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Oregon Coordinate Reference System

Handbook and User Guide

Version 1.0
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Abstract

This document contains the history, development, best practice methods, and technical creation of a new coordinate system for the State of Oregon. The Oregon Coordinate Reference System (OCRS) is based on a series of 'low distortion' map projections (zones) whose parameters have been defined such that lineal distortion is very minimal for certain geographic areas. Each zone has been optimized by design, to be useful for surveying, engineering, GIS, and cartographic mapping, where distances measured between points in the grid coordinate system will be very close to those same points physically measured on the ground. It is important to realize that rectangular grid coordinates for all of the OCRS map projections may now be calculated with formulas through computer programs that would have seemed too complicated in the past, but now maybe considered to be a routine exercise. These same computer programs also make it a relatively simple procedure to complete transformations, moving the coordinates of a point or group of points from one coordinate system referenced to one datum, into coordinates referenced to a different datum for a given epoch. While having numerous state coordinate systems may seem cumbersome at first, actual user application through highly precise GNSS and terrestrial measurement devices provide for a level of mapping accuracy that is beneficial to all mapping professionals.

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The Technical Development Team, many of whom volunteered their time and expense to travel to meetings to work on the development of the OCRS zones. Their energy, collaboration, and sometimes entertaining moments made the yearlong effort a very memorable one.

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The Oregon GPS Users Group (OGUG), whose support, resources, and co-sponsorship with ODOT, of a statewide workshop on Low Distortion Projections in November 2008 and the OCRS "rollout" workshop in April 2010 was a valuable asset in promoting the new Oregon Coordinate Reference System.

Ron Singh, PLS
ODOT Chief of Surveys/Geometronics Manager

Living Document

This OCRS Handbook and User Guide is designed to be a ‘living document’ and will be updated with information and additional OCRS coordinate systems as new low distortion map projections are developed over time.

The OCRS was created with public money and volunteer effort for the benefit of surveying, engineering, GIS, and mapping professionals in the State of Oregon. Oregon is one of several states that have created new coordinate systems based on 'low distortion' map projections.

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Chapter 1 History and Development of the OCRS

1.1 History and Development of the Oregon Coordinate Reference System (OCRS)

The utilization of electronic survey data by surveyors and GIS professionals is bringing awareness of the need for higher accuracy when working with measurements on the earth and their representation in electronic databases and on paper. Modern GIS and surveying software now brings the opportunity to create low distortion map projections and coordinate systems that can relate closely to distances measured on the ground. The function of low distortion projections is to minimize the distortions of distances, areas and to a lesser extent azimuths and angles. These distortions are ever present because we live on a semi-round spheroid, and are presented with the impossibility of representing a curved surface on a plane without distortion. We can minimize that distortion by creating a mathematical model (map projection) that will allow us to work in a coordinate grid where calculated positions and distances are represented closely by the same positions and distances we measure on the ground. For mapping and GIS professionals, low distortion projections may dramatically reduce the need to 'rubber-sheet' data sets to make features fit. Now both survey and GIS data can co-exist without either dataset being degraded.

1.1.1 The Beginning

For many years the Oregon Department of Transportation had been looking for a better way to deal with map distortion other than the currently used Local Datum Plane Coordinate system (LDPC). Ron Singh, (ODOT Chief of Surveys) decided to investigate the use of 'low distortion' projections after attending an ACSM conference session put on by Michael Dennis in 2007. Subsequently, Ron made a presentation at the 2008 ODOT Surveyors Conference to introduce the concept, which was enthusiastically received. Then, in April of 2009, the surveying and GIS community were queried to see if there was interest to develop the system as a collaborative effort. The decision followed to move forward with developing test projections which led to the creation of a Technical Development Team made up of interested stakeholders. The term Oregon Coordinate Reference System (OCRS) was suggested and accepted by the group as the name for a new series of coordinate systems for Oregon. This system will be based on optimized 'low distortion' map projections, which when fully developed, will provide movement away from using the (ODOT) Local Datum Plane Coordinate (LDPC) method.

1.2 The OCRS Technical Development Team

The Technical Development Team was formed by soliciting participants from meetings and workshops held to explore the interest in the OCRS, through April of 2009. The Team was later expanded to include anyone who was interested in actively participating in the development of an OCRS zone in a particular geographic region. For the names of the individuals that participated on the Technical Development Team see the acknowledgement inside the front cover. See Figure 1.2 for a graphic representation of the time line from March of 2008 to the expected future legislation to revise ORS Chapter 93 sometime in 2011. The Technical Development Team worked closely with Michael Dennis (consultant) over multi-day sessions to construct projections through a refined iterative process leading to a final optimized solution for each geographic area.

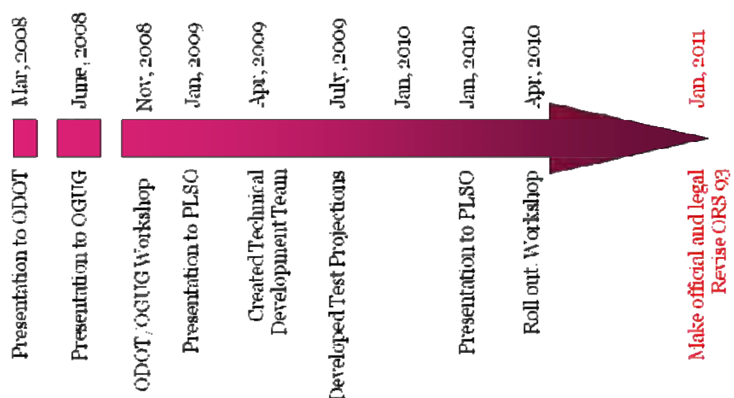


Figure 1.2: Historical Timeline for OCRS Meetings [rs]

1.3 OCRS 'Best Practice' Goals

During the spring and summer of 2009 several meetings were held and the following list of 'best practices' were developed by the Technical Development Team in an effort to focus on the critical elements that would lead to the creation of these new map projection zones. These 'best practices' continued to evolve during the process and are currently listed by number below.

1. The goal was established to use 1:100 000 ratio = ±10 ppm statewide [as big as zones as possible and still meet these criteria. No criteria difference between urban (local) and rural (regional) areas].
2. Use common and easy to implement map projections: Lambert, Transverse Mercator, with the Oblique Mercator (Rectified Skew Orthomorphic) added for special cases.
   a. Vendor software needs to support these projections. ODOT sent a letter to vendors letting them know that new coordinate systems for Oregon were under development.
3. The OCRS system would not require a site calibration (localization) by a surveyor for horizontal positioning in each projection zone coordinate system.
4. Each zone would have a positive NE coordinate system.
5. The false Northing's and Easting's for each zone would be designed to not conflict with one another and be markedly different than Oregon State Plane coordinates.
6. Units: (meters) - Considered dual units with international feet, but decided to move ahead with metric units for map projection parameters. Individuals may project into desired units.
7. The OCRS zones will be referenced to the National Spatial Reference System (NSRS). This is currently defined geometrically as NAD 83 (GRS-80 ellipsoid) and it will follow the NGS path (new datum definitions') in future. The projection parameters will not be affected by a specific realization of NAD 83, since all of these realizations reference the GRS 80 ellipsoid.
8. Projections created should be referenced to NAD 83 'generically' with specific realization of NAD 83 (such as HARN, CORS96 or NSRS2007) stated in the metadata associated with the observed <u>project</u> datasets.
9. The method used to create each zone will not involve scaling the ellipsoid. Scaling modifies GRS-80, making the resulting projection not compatible with NAD 83.
10. If an existing low distortion projection already exists it will be reviewed by the Technical Development Team to see if it meets these 'best practices' and also provides for the greatest available ±10ppm coverage for the area under consideration.
11. The vertical datum will be the current NAVD 88, but will also follow the NGS lead adopting the future NAVD based on a pure gravimetric geoid (via the Grav-D Project). The geoid model used is part of the metadata belonging to a full coordinate system; however the geoid is independent of the OCRS projection zone parameters.
12. The development of the OCRS system will include parameters for each zone that will be included in a future published Handbook and User Guide.
    a. The OCRS will ultimately have its own web page separate from the ORGN web page.
13. No artificial political boundaries will define the limits of a particular zone. Each zone will be defined by latitude and longitude limits, but may include the option to modify the zone limits to match key areas or include political boundaries (will try not to break populated areas into two zones).
14. Interact with NGS in the future to develop:
    a. Standard methodology for low distortion project zone development.
    b. In the future suggest the NGS develop an automated software tool for creating low distortion projection coordinate systems.
    c. Document/register/catalog zones on the NGS website
    d. Discuss the possibility of OCRS and other state legislated zones being included on NGS datasheet output files, including OPUS output results.

15. Involve stakeholders in the review of the OCRS development by giving presentations etc. (local users: PLSO, OACES, OGUG, GIS groups, OSU, OIT, etc.)
16. Involve software vendors so they can include the OCRS zones when they update their software.
17. The size of each zone to be determined when created. Zones will cover as large an area as possible and still meet the distortion criteria, so as to minimize the total number of zones.
19. For Lambert Conformal Conic (LCC) zones, the Latitude of grid origin shall be the same as the standard parallel chosen.
20. Each zone must have unique coordinate system origins that differ from one another by a significant amount so as not to be confused with one another.

1.4 Why the Oregon State Plane Coordinate System is Deficient for Certain Modern Day Uses

The State Plane Coordinate system was first studied in 1933 by the U.S. Dept. of Commerce, Coast and Geodetic Survey and eventually adopted for Oregon law (legal status) in 1945. Oregon is based on the Lambert Conformal Conic Projection with two zones (North-3601 and South-3602). By keeping the width of the zones under 158 miles (with the scale exact along the standard parallels), the maximum distortion (with respect to the ellipsoid) was kept to approximately one part in 9,500 (105 parts per million)(5). This distortion error occurs when these zones are constructed for mapping purposes and it is because of this, that the state plane system presents the following issues for the surveying and GIS community:

- Does not represent ground distances except near sea level elevations (along the coast and major river systems) and near the standard parallels.
- Does not minimize distortion over large areas and varying elevations
- Does not reduce convergence angles
- Does not support modern datum and geoid grid reference frames

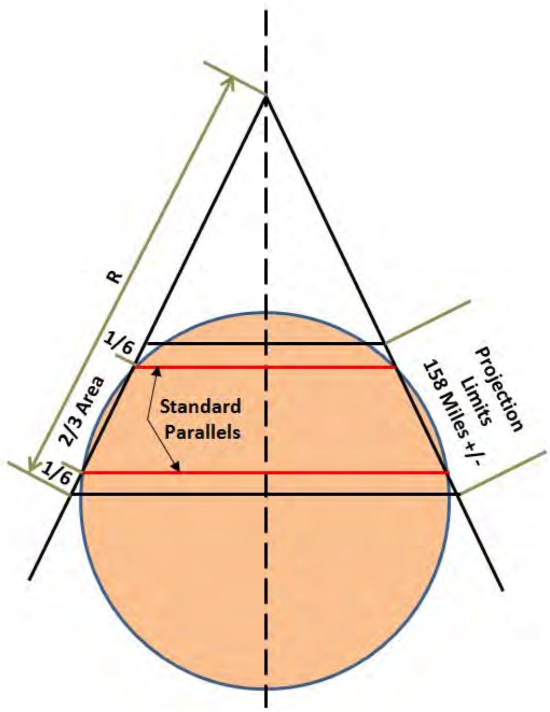
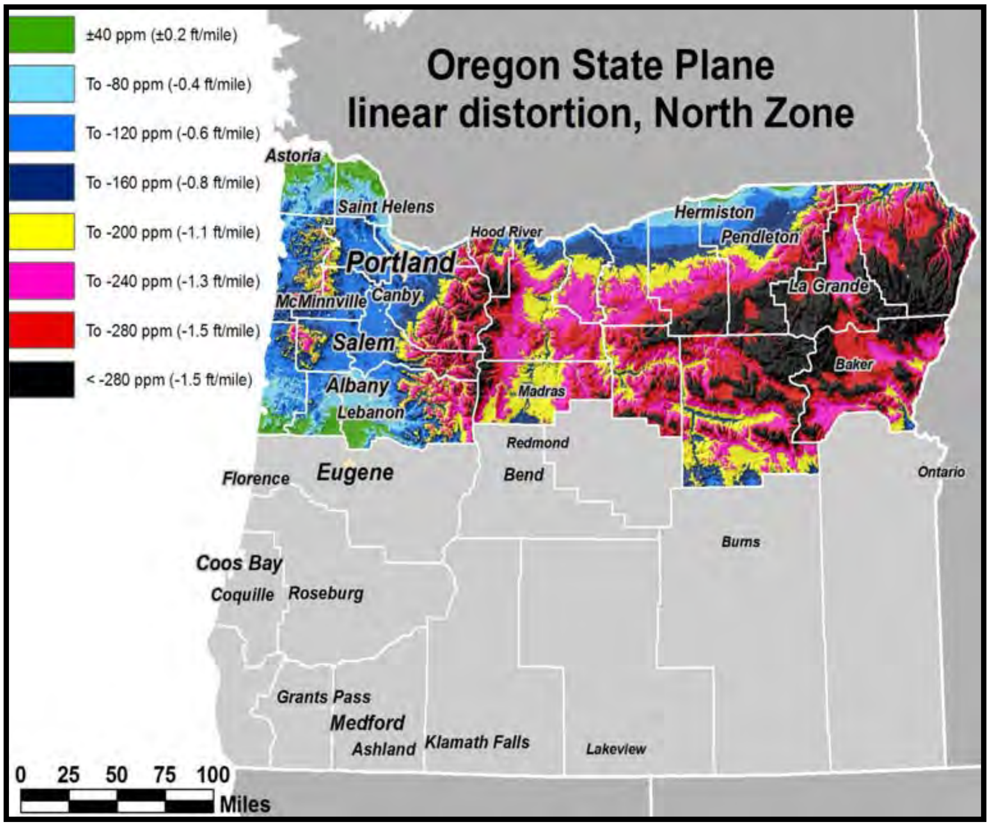
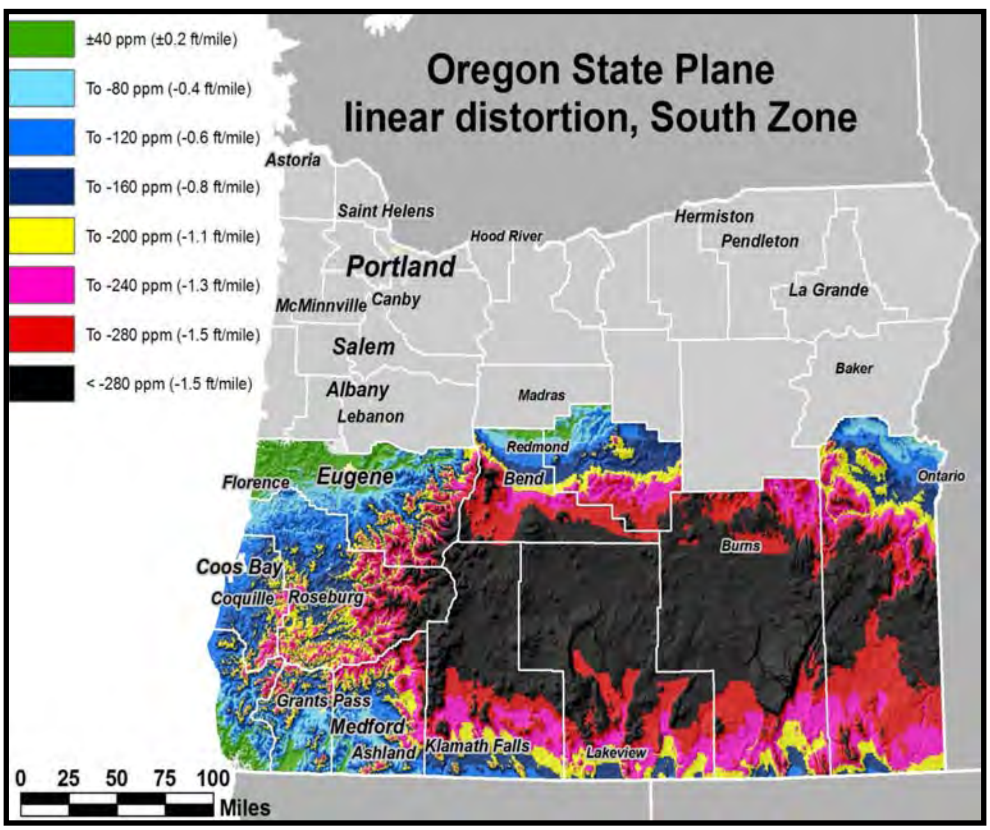


Figure 1.4: Oregon State Plane Two parallel Lambert Conformal Conic Projection [mla]

Currently State Plane coordinates are available for all Oregon's horizontal control points that reside in the National Geodetic Survey (NGS) Integrated Database (datasheets) and are also generated for all points submitted to the NGS Online Positioning User Service (OPUS). The Oregon State Plane Coordinate System still maintains some limited advantages for general surveying and mapping (GIS) at a statewide level, such as depicting physical, cultural, and human geography over large areas of the state. It also works well for mapping long linear facility lines such as highways, electrical transmission, and pipelines, which crisscross the state. The state plane coordinate system provides for a common reference (map projection) for conversions (transformations) between other coordinate systems including the zones of the OCRS. The Figures below (Figures 1.4.0.1 & 1.4.0.2) depict total linear distortion (at the topographic surface of the Earth) for both the North and South Oregon State Plane zones. Note that the minimum level of distortion (±40 ppm) covers a relatively small area and large urban areas of the State have significantly higher distortion.

Figures 1.4.0.1 & 1.4.0.2





1.4.1 Oregon State Plane Coordinate System Definitions

OREGON NORTH ZONE (Designation 3601)
Oregon State Plane North - NAD 1983
Lambert Conformal Conic Two Standard Parallel Projection (Secant)
Central Meridian: -120° 30’ (W)
Latitude of Origin: 43° 40’
Standard Parallel (South): 44° 20’
Standard Parallel (North): 46°
False Northing: 0.000 m
False Easting: 2 500 000.000 m
Max scale error: ~1:9 500 (±105 ppm) *Note:* This maximum scale error is distortion with respect to the ellipsoid, not the topographic surface, and occurs along the central parallel. The actual distortion at the topographic surface is typically greater, and it changes at a rate of 4.8 ppm per 100-ft change in height.

North Zone County Coverage:
BAKER, BENTON, CLACKAMAS, CLATSOP, COLUMBIA, GILLIAM, GRANT, HOOD RIVER, JEFFERSON, LINCOLN, LINN, MARION, MORROW, MULTNOMAH, POLK, SHERMAN, TILLAMOOK, UMATILLA, UNION, WALLOWA, WASCO, WASHINGTON, WHEELER, YAMHILL.

OREGON SOUTH ZONE (Designation 3602)
Oregon State Plane South - NAD 1983
Lambert Conformal Conic Two Standard Parallel Projection (Secant)
Central Meridian: -120° 30’ (W)
Latitude of Origin: 41° 40’
Standard Parallel (South): 42° 20’
Standard Parallel (North): 44°
False Northing: 0.000 m
False Easting: 1 500 000.000 m
Max scale error: ~1:9 500 (±105 ppm) *Note:* This maximum scale error is distortion with respect to the ellipsoid, not the topographic surface, and occurs along the central parallel. The actual distortion at the topographic surface is typically greater, and it changes at a rate of 4.8 ppm per 100-ft change in height.

South zone county coverage:
COOS, CROOK, CURRY, DESCHUTES, DOUGLAS, HARNEY, JACKSON, JOSEPHINE, KLAMATH, LAKE, LANE, MALHEUR.

1.5 Local Datum Plane Coordinate (LDPC) Method vs. Low Distortion Projection Method

1.5.1 Local Datum Plane Coordinate Systems

In the late 1930’s, ODOT adopted a system known as ‘Local Datum Plane Coordinates’ (LDPC) that scaled State Plane Coordinates to a plane close to the average ground elevation for a specific highway project. A ‘Combined Scale Factor’ was calculated from a ‘Projection Scale Factor’ (based on the local latitude at the center of a project) expressed as a ratio, multiplied by a ‘Sea Level Factor’ (originally based on the representative project elevation above sea level where (NGVD 29) sea level and ellipsoid height were coincidental). Traditionally these factors were determined from tables(14). Later with the advent of NAVD 88 and computer geodesy programs the ‘height above the ellipsoid’ was used in place of the elevation above sea level. Essentially, this project ‘Combined Scale Factor’ was divided into the Oregon

State Plane northing and easting coordinate values of the project control points, thereby scaling the values of the control points to yield LDPC coordinates. This method allows for the LDPC grid measurements to closely match actual ground distances measured and the project basis of bearing still remains the same as the Oregon State Plane grid. While this system generally works well, there are some inherent problems with this system:

- LDPC systems represent only small low distortion areas (i.e., in general does not minimize distortion over as large an area as can be achieved using a customized projection)
- LDPC coordinates look similar to state plane coordinates, but are NOT
- As a scaled version of a true map projection, it cannot be geo-referenced (requires reversion calculation back to State Plane Coordinates)
- Each project is on a unique stand alone LDPC system
- Not directly compatible with recognized datum or the National Spatial Reference System (NSRS).

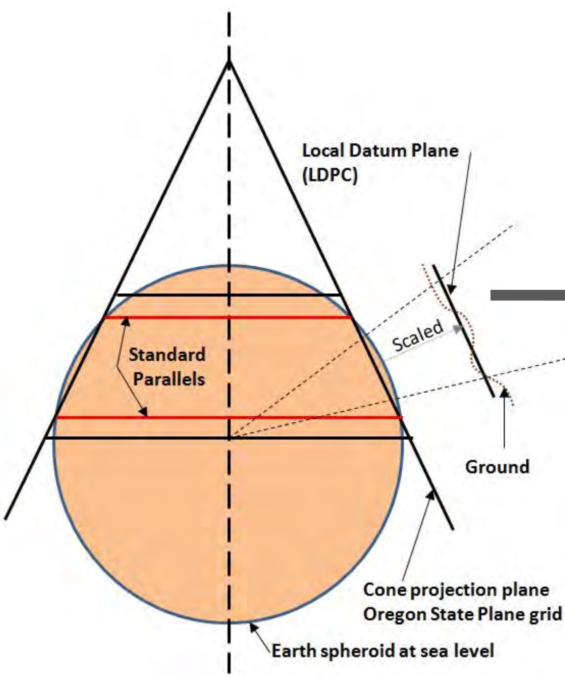


Figure 1.5: Local Datum Plane Coordinate System scaled from Oregon State Plane [mla]

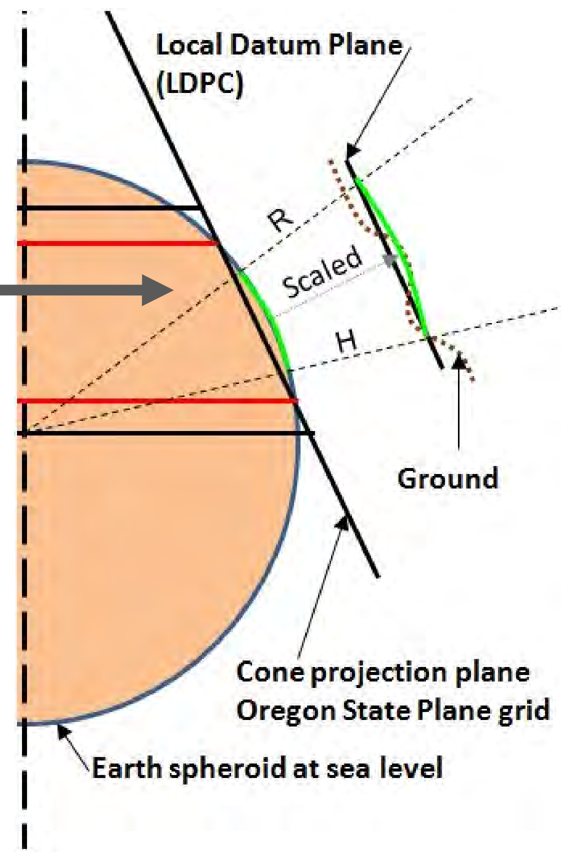


Figure 1.5.1: Local Datum Plane Coordinate System enlarged to show spheroid to LDPC plane

1.5.2 Low Distortion Map Projection Systems

Low distortion map projections (like those within the OCRS coordinate system) are based on true conformal projections designed to cover specific portions of urban and rural areas of the state. For conformal projections (e.g., Transverse Mercator, Lambert Conformal Conic, Stereographic, Oblique Mercator (RSO), regular Mercator, etc.), linear distortion is the same in every direction from a point. That is, the scale at any particular point is the same in any direction and figures on the surface of the Earth tend to retain their original form on the map. In addition, angles on the Earth are the same as on the map. The term 'low distortion' refers to minimizing the lineal horizontal distortion from two affects:

1) representing a curved surface on a plane and 2) departure of the elevated topography from the projection surface due to variation in the regional height of the area covered. See Section 2.2 for more information on map projection distortion.

The advantages of a low distortion projection are:

- Grid coordinate zone distances very closely match the same distance measured on the ground
- Allow for larger areas (than LDPC) to be covered with less distortion
- Reduced convergence angle (if the central meridian is centered within the zone)
- Quantitative distortion levels can be determined from topographic heights
- Clean zone parameter definitions compatible with common surveying, engineering, and GIS software
- Easy to transform between other coordinate systems
- Maintains a relationship to the National Spatial Reference System (NSRS) by allowing direct use of published NSRS control coordinates (i.e., latitude, longitude, and ellipsoid height)
- Can cover entire cities and counties making them useful for regional mapping and GIS

1.5.3 Projection Grid Coordinates

Because calculations relating latitude and longitude to positions of points on a given map can become quite involved, rectangular grids have been developed for the use of surveyors, engineers, and GIS mapping professionals. In this way, each point may be designated merely by its distance from two perpendicular axes on the 'plane' map. The '*Y*' axis normally coincides with a chosen central meridian, '*y*' increasing north. The '*X*' axis is perpendicular to the '*Y*' axis at a latitude of origin on the central meridian, with '*x*' increasing east. Commonly, '*x*' and '*y*' coordinates are called "eastings" and "northings," respectively, and to avoid negative coordinates may have "false eastings" and "false northings" added to relate to the projection grid origin.

Chapter 2 Coordinate System Geodesy

2.1 Types of Conformal Map Projections Used for the OCRS

2.1.1 Lambert Conformal Conic Projection

The Lambert Conformal Conic projection (created in 1772 by Johann Heinrich Lambert), is one of the most commonly used low distortion projections. As the name implies, the Lambert projection is conformal (preserves angles with a unique scale at each point). This projection superimposes a cone over the sphere of the Earth, with either one reference parallel tangent (or above the globe in the case of a low distortion projection) or with two standard parallels secant (a straight line that intersects with the globe in two places). Specifying a 'central meridian' orients the cone with respect to the ellipsoid. Scale error (distortion with respect to the ellipsoid) is constant along the parallel(s). Typically, it is best used for covering areas long in the east–west direction, or, for low distortion applications, where topographic height changes more-or-less uniformly in the north-south direction. The Lambert Conformal Conic projection for relatively large regions of the state (such as the OCRS 'low distortion zones') is designed as a single parallel Lambert projection. The cone of the projection is typically scaled up from the ellipsoid to 'best fit' an area and range of topographic height on the Earth's surface (see Figure 2.2.3).

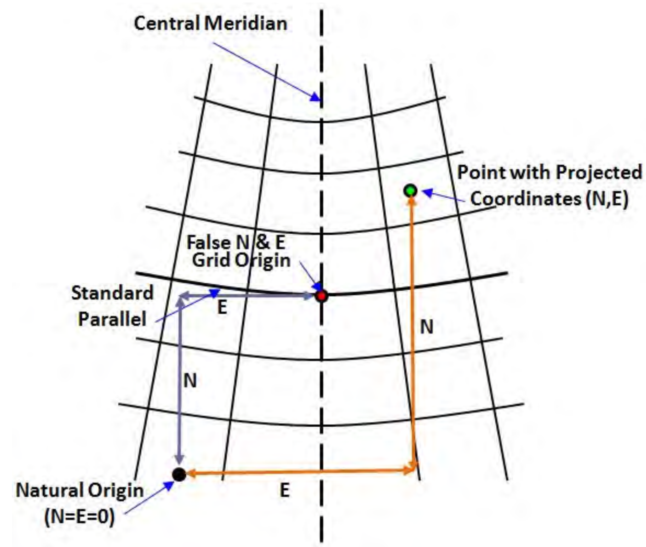


Figure 2.1.1: Diagram for Lambert Conical Conformal Projection with one standard parallel

2.1.2 Transverse Mercator Projection

The Transverse Mercator (ellipsoidal) map projection was originally presented by mathematician Carl Friedrich Gauss in 1822. It is a conformal projection that is characterized by a cylinder superimposed over the ellipsoid of the earth with a straight central meridian. Distances along the meridian have a constant scale. This projection is used for the familiar UTM (Universal Transverse Mercator) map projection series, and it is the most commonly used in geodetic mapping especially for areas of study that are relatively close to the central meridian. This project works particularly well for areas long in the north – south direction, and for low distortion applications where topographic height changes more-or-less uniformly in the east-west direction.

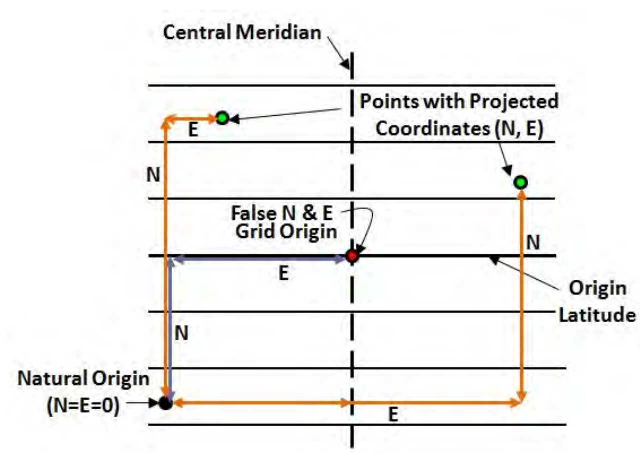


Figure 2.1.2: Diagram Transverse Mercator Projection [mla]

2.1.3 Oblique Mercator (RSO) Projection

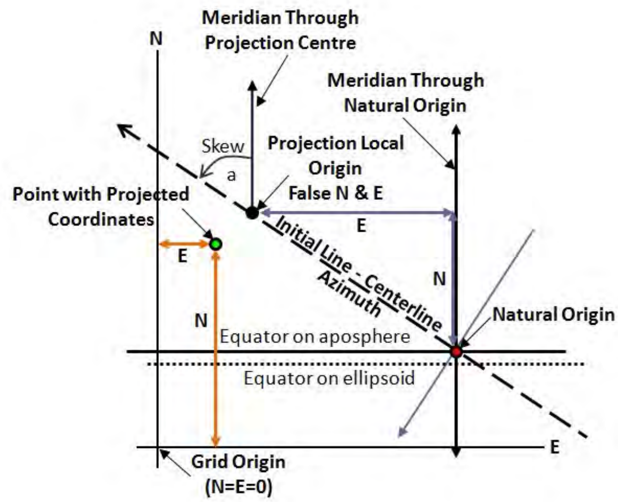


Figure 2.1.1: Diagram for Oblique Mercator (RSO) Projection [mla]

Various forms of the Oblique Mercator (OM) projection have been developed, and the ellipsoidal form used for the OCRS (as well as State Plane) was published by Martin Hotine in 1947(8). Hotine called it the Rectified Skew Orthomorphic (RSO) projection, and it still goes by this name in some publications and software. It is an oblique form (rotated cylinder) of the Mercator conformal map projection. The 'Initial Line' is the centerline (projection skew axis) and is specified with <u>one point</u> and an <u>azimuth</u> (or skew angle) which may be positive or negative (right or left). This projection is typically used for long linear features that run at 'angle' to what would otherwise be normal north-south or east-west conventions. Here the projection centerline is along a geodesic, at an oblique angle (rotated cylinder), and the process is to specify the projection local origin latitude and longitude together with the centerline (Initial Line) azimuth to be the line that runs parallel and centered near the alignment of the key object or landform such as a coast line, river, or island chain feature of the Earth. Along this Initial Line the scale is true (one) much like the normal Mercator projection and perpendicular from this line the scale varies from one. This projection works well when the areas of study are relatively close to this line. The specified 'grid origin' is located where north and east axes are zero. In contrast, the 'natural origin' of the projected coordinates is located where the 'Initial Line' of the projection crosses the 'equator of the aposphere' (a surface of constant total curvature), which is near (but not coincident with) the ellipsoid equator (see Figure 2.1.1). The ellipsoid is conform-ally mapped onto the aposphere, and then to a cylinder, which ensures that the projection is strictly conformal. However, unlike the TM projection, where the scale is constant along the central meridian, the scale (with respect to the ellipsoid) is not quite constant along the Initial Line (rather it is constant with respect to the aposphere). But the variation in scale along the Initial Line is small for areas the size of the state of Oregon. For example, the scale on the Initial Line of the OCRS Oregon Coast zone nominally equals 1, but it actually equals exactly 1 only at the local origin, and increases to 1.000 000 25 (+0.25 ppm) at the south end of the zone (42° 00' N) and decreases to 0.999 999 95 (-0.05 ppm) at the north end of the zone (46° 20' N).

