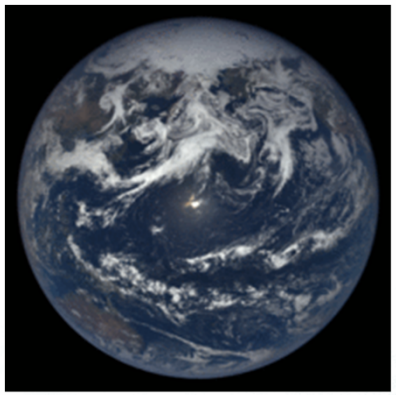
Beyond State Plane, A look at Custom Ground Coordinate Systems

Ken Martinez, ACI

Civil Technical Specialist, ECAD Inc.



AUTODESK. UNIVERSITY









About the speaker

Ken Martinez, Technical Specialist

- Over 25 years in Surveying and Civil Engineering Industry,
- Last 10 years working in the Autodesk Channel.
- Certified Autodesk Instructor – A.C.I.
- Civil 3D Professional 2014, 2015, 2016, 2017 and 2019.
- Civil 3D, Map 3D and Infraworks trainer.
- Civil 3D consultant and implementation expert.

ECAD, Inc.
GOING BEYOND SOFTWARE

Learning Objectives

- Learn how to create a Custom Ground Coordinate System definition in Civil 3D/Map 3d.
- Learn how to decipher the Survey Data provided by your Surveyor.
- Learn how to determine your Mapping Projection.
- Learn how to Validate your new Coordinate System definition.

Before we get started – future changes



NGS - 2022 SPCS Policy changes.

An update of the State Plane Coordinate System (SPCS) is part of the transition from the North American Datum of 1983 (NAD83) to the **2022 Terrestrial Reference Frames**. To this end, NGS will establish the State Plane Coordinate System of 2022 (SPCS2022), which will replace SPCS 83, the version referenced to NAD 83.

Source: https://www.ngs.noaa.gov/SPCS/draft-policy.shtml

Also, the end of an era! The 60+ years of simultaneously using both the U.S. survey and international foot will end after 2022, at which time the only definition recognized will be **1 foot = 0.3048 meter** exactly. Although this definition is used for the international foot, after 2022 it will simply be called the “foot.” There will be a webinar on this topic, December 12, 2019.

Source: https://geodesy.noaa.gov/web/science_edu/webinar_series/Webinars.shtml

The dilemma with Coordinate systems in Autocad



- All of the OOTB coordinate systems are in Grid, with the exception of a few states.
- Grid Distances do not equal Ground Distances.
- Survey Plats and Legal Descriptions cannot be in Grid, or can they?
- Engineering and Construction Plans cannot be in Grid, or can they?
- The Grid vs Ground dilemma.

A possible resolution to the dilemma



- Create a pseudo Low Distortion Projection (LDP).
- AutoCAD Terms, create a Custom Ground Coordinate System definition with Combined Scale Factor.
- Pros:
  - Minimize Linear Distortions.
  - Best fit Planar Surface to Topography.
  - Distances are true (the best part).
  - Lats and Longs are correct.
  - It satisfies the needs of everyone I,e, Surveying, Engineering, Construction, & GIS.
- Cons:
  - May not work so well if project area or city gains a significant amount of Elevation.
  - One combined scale factor over entire project area or city.

LDP Linear Distortion

Linear Distortion

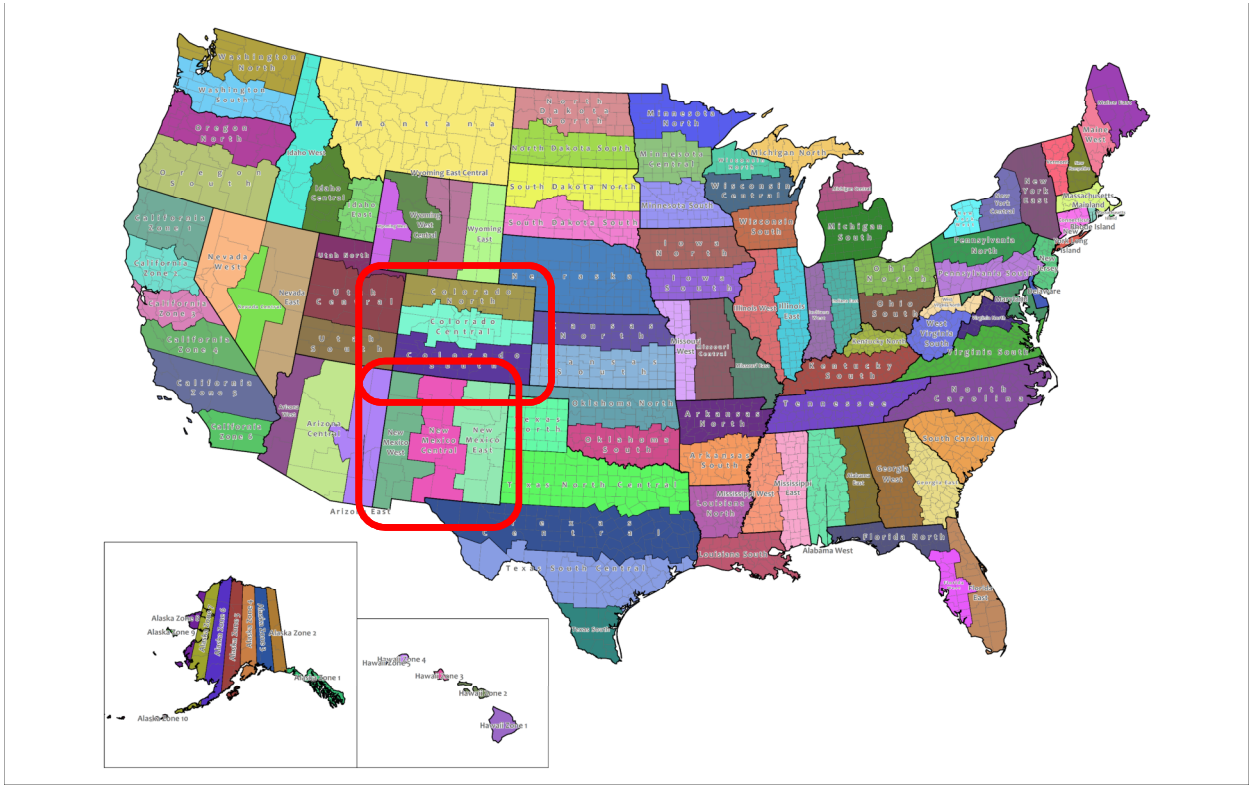
Maximum Projection Zone Width	Maximum Linear Horizontal Distortion		
	Parts per Million	Linear Distortion	Ratio
16 miles 26 km	1 ppm	0.005 ft/mi 1 mm/km	1 : 1,000,000
50 miles 80 km	10 ppm	0.05 ft/mi 10 mm/km	1 : 100,000
71 miles 114 km	20 ppm	0.1 ft/mi 20 mm/km	1 : 50,000
112 miles 180 km	50 ppm	0.3 ft/mi 50 mm/km	1 : 20,000
158 miles 254 km	100 ppm	0. 5 ft/mi 100 mm/km	1 : 10,000

Height Above and Below Projection Surface	Maximum Linear Horizontal Distortion		
	Parts per Million	Linear Distortion	Ratio
20 feet 6 meters	1 ppm	0.005 ft/mi 1 mm/km	1 : 1,000,000
210 feet 63 meters	10 ppm	0.05 ft/mi 10 mm/km	1 : 100,000
420 feet 127 meters	20 ppm	0.1 ft/mi 20 mm/km	1 : 50,000
1050 feet 319 meters	50 ppm	0.3 ft/mi 50 mm/km	1 : 20,000
2100 feet 637 meters	100 ppm	0. 5 ft/mi 100 mm/km	1 : 10,000
4200 feet 1.3 km	200 ppm	1.1 ft/mi 100 mm/km	1 : 5,000
7000 feet 2.1 km	300 ppm	1.8 ft/mi 100 mm/km	1 : 3,000

