Rocky Mountain Coordinate Reference System

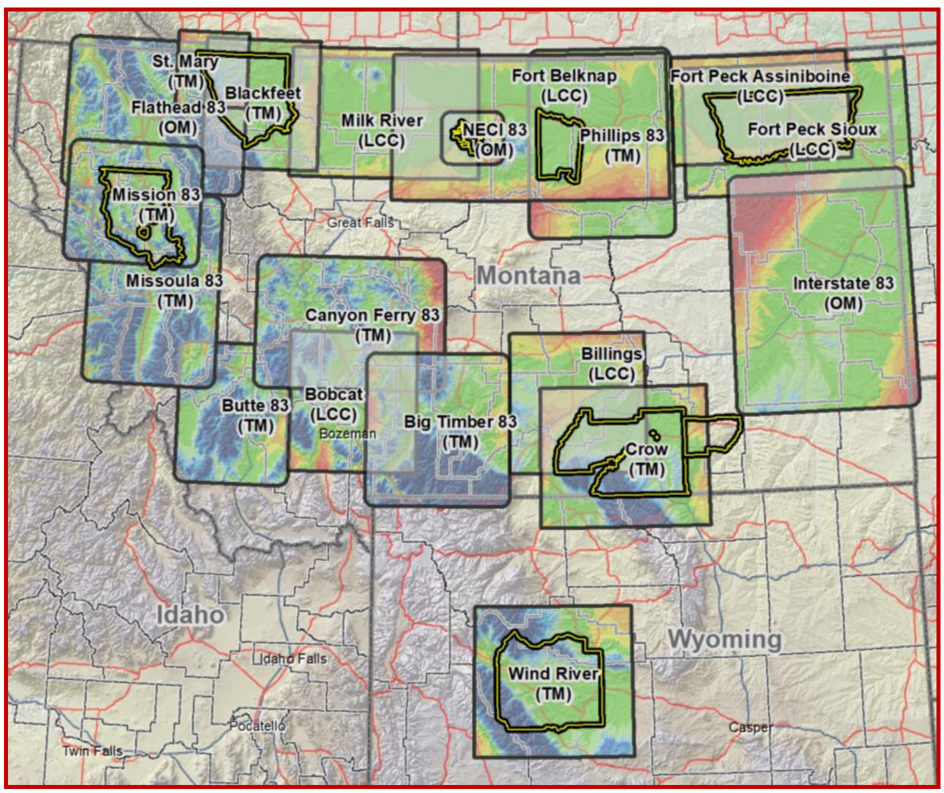
Handbook and User Guide

For

Montana

&

Wind River Wyoming



Version – v2.0
February 23, 2022

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Abstract

This document contains the history, development, best practice methods, and technical creation of a new coordinate system for the Rocky Mountain Tribal areas. The Rocky Mountain Tribal Coordinate Reference System (RMTCRS) 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 computed between points on the grid coordinate system will closely represent the distances physically measured between the same points on the ground within published zone tolerances. It is important to realize that rectangular grid coordinates for all of the RMTCRS map projections may now be calculated with formulas through computer programs that would have seemed too complicated in the past, but now may be 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.

Revision History

This document has been developed by Northern Engineering & Consulting, Inc. (NECI) from the Oregon Coordinate Reference System (OCRS) Handbook and User Guide, Version 2.00, Mark L. Armstrong, 25 March, 2011. NECI revised the OCRS Handbook in accordance with Montana and Wyoming survey systems and the coordinate reference systems developed for the study areas, but much of the original information contained in the OCRS remains in this publication.

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Acknowledgements

I would like to acknowledge and thank the people who contributed to the development of the Rocky Mountain Tribal Coordinate Reference System.

Stew J. Willis, PLS, CFedS, Montana Low Distortion Projection (LDP) champion. When LDPs became an option as a layer within the SPCS2022 Mr. Willis rallied the Montana Surveying and Engineering community to create LDPs covering western and south-central Montana doubling the number of LDPs and doubling the area covered by LDPs.

Michael Dennis, our Low Distortion Projection expert, whose tremendous knowledge, expertise, and the amazing software tools he developed were instrumental to this undertaking. Mr. Dennis as the "Greatest Generation" would say is battle tested and when attempting change on the magnitude we have hoped for having Mr. Dennis at our side has been a key to accomplishing as much as we have.

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Mark Armstrong, Oregon's Geodetic Advisor, who led the development of the Oregon manual, has advised the Rocky Mountain team as well. Mark has provided valuable insight and knowledge not only on Low Distortion Projection but he has conducted Low Distortion Projection trainings at our state surveyor's association conferences. He has helped pave the way for Low Distortion Projection acceptance among the Montana and Wyoming professional land survey community.

Jay Springer, Northern Engineering & Consulting, worked closely with Mr. Dennis in development and design of the Milk River and Crow Low Distortion Projections. His love of surveying has made the low distortion venture enjoyable. Further, Mr. Springer has advocated Low Distortion Projection implementation through his use of the projections in survey and design.

Rich Jensen, Sanderson Stewart, developed the Billings and assisted with the Bobcat Low Distortion Projections. Mr. Jensen's support, resources and promotion of low distortion projections have been instrumental to acceptance and implementation of the projections.

The **Tribal Team** is who has been instrumental in progression of our grass roots movement includes:

Don White	Blackfeet Tribal Transportation Program Director
Mark Magee	Blackfeet Land Department Director
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Robert Stewart	Crow DOT
Michael Stewart	Crow DOT
Titus Takes Gun	Crow MR&I Project
Myron Shield	Crow MR&I Project
John Healy	Fort Belknap Tribal Planning Department Director
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The engineers and surveyors who have assisted with the development include:

Jay Springer, PE, LS	Northern Engineering & Consulting
Amy Darlinton, PE	Northern Engineering & Consulting
Rich Jensen, PLS	Sanderson Stewart
Wallace Gladstone, RLS, PE	Northern Engineering & Consulting
Ethan Ostby, LS	Northern Engineering & Consulting

Jami Garrison, Northern Engineering & Consulting, Inc., whose tremendous knowledge, was instrumental to the creation of the v2.0 Low Distortion Projections. Her patience and positive attitude made work on v2.0 a pleasant experience.

Finally, the **Oregon Technical Development Team,** who developed, documented, and implemented the OCRS zones. The group blazed the trail and gave us permission to use their User Guide and Handbook as a template. Without their leadership, guidance, and template we would not have known where to begin. The Oregon Technical Development Team includes:

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Living Document

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

The RMTCRS was created with public money and effort for the benefit of surveying, engineering, GIS, and mapping professionals on the Blackfeet, Crow, Fort Belknap, Fort Peck, and Wind River Indian Reservations in Montana and Wyoming. The Rocky Mountain Tribal areas are among several states that have created new coordinate systems based on 'low distortion' map projections.

Contact Information for Revision to Document

If there are topics that you would like us to add, cover in more depth, clarify, if you discover an error in the content, or would like to suggest a particular workflow, please contact SJW Land Surveying, Inc. or Northern Engineering & Consulting, Inc.:

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Document Review History

The following people contributed edits, material and/or review comments for this document.

Draft v1.0 Inside and v1.1 Review

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Chapter 1 History and Development of the RMTCRS

1.1 History and Development of the Rocky Mountain Tribal Coordinate Reference System (RMTCRS)

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 surveyors in Montana and Wyoming have been looking for a better way to deal with map distortion other than the currently used State Plane Coordinate Systems. In 2009, John Smith, Shoshone and Arapahoe Department of Transportation, Tribal Roads Director, gave direction to investigate the use of 'low distortion' projections to determine the pros and cons of their use. At the 2010 Montana Association of Registered Land Surveyors conference Mr. Gladstone and Mr. Robertson, on behalf of Fort Peck, met with Curt Smith, NGS advisor, to discuss the subject and we were directed to Mr. Michael Dennis. We soon learned the surveying process could be standardized and simplified and that if we standardized the system a surveyor no longer needed to be a student of geodesy to use a GPS survey instrument to measure a line on the ground. We had an opportunity to create a standard coordinate system that could be used by all tribal surveyors and if we published the system it could be shared and beneficial to all members of the survey and engineering community. Mr. Smith gave direction to proceed. In 2011 Fort Peck formally joined the mission and the project became a tribal mapping project. The Blackfeet and Fort Belknap reservations joined in 2012 and the Crow in 2014. As our team learned more about the national survey system we learned about our regional survey foundation short comings therefore additional phases where added to our tribal mapping project.