Note that this projection can also be defined by specifying the Initial Line using two points. However, the conventional use for the OCRS definitions was a single point and a skew azimuth.

2.2 Managing Map Projection Distortion

2.2.1 Distortion is Unavoidable

Johann Carl Friedrich Gauss's (1777–1855) Theorema Egregium (Remarkable Theorem) mathematically proved that a curved surface (such as the Earth's ellipsoid model) cannot be represented on a plane without distortion. Since any method of representing a sphere's surface on a plane is a map projection, all map projections produce distortion and every distinct map projection distorts in a distinct way. For low distortion projections, deciding on the type of map projection in order to minimize the distortion for an area of the earth may not be an obvious or clear-cut task.

2.2.2 Two General Types of Map Projection Distortion by Michael L. Dennis, PE, RLS

1. Linear distortion - The difference in distance between a pair of grid (map) coordinates when compared to the true (ground) distance, is shown by *δ* in tables 2.2.2.1 and 2.2.2.2. This may be expressed as a ratio of distortion length to ground length: E.g., feet of distortion per mile; parts per million (= mm per km). *Note:* 1 foot / mile = 189 ppm = 189 mm / km.

Linear distortion can be positive or negative:
Negative distortion means the grid (map) length is shorter than the "true" horizontal (ground) length.
Positive distortion means the grid (map) length is longer than the "true" horizontal (ground) length.

(continued on next page)

Linear distortion due to Earth curvature

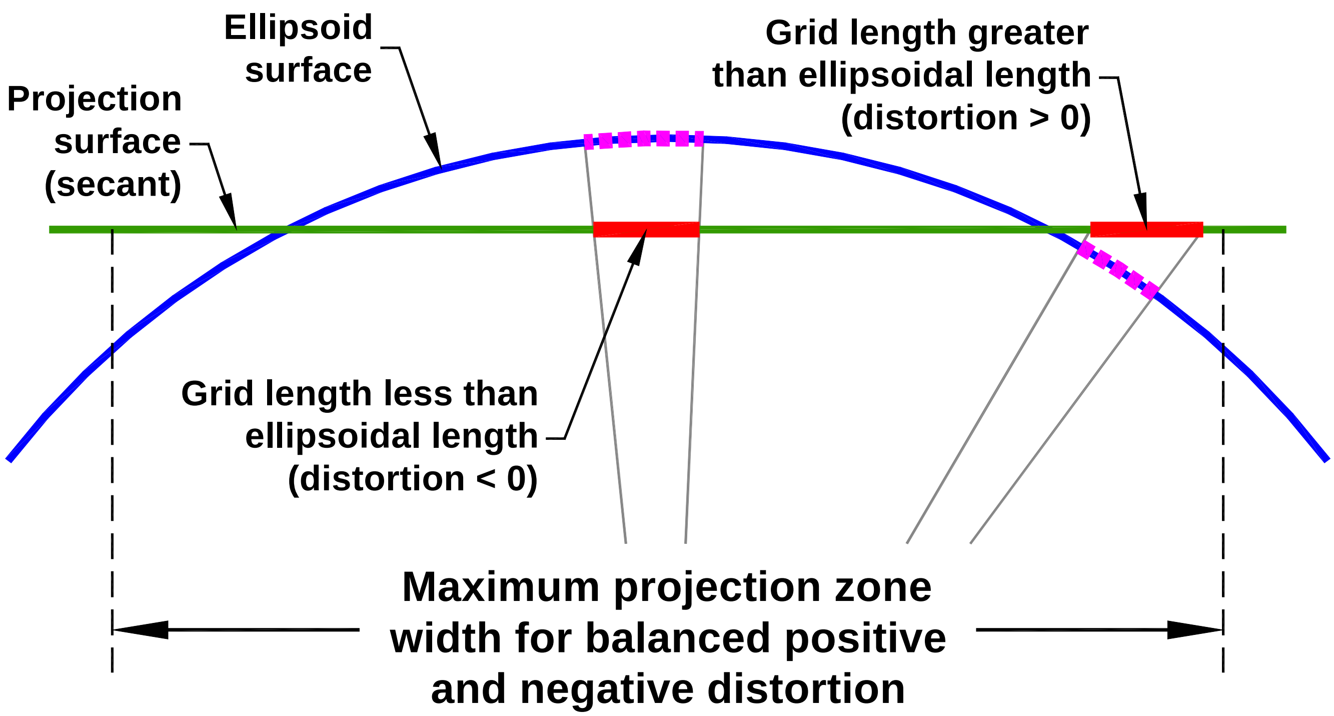


Table 2.2.2.1

Maximum zone width for secant projections (km and miles)	Maximum linear horizontal distortion, *δ*		
	Parts per million (mm/km)	**Feet per mile**	**Ratio (absolute value)**
25 km (16 miles)	±1 ppm	±0.005 ft/mile	1 : 1,000,000
57 km (35 miles)	±5 ppm	±0.026 ft/mile	1 : 200,000
81 km (50 miles)	±10 ppm	±0.05 ft/mile	1 : 100,000
114 km (71 miles)	±20 ppm	±0.1 ft/mile	1 : 50,000
180 km (112 miles)	±50 ppm	±0.3 ft/mile	1 : 20,000
255 km (158 miles) e.g., SPCS*	±100 ppm	±0.5 ft/mile	1 : 10,000
510 km (317 miles) e.g., UTM†	±400 ppm	±2.1 ft/mile	1 : 2,500

*State Plane Coordinate System; zone width shown is valid between ~0° and 45° latitude
†Universal Transverse Mercator; zone width shown is valid between ~30° and 60° latitude

Linear distortion due to ground height above ellipsoid

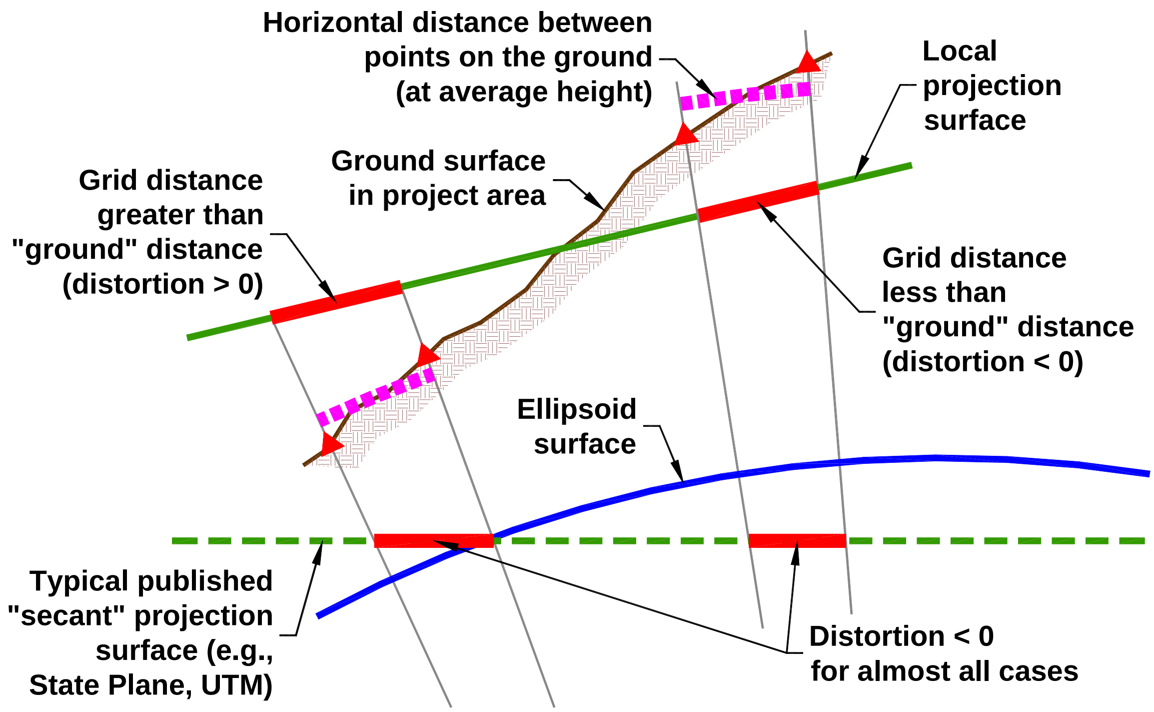


Table 2.2.2.2

Height below (–) and above (+) projection surface	Maximum linear horizontal distortion, δ		
	Parts per million (mm/km)	Feet per mile	Ratio (absolute value)
±30 m (±100 ft)	±4.8 ppm	±0.025 ft/mile	~1 : 209,000
±120 m (±400 ft)	±19 ppm	±0.10 ft/mile	~1 : 52,000
±300 m (±1000 ft)	±48 ppm	±0.25 ft/mile	~1 : 21,000
+600 m (+2000 ft)*	–96 ppm	–0.50 ft/mile	~1 : 10,500
+1000 m (+3300 ft)**	–158 ppm	–0.83 ft/mile	~1 : 6,300
+4400 m (+14,400 ft)†	–688 ppm	–3.6 ft/mile	~1 : 1,500

*Approximate mean topographic height of North America (US, Canada, and Central America)
** Approximate mean topographic height of western coterminous US (west of 100°W longitude)
† Approximate maximum topographic height in coterminous US

Rule of Thumb:

A 30 m (100-ft) change in height causes a 4.8 ppm change in distortion

Creating an LDP and minimizing distortion by the methods described in this document only makes sense for conformal projections. For conformal projections (e.g., Transverse Mercator, Lambert Conformal Conic, Stereographic, Oblique Mercator (RSO), regular Mercator, etc.), linear distortion is the same in every direction from a point. For all non-conformal projections (such as equal area projections), linear distortion generally varies with direction, so there is no single unique linear distortion (or "scale") at any point.

2. Angular distortion - For conformal projections (e.g., Transverse Mercator, Lambert Conformal Conic, Stereographic, Oblique Mercator, etc.), this equals the *convergence* (*mapping*) *angle* (γ). The convergence angle is the difference between grid (map) north and true (geodetic) north. Convergence angle is zero on the projection central meridian, positive east of the central meridian, and negative west of the central meridian as shown in table 2.2.2.3 below.

The magnitude of the convergence angle increases with distance from the central meridian, and its rate of change increases with increasing latitude.

Table 2.2.2.3 shows 'convergence angles' at a distance of one mile (1.6 km) east (positive) and west (negative) of projection central meridian (for both Transverse Mercator and Lambert Conformal Conic projections).

Table 2.2.2.3

Latitude	Convergence angle 1 mile from CM	Latitude	Convergence angle 1 mile from CM
0°	0° 00' 00"	50°	±0° 01' 02"
10°	±0° 00' 09"	60°	±0° 01' 30"
20°	±0° 00' 19"	70°	±0° 02' 23"
30°	±0° 00' 30"	80°	±0° 04' 54"
40°	±0° 00' 44"	89°	±0° 49' 32"

Usually convergence is not as much of a concern as linear distortion, and it can only be minimized by staying close to the projection central meridian (or limiting surveying and mapping activities to equatorial regions of the Earth). Note that the convergence angle is zero for the regular Mercator projection, but this projection is not suitable for large-scale mapping in non-equatorial regions. In many areas, distortion due to variation in ground height is greater than that due to curvature. **The total linear distortion of grid (map) coordinates is a combination of distortion due to Earth curvature and distortion due to ground height above the ellipsoid.**

2.2.3 Six Steps for Designing a Low Distortion Projection (LDP) by Michael L. Dennis, PE, RLS

Step 1. Define the project area and choose a representative ellipsoid height, h_o (<u>not</u> elevation)

The average height of an area may not be appropriate (e.g., for projects near a mountain). Usually there is no need to estimate height to an accuracy of better than about ±6 m (±20 ft). Note that as the size of the area increases, the effect of Earth curvature on distortion increases, and it must be considered in addition to the effect of topographic height, E.g., for areas wider than about 56 km (35 miles) perpendicular to the projection axis (i.e., ~28 km or ~18 miles either side of projection axis), distortion due to curvature alone exceeds 5 parts per million (ppm). The "projection axis" is defined in step #2.

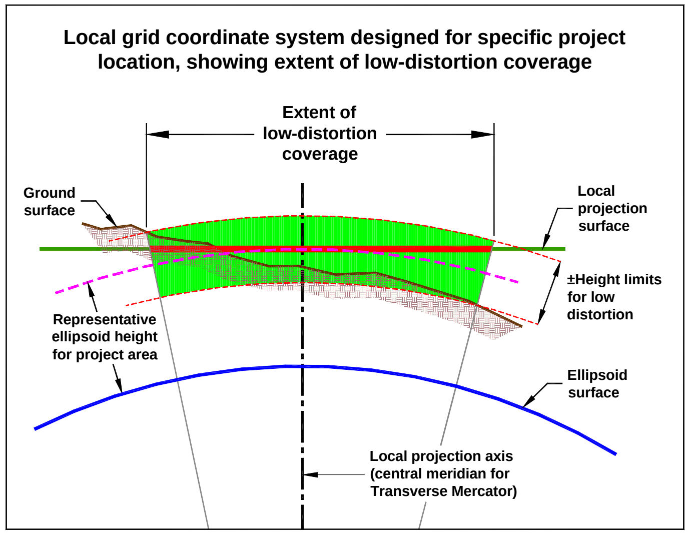


Figure 2.2.3: Diagram shows the affect of scaling the projection to a representative height above the ellipsoid [md]

Step 2. Choose the projection type and place the projection axis near the centroid of the project area. Select a well-known and widely used conformal projection, such as the Transverse Mercator (TM), one-parallel Lambert Conformal Conic (LCC), or Oblique Mercator (OM/RSO).

When minimizing distortion, it will not always be obvious which projection type to use, but for small areas (< ~55 km or ~35 miles wide perpendicular to the projection axis), usually both the TM and LCC will provide satisfactory results.

When in doubt, the TM is a good choice for most applications, since it is probably the map projection supported across the broadest range of software packages. However, commercial software vendors are adding more user-definable projections, and so over time the problem of projection availability should diminish.

In nearly all cases, a two-parallel LCC should ***not*** be used for an LDP with the NAD 83 datum definition (but note that some software may not support a one-parallel LCC). A two-parallel LCC should not be used because the reason there are two parallels is to make the projection secant to the ellipsoid (i.e., the central parallel scale is less than 1). This is at odds with the usual objective of scaling the projection so that the developable surface is at the topographic surface, which is typically above the ellipsoid, particularly in areas where reduction in distortion is desired.

The OM (RSO) projection can be very useful for minimizing distortion over large areas, especially areas that are more than about 56 km (35 miles) long in an oblique direction. It can also be useful in areas where the topographic slope varies gradually and more-or-less uniformly in a direction other than north-south or east-west. The disadvantage of this projection is that it is more difficult to evaluate, since another parameter must be optimized (the projection skew axis). In addition, this projection is more complex, and may not be available in as many software packages as the TM and LCC.

The Oblique Stereographic (OS) projection can also provide satisfactory results for small areas, but it has the disadvantage of not conforming to Earth curvature in any direction. In situations where this projection works well, there really is no reason to use it, because the TM projection will give equally good (if not better) results. In very rare cases this projection might give the best results, such as bowl-shaped areas.

Bear in mind that universal commercial software support is not an essential requirement for selecting a projection. In the rare cases where third parties must use a coordinate system based on a projection not supported in their software, it is always possible for them to get on the coordinate system implicitly (i.e., by using a best-fit procedure based on coordinate values).

The 'projection axis' is the line along which projection scale is constant (with respect to the ellipsoid). It is the central meridian for the TM projection, the standard (central) parallel for the one-parallel LCC projection, the (implicitly defined) central parallel for the two-parallel LCC projection, and the skew axis for the OM projection (actually the scale is not quite constant along the skew axis, as discussed in Section 2.1.3). The OS projection does not have a projection axis (projection scale is only constant at one point).

Place the central meridian of the projection near the east-west “middle” of the project area in order to minimize convergence angles (i.e., the difference between geodetic and grid north).

In some cases it may be advantageous to offset the projection axis from project centroid (e.g., if topographic height increases or decreases gradually and more-or-less uniformly perpendicular to the projection axis).

Step 3. Scale the central meridian of the projection to representative ground height, h_o

Compute map projection axis scale factor “at ground”: $k_0 = 1 + \frac{h_0}{R_G}$

For the TM projection, k_0 is the central meridian scale factor.

For the one-parallel LCC projection, k_0 is the standard (central) parallel scale factor.

For the OM projection, k_0 is the projection skew axis scale at the local origin.

For the OS projection, k_0 is the scale at the projection origin.

R_G is the geometric mean radius of curvature, $R_G = \frac{a\sqrt{1-e^2}}{1-e^2\sin^2\varphi}$

and φ = geodetic latitude of point, and for the GRS-80 ellipsoid:

a = semi-major axis = 6,378,137 m (exact) = 20,925,646.325 international ft.
= 20,925,604.474 US survey ft.

e^2 = first eccentricity squared = $2f - f^2$

f = geometric flattening = 1 / 298.257222101

Alternatively, can initially approximate R_G since k_0 will likely be refined in Step #4, by using R_G values in Table 2.2.3.1.

Geometric mean radius of curvature at various latitudes for the GRS-80 ellipsoid (rounded to nearest 1000 meters and feet).

Table 2.2.3.1

Latitude	R_G (meters)	R_G (feet)	**Latitude**	R_G (meters)	R_G (feet)
0°	6,357,000	20,855,000	50°	6,382,000	20,938,000
10°	6,358,000	20,860,000	60°	6,389,000	20,961,000
20°	6,362,000	20,872,000	70°	6,395,000	20,980,000
30°	6,367,000	20,890,000	80°	6,398,000	20,992,000
40°	6,374,000	20,913,000	90°	6,400,000	20,996,000

Step 4. Check the distortion at points distributed throughout project area

The best approach here is to compute distortion over entire area and generate distortion contours (this ensures optimal low-distortion coverage). This may require repeated evaluation using different k_0 values. It may also warrant trying different projection axis locations and different projection types.

Distortion computed at a point (at ellipsoid height *h*) as $\delta = k\left(\frac{R_G}{R_G + h}\right) - 1$

Where *k* = projection grid point scale factor (i.e. "distortion" with respect to the ellipsoid at a specific point). Note that computation of *k* is rather involved, and is often done by commercially available software. However, if your software does not compute *k*, or if you want to check the accuracy of *k* computed by your software, equations for doing so for the TM and LCC projections are provided later in this document. Because δ is a small number for low distortion projections, it is helpful to multiply δ by 1,000,000 to express distortion in parts per million (ppm).

Step 5. Keep the definition simple and clean

Define k_0 to no more than six decimal places, e.g., 1.000206 (exact). *Note:* A change of one unit in the sixth decimal place equals distortion caused by a 6.4-meter (21-foot) change in height. Defining central meridian and latitude of grid origin to nearest whole arc-minute is usually adequate (e.g., central meridian = 111°48'00" W).

Define grid origin using whole values with as few digits as possible (e.g., false easting = 50,000 for a system with maximum easting coordinate value < 100,000). Note that the grid origin definition has no effect whatsoever on the map projection distortion.

It is strongly recommended that the coordinate values everywhere in the design area be distinct from other coordinate system values for that area (such as State Plane or UTM) in order to reduce the risk of confusing the LDP with other systems. *Note:* In some applications, there may be an advantage to using other criteria for defining the grid origin. For example, it may be desirable for all coordinates in the design area to have the same number of digits (such as six digits, i.e., between 100,000 and 999,999). In other cases it may be useful to make the coordinates distinct from State Plane by using larger rather than smaller coordinates, especially if the LDP covers a very large area.

Step 6. Explicitly define linear unit and geometric reference system (i.e., geodetic datum)

E.g., Linear unit = metric; (or) Linear unit = international foot; Geometric reference system = NAD 83 (2007).

The international foot is shorter than the US survey foot by 2 ppm. Because coordinate systems typically use large values, it is critical that the type of foot used be identified (the values differ by 1 foot per 500,000 feet). *Note:* The reference system realization (i.e., "datum tag") is not an essential component of the coordinate system definition. However, the datum tag is an essential component for defining the spatial data used within the coordinate system. This is shown in a metadata example later in this document. For NAD 83, the NGS convention is to give the datum tag in parentheses after the datum name, usually as the year in which the datum was "realized" as part of a network adjustment. Common datum tags are listed below:

- "2007" for the current NSRS2007 (National Spatial Reference System of 2007) realization.
- "199*x*" for the various HARN (or HPGN) realizations, where *x* is the last digit of the year of the adjustment (usually done for a particular state). For example, a HARN/HPGN adjustment for Oregon was done in 1991, so its datum tag is "1991"(there was also a readjustment performed in 1998 with a corresponding "1998" datum tag). The HARN and HPGN abbreviations are equivalent, and they stand for "High Accuracy Reference Network" and "High Precision Geodetic Network", respectively.
- "CORS" for the realization based on the CORS network, and currently corresponding to 2002.00 for the coterminous US and Hawaii (and 2003.00 in Alaska).
- "1986" for the original NAD 83 realization. Because of the coordinate changes that occurred as part of the HARN/HPGN and NSRS2007 readjustments, this realization is not appropriate for data with horizontal accuracies of better than about 1 meter.

2.3 What Constitutes a Complete Coordinate System?

A complete 3D coordinate system is made up of a combination of horizontal and vertical datum, geoid model, and a map projection definition. Each of these has certain aspects to consider which are briefly discussed below.

2.3.1 Ellipsoid Models

The overall shape of the earth is modeled by an ellipsoid of revolution (sometimes referred to as a spheroid). In order to imagine an ellipsoid model for the earth, align the shorter axis with the polar axis of the earth. Centrifugal force caused by the earth's rotation creates a 'squash' effect where the radius of the earth is greater at the equator. The shape of the ellipsoid representing the earth is defined by mathematical models. Defining the latitude and longitude of particular points on the earth defines the origin and orientation of the ellipsoid. The North American Datum of 1983 (NAD 83) uses an ellipsoid model called the Geodetic Reference System of 1980 (GRS-80), which is very similar to the World Geodetic System of 1984 (WGS-84) ellipsoid. WGS-84, was created about the same time by the US Department of Defense. The WGS-84 datum definition continues to be minutely refined over time (although the WGS-84 ellipsoid definition remains fixed). Table 2.3.1 shows how similar GRS-80 is to WGS-84 in metric units, (note that the two numbers completely define the ellipsoid dimensions, and typical convention is to define the ellipsoid with the semi-major axis and reciprocal flattening, which are used to compute the semi-minor axis).

Table 2.3.1

Ellipsoid Model	Semi-Major Axis (exact by definition)	Semi-Minor Axis (computed)	Reciprocal Flattening (exact by definition)
WGS-84	6 378 137	6 356 752.314245	298.257223563
GRS-80	6 378 137	6 356 752.314140	298.257222101

2.32 Datum Transformations (seven parameter)

Sometimes called the Helmert Transformation after Friedrich Robert Helmert (1843-1917), this seven parameter transformation is the typical (common) geodetic method for moving the coordinates of a point or group of points from one coordinate system referenced to one datum into coordinates referenced to a different datum for a given instant in time. For the purposes of this discussion, a (local) <u>coordinate system</u> contains the necessary elements to convert WGS-84 geodetic positions observed with GPS (GNSS) to a particular coordinate/datum realization. Each projection zone coordinate system may be based on the choice of a particular defined datum, adjustment, and epoch such as NAD 83(2007), NAD 83(CORS)Epoch2002 or other NAD 83 realizations (see software vendor choices). As previously described, the defined datum relies on an ellipsoid model such as GRS-80 (used for NAD 83 and the ITRS). These seven parameters account for the following:

Translation X- Translation along the X-axis
Translation Y- Translation along the Y-axis
Translation Z- Translation along the Z-axis
Rotation X- Rotation about the X-axis
Rotation Y- Rotation about the Y-axis
Rotation Z- Rotation about the Z-axis
Scale Factor

Transformation equations and parameters provide a means of transforming coordinates referenced to one datum into coordinates referenced to a different datum. In general, two three-dimensional coordinate systems in space are related to each other by the following equation for <u>Cartesian</u> coordinates:

[X Y Z] Datum 'A' = [ΔX ΔY ΔZ] + (1 + ΔS) [1 -Rz Ry Rz 1 -Rx -Ry Rx 1] [X Y Z] Datum 'B'

Where;
ΔX: Shift along x-axis
ΔY: Shift along y-axis
ΔZ: Shift along z-axis
S: Scale factor
Rx: Rotation about x-axis
Ry: Rotation about y-axis
Rz: Rotation about z-axis

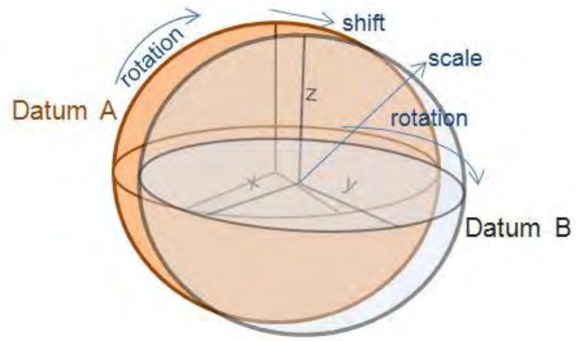


Fig. 2.3.2 [mla]

The first step is to know precisely the datum to which your input data are referenced. If your processing will require that this data be transformed to another coordinate system which is not based on the same datum, then you must consider the required datum transform. The following described example will consider the common case in which input data is referenced to WGS-84(G1150) and requires being converted to a coordinate system based on NAD 83(CORS96 or 2007), as these are the current versions of those datums. It is important to note here that for these particular datums, it will also be required to know the date to which the GPS data are processed, also known as the epoch of the data.

To consider a seven-parameter datum transform from WGS-84 to NAD 83, obtaining the required parameters for the Coordinate Frame datum transform is based on several assertions:
We can say that WGS-84(G1150) is equivalent to ITRF 00, the International Terrestrial Reference Frame of 2000, to an accuracy of approximately one centimeter(9). Also, a 14-parameter (add time variables) transform has been defined between ITRF 00 and NAD 83(CORS96) and, for a given instant in time, the 14-parameter transformation may be represented as a 7-parameter coordinate frame transform. While no direct transforms have been defined from WGS-84(G1150) to NAD 83(CORS96), the transform from NAD 83(CORS96) is defined from ITRF 00 which creates the path through which the desired transform can be completed. This 14-parameter transformation is specified in "*Transforming Position and Velocities between the International Terrestrial Reference Frame of 2000 and North American Datum of 1983*", by Tomas Soler and Richard Snay(10). Further discussion of 14-parameter transformations are beyond the scope of this document. For further discussion of this topic and tools for doing additional analysis, visit the NGS Horizontal Time-Dependent Positioning (HTDP) webpage: (http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml) and the CORS Coordinates webpage (http://www.ngs.noaa.gov/CORS/metadata1/). Tools are available at this site for transforming data between the datums described here and several others. Velocities for positions can also be predicted here, as well as transformation of points on different datums to different epochs.

2.3.3 Horizontal Reference Datum

A reference datum is a mathematical model of a realized known and constant surface which is used to determine the location of points on the earth. There are a large number of commonly referenced datums in use in North America but two of the most common in use are WGS-84/ITRF, and NAD 83. The North American Datum of 1983 (NAD 83) is a common horizontal control datum for the United States, Canada, Mexico, and Central America, based on a (nearly) geocentric origin and the Geodetic Reference System 1980 (GRS-80) ellipsoid. Horizontal datums also have 'realizations' or a variation of a model reference frame primarily created from official network adjustments performed by the National Geodetic Survey. For example, NAD 83(1986) is significantly different than NAD 83(CORS96), but NAD 83(CORS96) usually only differs by a few centimeters from NAD 83(HARN/HPGN), and NAD 83(CORS) only differs from NAD 83(2007) in the western US (they are considered functionally the same elsewhere in the US) Each of these is based on a particular adjustment (i.e., realization) of NAD 83. The suffix tag example 'CORS96 and the epoch date of 2002 (Epoch 2002)' refer to an upgrade of NAD 83 positions and velocities for all CORS sites, except those on the Pacific Islands and Alaska, so that they equal the transformed values, of the then computed, ITRF00 positions and velocities. Transforming from one adjustment datum to another will result in a coordinate position shift in your point positions.

NAD 83(1986) was officially (according to the National Geospatial Intelligence Agency (NGA) http://earth-info.nga.mil/GandG/coordsys/datums/_NATO_DT.pdf) a 'zero transform' from WGS-84 although the earth center and parameters for the two datum are slightly different. This 'zero transform' is commonly accepted by software vendors. This effectively made NAD 83(1986) and WGS-84(original) identical, except for extremely small difference in ellipsoid shape (maximum difference of 0.1 mm at the poles). This was referred to as NAD 83 "CONUS" (code NAR-C), and the "CONUS" designation continues to be used in various commercial software packages (although it is not used by the NGS). At the time this relationship was defined (1987), the location of earth's center of mass was only known to about ±2 m, so these datums were considered the 'same', to within ±2 m. Presently, the earth's center of mass is known to the centimeter level, and it is recognized that current realizations of NAD 83 and WGS-84 actually differ by about 1-2 m (depending on location). This legacy 'zero transform' is still commonly used by commercial software vendors, even though it is not actually correct, which has become a persistent source of confusion. Part of this confusion stems from the fact that "WGS-84" is the name of the ellipsoid and the datum, which is not typical geodetic practice (e.g., both NAD 83 and ITRF use the GRS-80 ellipsoid). Also, software vendors may have slight variations in datum naming conventions, especially those programs developed in foreign countries.