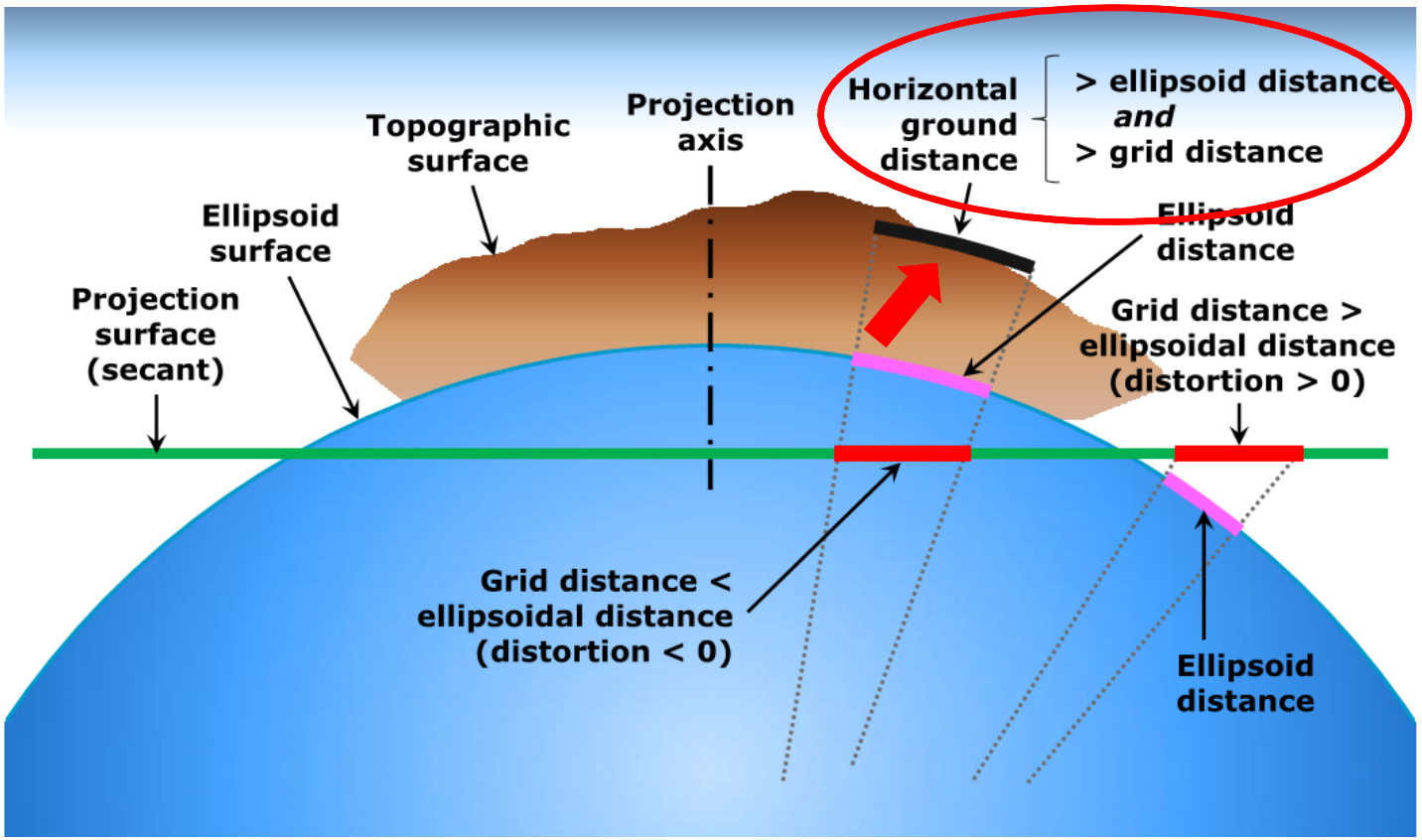
Source: Solving the Grid to Ground Problem with Custom Coordinate Systems.

State Plane Coordinate Zones - USA

- Create an LDP in two states.
- Colorado – Lambert State
- New Mexico - Transvers Mercator State



Linear distortion with respect to Ground and Ellipsoid



HERE IS WHAT WE WANT!

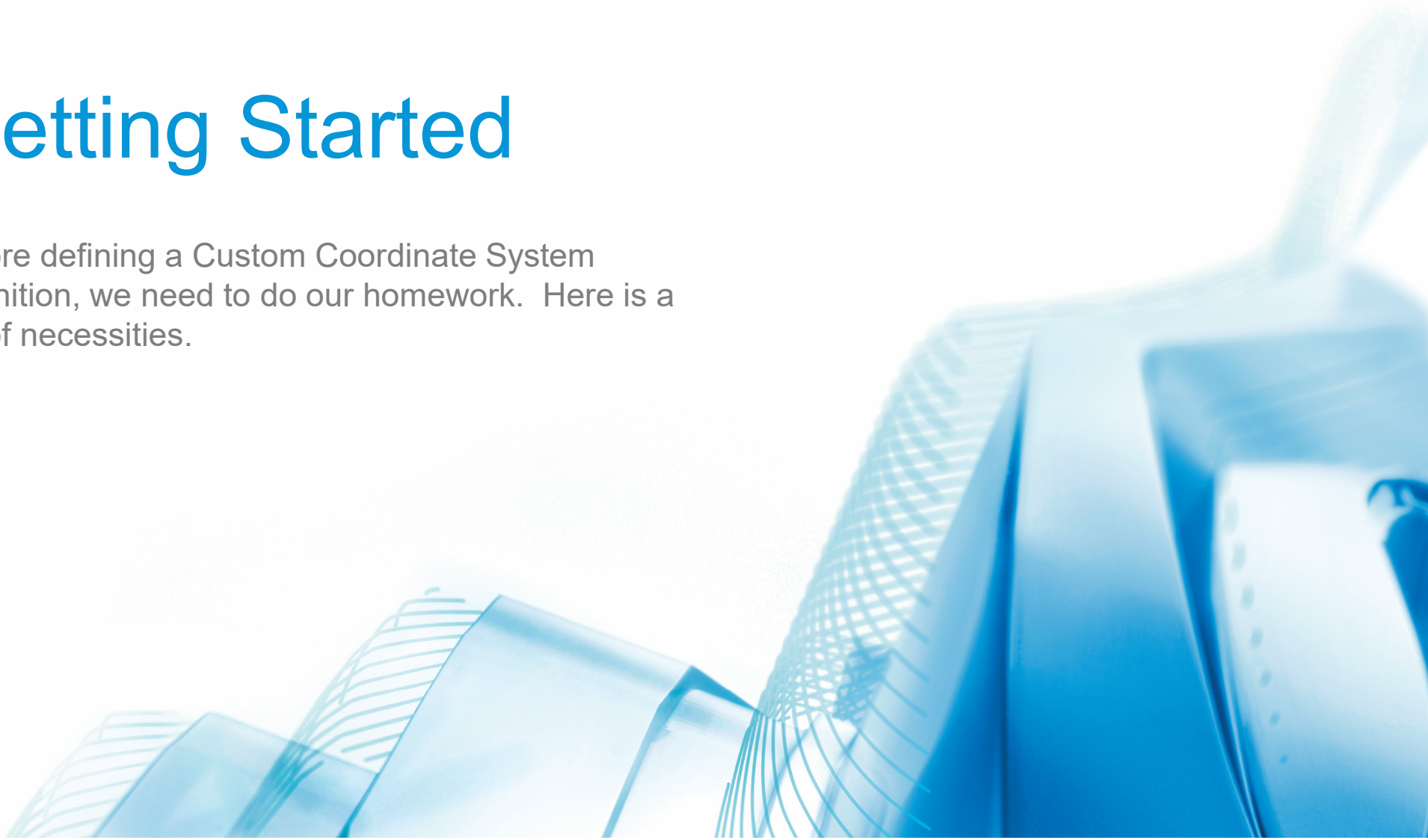
Are you a member?