The six phase Tribal Mapping project is described below:

- **Phase 1-Low Distortion Projection (LDP) Creation**-As described in this document, LDP's were established on each reservation to minimize map projection errors arising from the use of State Plane Coordinate Systems.
- **Phase 2-Control Point Establishment in the Tribal Coordinate Systems-**Ground based control points have been established for project control and quality assurance. NGS generally refers to this type of control as passive control and is no longer supporting it. The NGS movement has been toward CORS therefor we've added phase 4 to the mapping project.
- **Phase 3-Tribal Mapping Handbook Creation-**This handbook was created to guide users on LDP use, GPS input, and use in GIS systems.

- **Phase 4-Continuously Operating Reference Station (CORS) Establishment-**Static, survey grade GPS receivers will be established to provide access to the National Spatial Reference System (NSRS) to precisely identify latitude, longitude, and elevation.
- **Phase 5-Real Time Network (RTN) Establishment-**RTN stations will link to CORS to provide real-time data corrections and allow accurate GPS data to be collected in the field.
- **Phase 6-Survey Grade Data Collection and Compilation-**The mapping system will be used to collect highly accurate, survey grade data and compile the data in GIS systems for shared use.

1.2 The RMTCRS Technical Development Team

The Tribal Team was formed by tribal transportation directors, engineers and GIS users exploring interest in the tribal mapping project in meetings and initial rollouts through 2010. For the names of the tribal project managers and other contributors, see the acknowledgements inside the front cover. See Figure 1.2 for a graphic representation of the time line beginning in 2009 and continuing to the state and tribal adoption of the projections. The participating tribes and NECI worked closely with Michael Dennis of Geodetic Analysis, LLC to construct projections through a refined iterative process leading to a final optimized solution for each geographic area. In 2020 the NGS asked for comments on the State Plane Coordinate System (SPCS) 2022. The Rocky Mountain Tribes via the Rocky Mountain Tribal Leaders Council requested LDPs be part of the update. When states were notified LDPs would be accepted as part of NGS2022, Mr. Stew Willis, MARLS Geodetic Coordinator and NGS State Coordinator, formed a LDP workgroup and garnered support form multiple firms for a Montana grassroots movement that doubled the number of LDPs and doubled the area the LDPs covered.

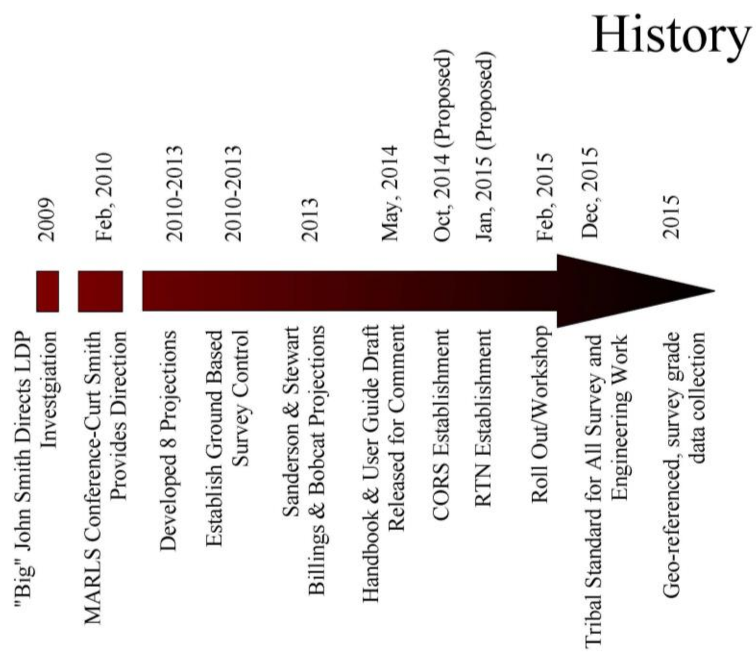


Figure 1.2: Historical Timeline for the RMTCRS

1.3 RMTCRS 'Best Practice' Goals

Best practices used for the RMTCRS program were developed by the Oregon CRS Technical Development Team in 2009 and adopted with minor edits by the RMTCRS team in 2010. The 'Best practices' focus on the critical elements lead to the creation of new map projection zones. These 'best practices' continued to evolve during the process and are currently listed below.

1. The goal was established to use 1:50 000 ratio = ±20 ppm for each reservation [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. The team is coordinating with vendors letting them know that new coordinate systems are under development.
3. The RMTCRS 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 State Plane coordinates.
6. Units: (meters) - Metric units for map projection parameters and individual users may project into desired units. Montana users project to international feet and Wyoming users project to US Feet.
7. The RMTCRS 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 ±20ppm 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 RMTCRS projection zone parameters.
12. The development of the RMTCRS system will include parameters for each zone that will be included in a future published Handbook and User Guide.
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 RMTCRS and other state legislated zones being included on NGS datasheet output files, including OPUS output results.
15. Involve stakeholders in the review of the RMTCRS development by giving presentations etc. (local users: MARLS, PLSW, MWTLC, ASCEMontana/Wyoming, GIS groups, MSU, tribal colleges, etc.)
16. Involve software vendors so they can include the RMTCRS 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.
18. For Lambert Conformal Conic (LCC) zones, the Latitude of grid origin shall be the same as the standard parallel chosen.
19. 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 State Plane Coordinate Systems are 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 to simplify geodetic calculations and avoid complex ellipsoid calculations. The Montana State Plane Coordinate System is a single zone system based on the Lambert Conformal Conic Projection. The Wyoming State Plane Coordinate System is based on the Transverse Mercator Projection and consists of four zones to minimize distortion. 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.

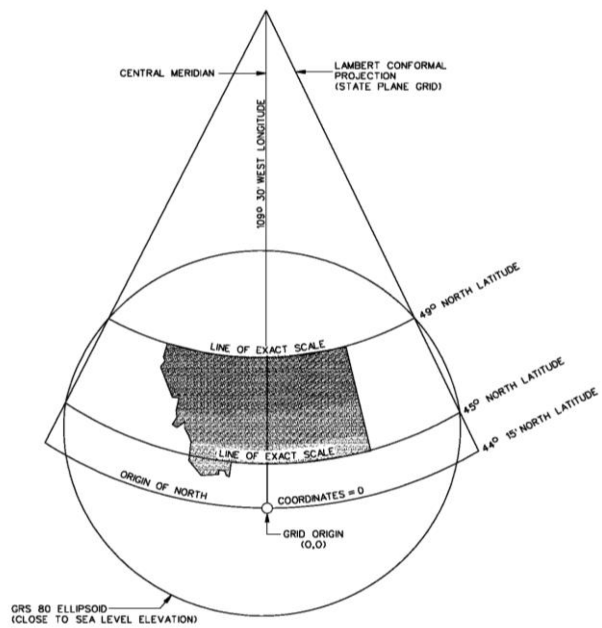


Figure 1.4.1: Montana State Plane Two parallel Lambert Conformal Conic Projection layout

Currently State Plane coordinates are available for all of Montana and Wyoming'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 State Plane Coordinate Systems 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 RMTCRS. The Figure below (Figure 1.6.0.1) depicts the total linear distortion (at the topographic surface of the Earth) for Montana. Note high distortion (greater than -4.5 feet/mile) occurs in the west central part of the state in areas of high elevation, where areas of low distortion occur near the north and south state lines at the parallels.