Most GPS (GNSS) processing software packages contain a large list of the world's datum from which to select. For the purposes of this document, ODOT staff and other users should generally accept (or seed) control values in the datum specified for the project or by contract specification (a notable exception is using current ITRF as seed coordinates for baseline processing when using precise ephemerides). The Oregon Real-time GPS Network (ORGN) currently sends correctors referenced to the NAD 83(CORS96)Epoch2002 datum. In 2010–2013 the NGS plans to adopt new NAD 83 coordinates and velocities for all U.S. CORS that are located where NAD 83 is defined.

Datums identified only as NAD 83 or WGS-84 are not specific enough to clearly define the reference frame of geodetic data. Additional information is needed that defines the realization or version of a particular datum. In the case of NAD 83, a "datum tag" must be appended to the name, such as NAD 83(1986) or NAD 83(CORS96) and NAD 83(2007); likewise for WGS-84: WGS-84(G1150), WGS-84(original), etc. NAD 83 (CORS96) and WGS-84(G1150) are the current versions of these systems. While NAD 83(1986) and WGS-84(original) were 'equivalent datums' (to within ±2 m), this is not the case for NAD 83(CORS96) and WGS-84(G1150). A datum transform is required when transforming points between any projected or geographic coordinate systems based on these datums. For these particular datums, the magnitude of the difference is on the order of two meters.

The NGS has adopted a realization of NAD 83 called NAD 83(2007) for the distribution of coordinates at ~70,000 passive geodetic control monuments. This realization *approximates* (but is not, and can never be, equivalent to) the more rigorously defined NAD 83(CORS96) realization in which Continuously Operating Reference Station (CORS) coordinates are distributed. NAD 83(2007) was created by adjusting GPS data collected during various campaign-style geodetic surveys performed between the mid-1980's through 2005. For this adjustment, NAD 83(CORS96) positional coordinates for ~700 CORS were held fixed (predominantly at the 2002.0 epoch for the stable north American plate, but 2007.0 in Alaska and western CONUS) to obtain consistent positional coordinates for the ~70,000 passive marks. Derived NAD 83(2007) positional coordinates should be consistent with corresponding NAD 83(CORS96) positional coordinates to within the accuracy of the GPS data used in the adjustment and the accuracy of the corrections applied to these data for systematic errors, such as refraction. In particular, there were no corrections made to the observations for vertical crustal motion when converting from the epoch of the GPS survey into the epoch of the adjustment, while the NAD 83(CORS96) coordinates do reflect motion in all three directions at CORS sites. For this reason alone, there can never be total equivalency between NAD 83(2007) and NAD 83(CORS96).

Control for the NAD 83(2007) adjustment was provided by the CORS. For all states except AZ, CA, OR, WA, NV and AK, the values used were the NAD 83 epoch 2002.0 values currently published by NGS. For AZ, OR, WA, NV and AK, HTDP (version 2.9) was used to convert the currently published NAD 83 positions of the CORS to epoch 2007.0 Typically, for all stations on the stable North American plate, an epoch date will be shown – as is currently the practice on datasheets (subject to change). For the other states, an epoch date of 2007.0 will be shown. In those states, except CA, HTDP can be used with the currently published CORS to determine the proper value to use. In CA, the values as currently published on the CSRC website should be used to maintain consistency with NAD 83(2007).

2.3.4 Vertical Reference Datum

The North American Vertical Datum of 1988 (NAVD 88) was established in 1991 from a simultaneous, least squares, minimum constraint adjustment of Canadian, Mexican and United States leveling observations. It held fixed, the height of the primary tidal bench mark, named 'Father Point' in Rimouski, Quebec, Canada. Additional tidal bench mark elevations were not held due to the demonstrated variations in sea surface topography, i.e., the fact that mean sea level (as recorded by tide gages) is not a gravitational equipotential surface. NAVD 88 replaces NGVD 29 as the national standard geodetic reference for heights and is the only current vertical datum that works seamlessly with GPS (GNSS) observation measurements and NAD 83. For more information on vertical datums see the NGS website http://www.ngs.noaa.gov/faq.shtml#WhatVD29VD88.

2.3.5 Geoid Models

A geoid [hybrid geoid model i.e., currently GEOID09(Conus)] used in geodetic adjustments is comprised of a gravimetric scientific model constrained to a 'best fit' of a current benchmark monumented network (currently GPSBM2009). This hybrid model is updated by the National Geodetic Survey (NGS) approximately every three to six years as more gravity and bench mark data becomes available, and as new computational methods are developed. When measuring coordinates with GPS (GNSS) equipment within a project and coordinate system a geoid model such as GEOID09(Conus) must be applied (geoid height 'N') to allow for the conversion of measured NAD 83 ellipsoid heights (h) to orthometric heights (H) [equation H=h-(N)] in the vertical datum NAVD88. The NGS 10 year plan outlines a transition to a pure gravimetric geoid model (GRAV-D) and new vertical datum by 2018.

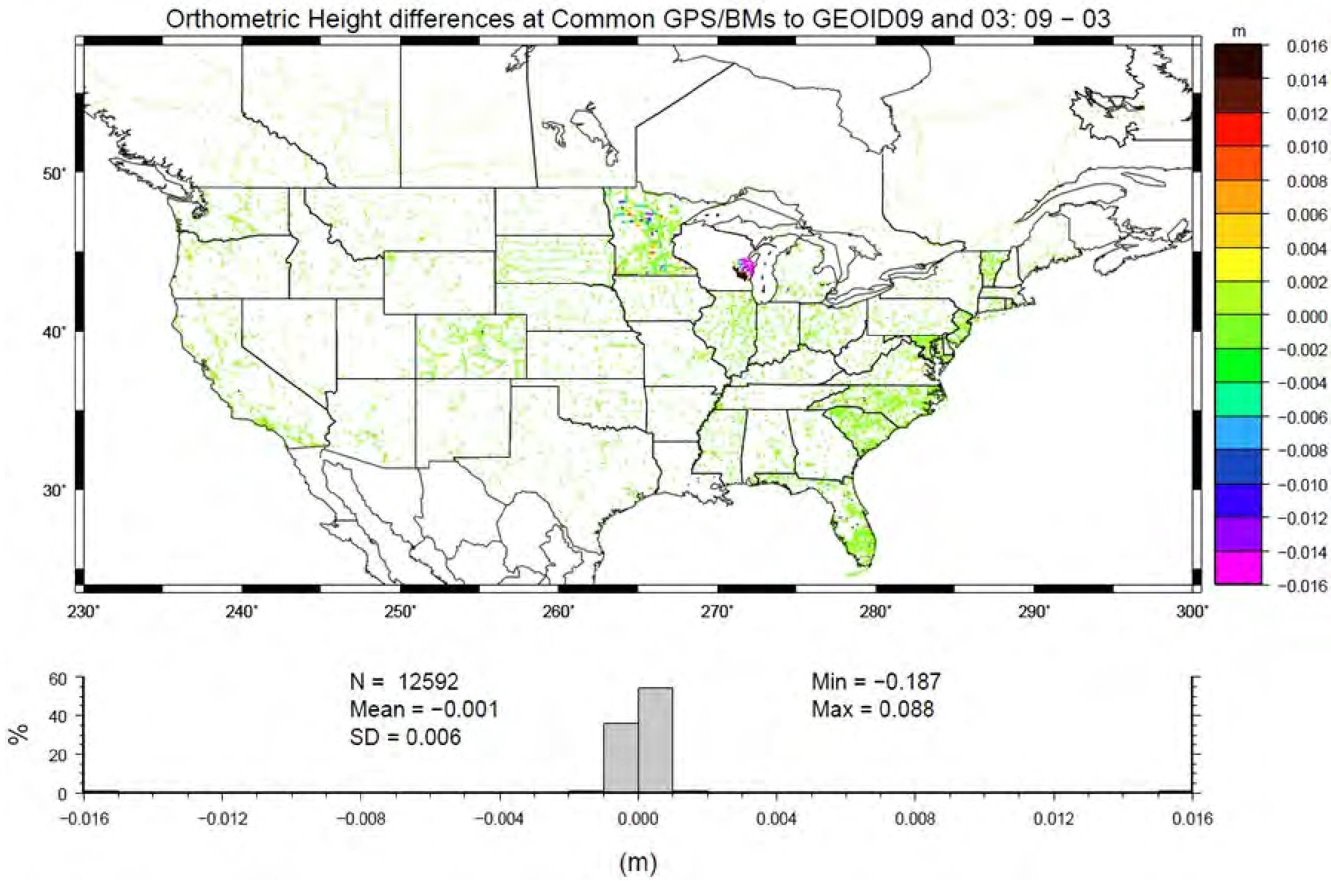
See: http://www.ngs.noaa.gov/GRAV-D/

For Oregon there are currently two notable hybrid geoid model choices available to select from, ie., GEOID03(Conus) and GEOID09(Conus). The GEOID09(Conus) model coverage over Oregon includes additional satellite gravity data based on the new global geopotential model (EGM08) but otherwise varies from GEOID03(Conus) in the following ways:

- Difference in ellipsoid heights (h) due to NSRS2007
- Difference in orthometric heights (H) due to (height modernization) leveling surveys in MN, FL, NC, and WI etc.
- New gravimetric geoid computations - EGM08 (2008 Earth Gravity Model) - Satellite gravity measurements

The choice of geoid model is generally available in your GNSS vendor survey, engineering or GIS software and also within the National Geodetic Survey Online Positioning User Service (OPUS) program (http://www.ngs.noaa.gov/OPUS/ under the Options menu). Figure 2.3.5 shows the general Orthometric Height differences at common bench marks for GEOID09 and GEOID03 (09 values minus 03 values).

Figure 2.3.5



2.3.6 OCRS Map Projection Parameter Units

As part of the 'best practices' approach to the creation of these zones, all of the OCRS map projection parameters are provided in metric units. Careful attention is needed when entering these map projection coordinate systems into the coordinate system management section of your GPS (GNSS) surveying, engineering, or GIS vendor software. When converting the provided metric data (false northing, false easting, etc.) to international feet, be sure to carry out the values to full sufficient significant figures (at least six decimal places) and check that the units are accepted by the software in the units you provide. Each software vendor (in the future) may elect to provide updated versions of their coordinate system management software with the OCRS zones already installed. Until that time it is recommended that you enter the projection parameters in metric units. Assigning units for a particular project, is a separate issue, and you may elect to choose English units of International Feet (Oregon standard).

2.3.7 Adding a Map Projection to a Coordinate System

Finally, a map projection must be chosen so the results can be displayed on a projected plane in a defined grid (northing's and easting's). In order to derive common northing and easting coordinates, a false northing and false easting are paired with the projection origin (central meridian and origin latitude). The map projection parameters (OCRS) provide a scale factor (based in part on the topographic height above ellipsoid) to better represent the local ground elevation within the useful limits (best range) of the zone topography (see figure 2.2.3). This scaling helps to define a threshold range in parts per million (ppm) of how closely the grid vs. ground distance measurements should match one another. For example, if the choice is to fit a threshold of ±10 parts per million (±10ppm) then the desire is to maintain an accuracy ratio maximum of 1:100 000, which would be a ten-fold improvement over the Oregon State Plane Coordinate System (as much as ~1:10 000 with respect to ellipsoid, and significantly greater distortion in high elevation areas).

Chapter 3 OCRS Map Projection Zones

3.1 The Development of OCRS Projection Zones in Oregon

The development of each map OCRS projection zone involved a hands-on process by the Technical Development Team of interested stakeholders, together with the aid of Michael Dennis of Geodetic Analysis LLC, Pima Arizona. Mr. Dennis has created proprietary software to facilitate the visualization of low distortion map projection zones. Each zone was developed through a multi-step iterative process to derive the best result as determined by the Technical Team using the 'best practices' approach outlined in Chapter 1. Additional zones may be created and added to this chapter as time goes on. If you work in a particular area of the state and no current OCRS zone covers that area, you may wish to discuss future plans for an additional zone for your work area. Please call and discuss your needs with the Geodetic Group of the Geometronics Unit in Salem.

3.1.1 The OCRS Zone Catalog

Table 3.1.1

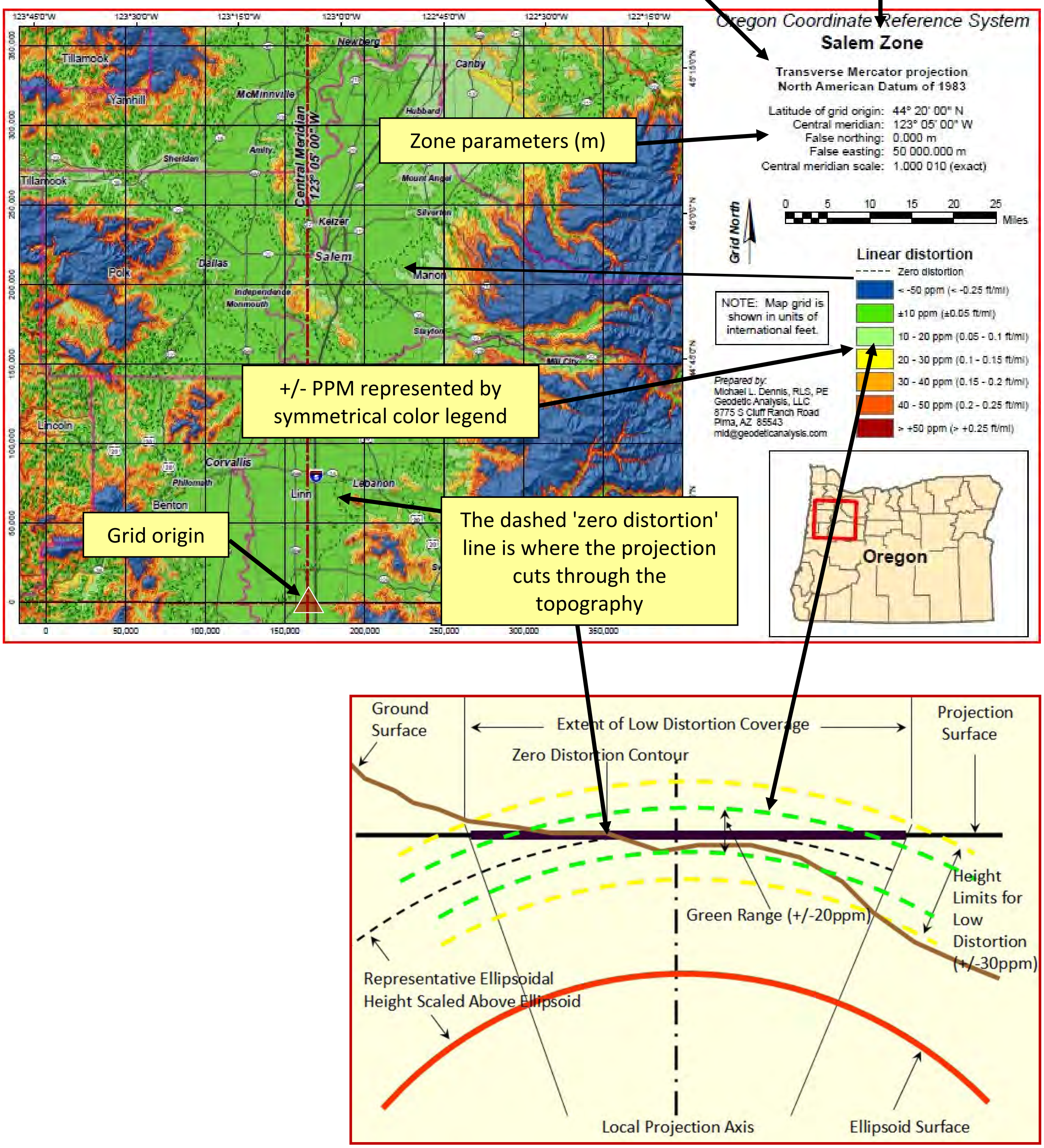
Zone Name*	Projection	Latitude of Grid Origin	Standard Parallel & Grid Origin	Central Meridian	False Northing (m)	False Easting (m)	Scale (exact)
Baker	TM	44°30'00"N		117°50'00"W	0	40 000	1.000 160
Bend-Klamath Falls	TM	41°45'00"N		121°45'00"W	0	80 000	1.000 200
Bend-Redmond-Prineville	LCC		44°40'00"W	121°15'00"W	130 000	80 000	1.000 120
Canyonville-Grants Pass	TM	42°30'00"N		123°20'00"W	0	40 000	1.000 070
Columbia River East	LCC		45°40'00"N	120°30'00"W	30 000	150 000	1.000 008
Cottage Grove-Canyonville	TM	42°50'00"N		123°20'00"W	0	50 000	1.000 023
Eugene	TM	43°45'00"N		123°10'00"W	0	50 000	1.000 015
Grants Pass-Ashland	TM	41°45'00"N		123°20'00"W	0	50 000	1.000 043
La Grande	TM	45°00'00"N		118°00'00"W	0	40 000	1.000 130
Ontario	TM	43°15'00"N		117°00'00"W	0	80 000	1.000 100
Pendleton	TM	45°15'00"N		119°10'00"W	0	60 000	1.000 045
Portland	LCC		45°30'00"N	122°45'00"W	50 000	100 000	1.000 002
Salem	TM	44°20'00"N		123°05'00"W	0	50 000	1.000 010
Zone Name*	**Projection**	**Latitude of Local Origin**	**Angle Skew or Azimuth**	**Longitude of Local Origin (m)**	**False Northing (m)**	**False Easting (m)**	**Scale (exact)**
Columbia River West	OM/RSO	45°55'00"N	-65°	123°00'00"W	-3 000 000	7 000 000	1.000 000
Oregon Coast	OM/RSO	44°45'00"N	+5°	124°03'00"W	-4 600 000	-300 000	1.000 000

TM = Transverse Mercator, LCC = Lambert Conformal Conic (Single Parallel), OM/RSO = Oblique Mercator/Rectified Skew Orthomorphic.
*All zones designed with an initial target distortion level of ± 10 ppm = 1:100 000 Ratio = ±0.05'/mile.
All lineal units are metric (m).
All zones reference the NAD 83 datum (Geometric Reference System)

Refer to the OCRS map series shown in Appendix 'A', noting on each map the defined areas shown in green. These areas define the area where one can work within the ±10 ppm threshold as defined in the catalog above. As the ppm range increases the colors change accordingly as shown in the legend on each individual map.

3.1.2 OCRS Zone Map Interpretation

Figure 3.1.2

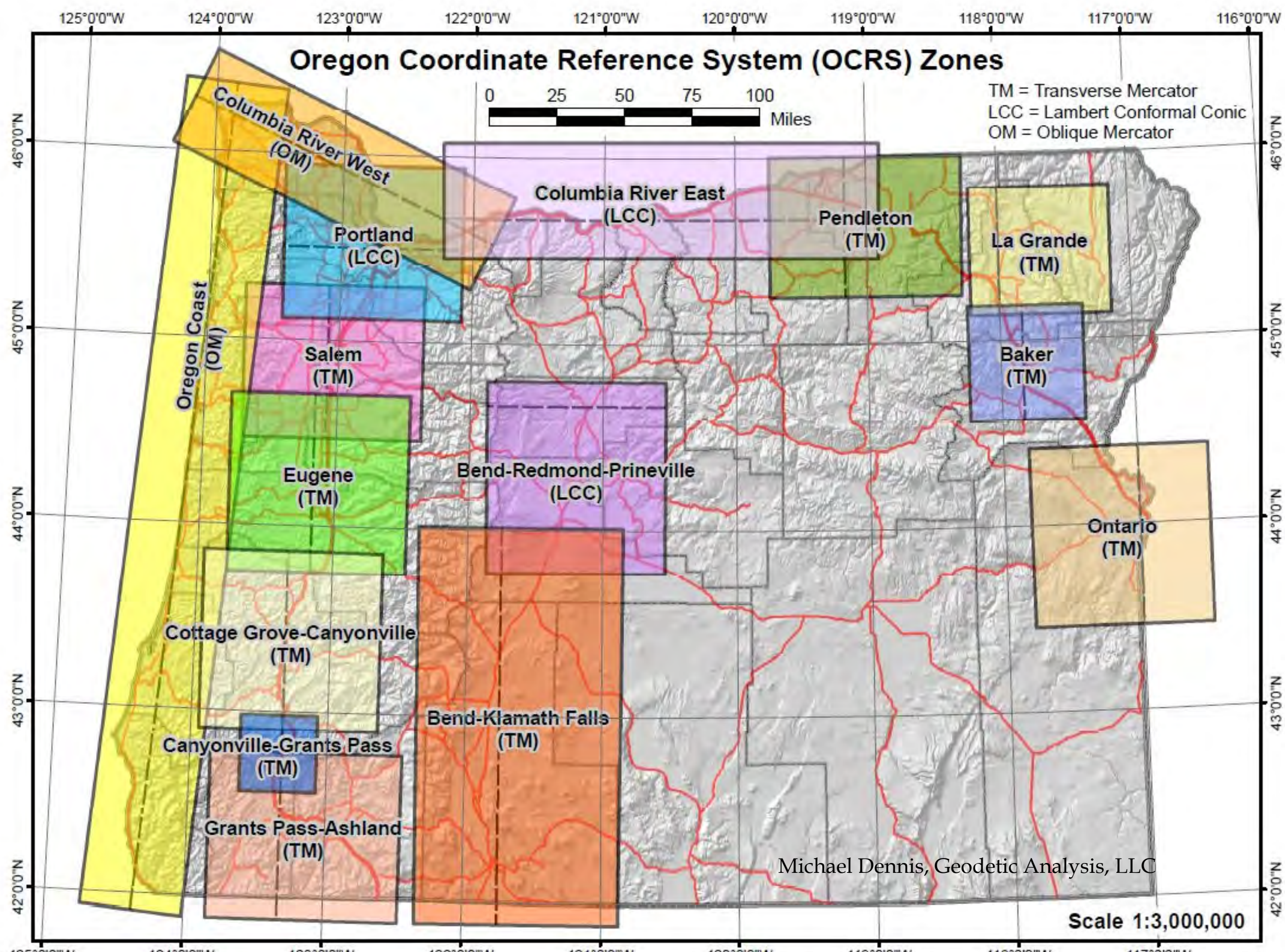


3.1.3 Picking a Zone to Use for a Survey/Engineering/GIS/Mapping Project

Many of OCRS map projection zones were designed with a zone overlap to allow users maximum choice in picking a zone to work in for their projects. For working in an overlap area, the users' goal would be to pick a zone that provides the least distortion in the project area, which often is correlated with elevation. For example, the Salem Zone projection scale factor is larger (higher) than the Portland Zone projection so if you're working in that overlap area at a relative higher elevation it would be best to use the Salem Zone.

The following State of Oregon map shows all fifteen current OCRS zones as boxes which are displayed in their correct locations. The size of each box considers the areas of low distortion coverage with extents to increments of 25,000 feet as appropriate. The boxes are not the absolute limits of the projections and there may be areas outside the boxes (and the included map set in Appendix 'A') where the zone coordinate system will still function well within the ± 10 to 20 ppm level.

Figure 3.1.3



Chapter 4 Using the OCRS in Software Programs

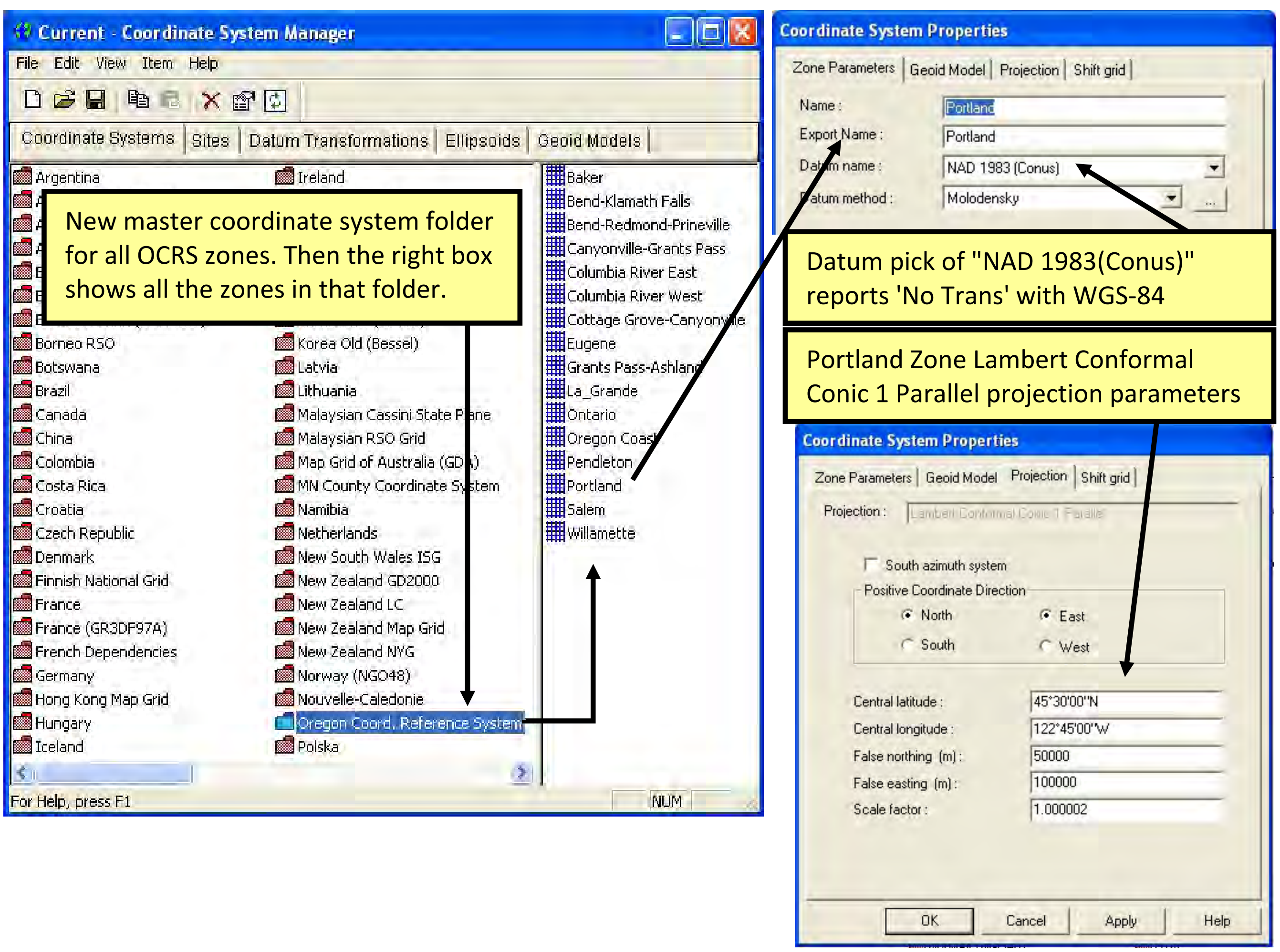
4.1 Adding an OCRS Zone Projection and Coordinate System to Software

When processing baselines and adjusting networks for projects it will be necessary to perform adjustments and input collected data from the field into projects created in certain vendor software. Input these OCRS zones into the appropriate 'coordinate system management/definition' module of that software. This chapter is designed to get you started, but it is recommended that you consult the 'help' documentation and tutorials of each piece of vendor software you plan to work with. Also, for future reference please go to the OCRS web page for updates and downloads.

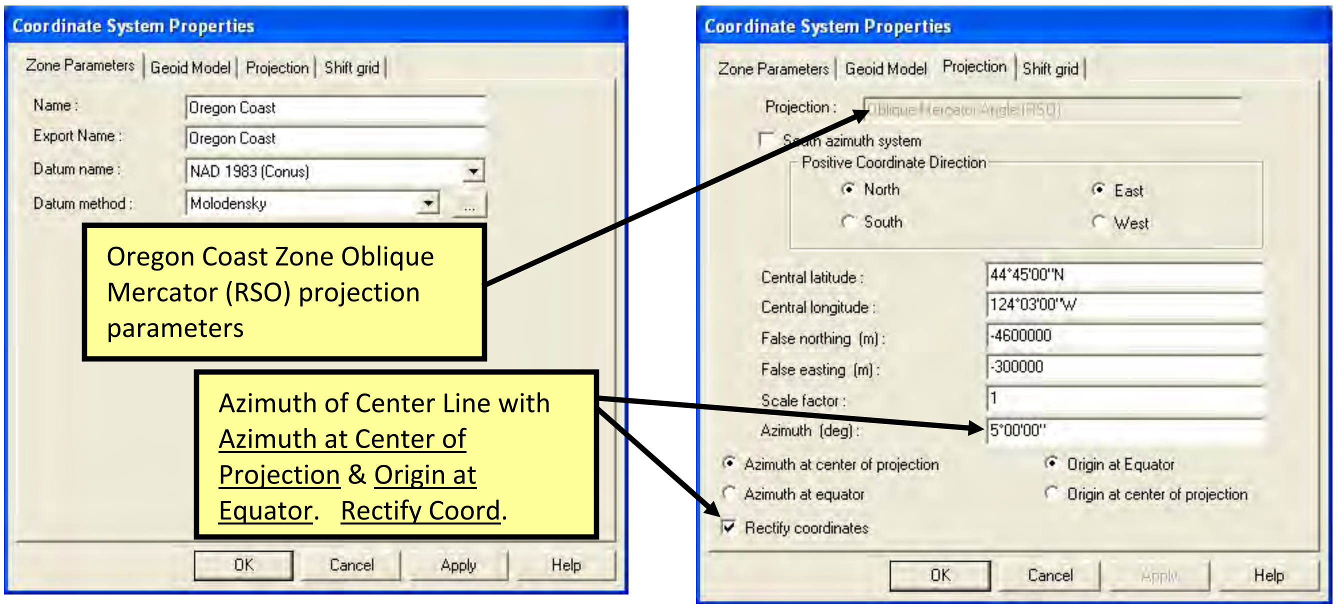
For the purposes of entering these low distortion projection parameters into particular vendor software, normally define the datum as NAD 83 (which uses the GRS-80 reference ellipsoid) for the OCRS. The software may typically assume that there are no transformation parameters (zero transform) between WGS-84 and NAD 83, and that is acceptable (but not truly correct). Later, when starting an actual project you may seed that project (within the software) with the local latitudes, longitudes, and heights for control points in the appropriate project datum, adjustment, and time epoch chosen.