The
FLAT EARTH
SOCIETY

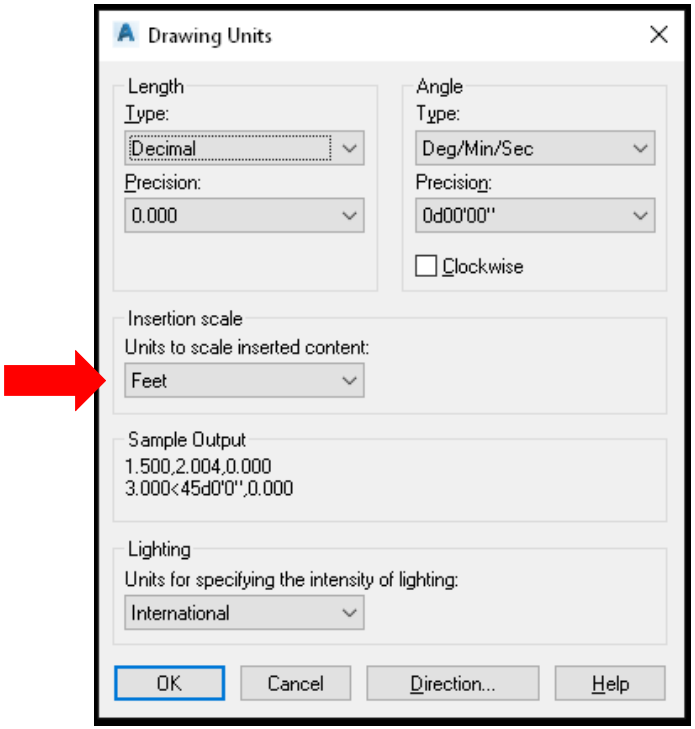
Getting Started

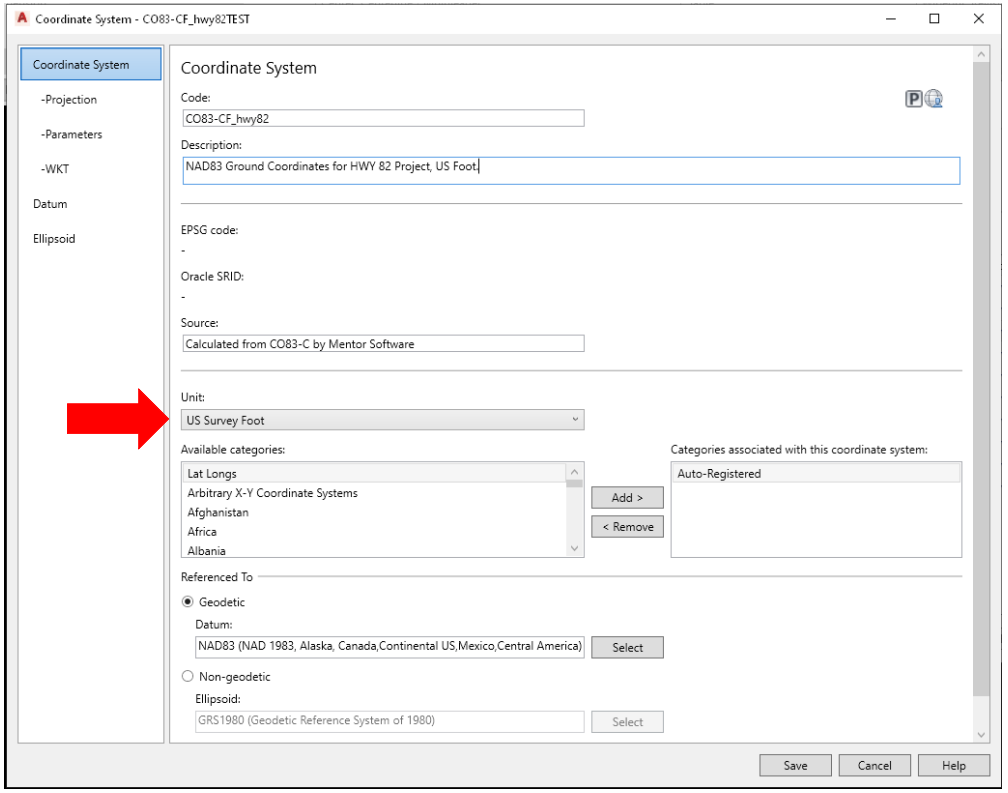
Before defining a Custom Coordinate System Definition, we need to do our homework. Here is a list of necessities.



Getting started - Units

- Units – determine what these are i.e. Meters, US Survey Feet or International Feet.
- Units – in your DWT Template set Autocad Units to:





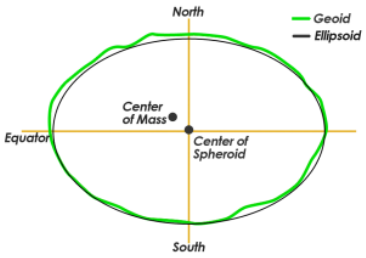
Getting started – Geodetic Reference

- What is a Geodetic Datum? A horizontal datum provides a frame of reference as a basis for placing specific locations at specific points on the spheroid. Geodesists use a horizontal datum as the model to translate a spheroid / ellipsoid into locations on Earth with latitude and longitude lines. Geodetic datums form the basis of coordinates of all horizontal positions on Earth. All coordinates on Earth are referenced to a horizontal datum.
- NAD83, uses the Ellipsoid GRS80:

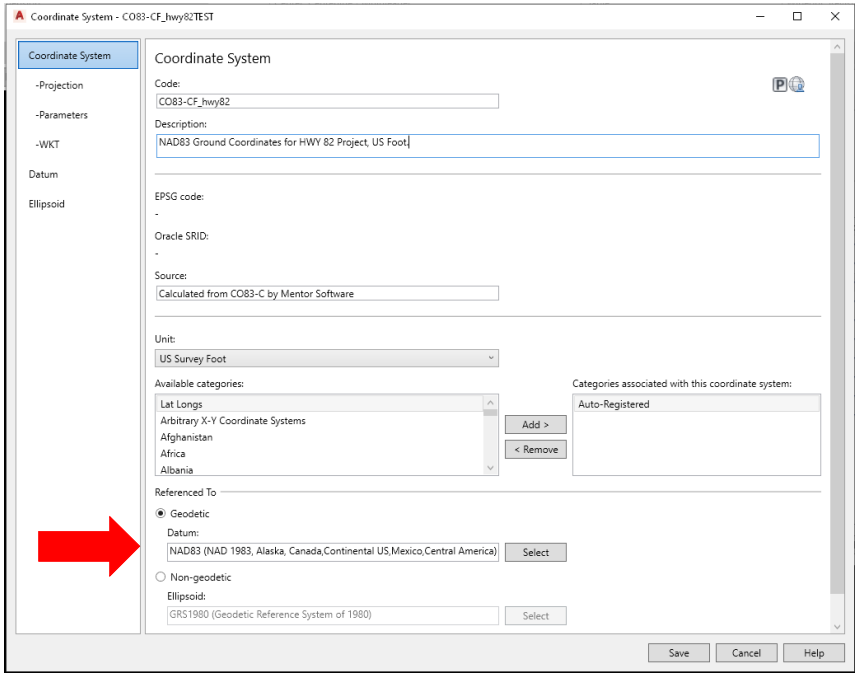
  Semi-major axis: 6,378,137.0 m

  Semi-minor axis: 6,356,752.3 m

  Inverse flattening: 298.26

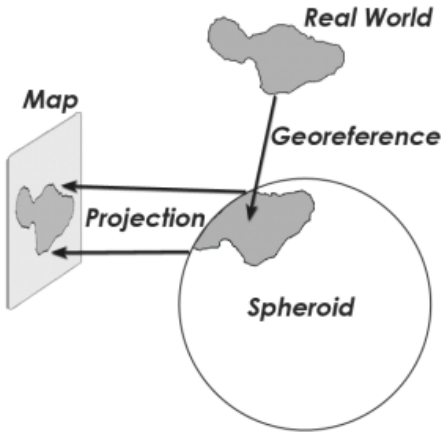


NAD83 Center of Mass



Getting started – Map Projection

- What is a Map Projection? A Map Projection simply put flattens a sphere into two dimensions. Imagine you have an orange. This is your imaginary Earth. When you look at it any direction, you won't be able to see all sides of it. But when you peel the orange, flatten and stretch it out, you can begin to see everything. However, at the edges of your orange peel is where you will experience distortion.