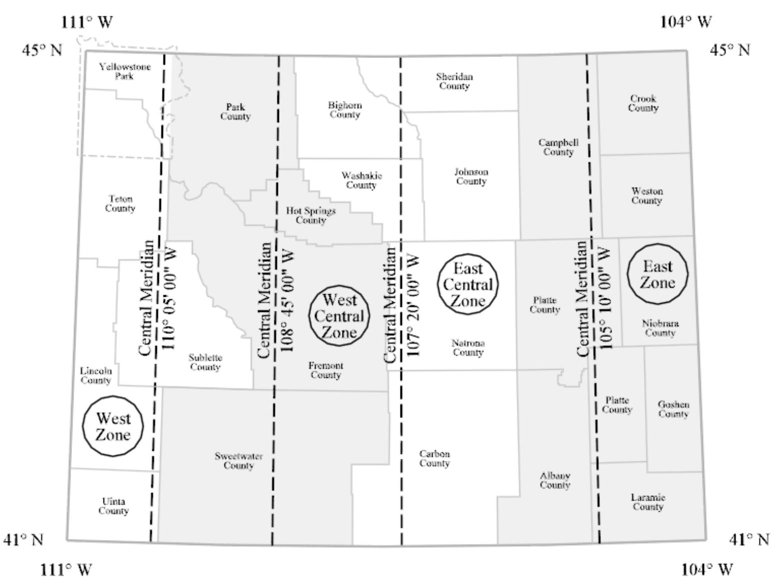
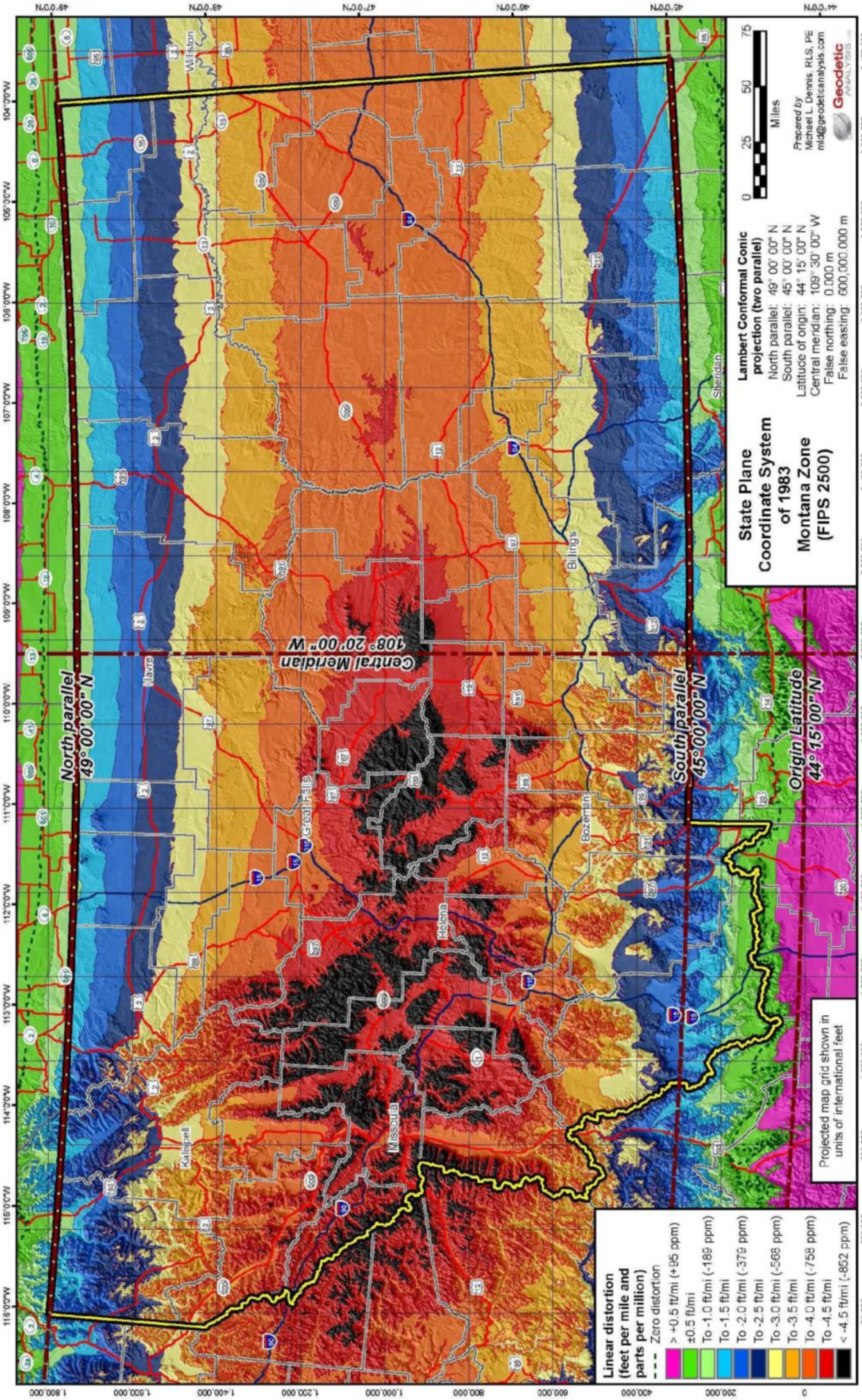


Figure 1.4.2: Wyoming Transverse Mercator State Plane Coordinate System Zones

Figure 1.4.3


State Plane
Coordinate System
of 1983
Montana Zone
(FIPS 2500)
Lambert Conformal Conic
projection (two parallel)
North parallel: 49° 00' 00" N
South parallel: 45° 00' 00" N
Latitude of origin: 44° 15' 00" N
Central meridian: 109° 30' 00" W
False northing: 0.000 m
False easting: 600,000.000 m
Miles
0 25 50 75
Central Meridian
108° 20' 00" W
North parallel
49° 00' 00" N
South parallel
45° 00' 00" N
Origin Latitude
44° 15' 00" N
Linear distortion
(feet per mile and
parts per million)
Zero distortion
> +0.5 ft/mi (+95 ppm)
±0.5 ft/mi
To -1.0 ft/mi (-189 ppm)
To -1.5 ft/mi
To -2.0 ft/mi (-379 ppm)
To -2.5 ft/mi
To -3.0 ft/mi (-568 ppm)
To -3.5 ft/mi
To -4.0 ft/mi (-758 ppm)
To -4.5 ft/mi
< -4.5 ft/mi (-852 ppm)
Projected map grid shown in
units of international feet
Kalispell
Missoula
Helena
Great Falls
Bozeman
Billings
Havre
Williston
Sheridan

1.4.1 State Plane Coordinate System Definitions

Montana and Wyoming State Plane Coordinate Systems are defined as follows in Table 1.1, below.

Table 1.1

State Plane Zone	Zone Number	Projection Type	Central Meridian	Latitude of Origin	Standard Parallel (South)	Standard Parallel (North)	False Easting (m)	False Northing (m)	Max Scale Error*
Wyoming East	4901	Transverse Mercator	-105° 10' (W)	40° 30'	-	-	200,000	0	
Wyoming East Central	4902	Transverse Mercator	-107° 20' (W)	40° 30'	-	-	400,000	100,000	
Wyoming West Central	4903	Transverse Mercator	-108° 45' (W)	40° 30'	-	-	600,000	0	
Wyoming West	4904	Transverse Mercator	-110° 05' (W)	40° 30'	-	-	800,000	100,000	
Montana	2500	Lambert Conformal Conic 2 Standard Parallel	-109° 30' (W)	44° 15'	45° 15'	49°	600,000	0	<-852 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.
Max scale errors have not yet been determined for Wyoming State Plane Zones.

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

1.5.1 Local Datum Plane Coordinate Systems

In both Montana and Wyoming, scale factors are used to compute grid distances from measured ground distances. In Montana, 'Combination Scale Factors' are the product of the specific scale factor (a factor based on local latitude used to compute the difference between the ellipsoid and grid distance) and the elevation scale factor (a factor based on project elevation used to compute the difference between ground distance and ellipsoid distance). In Wyoming, 'Datum Adjustment Factors' are computed in the same manner, by multiplying a grid scale factor by an elevation scale factor.

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, project Scale Factors were divided into the 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 State Plane grid. While this system generally works well, there are some inherent problems with this system:

- LDPC systems represent only 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 any recognized datum or the National Spatial Reference System (NSRS).