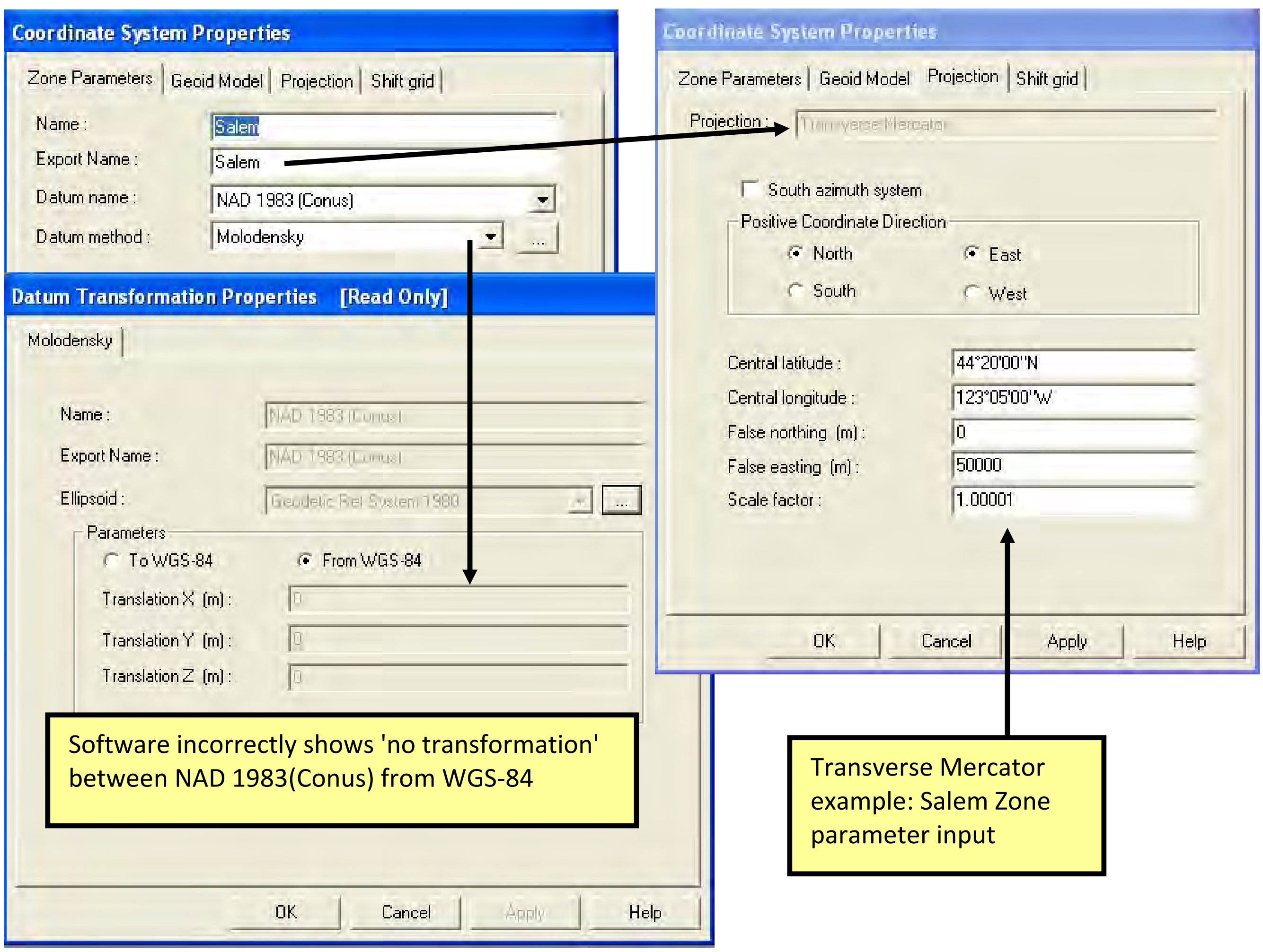
4.1.1 Trimble Coordinate System Manager

(…as used in Trimble Geomatics Office, Trimble Pathfinder Office, and Trimble Business Center software)
See screen shots of sample zone parameter entry below…



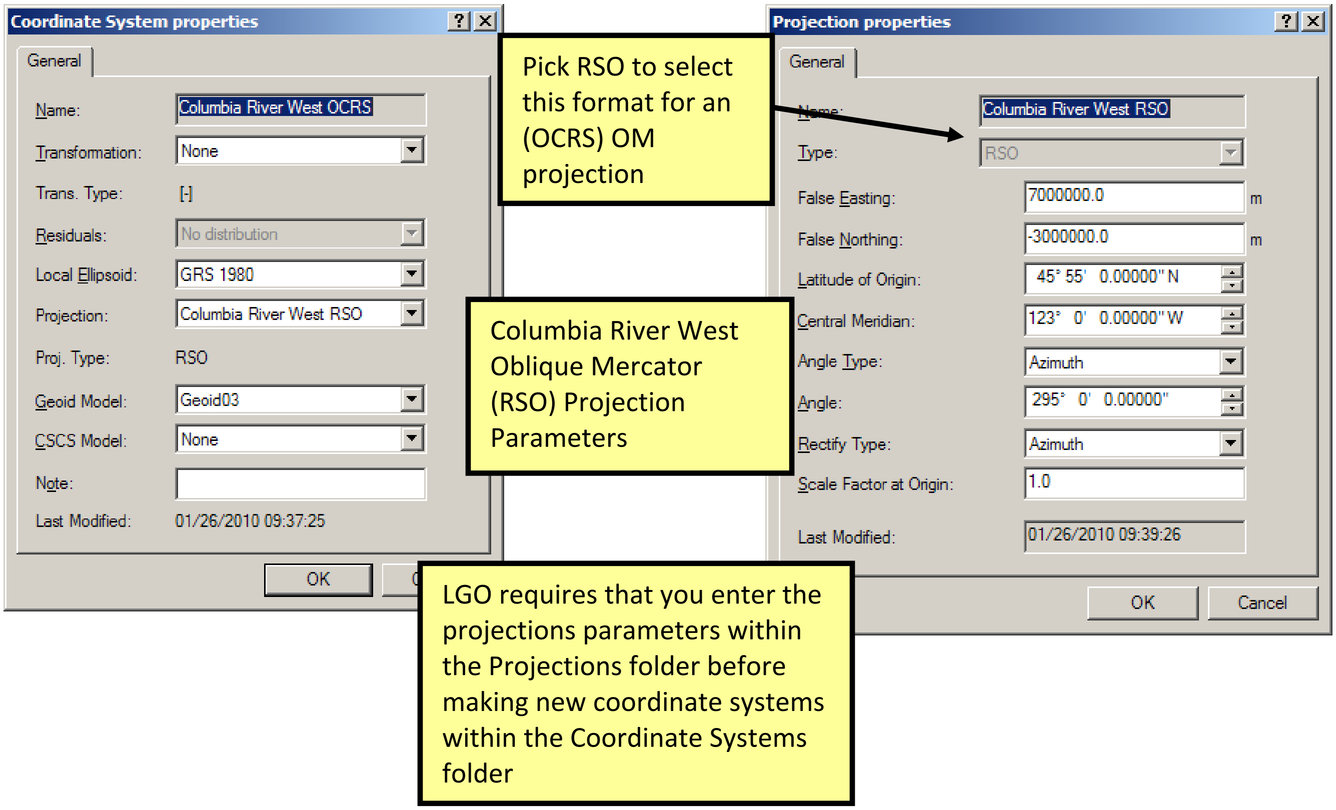
Trimble (cont.)

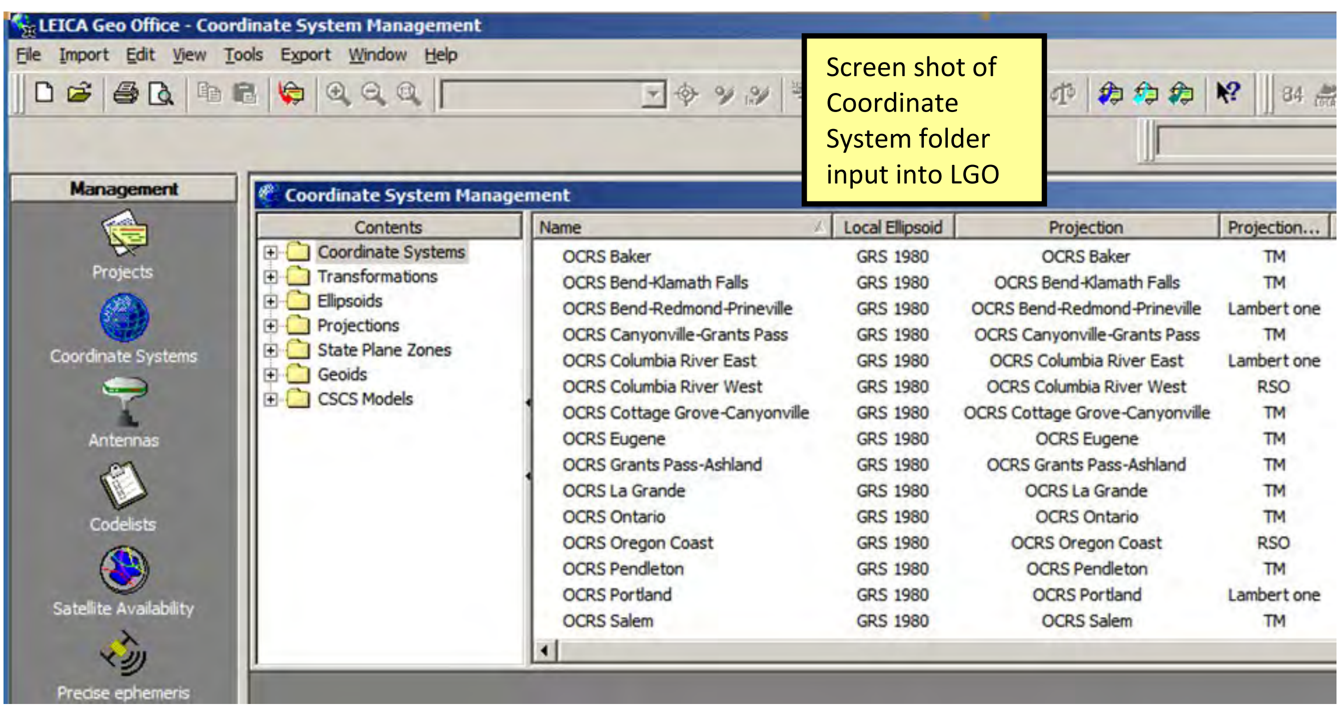




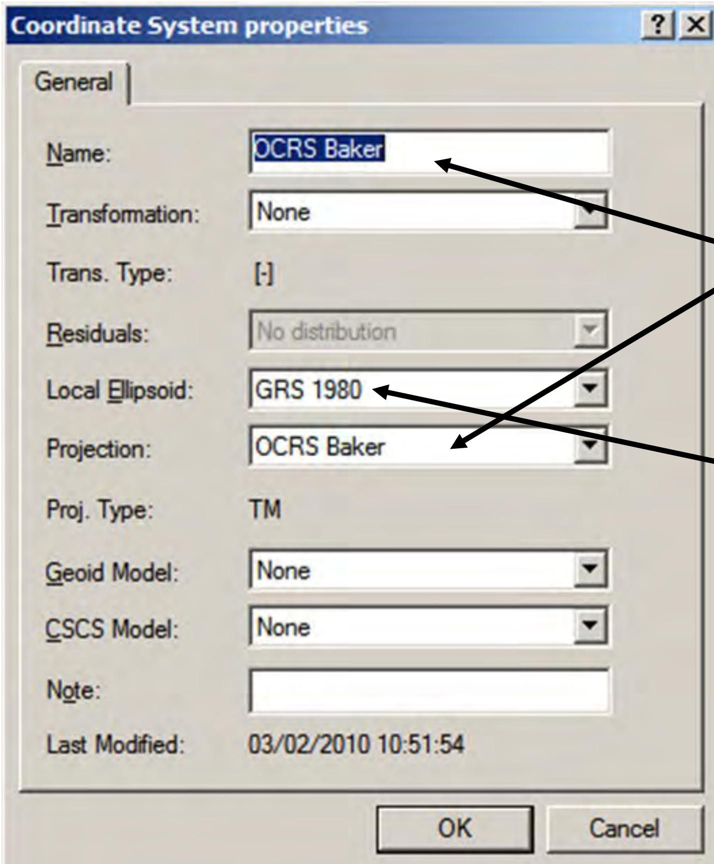
4.1.2 Leica Geomatics Office (LGO)

See screen shots of sample zone parameter entry below



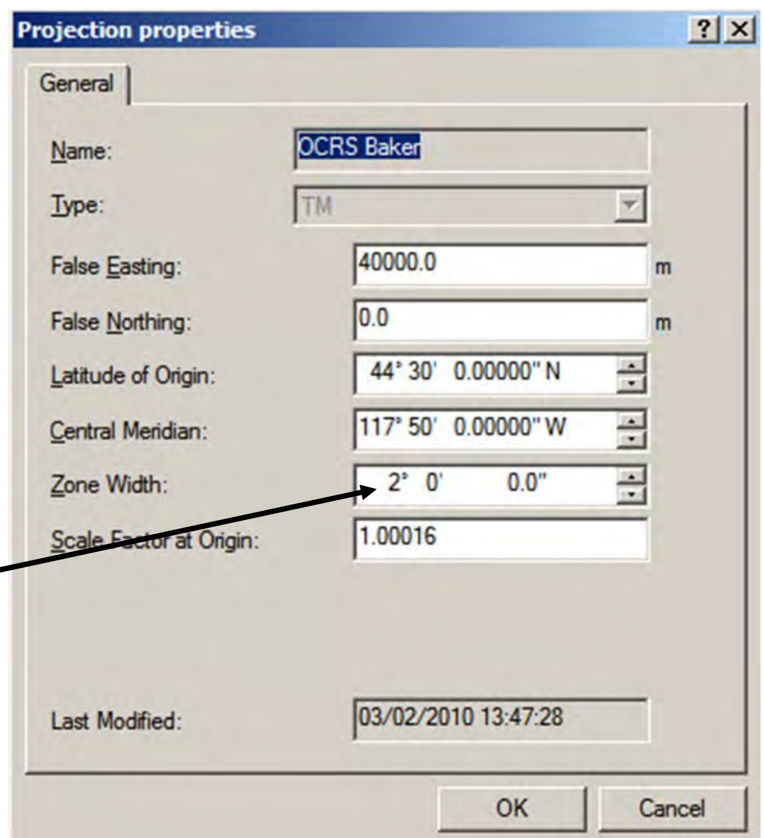


Leica (cont.)



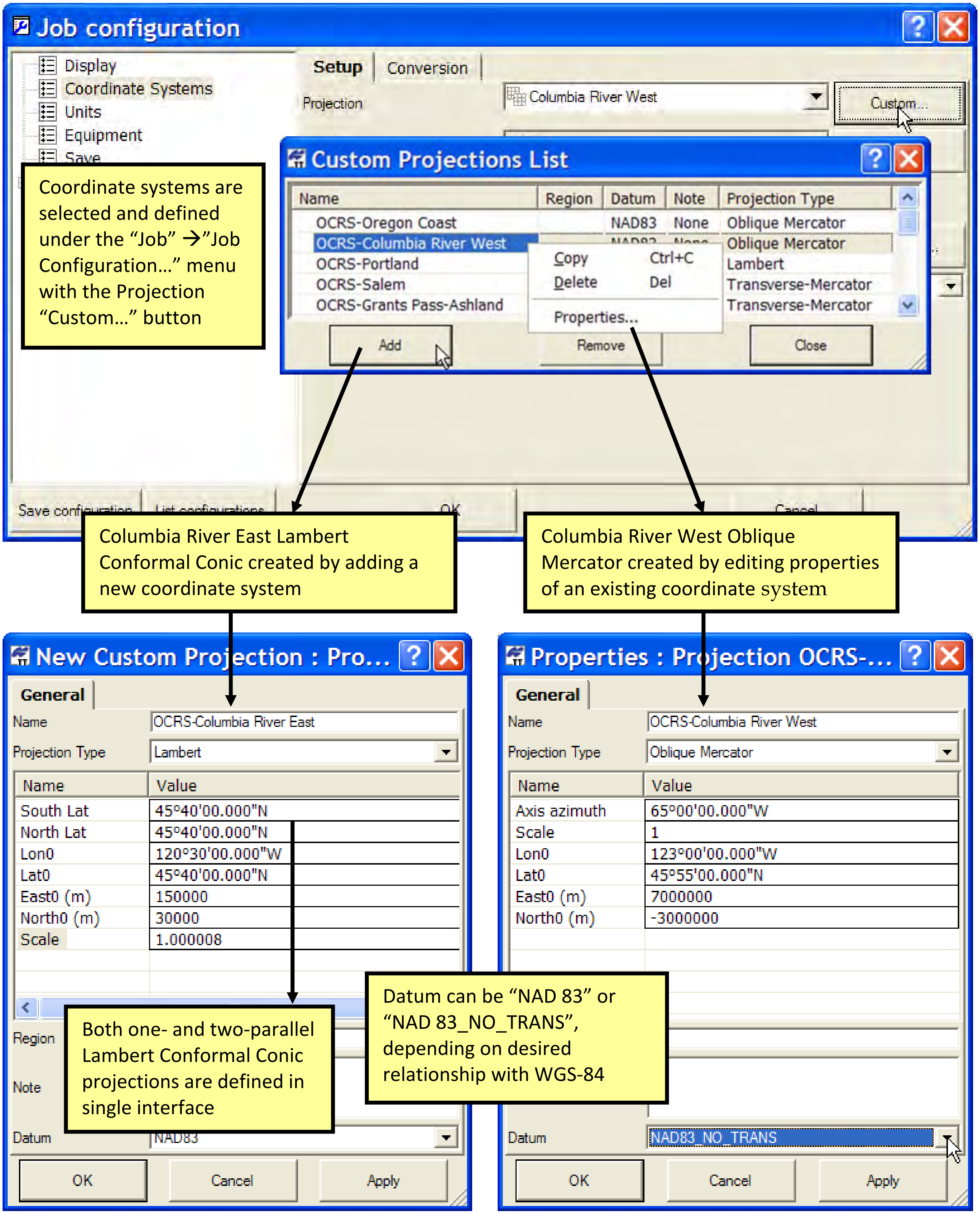
Note that it is recommended that you name the projection with the same name as the coordinate system name to make it easy to match them up

Note: GRS-80 is the normal Local Ellipsoid choice for all OCRS zones in LGO

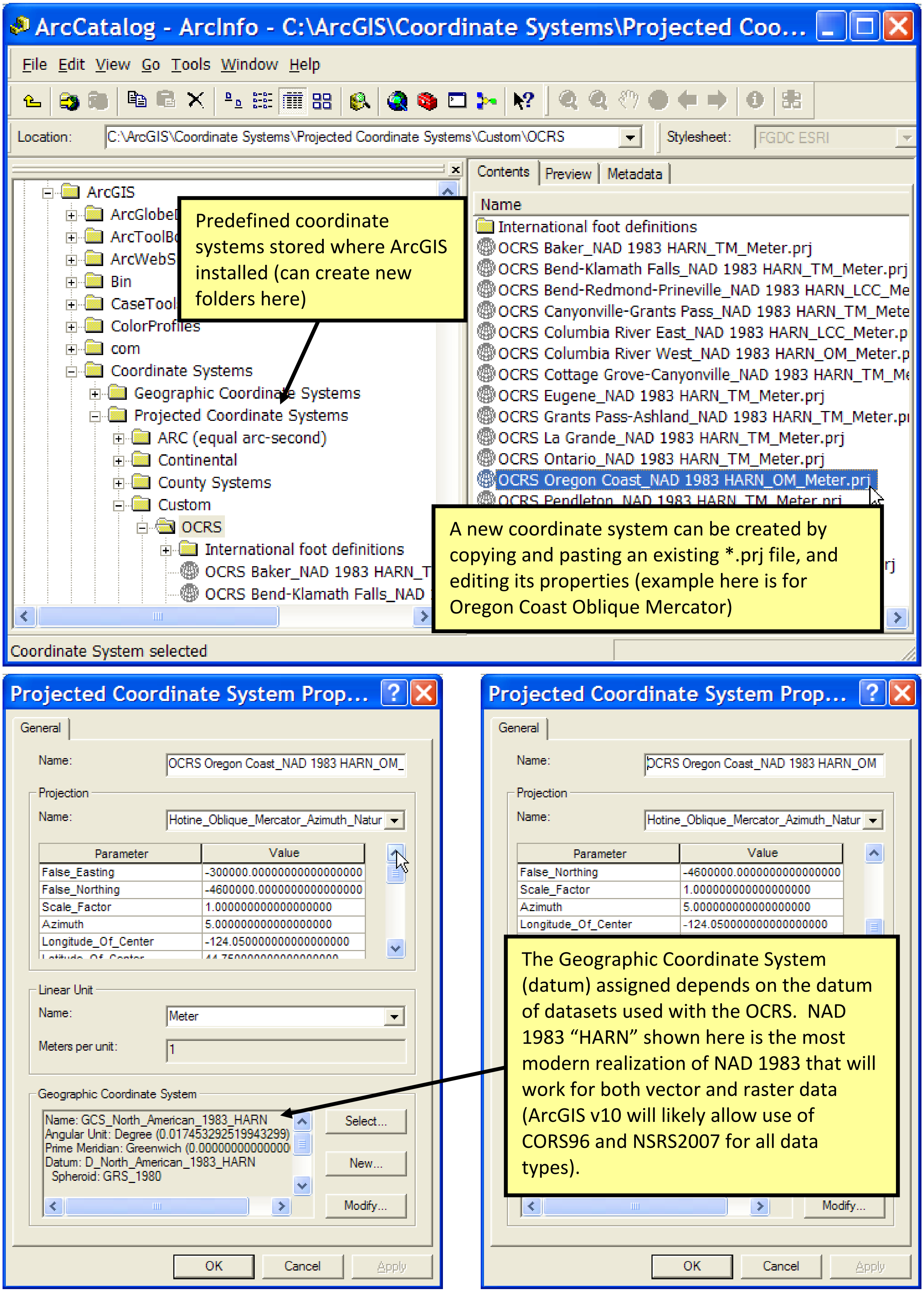


Note for all TM projection input into LGO it is recommended that you specify 2 degrees of coverage for the Zone Width

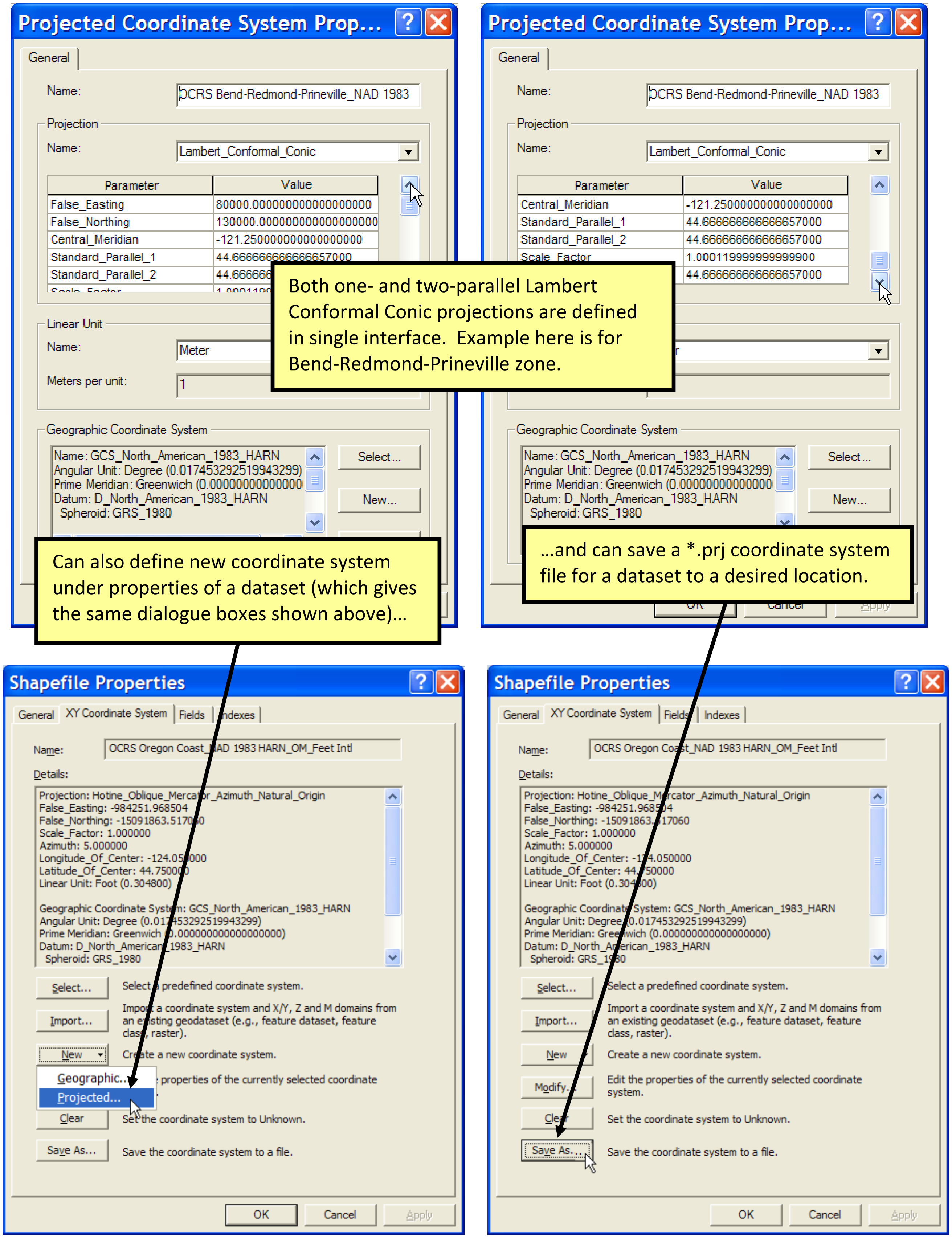
4.1.3 Topcon Tools (version 7.3) See screen shots of sample zone parameter entry below.



4.1.4 ESRI ArcGIS (version 9.3.1) Screen shots of coordinate system specifications through ArcCatalog (this page and next)



ESRI (cont.)


Projected Coordinate System Prop...
Both one- and two-parallel Lambert Conformal Conic projections are defined in single interface. Example here is for Bend-Redmond-Prineville zone.
Can also define new coordinate system under properties of a dataset (which gives the same dialogue boxes shown above)...
...and can save a *.prj coordinate system file for a dataset to a desired location.
Shapefile Properties
General
XY Coordinate System
Name:
OCRS Bend-Redmond-Prineville_NAD 1983
Projection
Lambert_Conformal_Conic
Parameter
Value
False_Easting
80000.000000000000000000
False_Northing
130000.000000000000000000
Central_Meridian
-121.250000000000000000
Standard_Parallel_1
44.666666666666657000
Standard_Parallel_2
Scale_Factor
1.000119999999999900
Linear Unit
Meter
Meters per unit:
Geographic Coordinate System
Name: GCS_North_American_1983_HARN
Angular Unit: Degree (0.017453292519943299)
Datum: D_North_American_1983_HARN
Spheroid: GRS_1980
OCRS Oregon Coast_NAD 1983 HARN_OM_Feet Intl
Projection: Hotine_Oblique_Mercator_Azimuth_Natural_Origin
False_Easting: -984251.968504
False_Northing: -15091863.517060
Scale_Factor: 1.000000
Azimuth: 5.000000
Longitude_Of_Center: -124.050000
Latitude_Of_Center: 44.750000
Linear Unit: Foot (0.304800)
Select a predefined coordinate system.
Import a coordinate system and X/Y, Z and M domains from an existing geodataset (e.g., feature dataset, feature class, raster).
Create a new coordinate system.
Edit the properties of the currently selected coordinate system.
Set the coordinate system to Unknown.
Save the coordinate system to a file.
Geographic...
Projected...
Save As...
OK
Cancel
Apply

4.2 Checking Software Output Grid Northing's and Easting's

The included table offers the correct grid northing and easting for three points in each OCRS zone. If you have entered the OCRS zone parameters into your vendor's software and successfully created coordinate systems, then, by entering the input lat/long values in the table, your project grid coordinates should match these results. The output data (northing's & easting's) in table 4.2 are carried out to five decimal places in order to check the math formulas used by each vendor. Regardless of the software, match these output values exactly (Trimble output varies in the ~last decimal place for the OM/RSO projections). If you do not match, refer back to section 4.1 and check your OCRS zone parameter input.

Table 4.2

INPUT DATA (From NGS Datasheets)						OUTPUT DATA	
OCRS Zone Name	NGS PID	Designation	Datum	Latitude (N)	Longitude (W)	Northing (m)	Easting (m)
Baker	QB1363	AIRPORT	NAD 83 (2007)	44 49 57.80936	117 48 54.56244	36980.20833	41437.60083
Baker	QB0884	E 305	NAD 83 (2007)	44 52 07.48389	117 54 26.35126	40986.29136	34152.16275
Baker	QB1364	MASON	NAD 83 (2007)	44 40 24.70946	117 59 40.97048	19299.09877	27201.54461
Bend-Kfalls	DH7225	ORK1 CORS ARP	NAD 83 (CORS)	42 17 19.71674	121 40 09.54146	59862.74501	86655.66105
Bend-Kfalls	DH3761	MDMT CORS ARP	NAD 83 (CORS)	42 25 06.01243	121 13 17.70770	74385.61148	123500.38364
Bend-Kfalls	NY0977	ALTAMONT	NAD 83 (2007)	42 12 32.57089	121 44 50.17150	50997.92871	80225.49733
Bend-Redmond-Prineville	AH2507	REDM CORS ARP	NAD 83 (CORS)	44 15 35.14513	121 08 52.31624	84783.59542	88157.16577
Bend-Redmond-Prineville	QD1644	BEND AIRPORT	NAD 83 (2007)	44 05 37.43097	121 12 11.97934	66327.93549	83738.15165
Bend-Redmond-Prineville	QD1879	SISTERS	NAD 83 (2007)	44 18 20.44566	121 33 21.22192	89927.19462	55588.29029
Canyonville-Grants_Pass	NZ0930	N 748	NAD 83 (2007)	42 37 15.80562	123 22 56.67677	13449.63952	35973.43780
Canyonville-Grants_Pass	AA5139	X 026	NAD 83 (2007)	42 48 41.75301	123 35 45.71429	34650.09185	18512.47686
Canyonville-Grants_Pass	NZ1329	AZAL	NAD 83 (2007)	42 47 56.60859	123 15 10.17963	33226.59339	46586.32144
Columbia_River_East	RD1615	C 719	NAD 83 (2007)	45 36 41.82270	122 01 15.12506	25007.74017	31373.11293
Columbia_River_East	RC1917	MOF	NAD 83 (2007)	45 37 22.73728	121 58 40.65328	26208.05388	34742.89853
Columbia_River_East	RC2012	CAS	NAD 83 (2007)	45 40 20.31754	121 52 36.28740	31549.15733	42729.28899
Columbia_River_West	AF9545	FTS1 CORS ARP	NAD 83 (CORS)	46 12 17.57866	123 57 21.88345	218152.78553	94514.71992
Columbia_River_West	RD4000	AIRPORT	NAD 83 (2007)	45 46 15.02108	122 51 37.48609	169474.85476	179157.87759
Columbia_River_West	SC2795	ASTO	NAD 83 (2007)	46 10 24.21823	123 49 55.47899	214545.28450	104047.54956
Cottage_Grove-Canyonville	DG9304	DCSO CORS ARP	NAD 83 (CORS)	43 12 39.61530	123 20 29.39067	41957.65613	49336.56065
Cottage_Grove-Canyonville	PC1124	ROSEBURG CBL 0	NAD 83 (2007)	43 13 57.45207	123 21 19.11848	44359.97917	48214.67944
Cottage_Grove-Canyonville	AI2000	LESLEE	NAD 83 (2007)	43 42 20.44764	123 14 15.15491	96922.63912	57721.03085
Eugene	DE6242	OBEC CORS ARP	NAD 83 (CORS)	44 03 57.45763	123 05 53.28029	35109.31719	55490.78035
Eugene	AH2486	CORV CORS ARP	NAD 83 (CORS)	44 35 07.91068	123 18 16.51921	92851.07880	39047.00734
Eugene	DE6236	LPSB CORS ARP	NAD 83 (CORS)	44 03 04.40693	123 05 24.25020	33472.46085	56138.37116
Grants_Pass-Ashland	NZ1330	ILLA	NAD 83 (2007)	42 06 16.06850	123 40 53.51268	39431.29476	21197.50808
Grants_Pass-Ashland	NZ1326	ASH	NAD 83 (2007)	42 12 56.39712	122 42 25.17018	51915.05751	101719.61390
Grants_Pass-Ashland	NZ0949	BEACON	NAD 83 (2007)	42 22 01.47650	122 52 28.13141	68646.39250	87798.66183
La_Grande	DF6418	LGD C	NAD 83 (2007)	45 17 13.18990	118 00 45.92076	31899.53873	38999.15169
La_Grande	AD9167	LGD B	NAD 83 (2007)	45 17 15.70482	118 00 43.70866	31977.18073	39047.37636
La_Grande	RA0822	COVE	NAD 83 (2007)	45 17 48.36576	117 49 12.11261	33001.29294	54118.35633
Ontario	OH1141	W 700	NAD 83 (2007)	43 59 45.82871	117 06 22.74797	82905.08851	71471.15057
Ontario	QB1232	ONTARIO	NAD 83 (2007)	44 01 35.30352	117 01 02.04955	86278.96757	78618.04382
Ontario	QB1158	U 701	NAD 83 (2007)	44 15 30.91593	117 34 57.00068	112237.85973	33478.59685
Oregon_Coast	AF9662	CABL CORS ARP	NAD 83 (CORS)	42 50 09.93918	124 33 47.98916	156617.94338	92771.55752
Oregon_Coast	DI0946	LFLO CORS ARP	NAD 83 (CORS)	43 59 00.96460	124 06 27.69262	283978.89187	130114.54983
Oregon_Coast	AJ6959	CHZZ CORS ARP	NAD 83 (CORS)	45 29 11.43812	123 58 41.18748	450992.95166	140363.83797
Pendleton	RB1366	PENDLETON	NAD 83 (2007)	45 40 01.47744	118 46 38.96233	46430.01635	90328.59835
Pendleton	DL3306	PNDL CORS ARP	NAD 83 (2007)	45 40 10.42949	118 47 29.47552	46701.19336	89233.83305
Pendleton	RB0505	H 113	NAD 83 (2007)	45 40 22.63117	118 48 49.44218	47070.05244	87501.19269
Portland	DG9893	NWBG CORS ARP	NAD 83 (CORS)	45 18 00.17000	122 58 31.85235	27802.06823	82311.82137
Portland	AJ8208	BTON CORS ARP	NAD 83 (CORS)	45 29 08.88672	122 47 50.56450	48423.08858	96296.00903
Portland	DE7967	WACO CORS ARP	NAD 83 (CORS)	45 31 23.21213	122 59 25.84389	52597.11898	81209.71492
Salem	AH2486	CORV CORS ARP	NAD 83 (CORS)	44 35 07.91068	123 18 16.51921	28048.57816	32429.22836
Salem	DH4503	P376 CORS ARP	NAD 83 (CORS)	44 56 28.31372	123 06 08.10051	67549.65038	48506.92980
Salem	DE6258	MCSO CORS ARP	NAD 83 (CORS)	44 58 25.70178	122 57 20.63967	71181.16936	60065.54709

4.3 Low Distortion Projects in the GIS Community

Modern GIS software incorporates on the fly projections. This allows users to simultaneously display data from differing coordinate systems in a common coordinate system on the computer screen. Low distortion projection systems can thus be easily and seamlessly incorporated for display of GIS databases. An advantage to LDPs is the fact that the historical data need not be modified. Past data can still reside in its original coordinate system and merely be re-projected in real time into the new coordinate system for use with new LDP data. Thus, as future LDPs are developed, multiple round-off error will not propagate with each time a new projection is applied. This will allow cities and counties to adopt the new LDPs while still using their original data without modification. New data can be acquired in the best LDP for the area and still be used with the historical data or other data collected by other agencies in different coordinate systems with minimal effort by the user.
Many cities and counties in Oregon use GIS data to manage their resources. Thus, because LDPs generally cover the typical extents of multiple counties, a LDP will provide excellent coverage for the entire area that agency is concerned with.