Lambert Conformal Conic

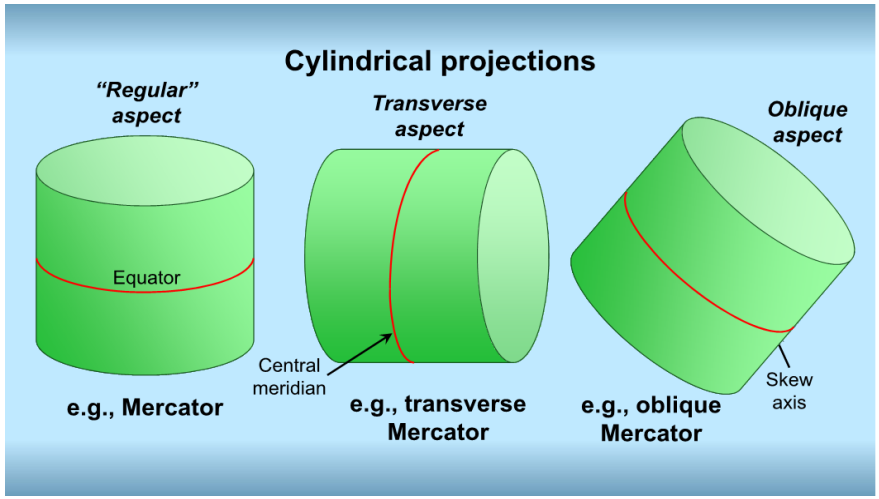


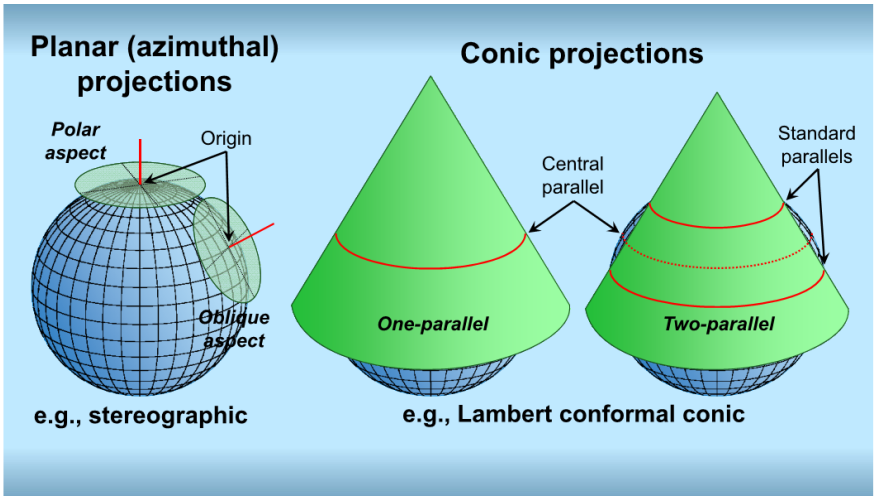
North America: Lambert Conformal Conic

Universal Transverse Mercator



North America: Mercator





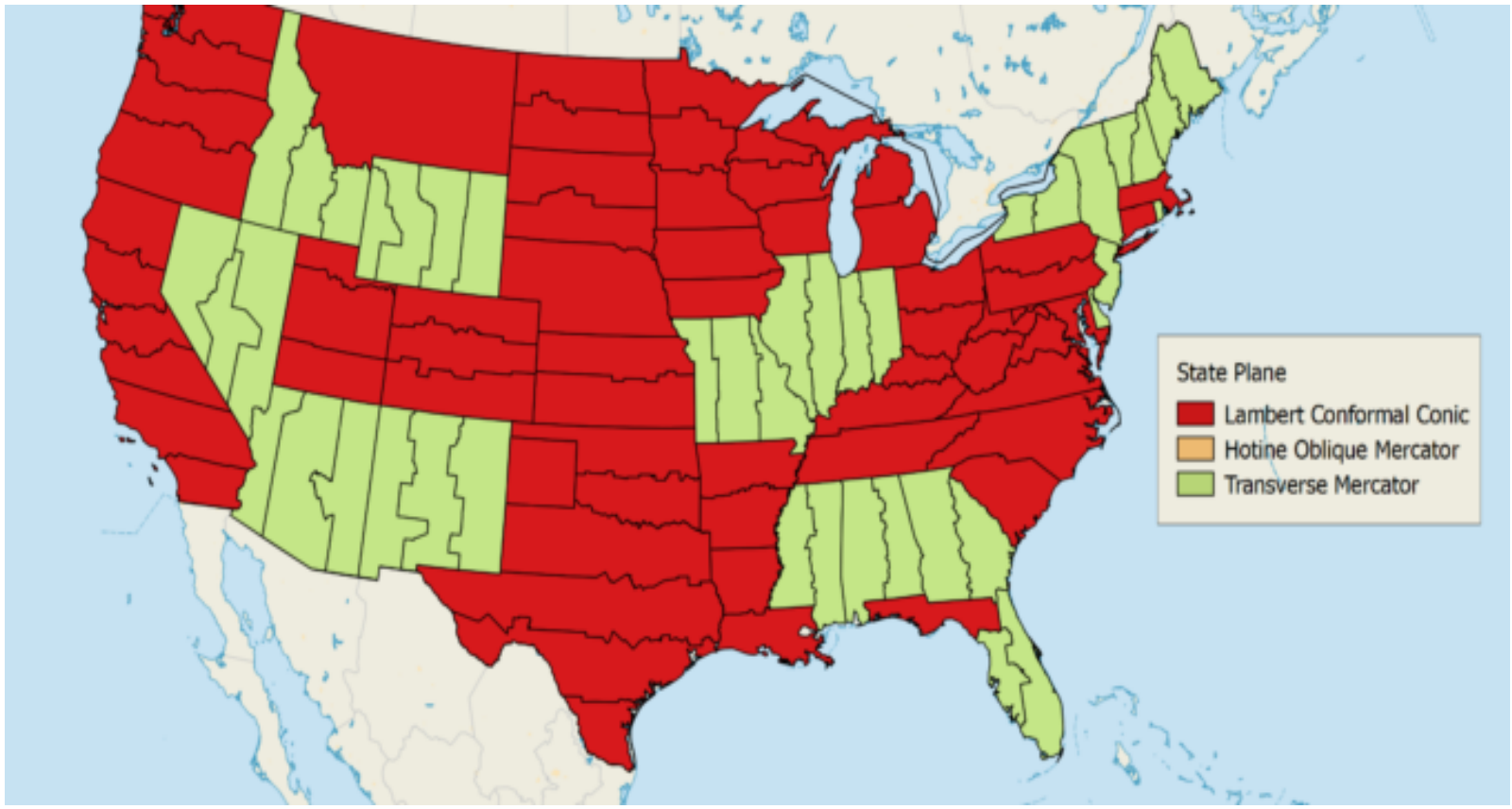
Transverse Mercator

If the Zone has a North to South orientation, it generally uses the Transverse Mercator (TM) Projection. State Plane Coordinate System zones use the Secant case of the TM projection. It cuts through the spheroid/ellipsoid along two small circles at a specific distance.

Lambert Conformal Conic

If the Zone has an East to West orientation. It generally uses the Lambert Conformal Conic Projection. While Cartographers use the LCC for Large Continents, it's the most common map Projection among the SPCS zones.

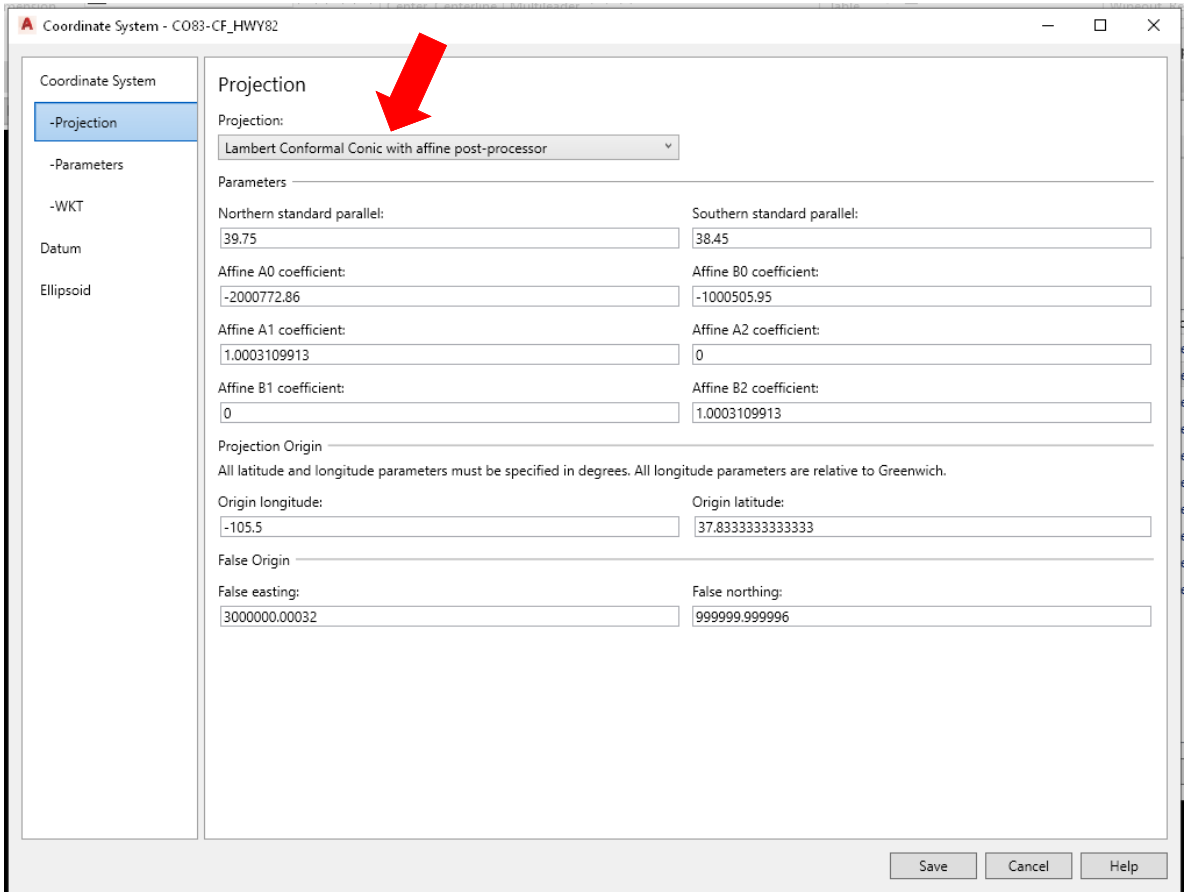
Getting started – Map Projections of USA