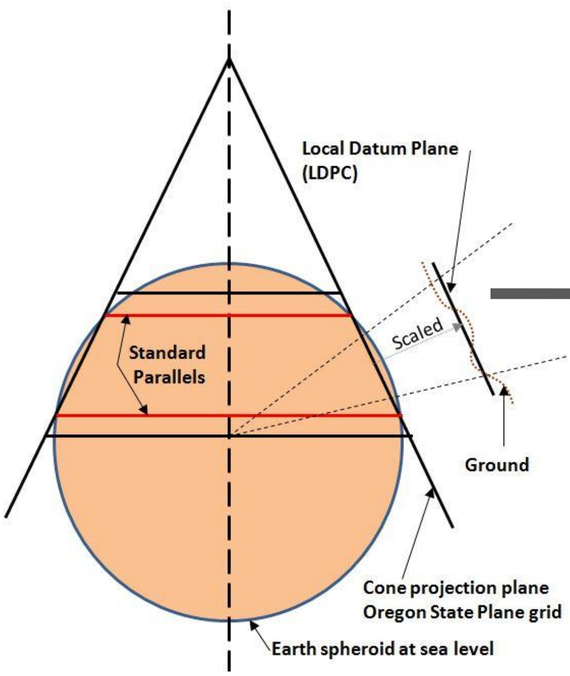


Figure 1.7: Local Datum Plane Coordinate System scaled from State Plane [mla]

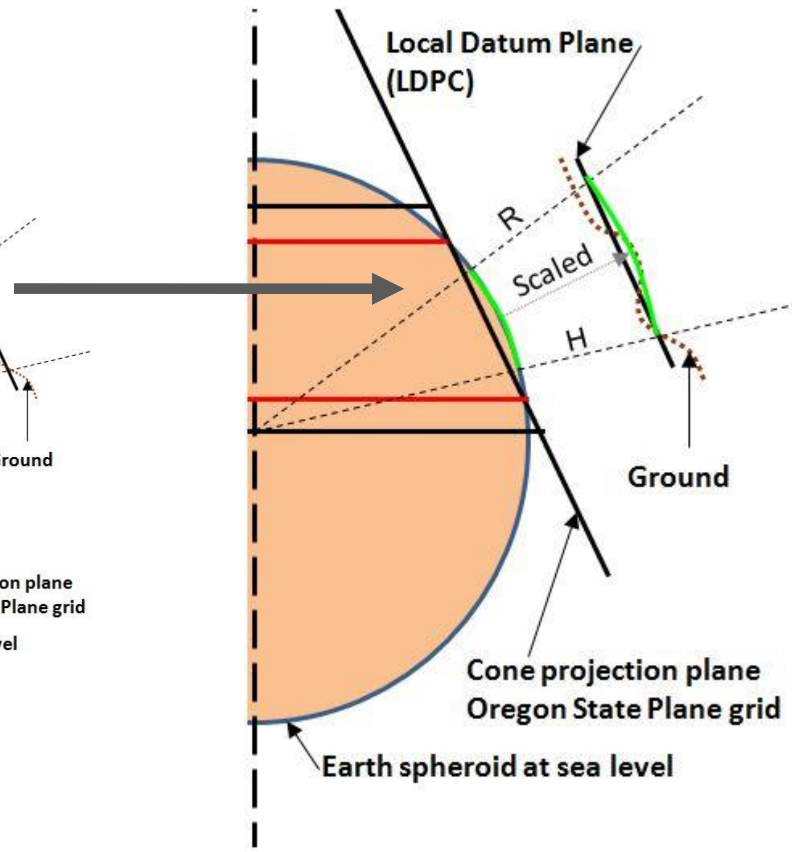


Figure 1.7.1: Local Datum Plane Coordinate System enlarged to show spheroid to LDPC plane

1.5.2 Low Distortion Map Projection Systems

Low distortion map projections (like those within the RMTCRS 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 RMTCRS

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 and was used for the Montana State Plane Coordinate System. 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 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).

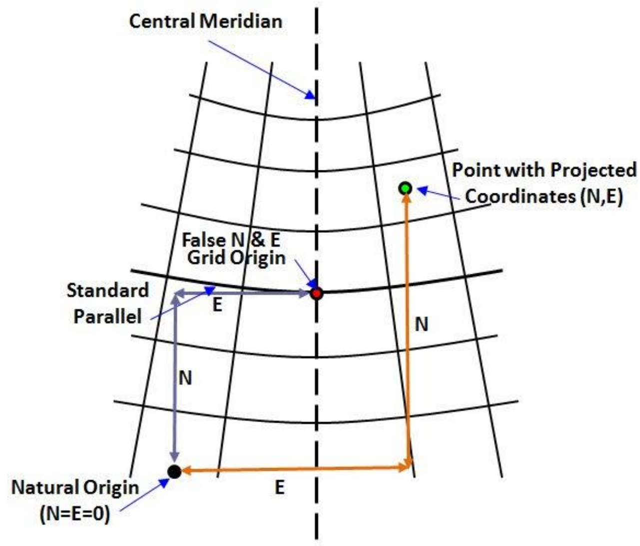


Figure 2.1.1: Diagram for Lambert Conical Conformal Projection with one standard parallel

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. This projection was used for the Wyoming State Plane Coordinate System.

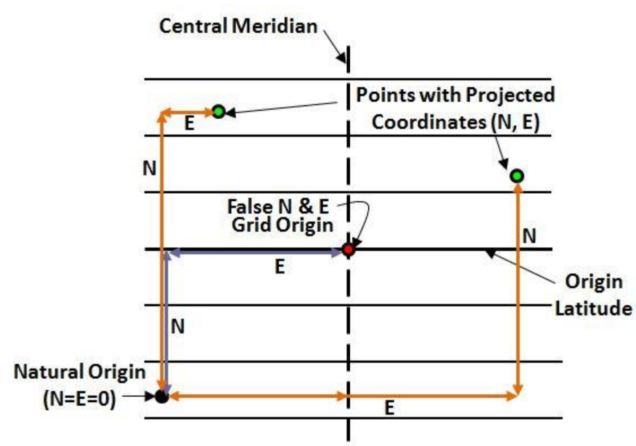


Figure 2.1.2: Diagram Transverse Mercator Projection [mla]

2.1.3 Oblique Mercator (RSO) Projection

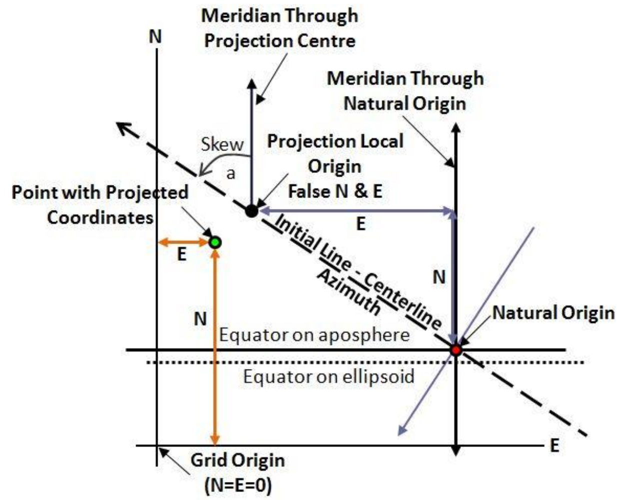


Figure 2.1.3: Diagram for Oblique Mercator (RSO) Projection [mla]

Although not used for the RMTCRS, various forms of the Oblique Mercator (OM) projection have been developed, and the ellipsoidal form used for 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 conformally 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 large areas. Note that this projection can also be defined by specifying the Initial Line using two points or with 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

<u>1. Linear distortion</u> - 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