GIS calculations of route distances, cut/fill volumes, etc. will be more accurate with use of LDPs because of the minimized distortion. Existing coordinate systems may be adequate for large, statewide analyses where data resolution is low (e.g. large grids cell sizes > 30m). The development of LDPs allows for new high resolution data (e.g. small grid cell sizes 0.1m to 2m) and digital terrain models (DTM) from LIDAR and other new technologies to be analyzed with minimal distortion in GIS environments when studies are performed on a localized county or city areas. Existing coordinate systems would provide a substantial amount of distortion when analyzing these DTMs. Hence, LDPs will allow for the development of more accurate GIS databases and help bridge the gap between GIS and surveying for mapping.

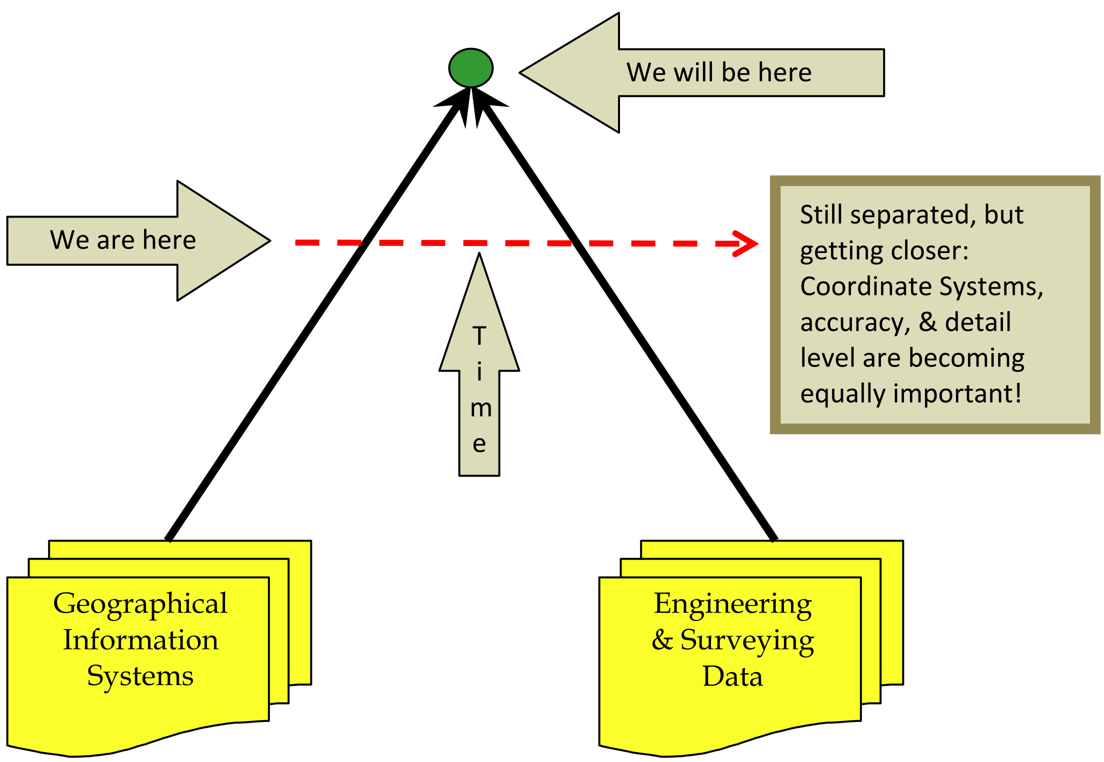


Figure 4.3, [mla,rs]

4.3.1 Managing GIS Data

Geographic Information System managers administer data. Data includes spatial and attribute information that is provided from many sources. The spatial data locates features across the landscape while the attributes provide characteristics of the features. GIS managers use the same reference frameworks as surveyors to define positions in space.

Nearly all GIS operations require accurate locations of geographic features. Accurate locations allow GIS users to integrate and/or combine information from various sources. Critical to the accurate locations of features is a record of the coordinate system and associated projection parameters. GIS managers often incorporate surveyed data into geographic databases. Conversion of coordinate information into a different map projection system from which it was collected is usually necessary. Critical to this process is a well defined set of existing and desired map projection parameters.

The newly defined OCRS low distortion projections, provide another reference system inwhich data will be collected. By having detailed descriptions of properties of the map projection, GIS software can re-project and transform the geographic locations of dataset elements into any appropriate coordinate system. This allows the integration of multiple GIS layers, a fundamental GIS capability.

A GIS or mapping project based on one of the new low distortion coordinate systems has significant advantages. The design of the coordinate system allows field based measurements (data collection) to be directly utilized in the GIS without translation, saving time and reducing error. The size, position and orientation of features in the system can match ground conditions, increasing confidence and reducing the need for repetitive observation.

Chapter 5 Testing Ground vs. Grid Distances in an OCRS Zone

5.1 Testing Methods 'Best Practices' Adopted for OCRS Trial Zones

1. Field test measurements shall include measurements independent of Oregon Real-time GPS Network (ORGN).
2. For short (1100 m - 1300 m) and medium (3000 m – 4500 m) baseline tests, perform EDM baseline checks in each zone. Then with two GPS receivers simultaneously occupy the monuments at the ends of the baseline courses. Use NGS Calibration Baselines for short baselines as appropriate.
3. For long (30 000 m – 50 000 m) baseline tests, use paper calculation with real ground heights (CORS stations). Compare grid / ground distances in the data collector while working within the beta test projection. The curved horizontal "ground" distance may be computed by scaling the Vincenty GRS-80 ellipsoid distance to the topographic surface. Vincenty's inverse formula will calculate the ellipsoid distance between the two points when given the latitude and longitude of each point. Then scale the resulting ellipsoid distance using the mean ellipsoid height of the end points and the geometric mean radius of curvature at the mean latitude of the endpoints.

Step 1. Vincenty Inverse Formula$_{(12)}$ for ellipsoidal distance (other variations exist):
Use GRS-80 ellipsoid parameters:
[a = 6 378 137 m, b = 6 356 752.314140 m, f = 1 /298.257222101]
a = ellipsoid semi-major axis (= 6 378 137 m for GRS-80 ellipsoid)
f = ellipsoid flattening (= 1 / 298.257222101 for GRS-80 ellipsoid)
$b = a(1 - f)$ = ellipsoid semi-minor axis
ϕ_1, ϕ_2 = geodetic latitude at end points p_1 and p_2 (positive north of equator)
L = difference in longitude (positive east)
λ = difference in longitude on an auxiliary sphere
s = length of the geodesic (distance on ellipsoid), in the same units as a
α_1 is the initial bearing, or forward azimuth (clockwise from north)
α_2 is the final bearing (in direction $p_1 \rightarrow p_2$)

U = reduced latitude, where

$U_1 = \mathrm{atan}((1-f).\tan\phi_1)$

$U_2 = \mathrm{atan}((1-f).\tan\phi_2)$

Begin with initial approximation $\lambda' = L$
Then iterate until change in λ' is negligible *(e.g. $10^{-12} \approx 0.06$ mm)*:

{

$\sin\sigma = \mathrm{sqrt}[\,(\cos U_2.\sin\lambda)^2 + (\cos U_1.\sin U_2 - \sin U_1.\cos U_2.\cos\lambda)^2\,]$

$\cos\sigma = \sin U_1.\sin U_2 + \cos U_1.\cos U_2.\cos\lambda$

$\sigma = \mathrm{atan}(\sin\sigma / \cos\sigma)$

$\sin\alpha = \cos U_1.\cos U_2.\sin\lambda / \sin\sigma$

$\cos 2\sigma_m = \cos\sigma - 2.\sin U_1.\sin U_2/\cos^2\alpha$

$C = (f/16).\cos^2\alpha.[4+f.(4-3.\cos^2\alpha)]$

$\lambda' = L + (1-C).f.\sin\alpha.\{\sigma+C.\sin\sigma.[\cos 2\sigma_m+C.\cos\sigma.(-1+2.\cos^2 2\sigma_m)]\}$

}

$u^2 = \cos^2\alpha.(a^2-b^2)/b^2$

$A = (1+u^2/16384).\{4096+u^2.[-768+u^2.(320-175.u^2)]\}$

$B = (u^2/1024).\{256+u^2.[-128+u^2.(74-47.u^2)]\}$

$\Delta\sigma = B.\sin\sigma.\{\cos 2\sigma_m+B/4.[\cos\sigma.(-1+2.\cos^2 2\sigma_m) - B/6.\cos 2\sigma_m.(-3+4.\sin^2\sigma).(-3+4.\cos^2 2\sigma_m)]\}$

$s = b.A.(\sigma-\Delta\sigma)$

$\alpha_1 = \mathrm{atan}((\cos U_2.\sin\lambda) / (\cos U_1.\sin U_2 - \sin U_1.\cos U_2.\cos\lambda))$

$\alpha_2 = \mathrm{atan}((\cos U_1.\sin\lambda) / (-\sin U_1.\cos U_2 + \cos U_1.\sin U_2.\cos\lambda))$

As an alternative to using the above method, the Vincenty inverse is also available in the NGS Geodetic Toolkit (http://www.ngs.noaa.gov/TOOLS/Inv_Fwd/Inv_Fwd.html).

In addition, many surveying and mapping software programs can perform this calculation (although it is recommended that commercial software be checked against the NGS version).

Now scale the Vincenty ellipsoid distance using the mean ellipsoid height of the end points and the geometric mean radius of curvature at the mean latitude of the endpoints using the following formula.

Step 2. Ground Distance = $(((h_1+h_2)/2) + R_G)/\ R_G$ x [Vincenty ellipsoid distance (meters) - from step 1 above]

Where:

h_1 & h_2 are the ellipsoid heights of the endpoints (meters)

R_G is the geometric mean ellipsoid radius of curvature (GRS-80) of the endpoints (meters)

$$R_G = \frac{a\sqrt{1-e^2}}{1-e^2\sin^2\varphi} =$$

Where: a = semi-major axis = 6,378,137 m (exact)

e^2 = first eccentricity squared = $2f - f^2$

f = geometric flattening = 1 / 298.257222101

4. Test ORGN complete software / hardware coordinate results across test projections. Latest RTCM protocol does support one standard parallel Lambert Projection. Using the ORGN, test 30 to 50 km baseline lengths across zones to prove projection distortion meets predicted tolerances/ppm thresholds (pending).

5.2 OCRS Field and Office Test Methods

As part of the development of low distortion projections for Oregon, field tests and calculations were employed to compare grid distances measured with GPS between two distinct points while working in a project defined by an OCRS zone coordinate system with the direct distance measured on the ground between the same two points. If the two comparative distances were less than or equal to the projections designed threshold of, say, ±10 ppm, then the goal was met.

Short, medium and long baselines were chosen to simulate the extreme limits of how people might use the projections. The short baselines chosen were on NGS Calibrated Baselines (CBL) because they represent ~1100 m to ~1400 m distances and are accessible in several of the zones. Also, the horizontal ground distances as measured by the NGS, with electronic distance measurement (EDM) were a matter of record for comparison. Multiple fast static GPS measurements were taken simultaneously at the end points of each baseline and then processed with baseline processing software (Trimble Geomatics Office) while in the particular OCRS grid zone coordinate system. The grid vs. ground distances were then compared to see if the threshold was achieved.

A similar test was conducted for medium baseline lengths of ~3000 m to ~5000 m distances and for this test two baselines were set (temporary points) and the horizontal ground distance measured with a (previously checked) Leica Total Station. One baseline was oriented east-west and the other north-south and each line was measured with a Leica Total Station TCRP 1201+ direct and reverse for a total of 30 measurements. The average of those measurements was again compared with multiple fast static GPS measurements and then processed with baseline processing software (Trimble Geomatics Office) while in the particular OCRS grid zone coordinate system. The grid vs. ground distances were then compared to see if the threshold was achieved.

For the test on long baseline lengths of ~20 000 m to ~80 000 m, one of the goals was to choose particular points beyond the edge of the planned useful area of the zone to 'break' the desired threshold and prove that it fails where it should fail (i.e., exceed the ppm design threshold). For this test, random Plate Boundary Observatory (PBO) CORS station data were used. For the grid distance baseline calculation, 24 hour RINEX files were downloaded for various PBO CORS stations, and the baselines between points were processed with baseline processing software (Trimble Geomatics Office) in the particular OCRS zone grid coordinate system. Since the ground distances were too long to physically measure with an EDM, the ground distances were calculated using the Vincinty Inverse Formula (as shown in Sec. 5.1). The curved horizontal "ground" distance was computed by scaling the Vincenty GRS-80 ellipsoid distance to the topographic surface. The scale factor to do this was computed using the mean ellipsoid height of the end points and the geometric mean radius of curvature at the mean latitude of the endpoints.

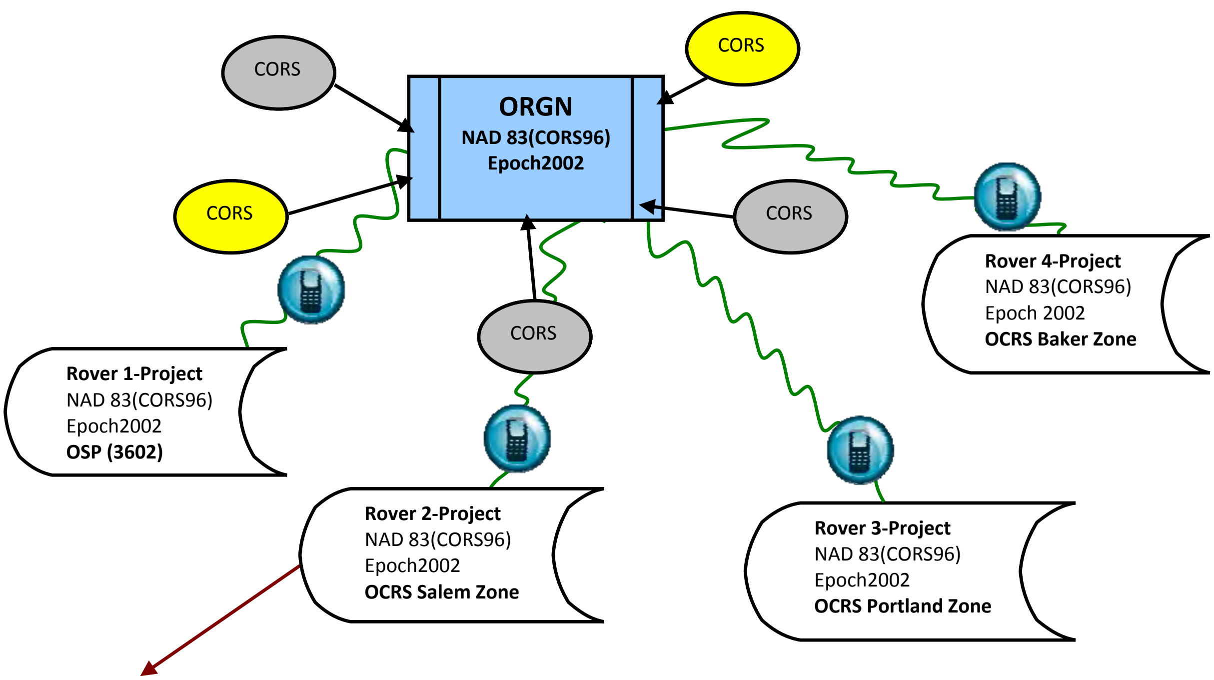
Refer to Appendix B for samples of the baseline test results.

Chapter 6 The OCRS and the Oregon Real-Time GPS Network (ORGN)

6.1 Using the ORGN with the OCRS

If you are a current user of the ODOT ORGN network, you know that the current ORGN horizontal reference datum is based on NAD 83(CORS96)Epoch2002 as derived from a statistical series of NGS Online Positioning User Service (OPUS) solutions for each network CORS station providing a data stream to the ORGN. The ORGN real-time network broadcasts correctors in a non-proprietary RTCM format relative to this horizontal datum. At the rover receiver, data collection occurs in conjunction with the current project and the chosen coordinate system (or OCRS zone). For example, if you wish to work in the Salem Zone you can enter the zone projection coordinate system parameters into your rovers' data collector coordinate system manager software (or download the data from the office software) and pick that particular coordinate system within the project you are working in. Once these steps are complete you should see, on the data collector screen, the Salem Zone northing and easting grid coordinates in real-time, as they would be converted (transformed) from the (rover) observed, network corrected, geodetic reference coordinates automatically. For more information on the ORGN, see: www.theorgn.net.

Figure 6.1



Sample Point: Local Lat. = 44° 55' 28.89159"N, Local Long. = 122° 59'33.83651"W, h=37.659 m
Grid N=65 719.115 m, E=57 153.024 m, H=60.583 m (GEOID03)

6.2 Field Checking Distances (Grid vs. Ground)

Each OCRS zone coordinate system was developed so that grid and ground distances match very closely within a given elevation range (within ± 10-20 ppm). If you are working near the fringe of a zone, or at elevations significantly (more than about a hundred feet) above or below the elevation limits of the zone's low distortion area, then you may want to check the ppm result between control points in your project. To do this, pick the two farthest points in your project that you can measure directly between with an EDM (total station). Measure the horizontal ground distance between the points and record the ground distance measurement. Then, while working in the particular OCRS grid Zone in your data collector, inverse the grid distance between the same two points. Subtract the grid distance from the ground distance (absolute value). Compare this absolute value difference with the ppm threshold desired. At 0 ppm the grid distance would exactly match the ground distance. See the example in Table 6.2

Table 6.2

Ground Distance =	1239.998m	Grid Distance =	1239.990m
Absolute Difference =	.008m		
OCRS Zone PPM Goal =	10	1:100 000 Threshold =	0.0124m
Test	Is 0.008<=0.0124	Yes	Pass (within threshold)

In this case, the actual ppm is well under the ±10 ppm level threshold. If the actual ppm is greater than ±10, then determine how much greater, and judge for yourself if you should be using that particular zone for your project location. There is nothing particularly wrong with exceeding the ±10 ppm level threshold if it makes sense for your project work. Even working at higher elevations up to 50 ppm level would be an improvement over using the Oregon State Plane Coordinate System. It's your choice on how you use the OCRS map projection zones and which one you choose to work in.

This type of test can also be performed using GPS (GNSS) data. One way to do this is to calculate the ground distance between the measured coordinates using Vincenty's formula with the geometric mean radius of curvature, as described previously. Many commercial surveying software packages can also compute the ground distance (it is recommended that the ground distance value be checked to ensure it is correctly computed).

Another method is to use a delta XYZ GPS (GNSS) vector to estimate the horizontal ground distance between points. Neglecting curvature, this can be computed as:

$$H = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2 - \Delta h^2}$$

where ΔX, ΔY, ΔZ are the GPS vector components (as ECEF Cartesian coordinate deltas)
Δh = change in ellipsoid height between vector end points

Accounting for curvature increases this horizontal ground distance, but for distances of less than 20 miles (about 30 km), the increase is less than 1 ppm (i.e., less than 3 cm).

The curvature correction factor can be approximated as:

$$C = (2R\sin^{-1}(H \div 2R)) \div H$$

where R is the earth radius. A value of R = 6 378 000 m (20,925,000 ft) works well for Oregon. The (straight) horizontal distance is multiplied by the correction factor to get the curved horizontal ground distance. Note that there is no need to account for refraction, because the GPS vector is computed, not observed.

Chapter 7 Legislative Adoption and Registration with the NGS

7.1 OCRS Legislative Adoption

The OCRS is substantially complete, thoroughly tested, and generally accepted by a wide audience of Oregon professional surveyors, engineers, GIS, cartographic, and academic professionals around the state. The next step is for the Oregon Department of Transportation's (ODOT) initiative to include the Oregon Coordinate Reference System (OCRS) into the Oregon Revised Statutes, Chapter 93. Legislative adoption will provide fundamental viable acceptance by engineering, surveying, and mapping professionals within the state as well as other Federal agencies such as the BLM, NGS and FEMA etc.

7.2 NGS Policy on Registration of the OCRS

POLICY ON CHANGES TO PLANE COORDINATE SYSTEMS, April 11, 2001
http://www.ngs.noaa.gov/INFO/Policy/SPCS4.html

The National Geodetic Survey (NGS) recognizes there may be States that want to implement changes to their existing North American Datum of 1983 (NAD 83) State Plane Coordinate System (SPCS) parameters or to create and employ supplemental plane coordinate projections. These changes could include: changing the number of zones, changing existing zone boundaries, and/or changing the geometric parameters (e.g., false northing/easting, origin, central meridian, etc.), and/or creating additional coordinate systems. NGS also recognizes that State and local surveying, mapping, and Geographic Information System (GIS) agencies may develop grid systems to support a variety of agency or local activities that may be in conflict with the policy detailed below. This policy details only those elements which must be met for NGS to publish these coordinate systems as part of the National Spatial Reference System (NSRS).

While NGS does not encourage States to change the current definition of the existing SPCS, NGS does recommend any proposed changes be thoroughly discussed in detail with NGS technical staff, including the NGS State Geodetic Advisor, if such an office exists in the State, prior to submitting a request to the Director, NGS.

NGS will adopt changes to SPCS or add supplemental projections into NSRS only under the following conditions:

1. All requests for changes must be submitted in writing to the Director, NGS, and must be co-signed by those State agencies and organizations most involved in the use, collection, and distribution of spatial data including, but not limited to, the State Department of Transportation, State Office of GIS, and state land surveyor professional organizations. Hereafter these groups are referred to as the "State." Required agencies and organizations will be determined by NGS on a state-by-state basis. A similar request must also be submitted to the U.S. Geological Survey (USGS) to ensure integrity of NSRS with USGS national mapping products and services.
2. All new SPC zones or supplemental projections shall use the two basic map projections, the Lambert Conformal Conic or the Mercator (transverse or oblique), defined at the surface of the ellipsoid of the current Datum (Geodetic Reference System 1980 - GRS 80).
3. All changes must be adopted by State Law (or State Regulation when such Regulation is regulated by public notices and hearings and no opposition exist). Such Law must include a complete description of the revised SPCS zones and geometric parameters. A specified conversion factor between meters and feet (U.S. Survey or International) is strongly

recommended to be included in the legislation. NGS will publish coordinates only in those legislated units.

4. Zones will continue to be defined by International, State and county boundaries, and by the counties contained therein. (See Federal Register Notice "Policy on Publication of Plane Coordinates," Vol. 42, Nol. 57, pages 15943-15944, published March 24, 1977.)
5. SPCS changes will ensure that the resulting coordinate differences are sufficiently large (by at least 10,000 meters) to ensure that no confusion will exist with the current NAD 83 coordinate values.
6. A naming convention shall be developed that ensures a distinct labeling between the existing and revised new coordinate zones.
7. Should NGS estimate significant expenses resulting from changes to the existing SPCS, NGS may require State reimbursement. These costs would be for coordinate conversion, data base extraction and publication software required to support computation, publication and distribution of new coordinate values as part of NSRS.
8. To facilitate public awareness, the State shall develop an education program that includes an article detailing the rationale for the development of the changes, the process of review and examination of the issues, the final design criteria, and a workshop or seminar to be presented at a State-wide surveying and mapping conference. The article shall be submitted for publication in one or more surveying and mapping periodicals (e.g., American Congress on Surveying and Mapping Bulletin, Professional Surveyor, or P.O.B. magazines). In addition, this article will be made available on the web sites of the sponsoring agencies defined as the "State." Any requests for technical support from NGS requiring travel expenses for NGS personnel shall be reimbursed by the State.

References

Presentations and papers

1. *ODOT/OGUG Low Distortion Projection Workshop Presentation*, November 4th, 2008, Ron Singh.
2. *Ground Truth - Low Distortion Projections for Surveying and GIS*, Oregon Edition 2008 – Presentation by Michael Dennis, RLS, PE.
3. *Ground Truth - Design and Documentation of Low Distortion Projections for Surveying and GIS, Arizona Edition November 2008*, Michael L. Dennis, RLS, PE.
4. *Low Distortion Map Projections (Local Map Projections) Academic Perspective* – OGUG Meeting Presentation, November 4th, 2008, Jack Walker, Ph.D.