Picture from GISGeography

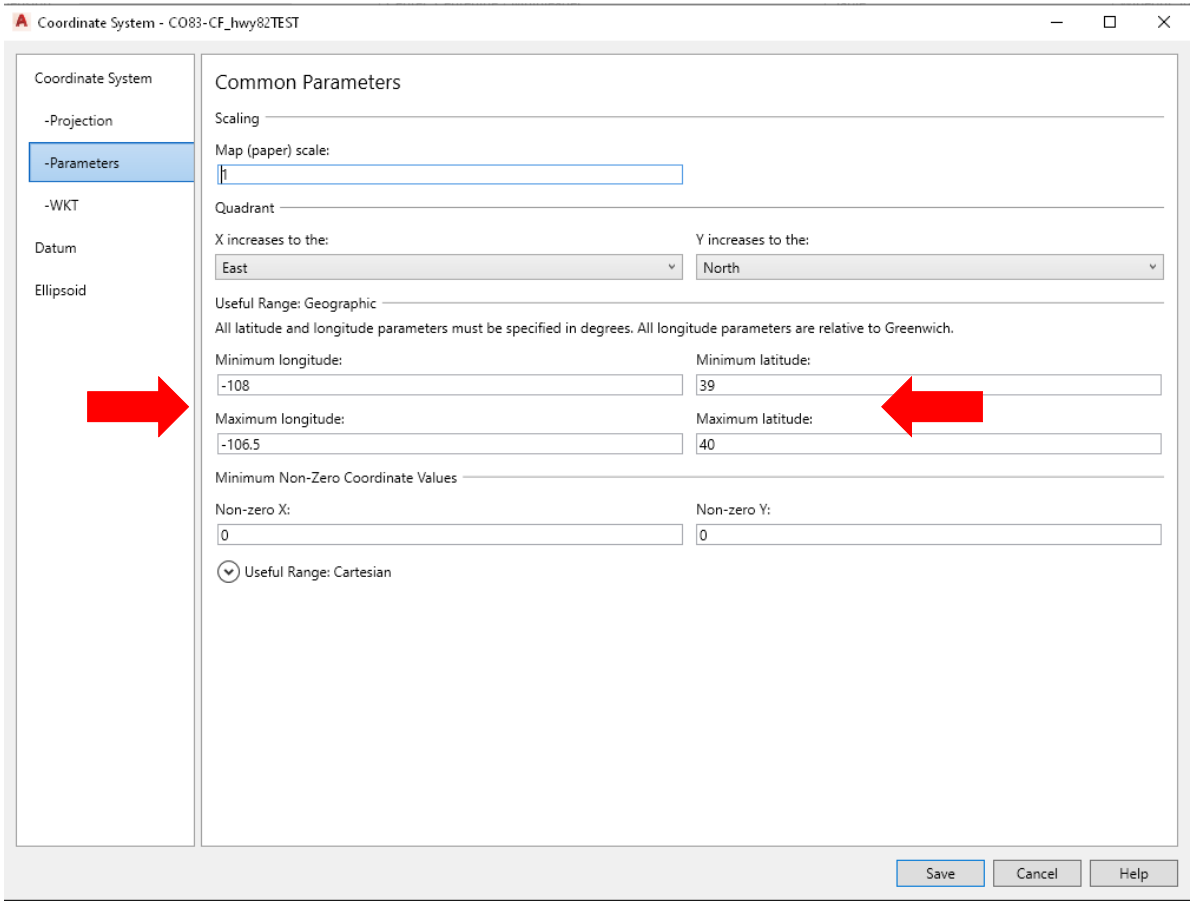
Getting Started – Map Projection

- The Map Projection? This is where you would set The Lambert Conic or the Transvers Mercator Projections. This is the most critical part, careful attention to detail needs to be done here.



Getting started – Parameters

- What are Parameters? This is the Limits or Extents of your Coordinate system Definition. A bounding Box so to speak. This is where you would set the Map Scale to 1, in addition, max/min Latitude and the max/min Longitude.

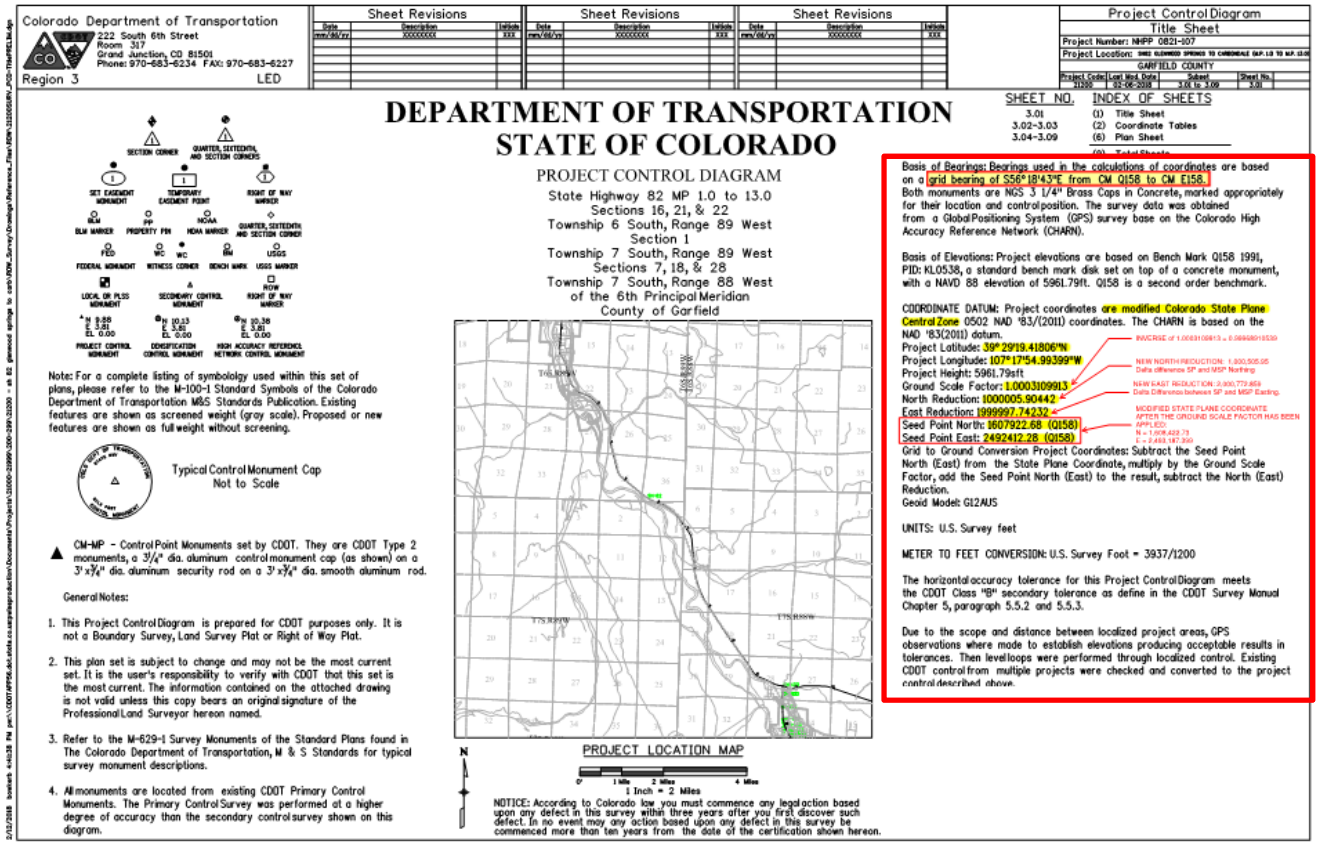


Demo - Scenario 1

We have two scenarios today. The first scenario is a Project specific location, a Road Project (Hwy 82) between Glenwood, CO and Aspen, CO.



Scenario 1 – From our Project Cover Sheet



Colorado Department of Transportation
222 South 6th Street
Room 317
Grand Junction, CO 81501
Phone: 970-683-6234 FAX: 970-683-6227
Region 3 LED

Sheet Revisions

Project Control Diagram
Title Sheet
Project Number: NHPP 0821-107
Project Location: [illegible] GLENWOOD SPRINGS TO CARBONDALE (MP 1.0 TO MP 13.0)
GARFIELD COUNTY
Project Code: 21205 | Last Mod. Date: 05-06-2018 | Subset: 3.01 to 3.09 | Sheet No.: 3.01

DEPARTMENT OF TRANSPORTATION
STATE OF COLORADO

PROJECT CONTROL DIAGRAM

State Highway 82 MP 1.0 to 13.0
Sections 16, 21, & 22
Township 6 South, Range 89 West
Section 1
Township 7 South, Range 89 West
Sections 7, 18, & 28
Township 7 South, Range 88 West
of the 6th Principal Meridian
County of Garfield

SHEET NO. | INDEX OF SHEETS
3.01 | (1) Title Sheet
3.02-3.03 | (2) Coordinate Tables
3.04-3.09 | (6) Plan Sheet
(9) Total Sheets

SECTION CORNER
QUARTER, SIXTEENTH, AND SECTION CORNERS
SET EASEMENT MONUMENT
TEMPORARY EASEMENT POINT
RIGHT OF WAY MARKER
BLM MARKER
PROPERTY PIN
NOAA MARKER
QUARTER, SIXTEENTH AND SECTION CORNER
FEDERAL MONUMENT
WITNESS CORNER
BENCH MARK
USGS MARKER
LOCAL OR PLSS MONUMENT
SECONDARY CONTROL MONUMENT
ROW RIGHT OF WAY MARKER
PROJECT CONTROL MONUMENT
DENSIFICATION CONTROL MONUMENT
HIGH ACCURACY REFERENCE NETWORK CONTROL MONUMENT

Note: For a complete listing of symbology used within this set of plans, please refer to the M-100-1 Standard Symbols of the Colorado Department of Transportation M&S Standards Publication. Existing features are shown as screened weight (gray scale). Proposed or new features are shown as full weight without screening.

Typical Control Monument Cap
Not to Scale

▲ CM-MP - Control Point Monuments set by CDOT. They are CDOT Type 2 monuments, a 3/4" dia. aluminum control monument cap (as shown) on a 3' x 3/4" dia. aluminum security rod on a 3' x 3/4" dia. smooth aluminum rod.

General Notes:

1. This Project Control Diagram is prepared for CDOT purposes only. It is not a Boundary Survey, Land Survey Plat or Right of Way Plat.
2. This plan set is subject to change and may not be the most current set. It is the user's responsibility to verify with CDOT that this set is the most current. The information contained on the attached drawing is not valid unless this copy bears an original signature of the Professional Land Surveyor hereon named.
3. Refer to the M-629-1 Survey Monuments of the Standard Plans found in The Colorado Department of Transportation, M & S Standards for typical survey monument descriptions.
4. All monuments are located from existing CDOT Primary Control Monuments. The Primary Control Survey was performed at a higher degree of accuracy than the secondary control survey shown on this diagram.

PROJECT LOCATION MAP
N
0' 1 Mile 2 Miles 4 Miles
1 Inch = 2 Miles

NOTICE: According to Colorado law you must commence any legal action based upon any defect in this survey within three years after you first discover such defect. In no event may any action based upon any defect in this survey be commenced more than ten years from the date of the certification shown hereon.