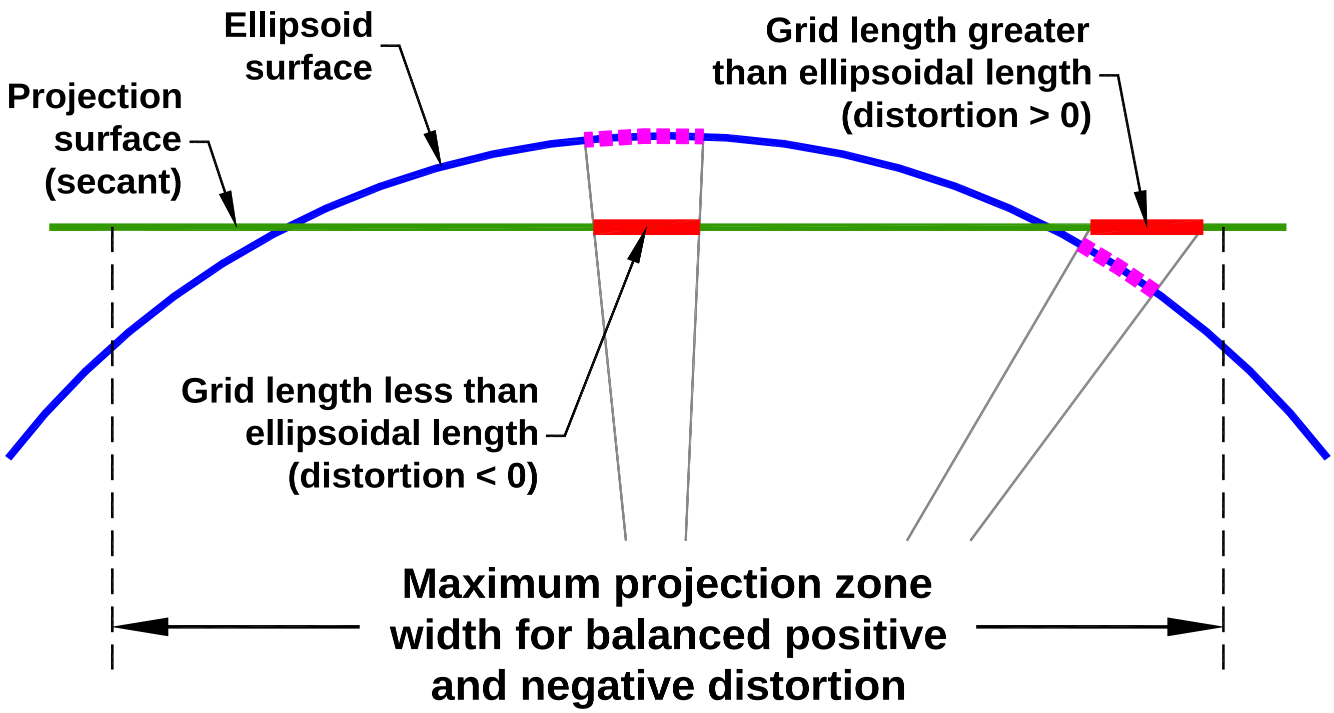


Table 2.2.2.1

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

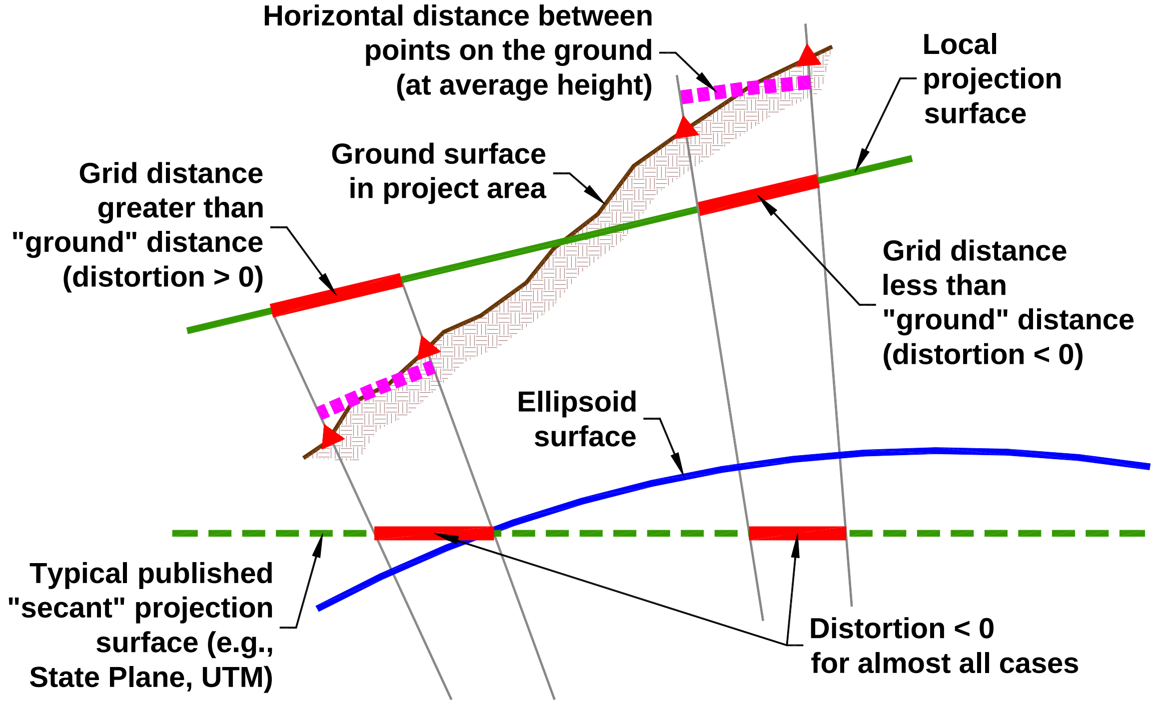


Table 2.2.2.2

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.

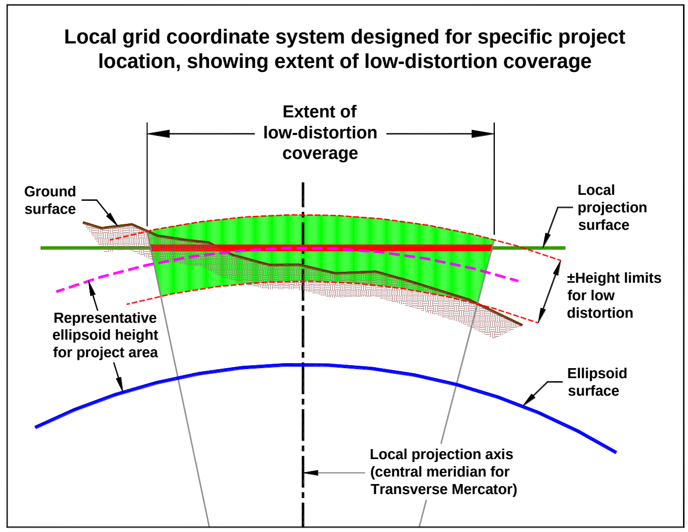


Figure 2.2.3: Diagram shows the effect of scaling the projection to a representative height above the ellipsoid [md]

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:

- "2011" for the NSRS2011 (National Spatial Reference System of 2011) realization.
- "2007" for the 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). In Montana and Wyoming a HARN/HPGN adjustment was done in 1992, so its datum tag is "1992"(there was also a readjustment performed in 1999 with a corresponding "1999" 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, a 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

2.3.2 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) coordinate system 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(2011), 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
Scale Factor
Rotation X- Rotation about the X-axis
Rotation Y- Rotation about the Y-axis
Rotation Z- Rotation about the Z-axis

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 Cartesian 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

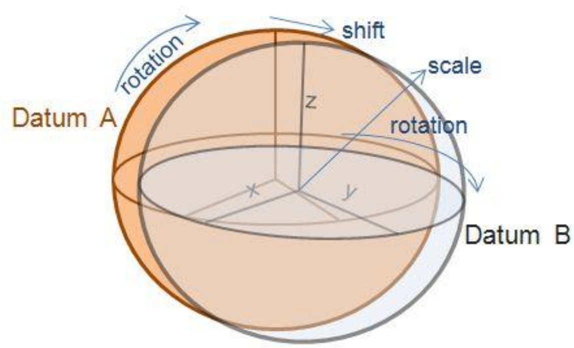


Fig. 2.3.2 [mla]

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, 2007, or 2011), 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). For the majority of Montana and Wyoming, the horizontal coordinate change from NAD83(2007) to NAD 83(2011) is 2 to 4 centimeters. 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, 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). Where available, real-time GPS Networks currently send correctors referenced to the NAD 83(2011) Epoch2010.00 datum. In 2012 the NGS adopted 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), NAD 83(CORS96), NAD 83(2007), or NAD83(2011); likewise for WGS-84: WGS-84(G1150), WGS-84(original), etc. NAD 83 (2011) 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(2011) 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(2011) that is based on new observations, but remains consistent with CORS observations. The NAD83 (2011) realization is not a new datum, but uses the same origin, scale, and orientation as the previous CORS realization. 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(2011) 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).

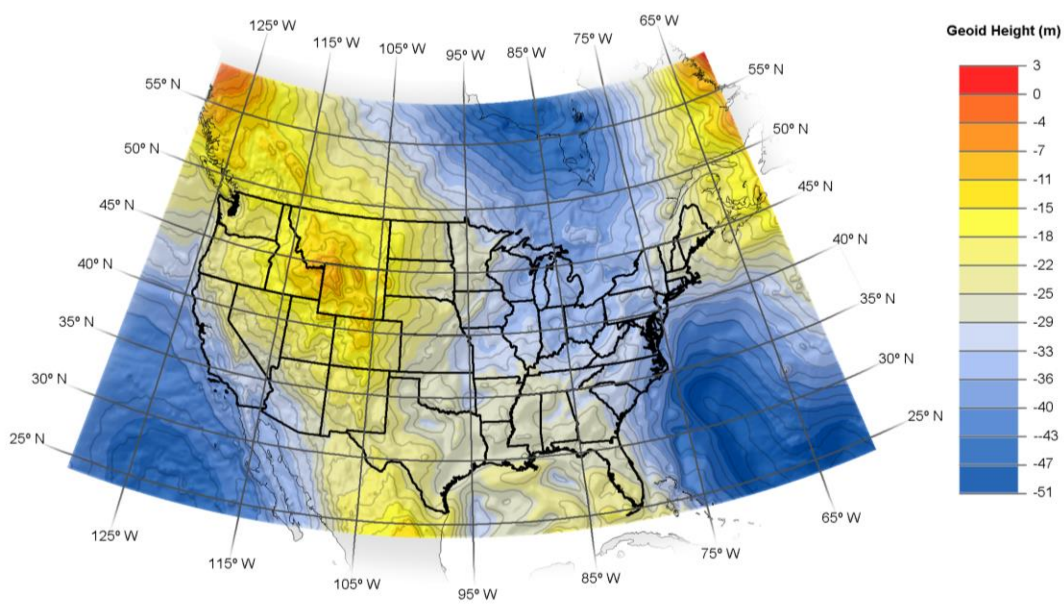
2.3.4 Vertical Reference Datum

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 GEOID12A used in geodetic adjustments is comprised of a gravimetric scientific model constrained to a 'best fit' of a current benchmark monumented network (currently GPSBM2012). 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 GEOID12A 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 2022.