Federal and academic documents

5. U. S. Dept. of Commerce, *The Practical Use of the Oregon State Plane Coordinate System,* by Buford K. Meade, 1964
6. Federal Geographic Data Committee (1998) *Geospatial Positioning Accuracy Standards*, FGDC-STD-007.2-1998, Federal Geographic Data Committee, Reston, Virginia, USA, 128 pp., http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/, [includes Standards for Geodetic Networks (Part 2), National Standard for Spatial Data Accuracy (Part 3), and Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management (Part 4)].
7. National Geodetic Survey, *User Guidelines for Single Base Real Time GNSS Positioning v3.0,* by William Henning, Lead Author
8. Snyder, J.P. (1987) *Map Projections - A Working Manual*, U.S. Geological Survey Professional Paper 1395, U.S. Government Printing Office, Washington, D.C., USA, 383 pp.
9. "*A Refinement to the World Geodetic System 1984 Reference Frame*", by Merrigan, Swift, Wong, and Saffel.
10. "*Transforming Position and Velocities between the International Terrestrial Reference Frame of 2000 and North American Datum of 1983*", by Tomas Soler and Richard Snay.
11. National Imagery and Mapping Agency, 2000, *Department of Defense World Geodetic System of 1984: Its Definition and Relationships with Local Geodetic Systems (3rd Edition), Amendment 1, NIMA Technical Report 8350.2*, National Imagery and Mapping Agency (now the National Geospatial-Intelligence Agency), 175 pp., http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html.
12. Vincenty, T., 1975. *Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations, Survey Review, Vol. 23, No. 176, pp. 88-93*, http://www.ngs.noaa.gov/PUBS_LIB/ inverse.pdf.
13. National Geodetic Survey, *NOAA Manual NOS NGS 5, State Plane Coordinate System of 1983*, James E. Stem, 1989. http://www.ngs.noaa.gov/PUBS_LIB/ManualNOSNGS5.pdf
14. War Department Corps of Engineers, *Plane Co-ordinate Computation for the State or Oregon*, with tables by the US Coast and Geodetic Survey, ~1964

General website references

Control station datasheets: http://www.ngs.noaa.gov/cgi-bin/datasheet.prl

The Geodetic Tool Kit: http://www.ngs.noaa.gov/TOOLS/

Online Positioning User Service (OPUS): http://www.ngs.noaa.gov/OPUS/

Continuously Operating Reference Stations (CORS): http://www.ngs.noaa.gov/CORS/

The GEOID Page: http://www.ngs.noaa.gov/GEOID/

NGS State Geodetic Advisors: http://www.ngs.noaa.gov/ADVISORS/AdvisorsIndex.shtml

Geotools Page: http://geotools.org/javadocs/org/geotools/referencing/operation/projection/ObliqueMercator.html

POSC Specifications – Hotline Oblique Mercator: http://posc.org/Epicentre.2/DataModel/ExamplesofUsage/eu_cs34i.html

Radius at a given geodetic latitude: https://visualization.hpc.mil/wiki/Radius_of_the_Earth

Vincenty Formula: http://www.movable-type.co.uk/scripts/latlong-vincenty.html

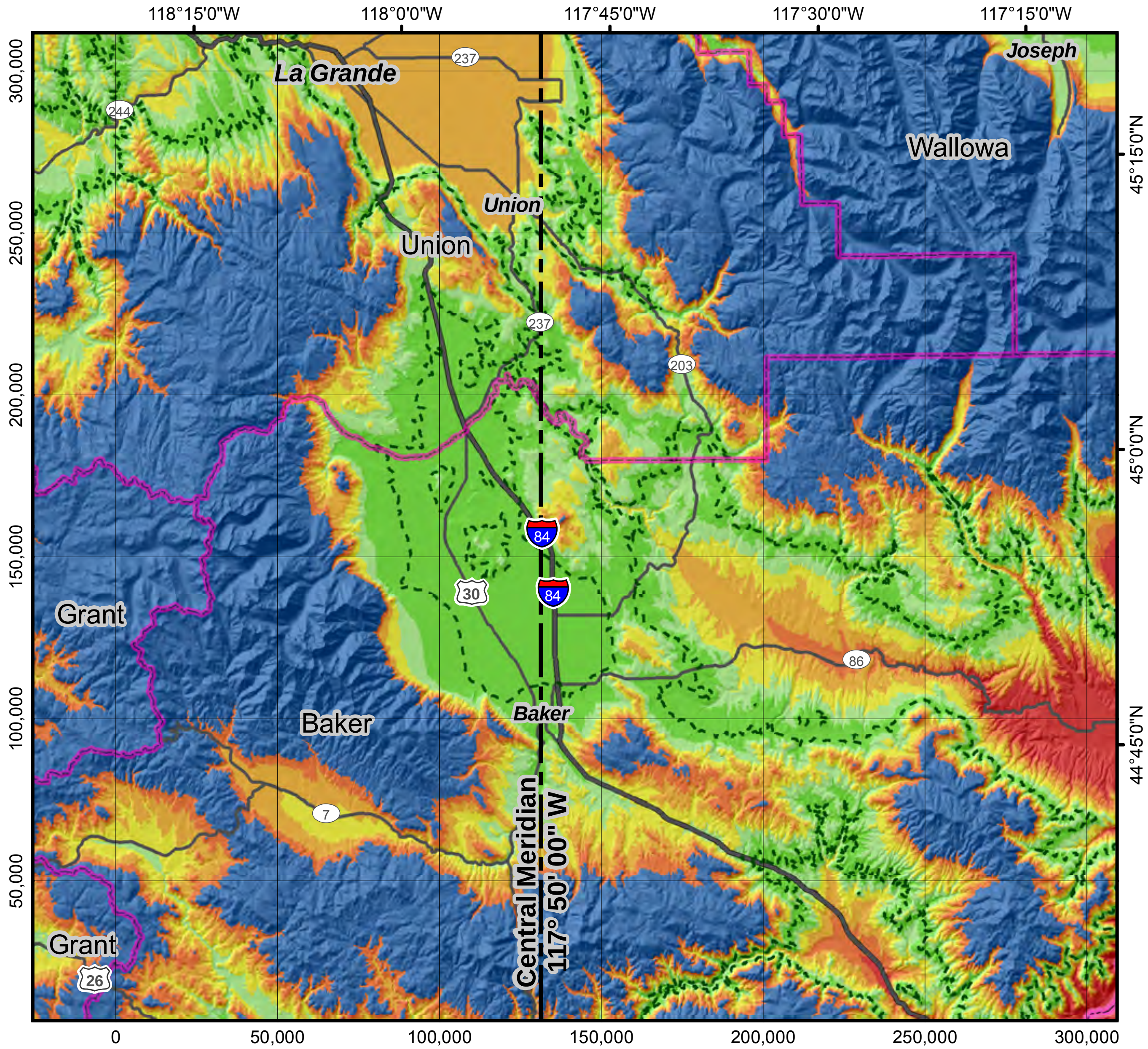
Helmert Transformations: http://earth-info.nga.mil/GandG/coordsys/datums/helmert.html

Ordnance Survey:
http://www.ordnancesurvey.co.uk/oswebsite/gps/information/coordinatesystemsinfo/guidecontents/guide6.html

Datum transformations: http://www.niirs10.com/support/ct_geocue/geocue_ct_3.pdf

Appendix A

OCRS Zone Maps



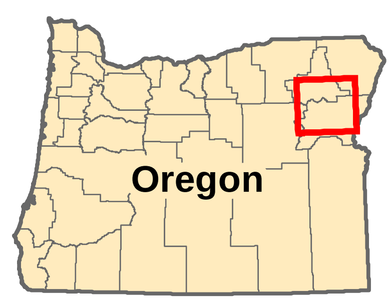
Oregon Coordinate Reference System

Baker Zone

Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	44° 30' 00" N
Central meridian:	117° 50' 00" W
False northing:	0.000 m
False easting:	40 000.000 m
Central meridian scale:	1.000 160 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:600,000

0 5 10 15 20

Miles

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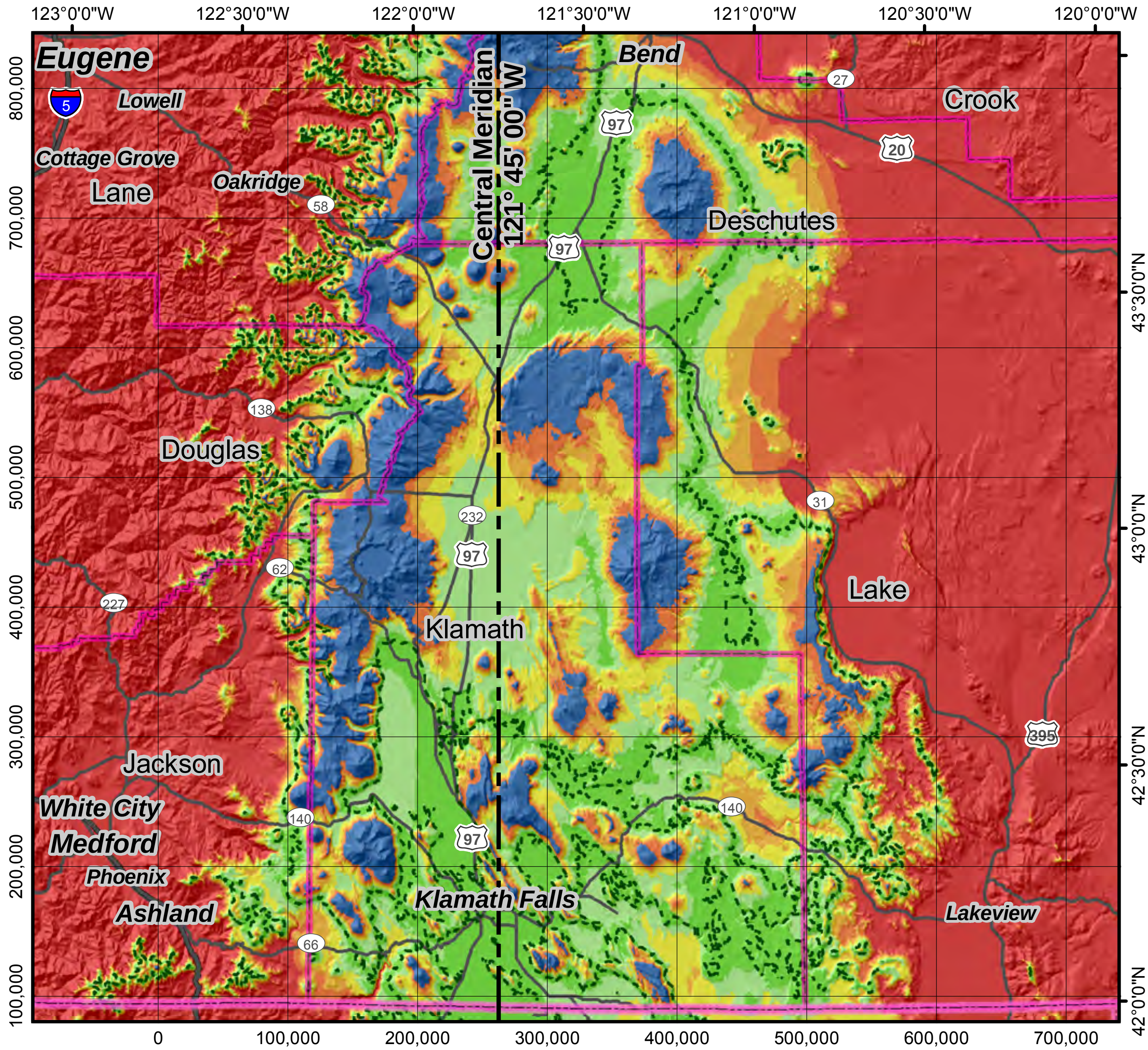
mld@geodeticanalysis.com

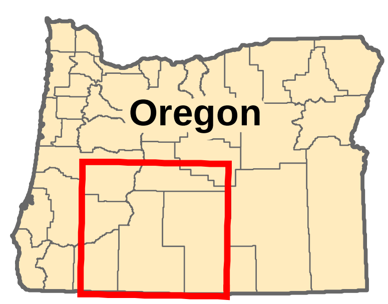


Oregon Coordinate Reference System
Bend-Klamath Falls Zone

Transverse Mercator projection
North American Datum of 1983

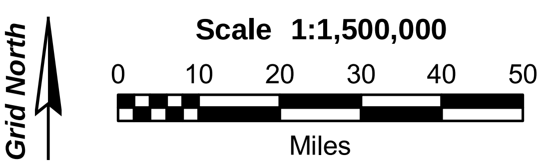
Latitude of grid origin:	41° 45' 00" N
Central meridian:	121° 45' 00" W
False northing:	0.000 m
False easting:	80 000.000 m
Central meridian scale:	1.000 200 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)



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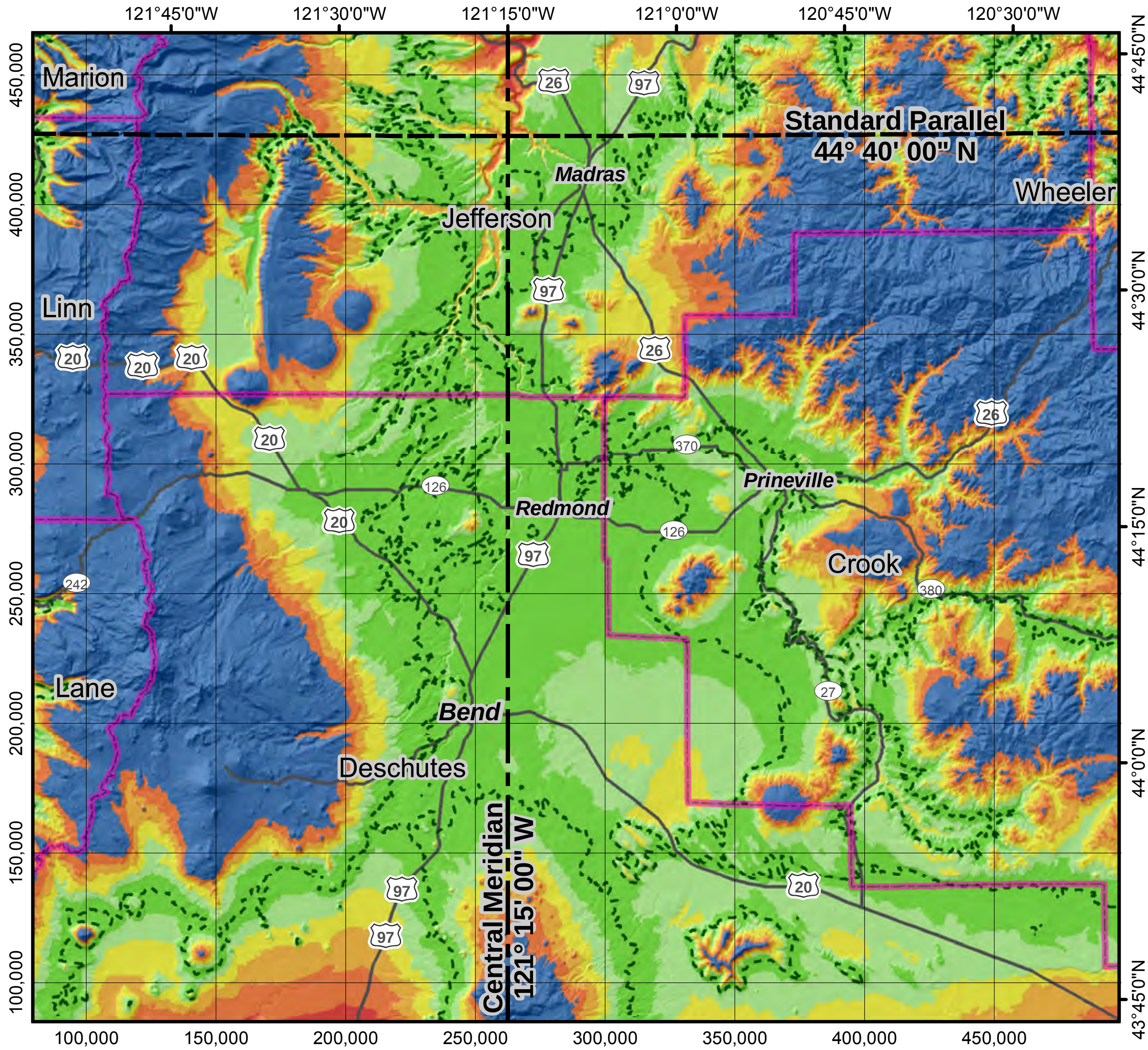


Oregon Coordinate Reference System

Bend-Redmond-Prineville Zone

Lambert Conformal Conic projection
(single parallel)
North American Datum of 1983

Stnd parallel & grid origin:	44° 40' 00" N
Central meridian:	121° 15' 00" W
False northing:	130 000.000 m
False easting:	80 000.000 m
Standard parallel scale:	1.000 120 (exact)

Grid North

Scale 1:750,000

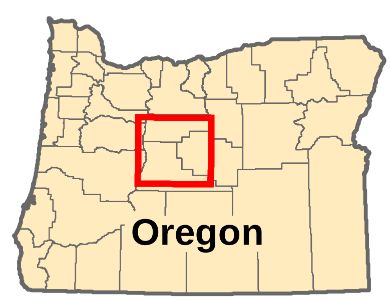
0 5 10 15 20 25

Miles

Projected map grid is shown in units of international feet

Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)



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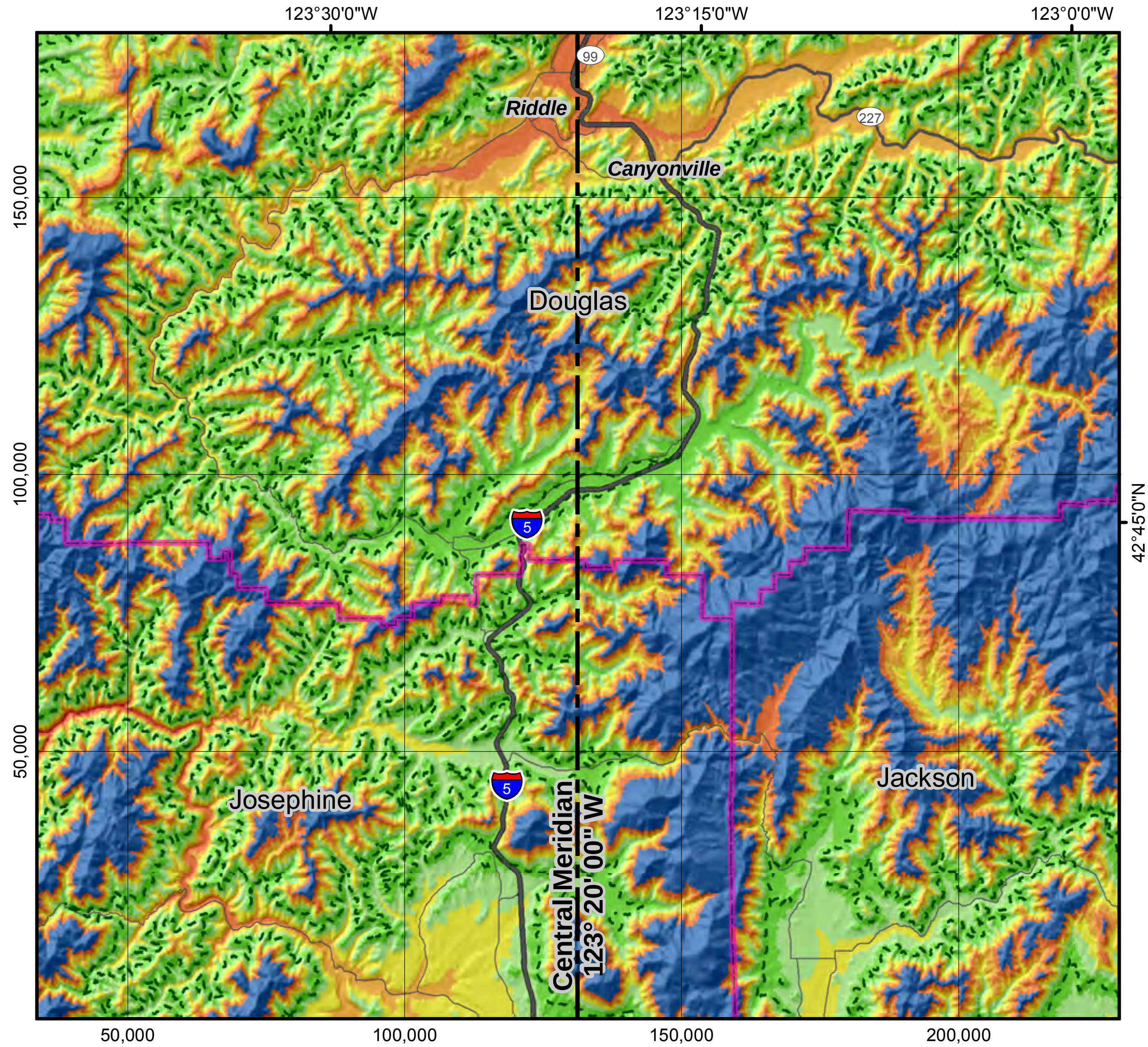
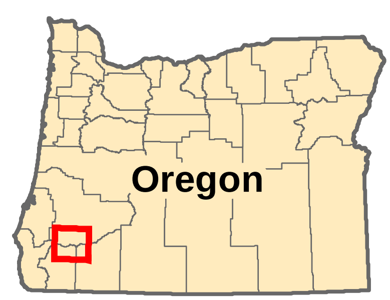


Oregon Coordinate Reference System
Canyonville-Grants Pass Zone

Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	42° 30' 00" N
Central meridian:	123° 20' 00" W
False northing:	0.000 m
False easting:	40 000.000 m
Central meridian scale:	1.000 070 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:350,000

0 5 10

Miles

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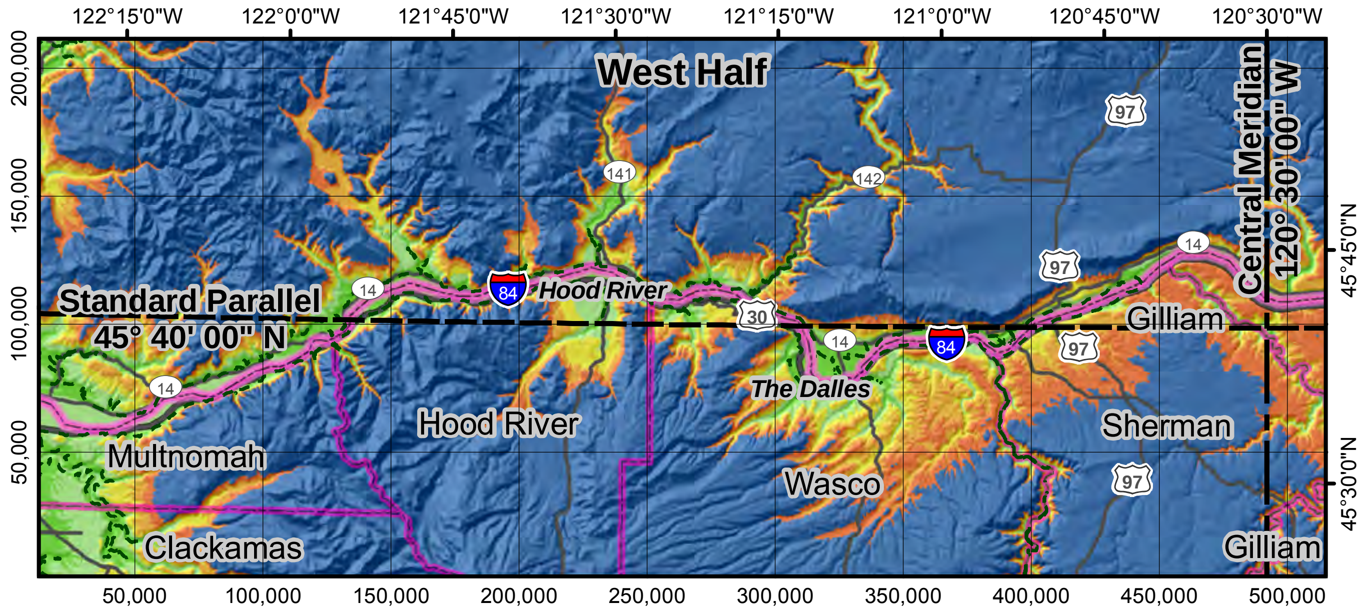
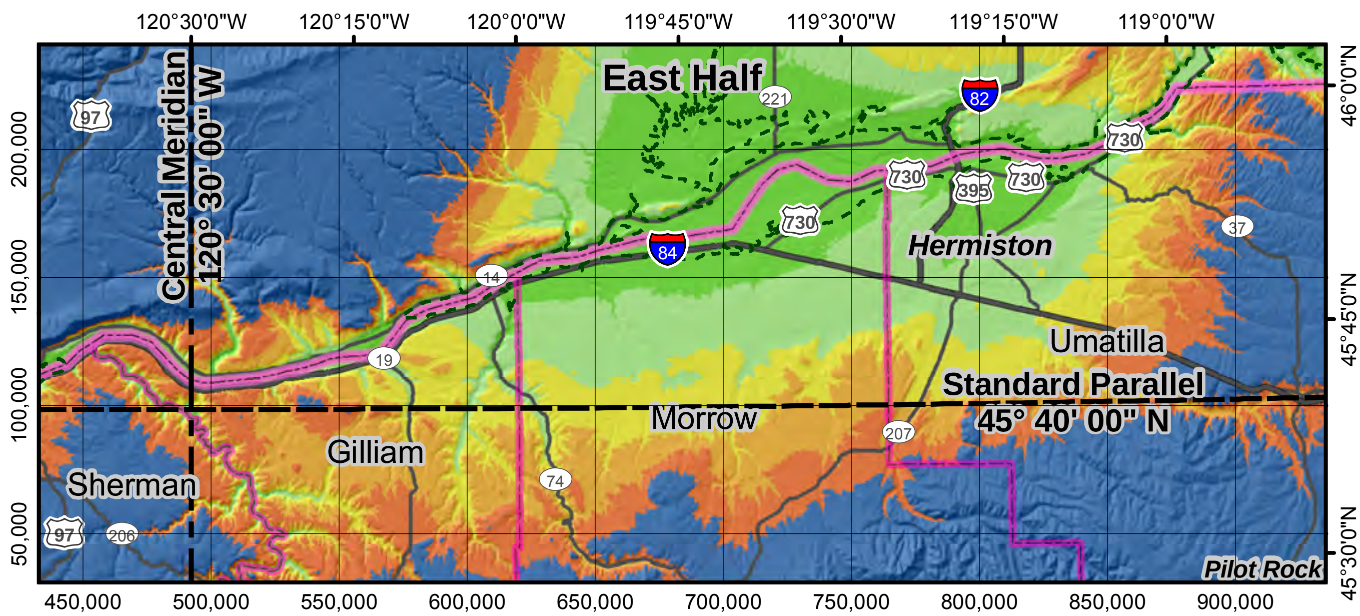




Oregon Coordinate Reference System

Columbia River East Zone

Lambert Conformal Conic projection
(single parallel)
North American Datum of 1983

Stnd parallel & grid origin:	45° 40' 00" N
Central meridian:	120° 30' 00" W
False northing:	30 000.000 m
False easting:	150 000.000 m
Standard parallel scale:	1.000 008 (exact)

Grid North

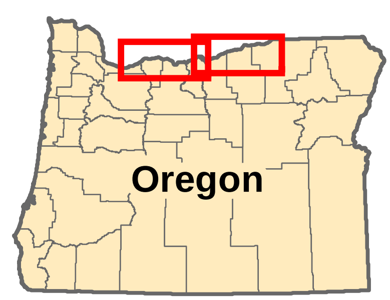
Scale 1:900,000

0 10 20 30
Miles

Projected map grid is shown in units of international feet

Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)



Prepared by:
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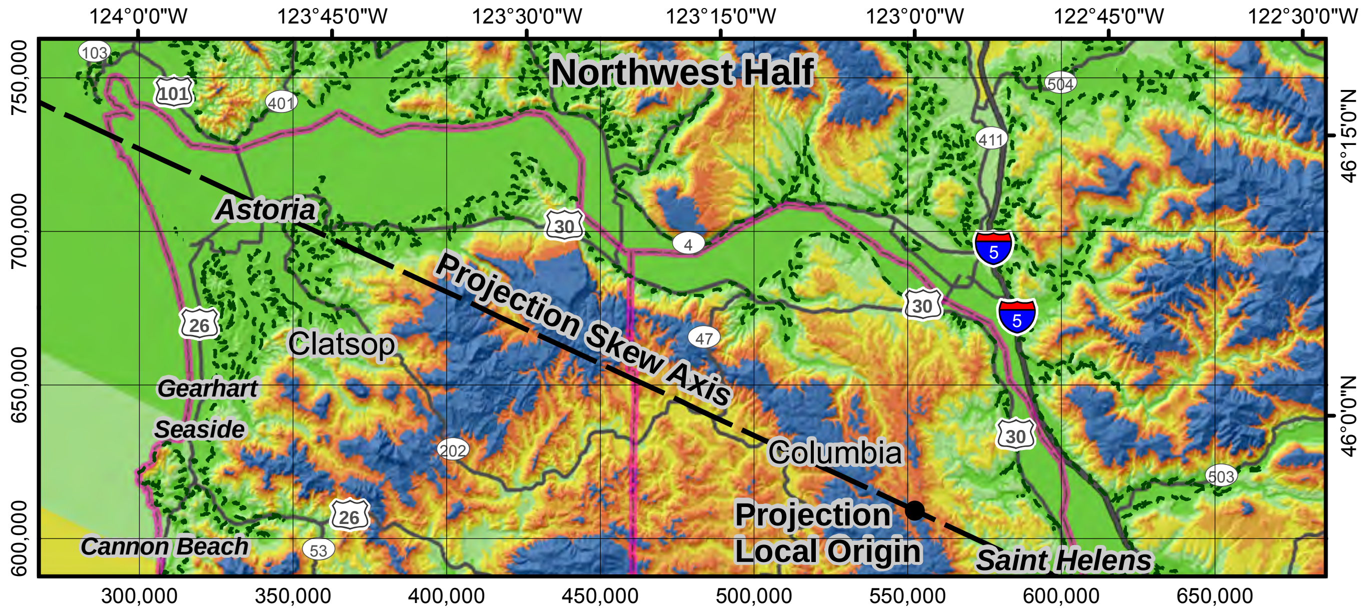
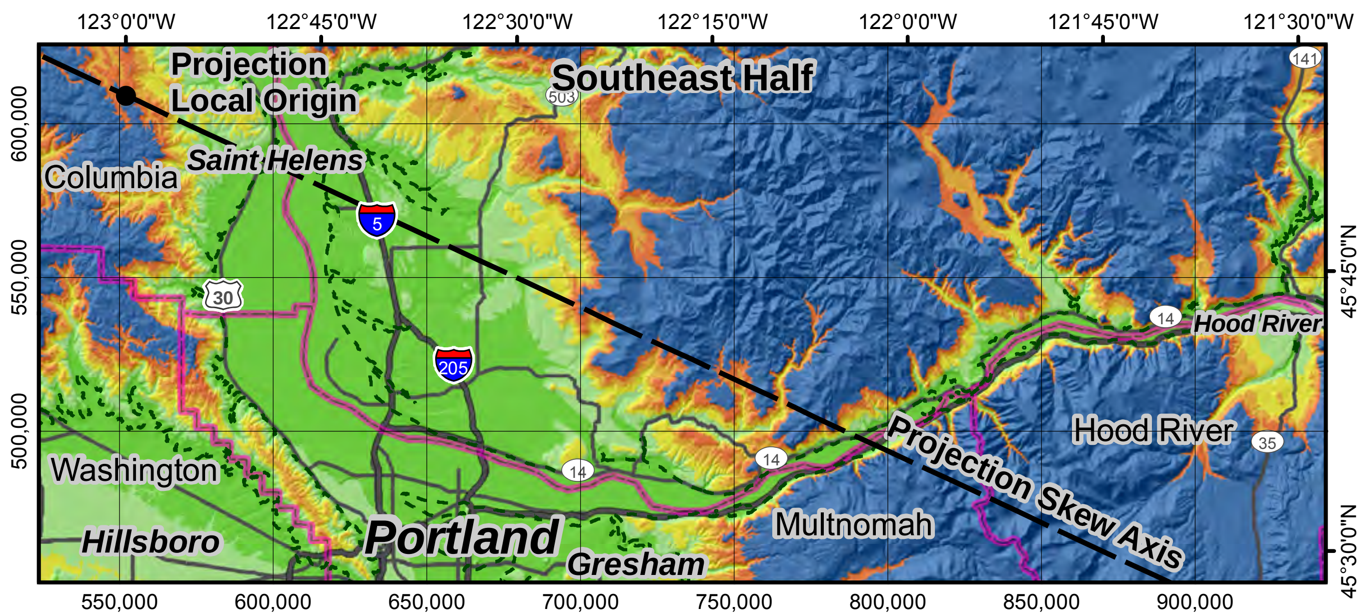




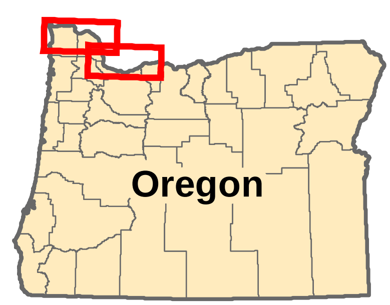
Oregon Coordinate Reference System

Columbia River West Zone

Oblique Mercator projection
North American Datum of 1983

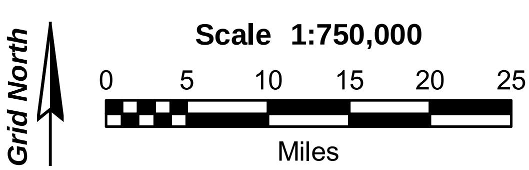
Latitude of local origin:	45° 55' 00" N
Longitude of local origin:	123° 00' 00" W
False northing:	-3 000 000.000 m
False easting:	7 000 000.000 m
Projection skew axis scale:	1.000 000 (exact)
Skew axis azimuth at origin:	-65° 00' 00"

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)