Basis of Bearings: Bearings used in the calculations of coordinates are based on a grid bearing of S56°18'43"E from CM Q158 to CM E158.
Both monuments are NGS 3 1/4" Brass Caps in Concrete, marked appropriately for their location and control position. The survey data was obtained from a Global Positioning System (GPS) survey base on the Colorado High Accuracy Reference Network (CHARN).

Basis of Elevations: Project elevations are based on Bench Mark Q158 1991, PID: KL0538, a standard bench mark disk set on top of a concrete monument, with a NAVD 88 elevation of 5961.79ft. Q158 is a second order benchmark.

COORDINATE DATUM: Project coordinates are modified Colorado State Plane Central Zone 0502 NAD '83/(2011) coordinates. The CHARN is based on the NAD '83(2011) datum.
Project Latitude: 39° 29'19.41806"N
Project Longitude: 107° 17'54.99399"W
Project Height: 5961.79sft
Ground Scale Factor: 1.0003109913
North Reduction: 1000005.90442
East Reduction: 1999997.74232
Seed Point North: 1607922.68 (Q158)
Seed Point East: 2492412.28 (Q158)
Grid to Ground Conversion Project Coordinates: Subtract the Seed Point North (East) from the State Plane Coordinate, multiply by the Ground Scale Factor, add the Seed Point North (East) to the result, subtract the North (East) Reduction.
Geoid Model: G12AUS

UNITS: U.S. Survey feet

METER TO FEET CONVERSION: U.S. Survey Foot = 3937/1200

The horizontal accuracy tolerance for this Project Control Diagram meets the CDOT Class "B" secondary tolerance as define in the CDOT Survey Manual Chapter 5, paragraph 5.5.2 and 5.5.3.

Due to the scope and distance between localized project areas, GPS observations where made to establish elevations producing acceptable results in tolerances. Then level loops were performed through localized control. Existing CDOT control from multiple projects were checked and converted to the project control described above.

Scenario 1

- Right side, from the Cover Sheet of our Project reads the following information.
- Below are our Project Coordinates and Geodetic Coordinates.
- Project located in CO83-CF Zone.

CARB COR	575248.64	516229.56		COR STATION
CBN	561611.03	559631.11	6589.75	NGS 3 1/4" BRASS CAP IN BRIDGE ABUT
E158	554774.98	572133.11	6754.31	NGS 3 1/4" BRASS CAP IN BRIDGE ABUT
Q158	607916.78	492414.54	5961.79	NGS 3 1/4" BRASS CAP IN CONCRETE
ROSEBUD	617904.40	487367.81	5859.57	NGS 3 1/4" BRASS CAP IN CONCRETE

Point No.	Geodetic Coordinates NAD-83(XX) (CHARN)		Elip Height (NAVD88) (m)	Ortho Height ft	Grid Scale Factor	NAD 83(XX) Zone XXXX	
	Latitude(N)	Longitude(W)				SP Northing ft	SP Easting ft
CARB COR	39°24'01.24152"	107°12'43.51794"	1879.673	6216.400	0.999949520	1575264.70000	2516219.9000
CBN	39°21'54.22953"	107°03'27.87563"	1994.171	6590.086	0.999946500	1561631.33000	2559607.9500
E158	39°20'48.78060"	107°00'47.30726"	2044.386	6754.311	0.999945090	1554797.41000	2572106.0700
Q158	39°29'19.41806"	107°17'54.99399"	1802.349	5961.731	0.999958750	1607922.68000	2492412.2800
ROSEBUD	39°30'57.08902"	107°19'01.88237"	1771.337	5859.499	0.999962070	1617907.20000	2487367.1200

Basis of Bearings: Bearings used in the calculations of coordinates are based on a grid bearing of S56°18'43"E from CM Q158 to CM E158.
Both monuments are NGS 3 1/4" Brass Caps in Concrete, marked appropriately for their location and control position. The survey data was obtained from a Global Positioning System (GPS) survey base on the Colorado High Accuracy Reference Network (CHARN).

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East Reduction: 1999997.74232
Seed Point North: 1607922.68 (Q158)
Seed Point East: 2492412.28 (Q158)

INVERSE of 1.0003109913 = 0.99968910539
NEW NORTH REDUCTION: 1,000,505.95
Delta difference SP and MSP Northing
NEW EAST REDUCTION: 2,000,772.859
Delta Difference between SP and MSP Easting.
MODIFIED STATE PLANE COORDINATE AFTER THE GROUND SCALE FACTOR HAS BEEN APPLIED:
N = 1,608,422.73
E = 2,493,187.399

Grid to Ground Conversion Project Coordinates: Subtract the Seed Point North (East) from the State Plane Coordinate, multiply by the Ground Scale Factor, add the Seed Point North (East) to the result, subtract the North (East) Reduction.
Geoid Model: G12AUS

UNITS: U.S. Survey feet

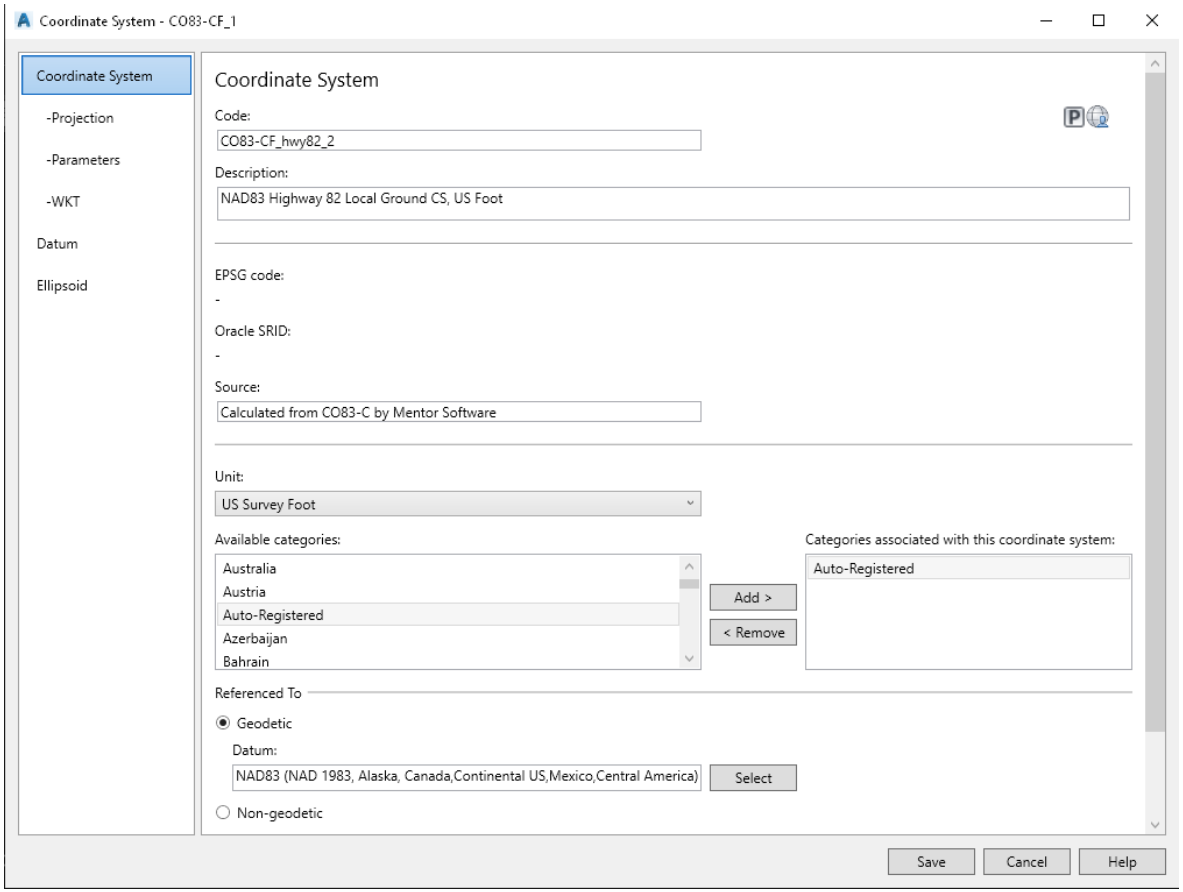
METER TO FEET CONVERSION: U.S. Survey Foot = 3937/1200

The horizontal accuracy tolerance for this Project Control Diagram meets the CDOT Class "B" secondary tolerance as define in the CDOT Survey Manual Chapter 5, paragraph 5.5.2 and 5.5.3.

Due to the scope and distance between localized project areas, GPS observations where made to establish elevations producing acceptable results in tolerances. Then level loops were performed through localized control. Existing CDOT control from multiple projects were checked and converted to the project control described above.

Scenario 1 - Coordinate System

- Command: MAPCSLIBRARY
- Create a duplicate (or copy) of CO83-CF,
- Type in your new Code.
- Type in your new Description.
- Units:
- Available Categories:
- Reference to: NAD83



Scenario 1 - Projection Calc's

- Create a duplicate (or copy) of CO83-CF, Coordinate System, this will have the "Lambert Conformal Conic, double standard parallel" by default.
- Change to "Lambert Conformal Conic, with affine post-processor".
- Northern Standard Parallel remains at 39.75 Latitude. Southern Standard Parallel remains at 38.45 Latitude.
- The truncation piece to get coordinates from Grid to Project (Ground). Do this both for Northing and Easting.