Figure 2.3.5 GEOID12A Model Heights



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

For Montana and Wyoming, the GEOID12A hybrid model is currently used. The GEOID99, 03, 06, and GEOID09(Conus) model were built with observation data and are no longer considered consistent with the physical earth. The GEOID12A model coverage over Montana and Wyoming includes additional satellite gravity data based on the new global geopotential model (EGM08) but otherwise varies from GEOID09 (Conus) in the following ways:

- Difference in ellipsoid heights (h) due to NGS's National Adjustment of 2011.
- Difference in control data sets available at the time of generation.
- An additional signal (GOCO02S) was incorporated in the 2012 model, providing for more accurate and consistent terrain models.

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).

2.3.6 RMTCRS Map Projection Parameter Units

As part of the 'best practices' approach to the creation of these zones, all of the RMTCRS 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 or US 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 RMTCRS 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. Note that Montana requires the use of the International Foot where Wyoming requires the use of the US Foot.

2.3.7 US Foot vs. International Foot

The Rocky Mountain Tribal Coordinate Reference System grids were created and are defined by metric units. However, to conform to conventional survey practices, the projections are converted to the US Foot or the International Foot depending on state legislation. Foot type selection has long been the subject of internal debate among the professional survey community and this section is provided to clarify conversion from metric to imperial units.

Although both the US Foot and International Foot have merits, it is important to remain consistent in the use of the selected foot system. Use of the US Foot versus the International Foot is irrelevant when establishing a new coordinate system if all parties use the same foot system. To reference an existing project to a RMTCRS, the existing project must be re-projected into a RMTCRS. Once projected in a RMTCRS, the units may be changed between US and International feet using the 2 ppm conversion factor described below. Each existing project would require the same re-projection process regardless of type of "Foot" used. What is paramount is the same "Foot" is used for the current RMTCRS. Below is information regarding US Foot and International Foot from the NGS website:

What are the official conversions used by NGS to convert 1) meters to inches, and 2) meters to feet?

First, remember this rule: There is only one meter, BUT, there are two types of feet.

The two types of feet are:

1. The U.S. Survey Foot
It is defined as: 1 meter = 39.37 inches.
If you divide 39.37 by 12 (12 inches per foot), you get the conversion factor: 1 meter = 3.280833333... U.S. Survey Feet.

2. The International Foot
It is defined as: 1 inch = 2.54 centimeters.
If you convert this to meters and feet, you get the conversion factor: 1 International Foot = 0.3048 meters.

These two conversion factors produce results that differ by 2 parts per million; hence for most practical work it does not make any difference to the average surveyor which one is used since they usually do not *encounter distances this large. For example, converting a distance of 304,800 meters (about 1,000,000 feet) to feet using the two conversion factors, these are the results:*

304,800 meters = 999,998.000 U.S. Survey Feet
304,800 meters = 1,000,000.000 International Feet

A difference of 2 feet in 1 million feet.

NGS has always used meters in their computations, so this has not been an issue for us. However, the one place where NGS does use feet, and the numbers are large enough to make a difference, is in the publication of rectangular State Plane Coordinates (SPCs).

For most of the years surveying has been undertaken in the United States, surveyors have used the U.S. Survey Foot. (Note: Some surveying historians will mention that other types of linear measure, mostly of Spanish origin, was also used in the United States) In fact, NGS originally computed and published SPCs in U.S. Survey Feet for many years when the reference system was the North American Datum of 1927 (NAD 27). And the conversion formulas (latitude/longitude to SPCs) were developed to produce U.S. Survey Foot values. In fact, NGS never published NAD 27 SPCs in meters.

However, most other countries, and the engineering community in the United States, began using the International Foot as established by the National Bureau of Standards (NBS), now the National Institute of Standards and Technology (NIST).

To make the transition in the surveying community, in 1959 NBS published a Federal Register notice stating that the U.S. surveying community would convert to the International Foot the next time the National Coordinate Reference System was updated with revised values. That revision of coordinate values (i.e., latitudes and longitudes) was realized when the North American Datum of 1983 (NAD 83) was computed and published in 1986.

NGS began publishing SPCs in meters because going metric was the direction the Federal government was heading to be consistent in a global economy, AND, the change in the size of the SPCs values was a way to alert users that they were using a new horizontal datum. Also, the new conversion formula (latitude/longitude to SPCs) produced meters, not feet. However, the surveying community in various states still wanted SPCs in feet. NGS did not want to mandate which foot (U.S. Survey or International) a state should use. So, NGS left that decision to the individual states.

NGS does NOT have an "official" conversion factor. NGS works in meters ONLY. NGS only uses feet to publish SPCs, and those are converted from meters using the conversion factor as defined by the individual states who have requested that we publish SPCs in feet.

The only other instance where NGS publishes linear values in feet is for elevations, i.e., orthometric heights. All computations are still done in meters, but for publication purposes we convert meters to feet. That conversion is done using the U.S. Survey Foot conversion factor. We publish elevations in meters to the nearest millimeter (3 decimal places) and in feet to hundredths of a foot (2 decimal places). For elevations above 5,000 feet (1,524 meters), the conversion factor will change the foot value by one in the second place.

2.3.8 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 (RMTCRS) 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 State Plane Coordinate Systems (as much as ~1:10 000 with respect to ellipsoid, and significantly greater distortion in high elevation areas.

Chapter 3 RMTCRS Map Projection Zones

3.1 The Development of RMTCRS Projection Zones in the Rocky Mountain Tribal Areas

The development of each map RMTCRS 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. Two additional low distortion reference systems in Montana have been developed for the Billings and Bobcat (Bozeman) areas by Mr. Dennis and Rich Jensen, PLS with Sanderson and Stewart, but are not part of the tribal mapping project. 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 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 Northern Engineering & Consulting in Billings, Montana.