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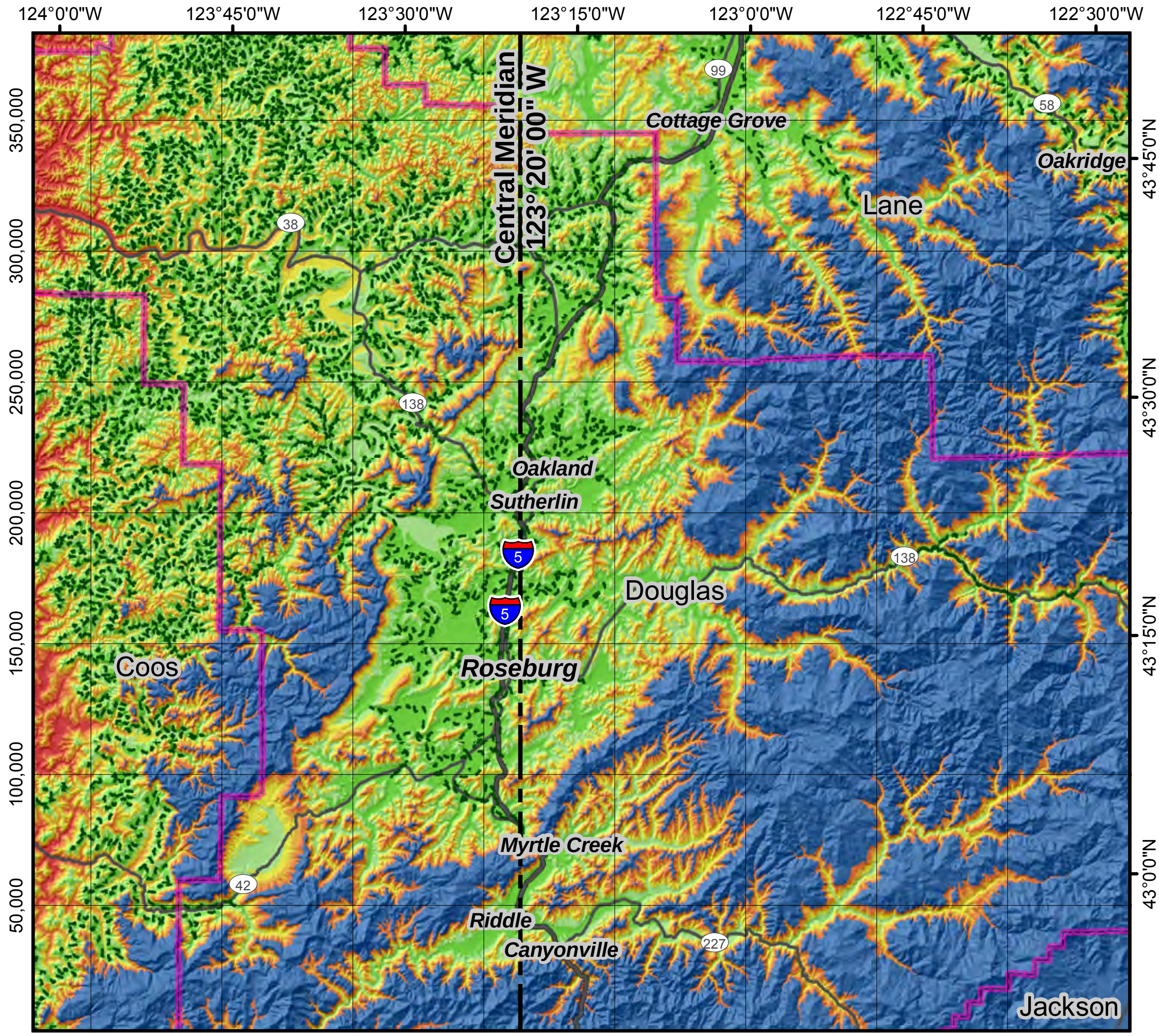


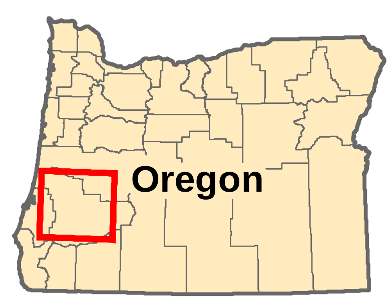
Oregon Coordinate Reference System

Cottage Grove-Canyonville Zone

Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	42° 50’ 00" N
Central meridian:	123° 20’ 00" W
False northing:	0.000 m
False easting:	50 000.000 m
Central meridian scale:	1.000 023 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:750,000

0 5 10 15 20 25

Miles

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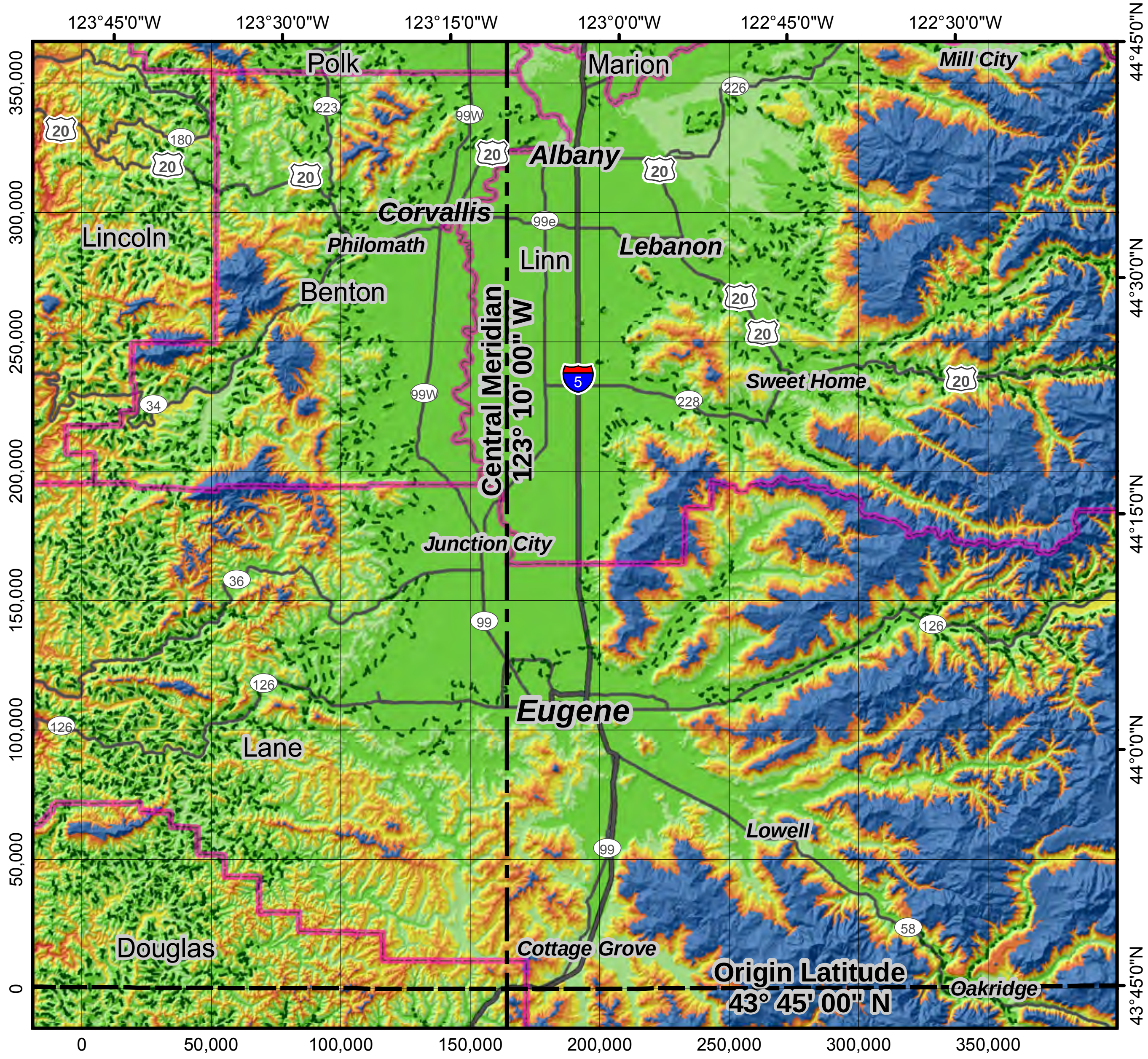


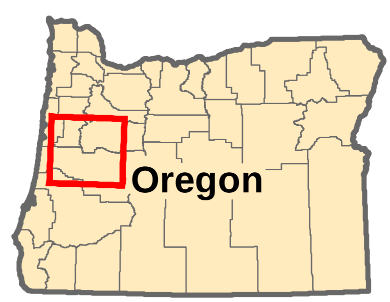
Oregon Coordinate Reference System

Eugene Zone

Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	43° 45' 00" N
Central meridian:	123° 10' 00" W
False northing:	0.000 m
False easting:	50 000.000 m
Central meridian scale:	1.000 015 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:750,000

0 5 10 15 20 25

Miles

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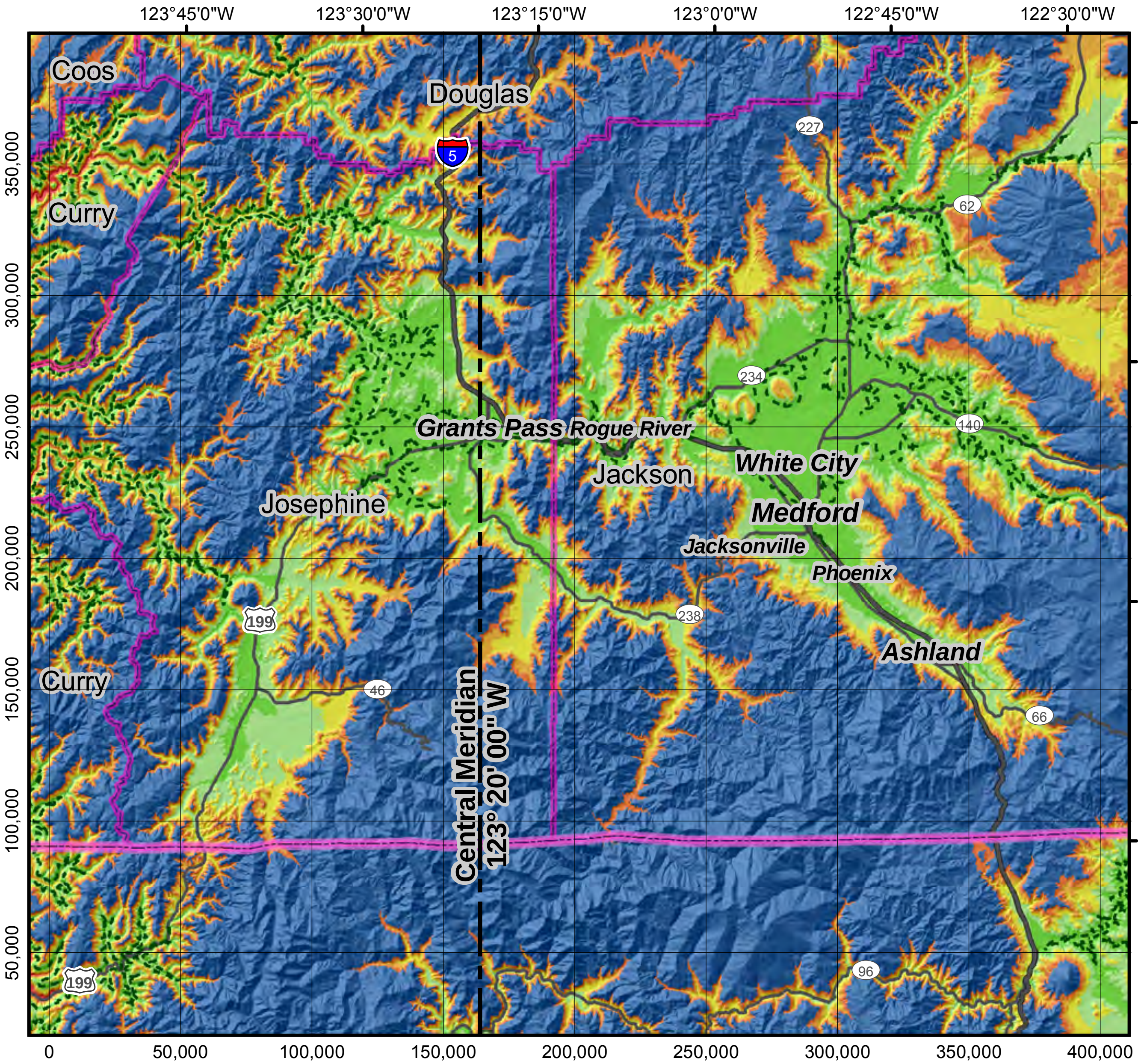


Oregon Coordinate Reference System

Grants Pass-Ashland Zone

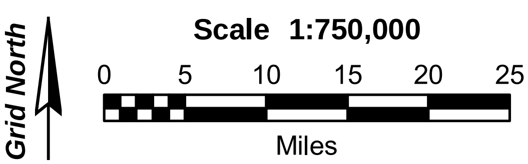
Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	41° 45' 00" N
Central meridian:	123° 20' 00" W
False northing:	0.000 m
False easting:	50 000.000 m
Central meridian scale:	1.000 043 (exact)

Projected map grid is shown in units of international feet

Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)



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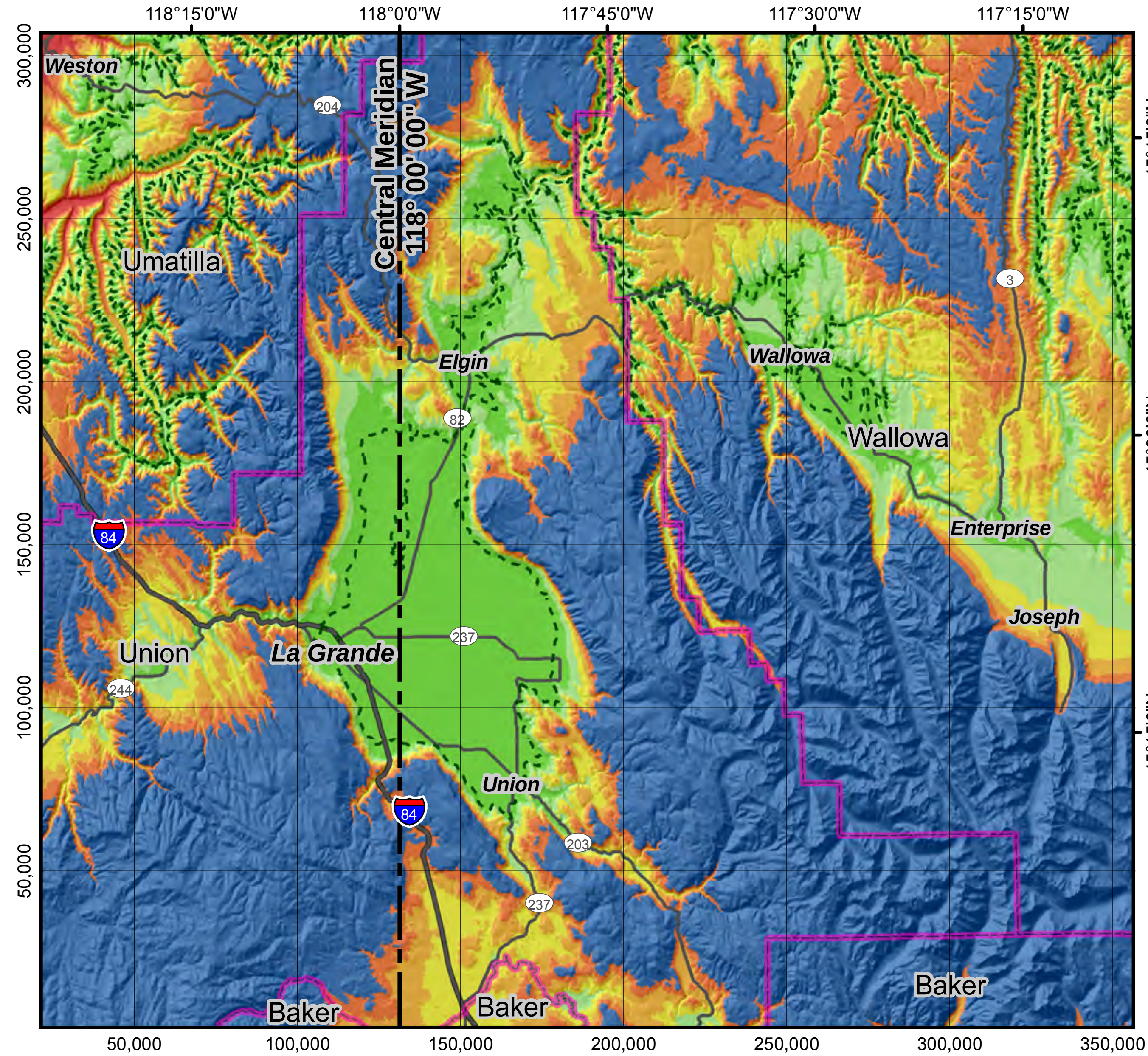
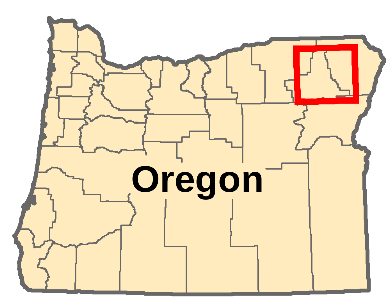


Oregon Coordinate Reference System
La Grande Zone

Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	45° 00' 00" N
Central meridian:	118° 00' 00" W
False northing:	0.000 m
False easting:	40 000.000 m
Central meridian scale:	1.000 130 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:600,000

0 5 10 15 20

Miles

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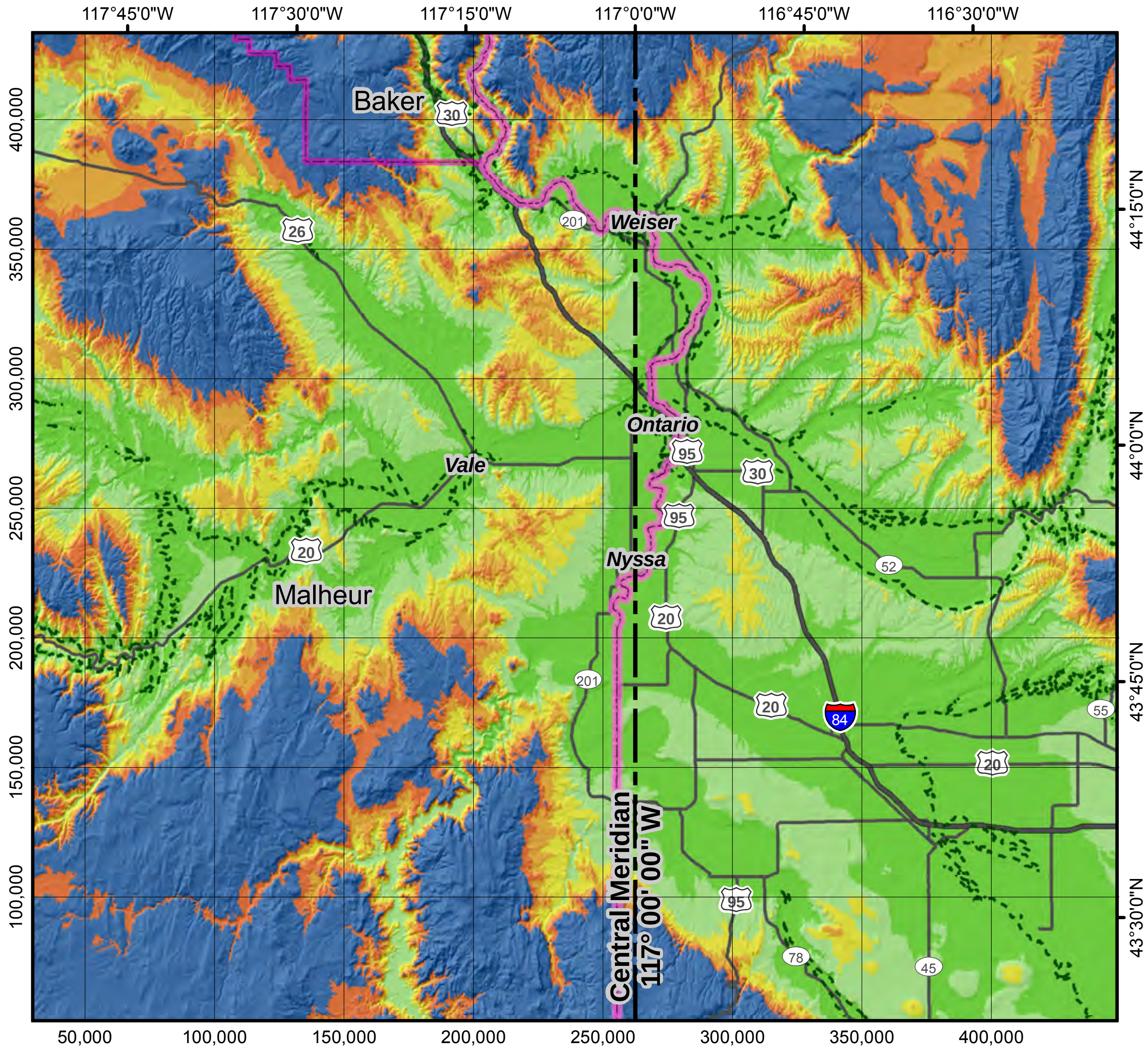
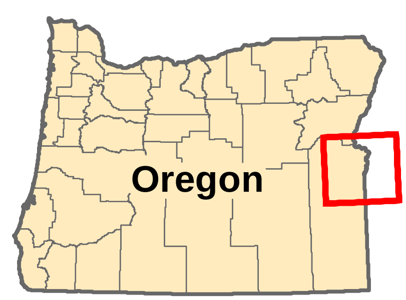


Oregon Coordinate Reference System
Ontario Zone

Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	43° 15' 00" N
Central meridian:	117° 00' 00" W
False northing:	0.000 m
False easting:	80 000.000 m
Central meridian scale:	1.000 100 (exact)

Projected map grid is shown in units of international feet



Linear distortion
- - - Zero distortion
< -50 ppm (< -0.25 ft/mi)
±10 ppm (±0.05 ft/mi)
10 - 20 ppm (0.05 - 0.1 ft/mi)
20 - 30 ppm (0.1 - 0.15 ft/mi)
30 - 40 ppm (0.15 - 0.2 ft/mi)
40 - 50 ppm (0.2 - 0.25 ft/mi)
> +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:750,000
0 5 10 15 20 25
Miles

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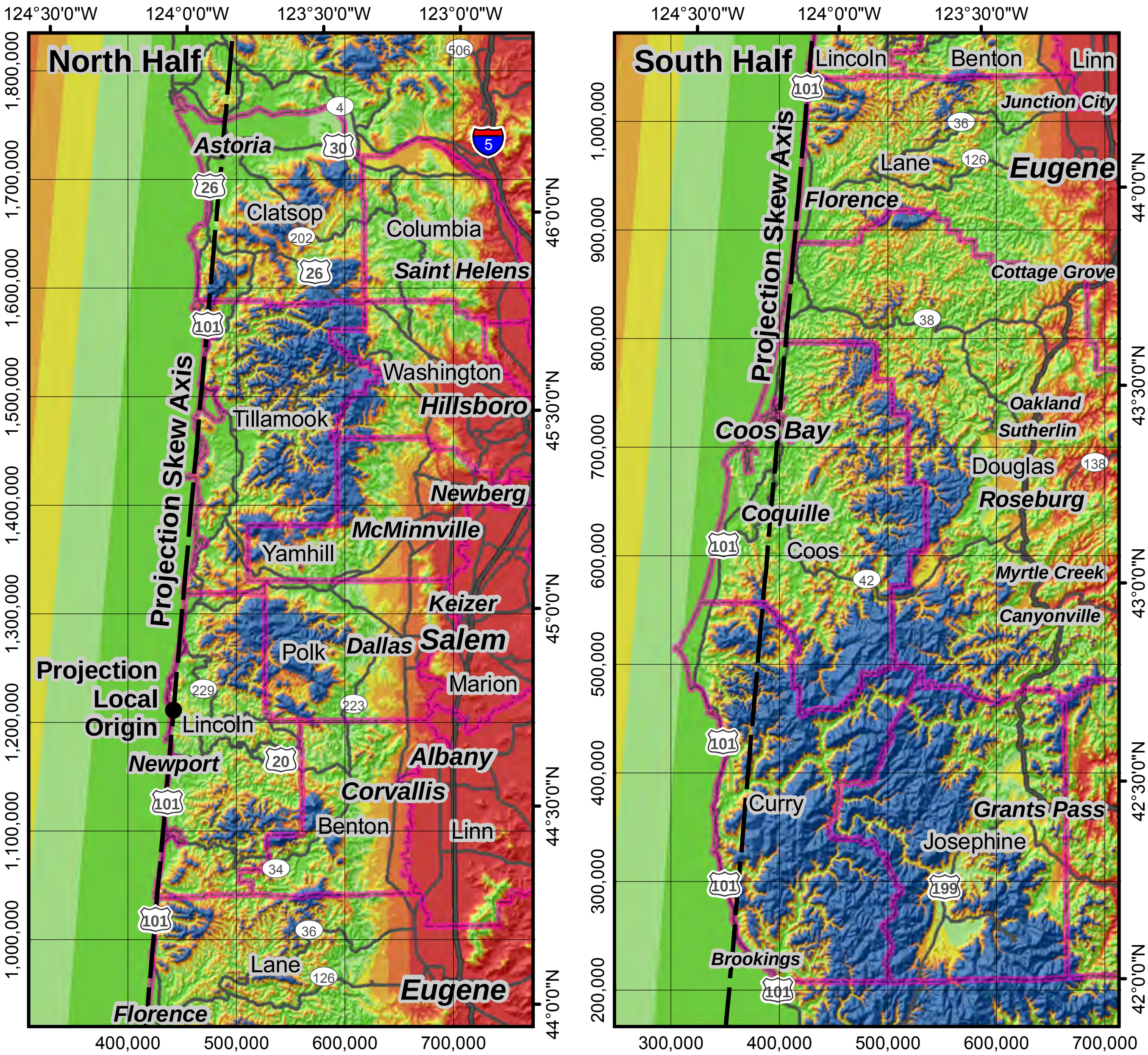


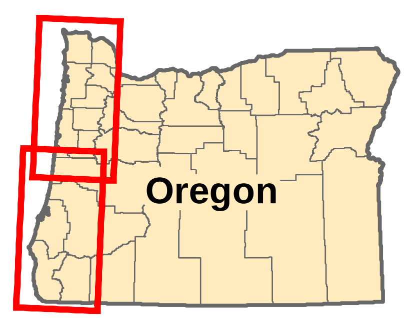
Oregon Coordinate Reference System

Oregon Coast Zone

Oblique Mercator projection
North American Datum of 1983

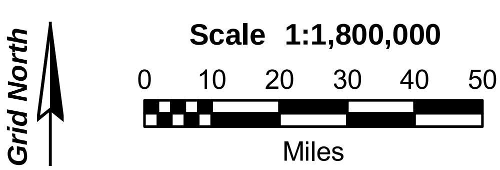
Latitude of local origin:	44° 45' 00" N
Longitude of local origin:	124° 03' 00" W
False northing:	-4 600 000.000 m
False easting:	-300 000.000 m
Projection skew axis scale:	1.000 000 (exact)
Skew axis azimuth at origin:	+5° 00' 00"

Projected map grid is shown in units of international feet



Linear distortion

- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)



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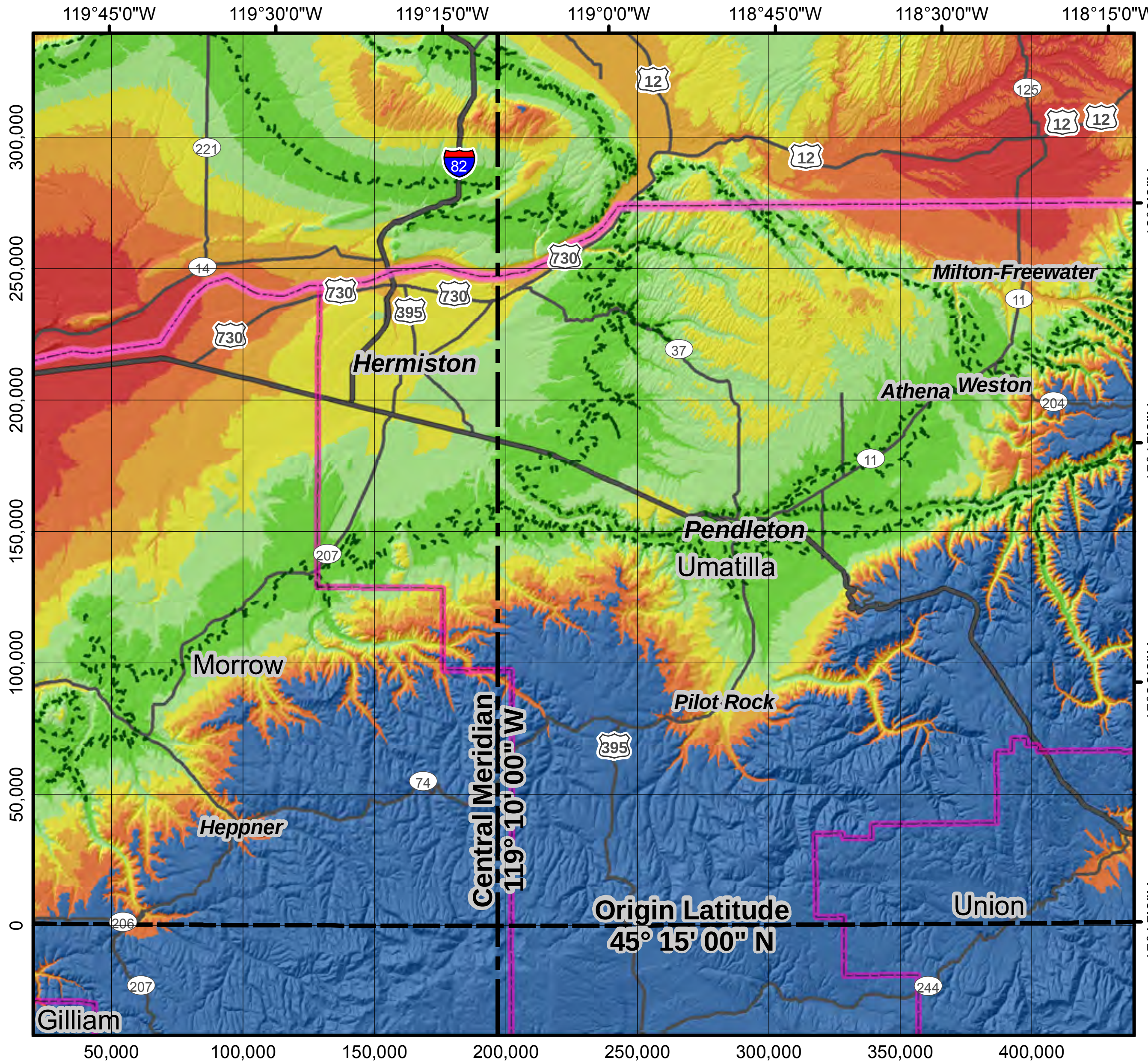


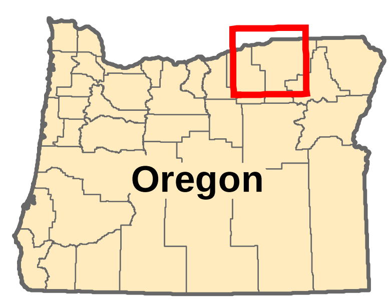
Oregon Coordinate Reference System

Pendleton Zone

Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	45° 15' 00" N
Central meridian:	119° 10' 00" W
False northing:	0.000 m
False easting:	60 000.000 m
Central meridian scale:	1.000 045 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:750,000

