ΔZ m	Mark to Mark Dist.			
Record	8.533	-85.468	-128.286	154.386 m			
Observed	8.538	-85.477	-128.261	154.370 m			
				Diff = -0.016 m	or	**1:9648**	
	Δe m	**Δn** m	**Δu** m	Hor Dist.	Geodetic (3-D) Azi.		
Record	32.543	-150.917	-0.077	154.386 m	167	49	52.25
Observed	32.551	-150.899	-0.058	154.370 m	167	49	37.73
		Diff =	0.019	-0.016 m			-14.52

What About Record Accuracy?

- Supreme Court Report values:
  - Horizontal given to .001 seconds (0.03 m)
  - Vertical given to 0.001 feet (0.0003 m)
- Use those as standard deviations
- Input into BURKORD9
- Inverse between points for:
  - Distance = 73.627 m +/- 0.042 m
  - Azimuth = 44-25-13.42 +/- 118.9 sec.