3.1.1 The RMTCRS Zone Catalog for the Rocky Mountain Tribal Area

Table 3.1.1

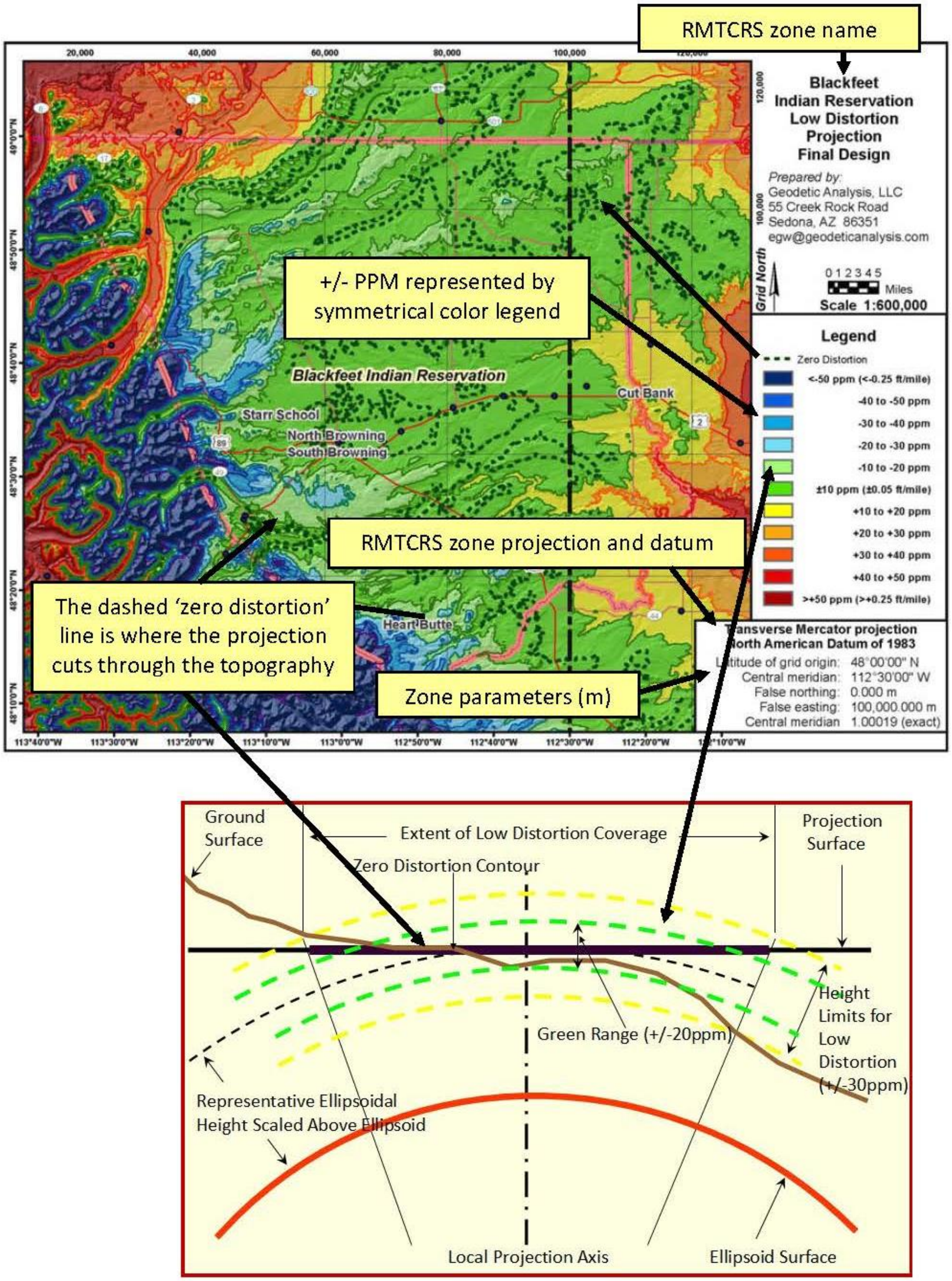
Zone Name	Projection	Latitude of Grid Origin	Central Meridian	False Northing (m)	False Easting (m)	Scale (exact)
Big Timber 83	TM	44° 00' 00'' N	110° 00' 00'' W	0	175,000	1.000 209
Billings	LCC	45° 47' 00'' N	108° 25' 00'' W	50,000	200,000	1.000 1515
Blackfeet	TM	48° 00' 00'' N	112° 30' 00'' W	0	100,000	1.000 190
Bobcat	LCC	46° 15' 00'' N	111° 15' 00'' W	100,000	100,000	1.000 185
Butte 83	TM	44° 09' 00'' N	112° 48' 00'' W	0	200,000	1.000 252
Canyon Ferry 83	TM	45° 30' 00'' N	111° 48' 00'' W	0	200,000	1.000 188
Crow	TM	44° 45' 00'' N	107° 45' 00'' W	0	200,000	1.000 148
Flathead 83	OM	48° 24' 00'' N	114° 27' 00'' W	150,000	150,000	1.000 142
Fort Belknap	LCC	48° 30' 00'' N	108° 30' 00'' W	150,000	200,000	1.000 120
Fort Peck - Assiniboine	LCC	48° 20' 00'' N	105° 30' 00'' W	100,000	200,000	1.000 120
Fort Peck -Sioux	LCC	48° 20' 00'' N	105° 30' 00'' W	50,000	100,000	1.000 090
Interstate 83	OM	47° 03' 00'' N	104° 39' 00'' W	225,000	200,000	1.000 105
Milk River	LCC	48° 30' 00'' N	111° 00' 00'' W	200,000	150,000	1.000 145
Mission 83	TM	46° 45' 00'' N	114° 39' 00'' W	0	100,000	1.000 126
Missoula 83	TM	45° 30' 00'' N	114° 09' 00'' W	0	100,000	1.000 158
NECI 83	OM	48° 15' 00'' N	112° 00' 00'' W	100,000	50,000	0.999 985
Phillips 83	TM	46° 45' 00'' N	107° 39' 00'' W	0	175,000	1.000 110
St Mary's Valley	TM	48° 30' 00'' N	112° 30' 00'' W	0	150,000	1.000 160
Wind River	TM	42° 40' 00'' N	108° 20' 00'' W	0	100,000	1.000 240

TM = Transverse Mercator
LCC = Lambert Conformal Conic projection (single parallel)
*All zones designed with an initial target distortion level of ± 20 ppm = 1:50 000 Ratio = ±0.10'/mile.
All lineal units are metric (m).
All zones reference the NAD 83 (2011) datum (Geometric Reference System)

Refer to the RMTCRS 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 or ±20 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 RMTCRS Zone Map Interpretation

Figure 3.1.2 : RMTCRS Zone Map Interpretation

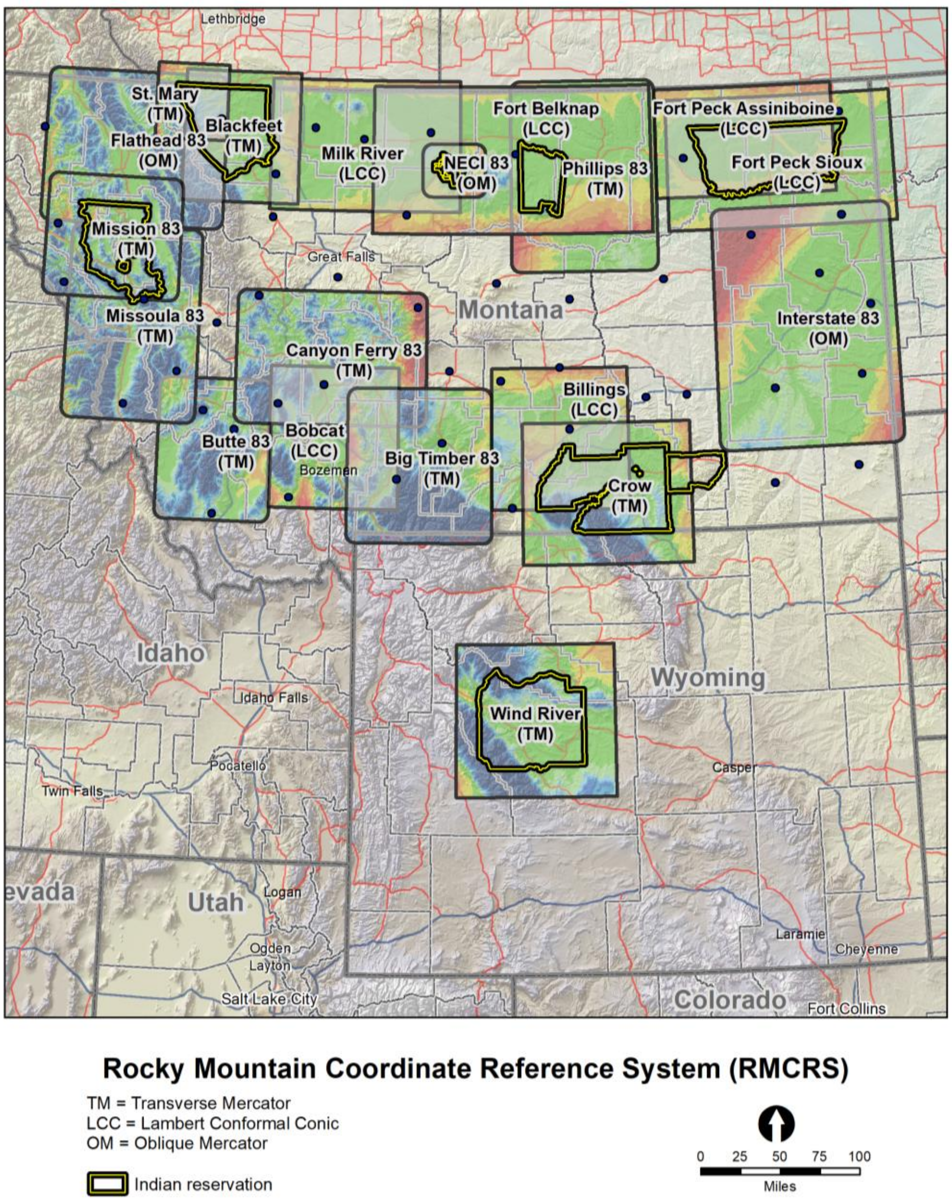


3.1.3 Picking a Zone to Use for a Survey/Engineering/GIS/Mapping Project

Some of RMTCRS map projection zones have zone overlap. Overlap allows 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 Fort Peck Assiniboine High Zone projection scale factor is larger (higher) than the Fort Peck Sioux Low Zone projection so if you're working in that overlap area at a relative higher elevation it would be best to use the Fort Peck Assiniboine High Zone.