Northing

(SP northing) x 1.000109913 = (MSP northing)

(MSP northing) – (SP northing) = (Δ difference northing)

(Δ difference northing) + NRF = (New NRF) ……type this in the "Affine B0 coefficient" value.

Easting

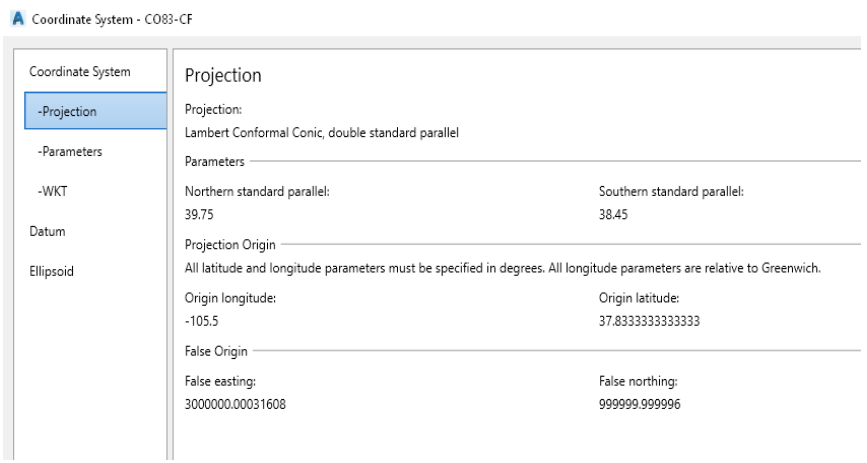
(SP easting) x 1.000109913 = (MSP easting)

(MSP easting) – (SP easting) = (Δ difference easting)

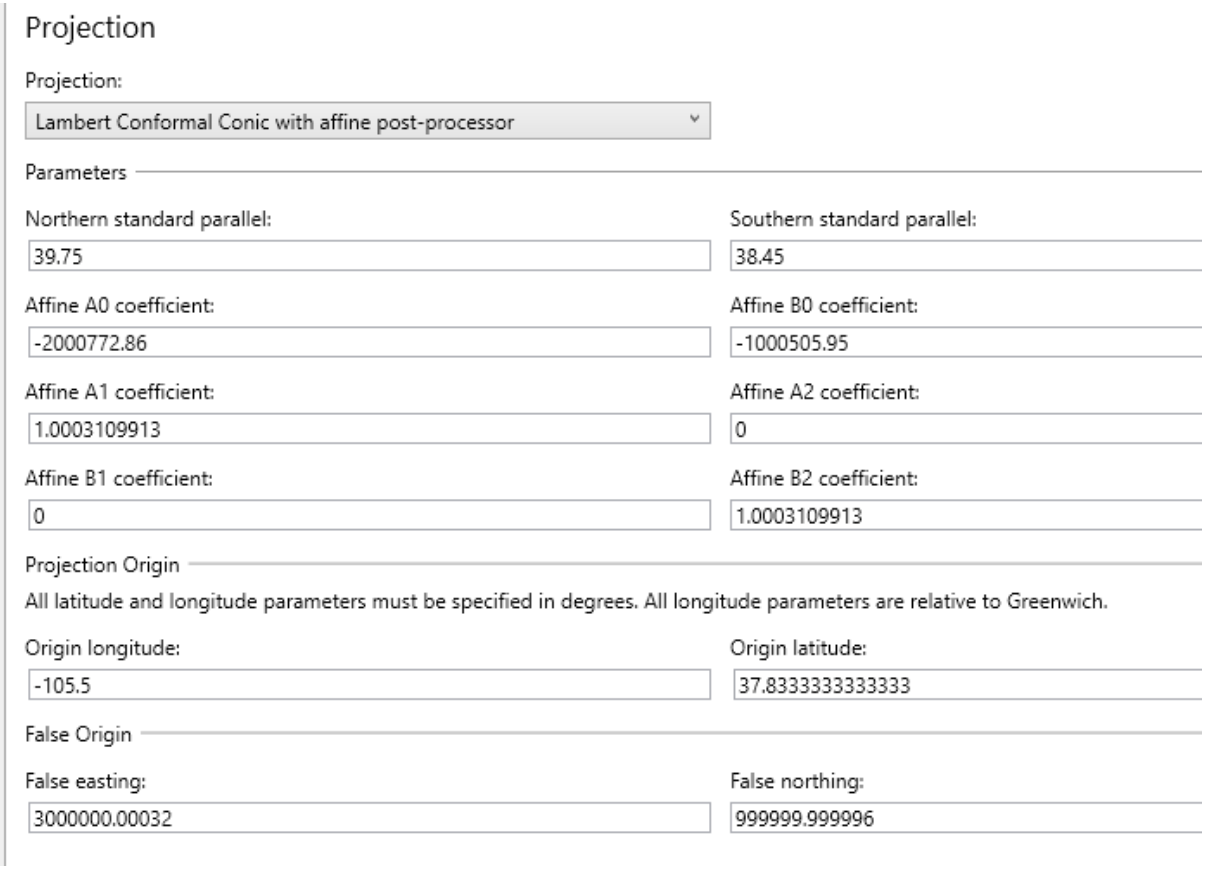
(Δ difference easting) + NRF = (New NRF) ……type this in the "Affine A0 coefficient" value.

Scenario 1 - Projection Calc’s

Snapshot of CO83-CF.



Snapshot of our CCS.



Scenario 1 – Test your new Coordinate System

- The final step is to test your new Coordinate System Definition.
- Import Survey Cogo Points from another Coordinate System (i.e. CO83-CF) and confirm if they Transform into your Project Coordinates.
- Import a Local Jurisdictional ESRI shp file, and confirm that it fall into the correct location.

Demo - Scenario 2

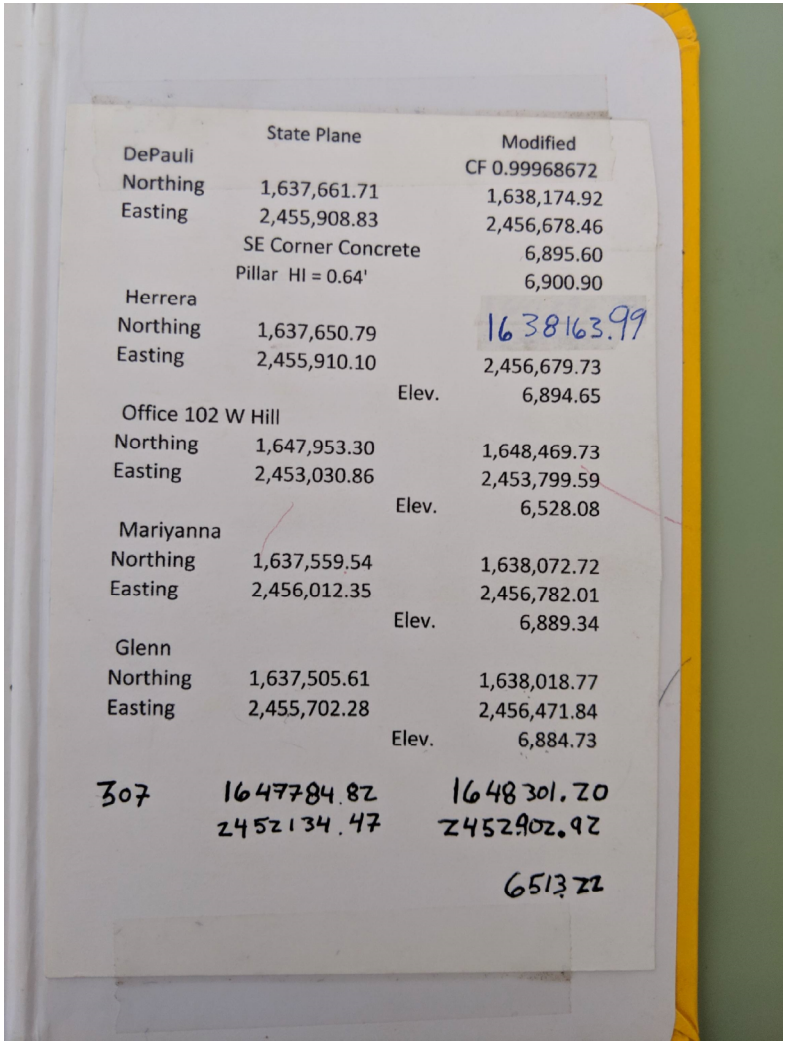
The second scenario is a custom Ground Coordinate system for the City of Gallup, NM.