0 5 10 15 20 25

Miles

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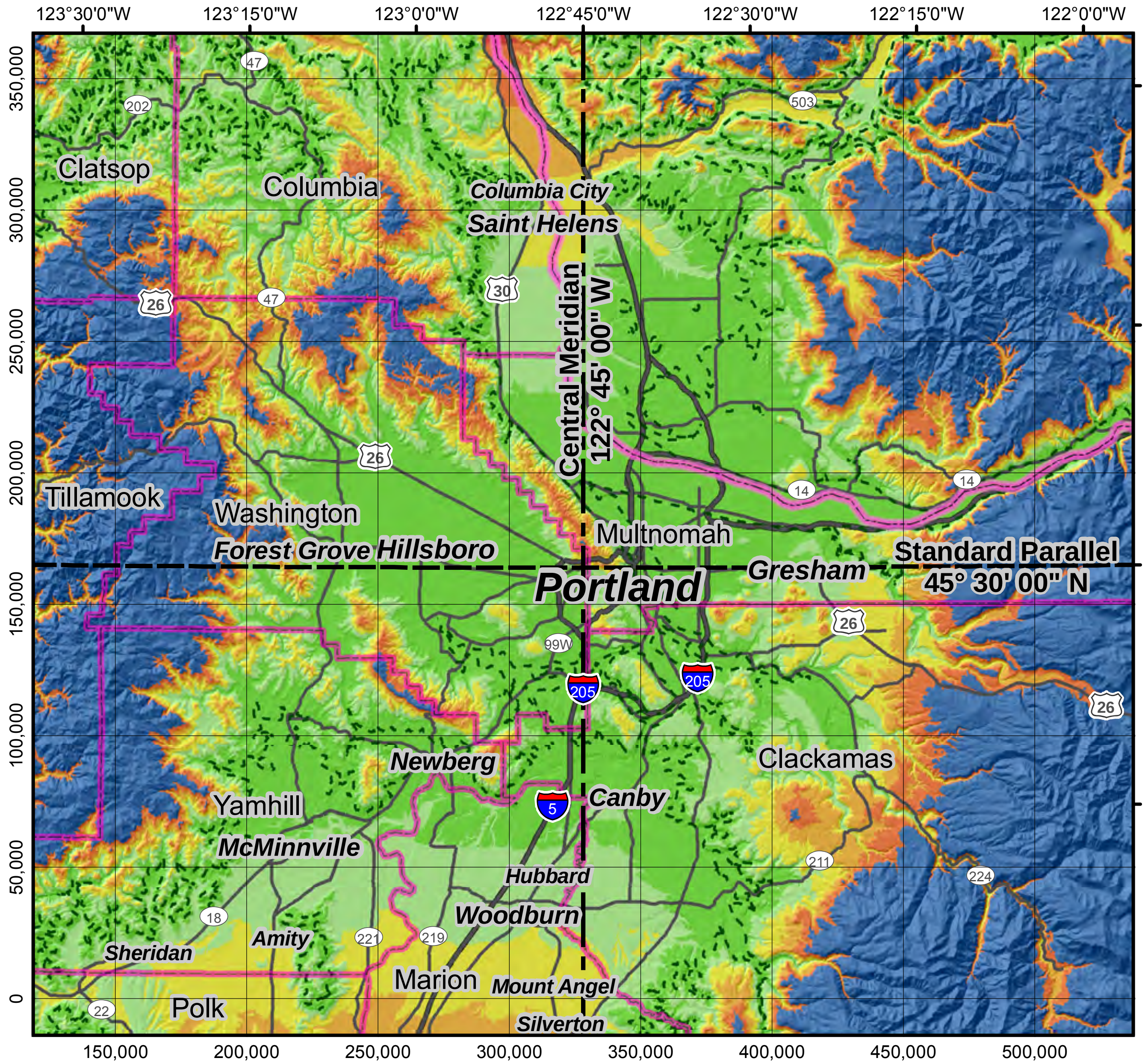


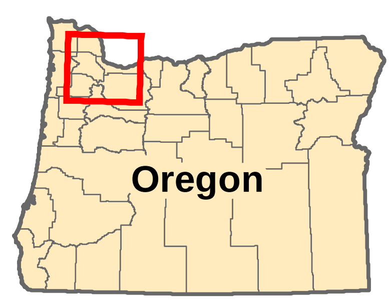
Oregon Coordinate Reference System

Portland Zone

Lambert Conformal Conic projection
(single parallel)
North American Datum of 1983

Stnd parallel & grid origin:	45° 30' 00" N
Central meridian:	122° 45' 00" W
False northing:	50 000.000 m
False easting:	100 000.000 m
Standard parallel scale:	1.000 002 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:750,000

0 5 10 15 20 25

Miles

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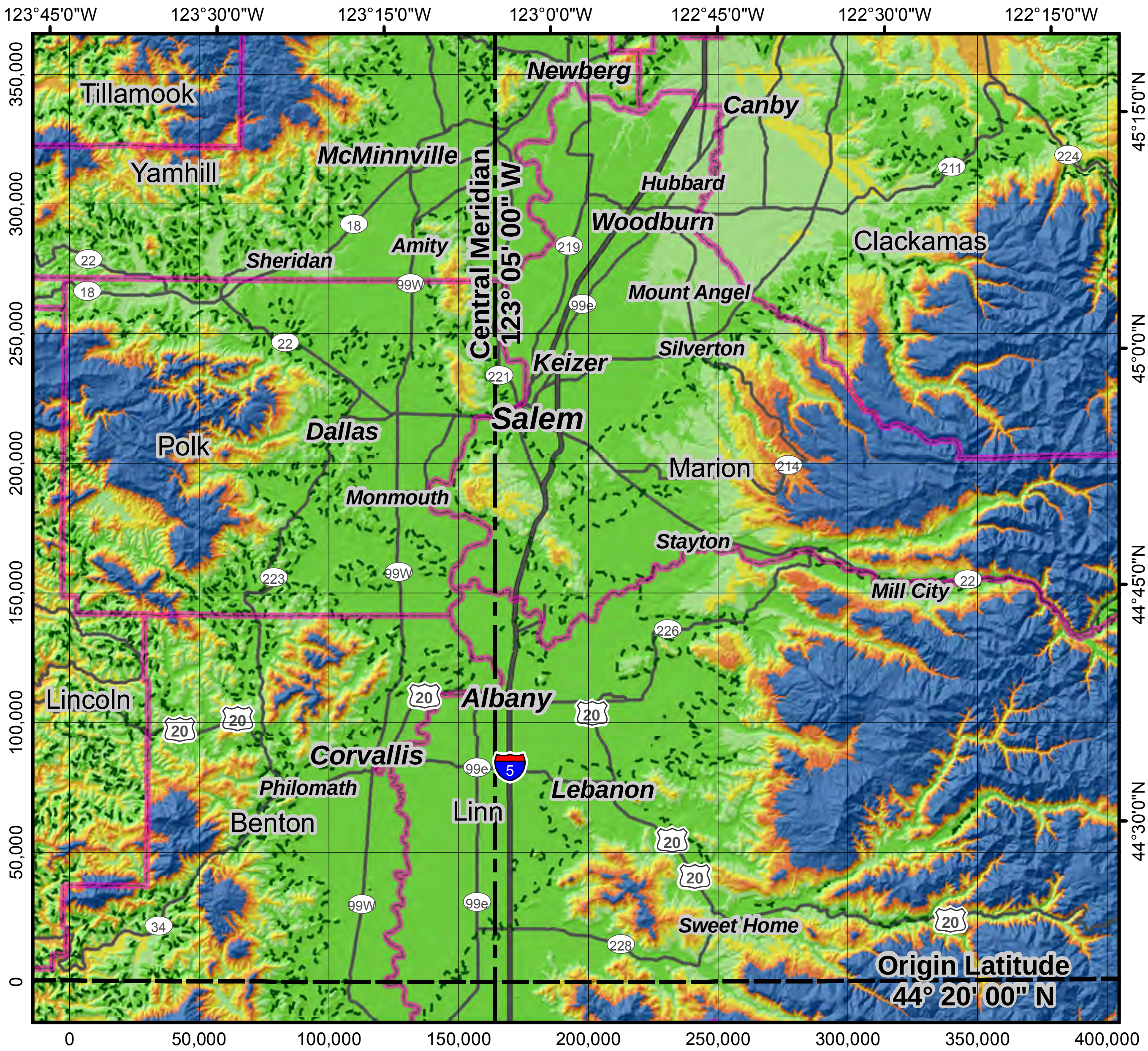


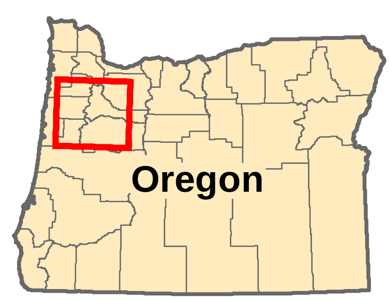
Oregon Coordinate Reference System

Salem Zone

Transverse Mercator projection
North American Datum of 1983

Latitude of grid origin:	44° 20' 00" N
Central meridian:	123° 05' 00" W
False northing:	0.000 m
False easting:	50 000.000 m
Central meridian scale:	1.000 010 (exact)

Projected map grid is shown in units of international feet



Linear distortion

- - - Zero distortion
- < -50 ppm (< -0.25 ft/mi)
- ±10 ppm (±0.05 ft/mi)
- 10 - 20 ppm (0.05 - 0.1 ft/mi)
- 20 - 30 ppm (0.1 - 0.15 ft/mi)
- 30 - 40 ppm (0.15 - 0.2 ft/mi)
- 40 - 50 ppm (0.2 - 0.25 ft/mi)
- > +50 ppm (> +0.25 ft/mi)

Grid North

Scale 1:750,000

0 5 10 15 20 25

Miles

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Appendix B

OCRS Trial – Field Testing Results

OCRS Testing - Short Baseline Testing On NOAA Calibrated Base Lines (Pass/Fail Threshold Test)
GPS Measurement of Grid Zone Distances vs. NGS Record Ground Distances (Horizontal)

The NGS hor. distance is considered the record value (blue box).

The NGS CBL record value has been extracted from the NGS webpage: http://www.ngs.noaa.gov/CBLINES/BASELINES/or

The absolute value horizontal difference is shown in the orange box. The allowable error at 10ppm is shown in the dark green box.

This is a Pass/Fail test. Fail only means that the result is outside of the 10ppm (or 20ppm) level.

If the difference is less than or equal to the allowed error then the measurement on the map projection passes (lt. green box).

The only entry needed is the appropriate local zone grid distance entered in the yellow box.

Local Portland Zone (10ppm Single Parallel Lambert Map Projection)

HILLSBORO CBL (1987) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	60.960	1370	52.391	1369.9949	1370.0217	0.4

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1369.995	H. Ground Dist. From NGS=	1369.995	Difference=	0.000	meters
GPS data gathered by Randy Oberg. Processed by Mark Armstrong			1:100 000 Allowed Error=	0.0137	Pass/Fail=	Pass	

AURORA CBL (1976, 1990, 2000 REMEASURED) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0 (PLSO 1)	58.640	1530 (PLSO 7)	58.361	1530.5701	1530.5701	0.2

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1530.578	H. Ground Dist. From NGS=	1530.570	Difference=	0.008	meters
Data from Marion County			1:100 000 Allowed Error=	0.0153	Pass/Fail=	Pass	

MCMINNVILLE CBL (1986, 2001) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	48.375	1130	47.223	1129.9614	1129.9620	0.2

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1129.964	H. Ground Dist. From NGS=	1129.961	Difference=	0.003	meters
GPS data gathered by Randy Oberg. Processed by Mark Armstrong			1:100 000 Allowed Error=	0.0113	Pass/Fail=	Pass	

Local Salem Zone (10ppm Transverse Mercator Map Projection)

ALBANY CBL (1982, 2000 REMEASURED)

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	66.689	1240	67.056	1239.9899	1239.9901	0.2

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1239.998	H. Ground Dist. From NGS=	1239.990	Difference=	0.008	meters
Data from Marion County			1:100 000 Allowed Error=	0.0124	Pass/Fail=	Pass	

MCMINNVILLE CBL (1986, 2001) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	48.375	1130	47.223	1129.9614	1129.9620	0.2

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1129.957	H. Ground Dist. From NGS=	1129.961	Difference=	0.004	meters
GPS data gathered by Randy Oberg. Processed by Mark Armstrong			1:100 000 Allowed Error=	0.0113	Pass/Fail=	Pass	

Local Eugene Zone (10ppm Transverse Mercator Map Projection)

EUGENE CBL (1994, 2001 REMEASURED) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	120.578	1200	118.553	1199.9714	1199.9731	0.1

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1199.970	H. Ground Dist. From NGS=	1199.971	Difference=	0.002	meters
GPS data gathered by Randy Oberg and Mark Armstrong			1:100 000 Allowed Error=	0.0120	Pass/Fail=	Pass	

Regional Willamette Zone (20ppm Transverse Mercator Map Projection)

HILLSBORO CBL (1987) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	60.960	1370	52.391	1369.9949	1370.0217	0.4

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1370.009	H. Ground Dist. From NGS=	1369.995	Difference=	0.014	meters
GPS data gathered by Randy Oberg. Processed by Mark Armstrong			2:100 000 Allowed Error=	0.0274	Pass/Fail=	Pass	

AURORA CBL (1976, 1990, 2000 REMEASURED) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0 (PLSO 1)	58.640	1530 (PLSO 7)	58.361	1530.5701	1530.5701	0.2

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1530.576	H. Ground Dist. From NGS=	1530.570	Difference=	0.006	meters
Data from Marion County			2:100 000 Allowed Error=	0.0306	Pass/Fail=	Pass	

ALBANY CBL (1982, 2000 REMEASURED)

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	66.689	1240	67.056	1239.9899	1239.9901	0.2

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1240.002	H. Ground Dist. From NGS=	1239.990	Difference=	0.012	meters
Data from Marion County			2:100 000 Allowed Error=	0.0248	Pass/Fail=	Pass	

MCMINNVILLE CBL (1986, 2001) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	48.375	1130	47.223	1129.9614	1129.9620	0.2

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1129.964	H. Ground Dist. From NGS=	1129.961	Difference=	0.003	meters
GPS data gathered by Randy Oberg. Processed by Mark Armstrong			2:100 000 Allowed Error=	0.0226	Pass/Fail=	Pass	

EUGENE CBL (1994, 2001 REMEASURED) US DEPARTMENT OF COMMERCE - NOAA CALIBRATION BASE LINE DATA

FROM STATION	ELEV.(M)	TO STATION	ELEV.(M)	HORIZONTAL	MARK - MARK	ERROR(MM)
0	120.578	1200	118.553	1199.9714	1199.9731	0.1

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	1199.973	H. Ground Dist. From NGS=	1199.971	Difference=	0.001	meters
GPS data gathered by Randy Oberg and Mark Armstrong 8-28-09			2:100 000 Allowed Error=	0.0240	Pass/Fail=	Pass	

OCRS Testing - Medium Length Baseline Testing On EDM measured base Lines (Pass/Fail Threshold Test)

GPS Measurement of Grid Zone Distances vs. EDM Record Ground Distances (Horizontal)

The horizontal mean distance is considered the record value (blue box).

The absolute value horizontal difference is shown in the orange box. The allowable error at 10ppm (or 20ppm) is shown in the dark green box.

This is a Pass/Fail test. Fail only means that the result is outside of the 10ppm (or 20ppm) level.

If the difference is less than or equal to the allowed error then the measurement on the map projection passes.

Local Salem Zone (10ppm Transverse Mercator Map Projection)

Medium Baseline on Ridge Road and I-5

FROM STATION 1 TO STATION 2 HORIZONTAL MARK - MARK EAST-WEST

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	5154.006	H. Ground Dist. From EDM=	5154.0049	Difference=	0.001	meters
Data from ODOT			1:100 000 Allowed Error=	0.0515	Pass/Fail=	Pass	

Medium Baseline on Ridge Road and I-5

FROM STATION 1 TO STATION 3 HORIZONTAL MARK - MARK NORTH-SOUTH

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	4813.135	H. Ground Dist. From EDM=	4813.1512	Difference=	0.0162	meters
Data from ODOT			1:100 000 Allowed Error=	0.0481	Pass/Fail=	Pass	

Local Eugene Zone (10ppm Transverse Mercator Map Projection)

Medium Baseline on Ridge Road and I-5

FROM STATION 1 TO STATION 2 HORIZONTAL MARK - MARK EAST-WEST

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	5154.039	H. Ground Dist. From EDM=	5154.0049	Difference=	0.034	meters
Data from ODOT			1:100 000 Allowed Error=	0.0515	Pass/Fail=	Pass	

Medium Baseline on Ridge Road and I-5

FROM STATION 1 TO STATION 3 HORIZONTAL MARK - MARK NORTH-SOUTH

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	4813.164	H. Ground Dist. From EDM=	4813.1512	Difference=	0.0128	meters
Data from ODOT			1:100 000 Allowed Error=	0.0481	Pass/Fail=	Pass	

Regional Willamette Zone (20ppm Transverse Mercator Map Projection)

Medium Baseline on Ridge Road and I-5

FROM STATION 1 TO STATION 2 HORIZONTAL MARK - MARK EAST-WEST

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	5154.021	H. Ground Dist. From EDM=	5154.0049	Difference=	0.016	meters
Data from ODOT			2:100 000 Allowed Error=	0.1031	Pass/Fail=	Pass	

Medium Baseline on Ridge Road and I-5

FROM STATION 1 TO STATION 3 ELEV.(M) HORIZONTAL MARK - MARK

ORGN or Static GPS Method	Meas. Grid Zone Horiz. Distance=	4813.155	H. Ground Dist. From EDM=	4813.1512	Difference=	0.004	meters
Data from ODOT			2:100 000 Allowed Error=	0.0963	Pass/Fail=	Pass	

EDM Measurements

	1 to 3	1 to 2
	4813.153	5154.006
	4813.152	5154.003
	4813.152	5154.005
	4813.151	5154.002
	4813.152	5154.003
	4813.152	5154.006
	4813.150	5154.005
	4813.151	5154.003
	4813.152	5154.004
	4813.151	5154.005
	4813.151	5154.003
	4813.151	5154.005
	4813.152	5154.005
	4813.151	5154.006
	4813.151	5154.010
	4813.151	5154.008
	4813.151	5154.003
	4813.151	5154.002
	4813.151	5154.002
	4813.151	5154.005
	4813.151	5154.006
	4813.150	5154.006
	4813.150	5154.006
	4813.151	5154.005
	4813.151	5154.005
	4813.151	5154.006
	4813.152	5154.006
	4813.151	5154.005
	4813.151	5154.005
	4813.151	5154.005
Average=	4813.1512	5154.0049

OCRS Long Baseline Testing - OCRS Portland Zone

Inverse Report

CORS chosen to test ppm map legend boundaries from 10ppm - 50ppm level.

Coordinate Units	Meters
Distance Units	Meters
Height Units	Meters

Ground distance manual calculation [Vincenty formula scaled by the average height of the end points]**

Data from PBO CORS stations - 24 hour Rinex files from date 8-19-2009 Processed and inversed in TGO.

Coordinates are not from a fixed adjustment and for baseline distance determination only (unconstrained positions).

Grid			Local		Cartesian (WGS-84)	
From:	P409					
Northing:	89159.980m		Latitude:	45°51'04.63480"N	X:	-2439395.850m
Easting:	61982.732m		Longitude:	123°14'22.05971"W	Y:	-3722187.913m
Elevation:	198.698m		Height:	177.704	Z:	4553877.521m
Convergence:	-0°20'56.789878"					
Inverse:						
Grid Azimuth:	169°55'08"		NS Fwd Azimuth:	169°34'11"	Delta X:	-8260.393m
Grid Distance:	35403.962		NS Back Azimuth:	349°37'43"	Delta Y:	-24297.355m
Delta Elevation:	-93.131m		Ellipsoid Dist:	35403.643	Delta Z:	-24390.150m
t-T Correction:	0°00'00.446791"		Ground Dist (TGO):	35404.370	Slope Dist:	35404.449
Elevation Scale Factor:		0.99997947	Delta Height:	-93.879m		
Grid Scale Factor:		1.000009				
Combined Factor:		0.99998847	Ground Dist. Calc.**:	35404.369		
To:	P411					
Northing:	54302.609m		Latitude:	45°32'16.75202"N	X:	-2447656.243m
Easting:	68179.844m		Longitude:	123°09'26.64210"W	Y:	-3746485.268m
Elevation:	105.567m		Height:	83.825	Z:	4529487.371m
Convergence:	-0°17'26.083137"					
10PPM THRESHOLD=		0.3540				
GRID - GROUND=		0.4080	Fail	Fail just means beyond +/-10ppm threshold		

Grid			Local		Cartesian (WGS-84)	
From:	P409					
Northing:	89159.980m		Latitude:	45°51'04.63480"N	X:	-2439395.850m
Easting:	61982.732m		Longitude:	123°14'22.05971"W	Y:	-3722187.913m
Elevation:	198.698m		Height:	177.704	Z:	4553877.521m
Convergence:	-0°20'56.789878"					
Inverse:						
Grid Azimuth:	92°36'57"		NS Fwd Azimuth:	92°15'56"	Delta X:	34957.867m
Grid Distance:	42504.069		NS Back Azimuth:	272°39'28"	Delta Y:	-24139.489m
Delta Elevation:	-112.417m		Ellipsoid Dist:	42503.222	Delta Z:	-1353.189m
t-T Correction:	0°00'04.152909"		Ground Dist (TGO):	42504.027	Slope Dist:	42504.1
Elevation Scale Factor:		0.99998106	Delta Height:	-113.434m		
Grid Scale Factor:		1.00001993				
Combined Factor:		1.00000099	Ground Dist. Calc.**:	42504.028		
To:	P414					
Northing:	87220.077m		Latitude:	45°50'05.50428"N	X:	-2404437.983m
Easting:	104442.509m		Longitude:	122°41'34.15594"W	Y:	-3746327.401m
Elevation:	86.281m		Height:	64.27	Z:	4552524.333m
Convergence:	0°02'26.818370"					
10PPM THRESHOLD=		0.4250				
GRID - GROUND=		0.0420	Pass	Pass just means within +/-10ppm threshold		

Grid			Local		Cartesian	
					(WGS-84)	
From:	P429					
Northing:	69944.103m		Latitude:	45°40'34.03756"N	X:	-2357536.407m
Easting:	167991.272m		Longitude:	121°52'38.43761"W	Y:	-3790878.998m
Elevation:	47.354m		Height:	26.019	Z:	4540186.595m
Convergence:	0°37'20.720788"					
Inverse:						
Grid Azimuth:	285°12'31"		NS Fwd Azimuth:	285°49'56"	Delta X:	-46901.576m
Grid Distance:	65855.179		NS Back Azimuth:	105°14'52"	Delta Y:	44551.597m
Delta Elevation:	38.927m		Ellipsoid Dist:	65854.37	Delta Z:	12337.738m
t-T Correction:	-0°00'04.106661"		Ground Dist (TGO):	65854.835	Slope Dist:	65854.555
Elevation Scale Factor:		0.99999293	Delta Height:	38.251m		
Grid Scale Factor:		1.00001228				
Combined Factor:		1.00000522	Ground Dist. Calc.**:	65854.836		
To:	P414					
Northing:	87220.077m		Latitude:	45°50'05.50428"N	X:	-2404437.983m
Easting:	104442.509m		Longitude:	122°41'34.15594"W	Y:	-3746327.401m
Elevation:	86.281m		Height:	64.27	Z:	4552524.333m
Convergence:	0°02'26.818370"					
10PPM THRESHOLD=		0.6586				
GRID - GROUND=		0.3440	Pass	Pass just means within +/-10ppm threshold		

Grid			Local		Cartesian	
					(WGS-84)	
From:	P427					
Northing:	42320.923m		Latitude:	45°25'48.62090"N	X:	-2398596.467m
Easting:	132036.229m		Longitude:	122°20'26.21334"W	Y:	-3788254.231m
Elevation:	171.983m		Height:	149.65	Z:	4521133.056m
Convergence:	0°17'31.178997"					
Inverse:						
Grid Azimuth:	328°25'35"		NS Fwd Azimuth:	328°43'06"	Delta X:	-5841.516m
Grid Distance:	52700.545		NS Back Azimuth:	148°28'00"	Delta Y:	41926.829m
Delta Elevation:	-85.702m		Ellipsoid Dist:	52700.189	Delta Z:	31391.277m
t-T Correction:	-0°00'00.502290"		Ground Dist (TGO):	52701.073	Slope Dist:	52700.992
Elevation Scale Factor:		0.99998322	Delta Height:	-85.380m		
Grid Scale Factor:		1.00000675				
Combined Factor:		0.99998997	Ground Dist. Calc.**:	52701.073		
To:	P414					
Northing:	87220.077m		Latitude:	45°50'05.50428"N	X:	-2404437.983m
Easting:	104442.509m		Longitude:	122°41'34.15594"W	Y:	-3746327.401m
Elevation:	86.281m		Height:	64.27	Z:	4552524.333m
Convergence:	0°02'26.818370"					
10PPM THRESHOLD=		0.5270				
GRID - GROUND=		0.5280	Fail	Fail just means beyond +/-10ppm threshold		

Grid			Local		Cartesian	
					(WGS-84)	
From:	P427					
Northing:	42320.923m		Latitude:	45°25'48.62090"N	X:	-2398596.467m
Easting:	132036.229m		Longitude:	122°20'26.21334"W	Y:	-3788254.231m
Elevation:	171.983m		Height:	149.65	Z:	4521133.056m
Convergence:	0°17'31.178997"					
Inverse:						
Grid Azimuth:	280°37'38"		NS Fwd Azimuth:	280°55'08"	Delta X:	-49059.777m
Grid Distance:	64970.753		NS Back Azimuth:	100°20'12"	Delta Y:	41768.963m
Delta Elevation:	-66.416m		Ellipsoid Dist:	64970.611	Delta Z:	8354.316m
t-T Correction:	0°00'00.602411"		Ground Dist (TGO):	64971.799	Slope Dist:	64971.552
Elevation Scale Factor:		0.99998173	Delta Height:	-65.825m		
Grid Scale Factor:		1.00000218				
Combined Factor:		0.99998391	Ground Dist. Calc.**:	64971.800		
To:	P411					
Northing:	54302.609m		Latitude:	45°32'16.75202"N	X:	-2447656.243m
Easting:	68179.844m		Longitude:	123°09'26.64210"W	Y:	-3746485.268m
Elevation:	105.567m		Height:	83.825	Z:	4529487.371m
Convergence:	-0°17'26.083137"					
10PPM THRESHOLD=		0.6497				
GRID - GROUND=		1.0460	Fail	Fail just means beyond +/-10ppm threshold		

Grid			Local		Cartesian	
					(WGS-84)	
From:	P406					
Northing:	15666.665m		Latitude:	45°11'25.31837"N	X:	-2462331.547m
Easting:	68389.432m		Longitude:	123°09'08.06508"W	Y:	-3769689.353m
Elevation:	49.545m		Height:	27.719	Z:	4502302.967m
Convergence:	-0°17'12.833066"					
Inverse:						
Grid Azimuth:	359°41'21"		NS Fwd Azimuth:	359°24'08"	Delta X:	14675.303m
Grid Distance:	38636.513		NS Back Azimuth:	179°23'55"	Delta Y:	23204.086m
Delta Elevation:	56.022m		Ellipsoid Dist:	38636.268	Delta Z:	27184.404m
t-T Correction:	0°00'00.022033"		Ground Dist (TGO):	38636.607	Slope Dist:	38636.588
Elevation Scale Factor:		0.99999124	Delta Height:	56.106m		
Grid Scale Factor:		1.00000632				
Combined Factor:		0.99999756	Ground Dist. Calc.**:	38636.606		
To:	P411					
Northing:	54302.609m		Latitude:	45°32'16.75202"N	X:	-2447656.243m
Easting:	68179.844m		Longitude:	123°09'26.64210"W	Y:	-3746485.268m
Elevation:	105.567m		Height:	83.825	Z:	4529487.371m
Convergence:	-0°17'26.083137"					
10PPM THRESHOLD=		0.3864				
GRID - GROUND=		0.0940	Pass	Pass just means within +/-10ppm threshold		

Grid			Local		Cartesian	
					(WGS-84)	
From:	P406					
Northing:	15666.665m		Latitude:	45°11'25.31837"N	X:	-2462331.547m
Easting:	68389.432m		Longitude:	123°09'08.06508"W	Y:	-3769689.353m
Elevation:	49.545m		Height:	27.719	Z:	4502302.967m
Convergence:	-0°17'12.833066"					
Inverse:						
Grid Azimuth:	85°40'18"		NS Fwd Azimuth:	85°23'09"	Delta X:	38465.976m
Grid Distance:	44376.049		NS Back Azimuth:	265°47'08"	Delta Y:	-21992.736m
Delta Elevation:	26.650m		Ellipsoid Dist:	44375.378	Delta Z:	2424.922m
t-T Correction:	-0°00'03.719301"		Ground Dist (TGO):	44375.661	Slope Dist:	44375.579
Elevation Scale Factor:		0.99999363	Delta Height:	25.952m		
Grid Scale Factor:		1.00001511				
Combined Factor:		1.00000874	Ground Dist. Calc.**:	44375.661		
To:	P412					
Northing:	19015.818m		Latitude:	45°13'15.95873"N	X:	-2423865.570m
Easting:	112638.917m		Longitude:	122°35'20.70585"W	Y:	-3791682.089m
Elevation:	76.195m		Height:	53.671	Z:	4504727.889m
Convergence:	0°06'53.181815"					
10PPM THRESHOLD=		0.4438				
GRID - GROUND=		0.3880	Pass	Pass just means within +/-10ppm threshold		

Grid			Local		Cartesian	
					(WGS-84)	
From:	P414					
Northing:	87220.077m		Latitude:	45°50'05.50428"N	X:	-2404437.983m
Easting:	104442.509m		Longitude:	122°41'34.15594"W	Y:	-3746327.401m
Elevation:	86.281m		Height:	64.27	Z:	4552524.333m
Convergence:	0°02'26.818370"					
Inverse:						
Grid Azimuth:	173°08'51"		NS Fwd Azimuth:	173°11'17"	Delta X:	-19427.588m
Grid Distance:	68694.993		NS Back Azimuth:	353°15'44"	Delta Y:	-45354.688m
Delta Elevation:	-10.086m		Ellipsoid Dist:	68694.52	Delta Z:	-47796.443m
t-T Correction:	0°00'00.301154"		Ground Dist (TGO):	68695.156	Slope Dist:	68694.824
Elevation Scale Factor:		0.99999074	Delta Height:	-10.599m		
Grid Scale Factor:		1.00000689				
Combined Factor:		0.99999763	Ground Dist. Calc.**:	68695.155		
To:	P412					
Northing:	19015.818m		Latitude:	45°13'15.95873"N	X:	-2423865.570m
Easting:	112638.917m		Longitude:	122°35'20.70585"W	Y:	-3791682.089m
Elevation:	76.195m		Height:	53.671	Z:	4504727.889m
Convergence:	0°06'53.181815"					
10PPM THRESHOLD=		0.6869				
GRID - GROUND=		0.1630	Pass	Pass just means within +/-10ppm threshold		

Grid		Local		Cartesian	
				(WGS-84)	
From:	P429				
Northing:	69944.103m	Latitude:	45°40'34.03756"N	X:	-2357536.407m
Easting:	167991.272m	Longitude:	121°52'38.43761"W	Y:	-3790878.998m
Elevation:	47.354m	Height:	26.019	Z:	4540186.595m
Convergence:	0°37'20.720788"				
Inverse:					
Grid Azimuth:	261°05'37"	NS Fwd Azimuth:	261°43'01"	Delta X:	-90119.837m
Grid Distance:	101029.588	NS Back Azimuth:	80°48'08"	Delta Y:	44393.730m
Delta Elevation:	58.213m	Ellipsoid Dist:	101029.182	Delta Z:	-10699.224m
t-T Correction:	-0°00'03.703739"	Ground Dist (TGO):	101030.050	Slope Dist:	101029.014
Elevation Scale Factor:	0.9999914	Delta Height:	57.807m		
Grid Scale Factor:	1.00000402				
Combined Factor:	0.99999543	Ground Dist. Calc.**:	101030.052		
To:	P411				
Northing:	54302.609m	Latitude:	45°32'16.75202"N	X:	-2447656.243m
Easting:	68179.844m	Longitude:	123°09'26.64210"W	Y:	-3746485.268m
Elevation:	105.567m	Height:	83.825	Z:	4529487.371m
Convergence:	-0°17'26.083137"				
10PPM THRESHOLD=	1.0103				
GRID - GROUND=	0.4620	Pass	Pass just means within +/-10ppm threshold		