Scenario 2 – Info from Surveyor

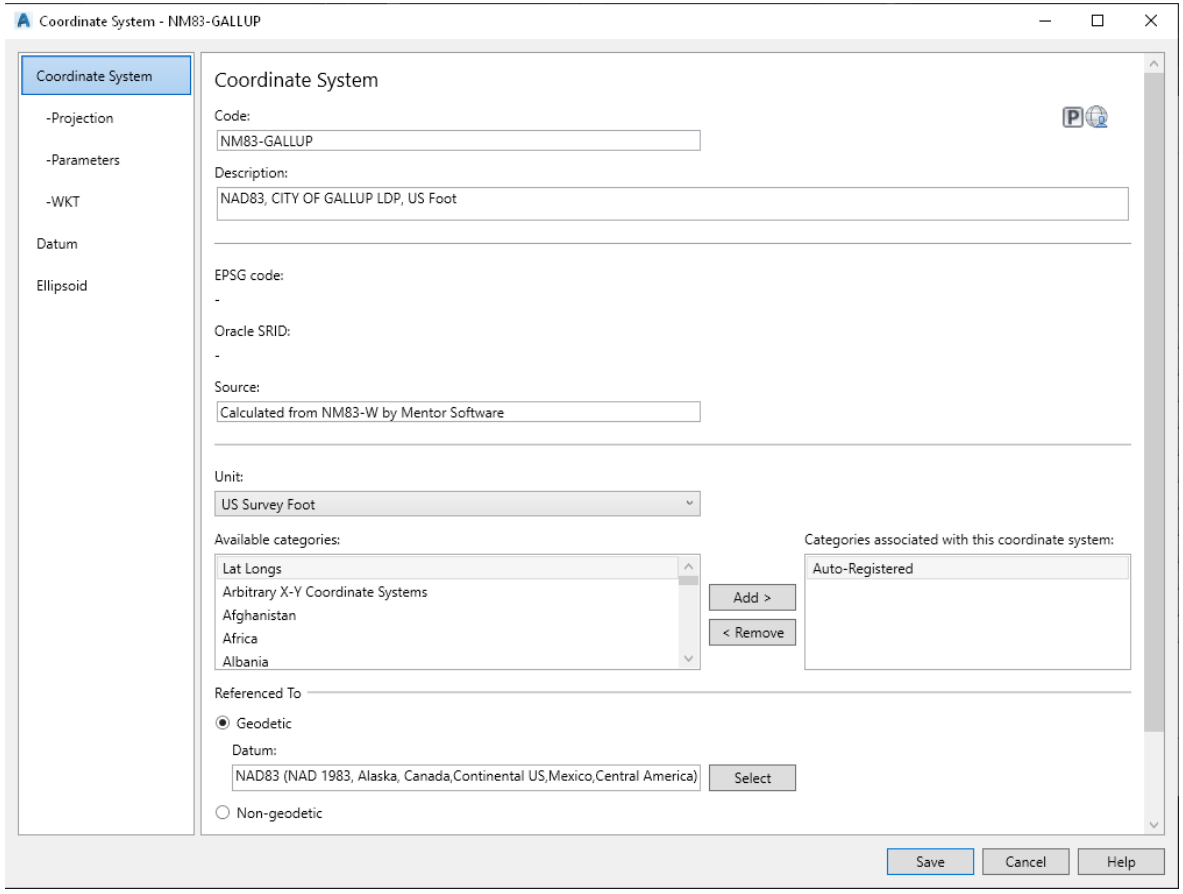
- Right side, Field Book of local Control Points obtained by resident Surveyor.
- Below, I enlisted a little help from NGS Website for another check.
- Gallup, NM located on NM83-WF Zone.

```
FP0541                          *CURRENT SURVEY CONTROL
FP0541  ______________________________________________________________________
FP0541* NAD 83(1992) POSITION- 35 31 33.44475(N) 108 44 10.70707(W)   ADJUSTED
FP0541* NAVD 88 ORTHO HEIGHT -   2012.9    (meters)      6604.     (feet) VERTCON
FP0541  ______________________________________________________________________
FP0541  GEOID HEIGHT    -        -21.182 (meters)                     GEOID12B
FP0541  LAPLACE CORR    -          3.85  (seconds)                    DEFLEC12B
FP0541  HORZ ORDER      -  SECOND
FP0541
FP0541.The horizontal coordinates were established by classical geodetic methods
FP0541.and adjusted by the National Geodetic Survey in December 1993.
FP0541.
FP0541.The NAVD 88 height was computed by applying the VERTCON shift value to
FP0541.the NGVD 29 height (displayed under SUPERSEDED SURVEY CONTROL.)
FP0541
FP0541.Significant digits in the geoid height do not necessarily reflect accuracy.
FP0541.GEOID12B height accuracy estimate available here.
FP0541
FP0541.The Laplace correction was computed from DEFLEC12B derived deflections.
FP0541
FP0541. The following values were computed from the NAD 83(1992) position.
FP0541
FP0541;                    North          East      Units Scale Factor Converg.
FP0541;SPC NM W      -   502,304.240   748,105.781   MT  0.99999929   -0 31 29.0
FP0541;SPC NM W      - 1,647,976.49  2,454,410.38   sFT  0.99999929   -0 31 29.0
FP0541;UTM  12       - 3,933,728.983   705,252.708   MT  1.00011918   +1 18 57.0
FP0541
FP0541!              -  Elev Factor  x  Scale Factor =   Combined Factor
FP0541!SPC NM W      -   0.99968749  x   0.99999929  =   0.99968678
FP0541!UTM  12       -   0.99968749  x   1.00011918  =   0.99980663
```



Scenario 2 - Coordinate System

- Command: MAPCSLIBRARY
- Create a duplicate (or copy) of NM83-WF,
- Type in your new Code.
- Type in your new Description.
- Units:
- Available Categories: Auto-Registered
- Reference to: NAD83



Scenario 2 (cont.) - Projection Calc's

- Create a duplicate (or copy) of NM83-WF, Coordinate System, this will have the "Transverse Mercator" by default.
- Leave it set to "Transverse Mercator".
- Northern Standard Parallel remains at 39.75 Latitude. Southern Standard Parallel remains at 38.45 Latitude.
- The truncation piece to get coordinates from Grid to Project (Ground).

  (SP False easting) x (CSF) = (New SP False easting)

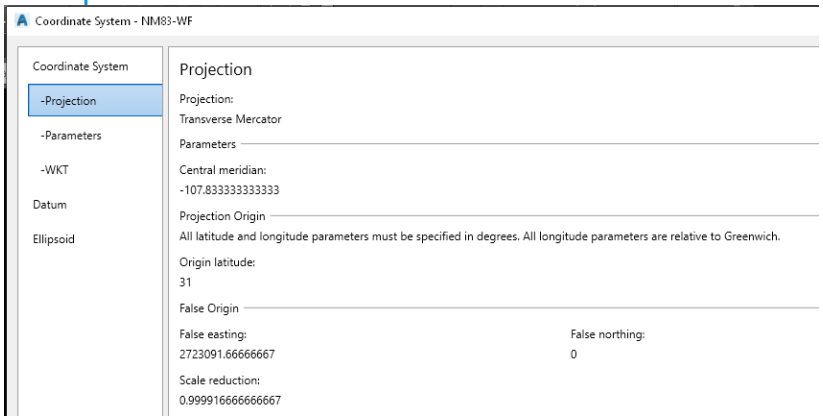
  (SR factor) x (CSF) = (New SR factor).

  (2,723,091.66666667) x 1.00031337818 = (2,723,945.02418 New False Easting)

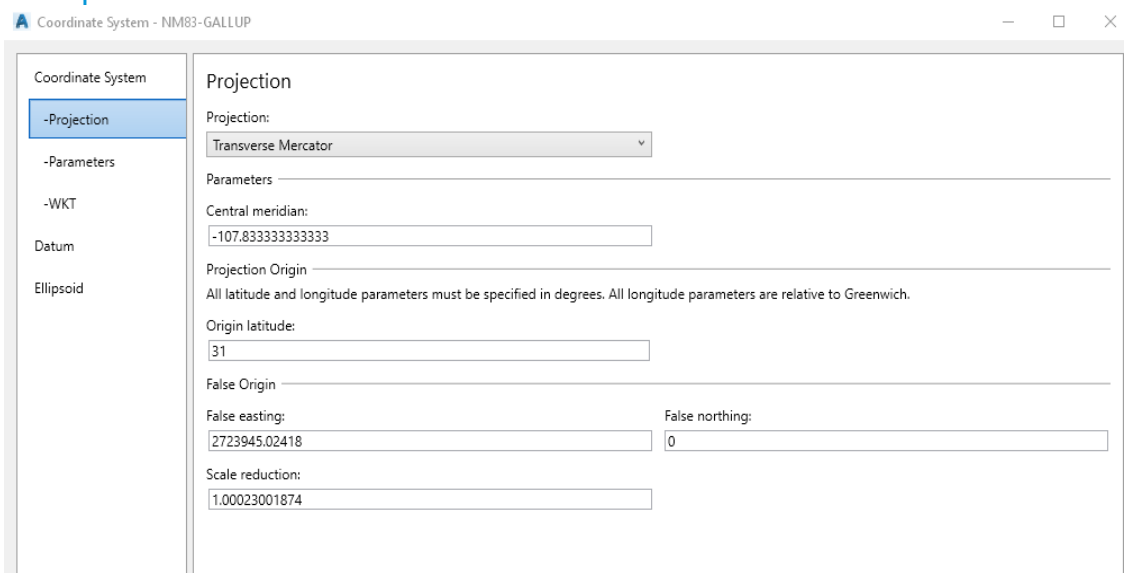
  (0.999916666666667) x 1.00031337818 = (1.00023001874 New Scale Reduction)

Scenario 2 (cont.) - Projection Calc's

Snapshot of NM83-WF.



Snapshot of our CCS.



Scenario 2 cont. – Test your new Coordinate System

- The final step is to test your new Coordinate System Definition.
- Import Survey Cogo Points from another Coordinate System (i.e. NM83-WF) and confirm if they Transform into your Project Coordinates.
- Import a Local Jurisdictional ESRI shp file, and confirm that it fall into the correct location.



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