Figure 3.1.3 shows all current RMTCRS zones as boxes which are displayed in their correct locations. The size of each box considers the areas of low distortion coverage 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 RMTCRS in Software Programs

4.1 Adding an RMTCRS 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 RMTCRS 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.

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 RMTCRS. 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.

The screenshots shown below illustrate the upload process into various software programs. Although the screenshots are shown for the Oregon Coordinate Reference System, the same process shall be used for the RMCRS. Once the RMTCRS parameters are accepted and incorporated into vendor software, this section will be updated with RMTCRS screen shots.

4.1.1 Trimble Coordinate System Manager

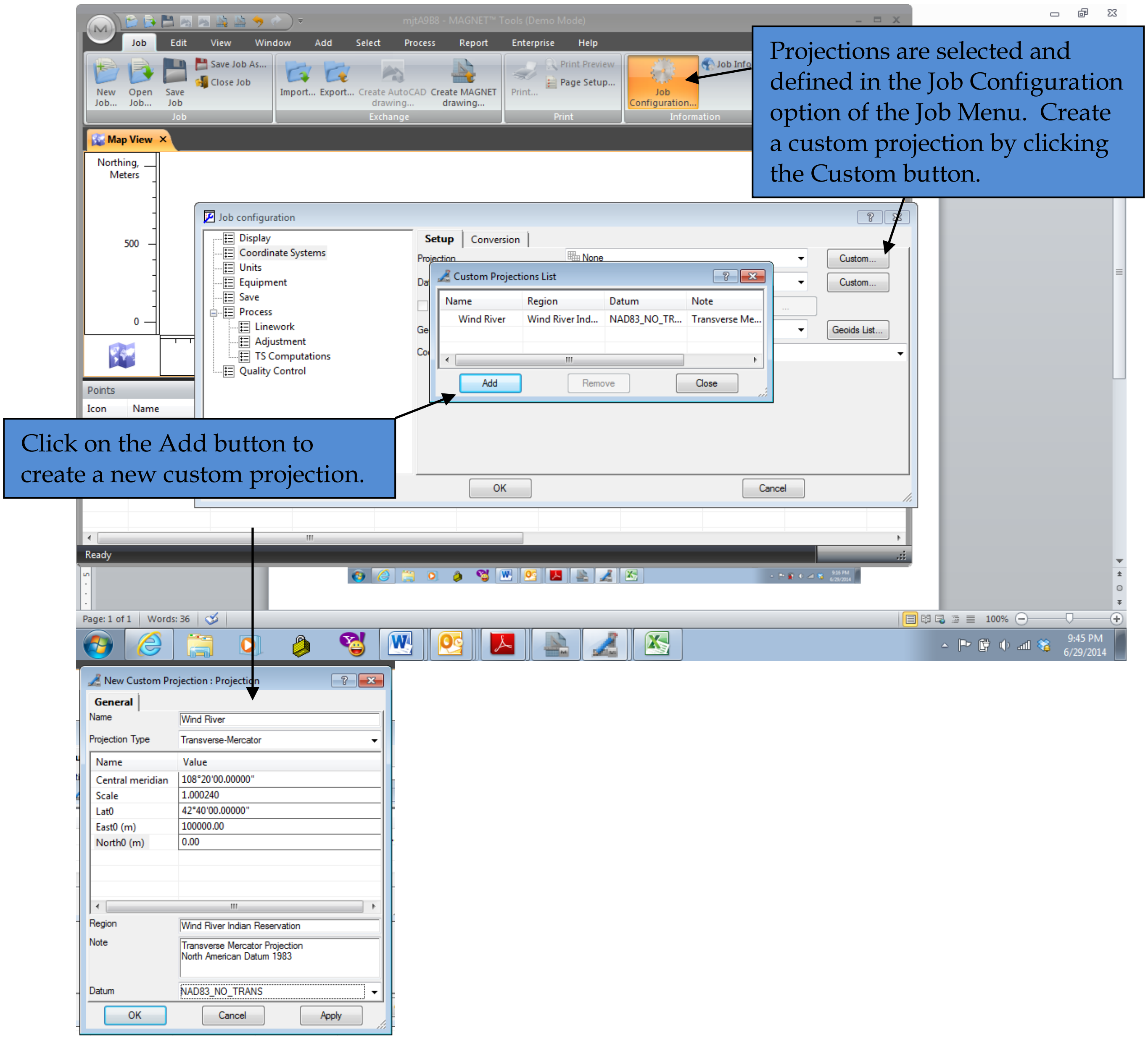
Trimble has created *.csd projection files to use with field and office software. The files and an Operation and Procedure Guide can be downloaded at www.MARLS.com. The *.csd projection files and the Operation and Procedure Guide may also be obtained by contacting Kyle Engel, Geospatial Representative with Frontier Precision at kyle@frontierprecision.com.

4.1.2 Carlson

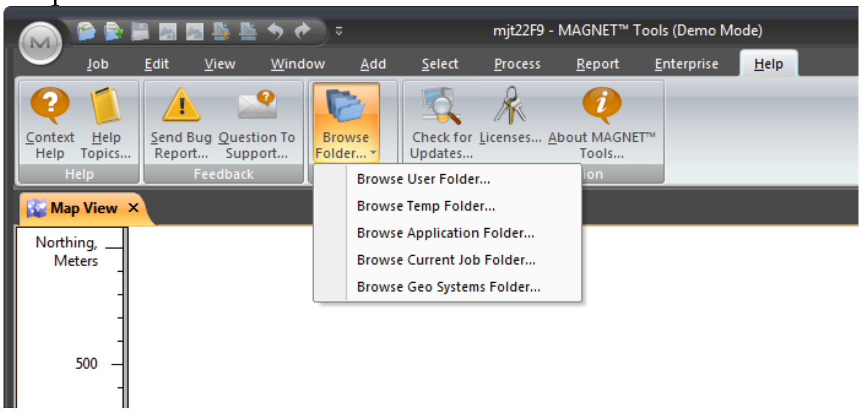
Carlson is working to add the projections to the software drop down menus. In the meantime Jim Reinbold has created *.csl files available upon request.

4.1.3 Topcon Magnet Office Tools (version 2.6)

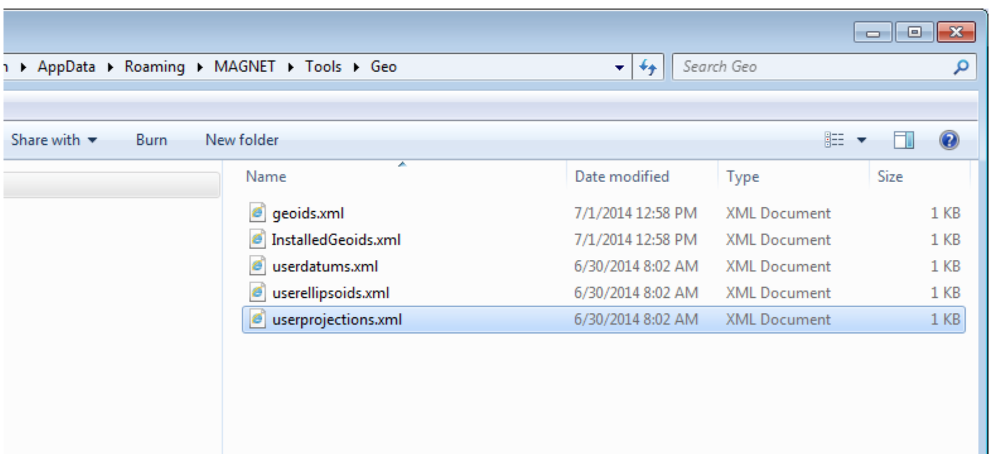
As shown below, Topcon has developed a procedure to define the RMTCRS zones in Magnet Office Tools Software. Projection input parameters for RMTCRS zones are provided in Table 3.1.1. Contact Todd Ferris at RDO Integrated Controls in Billings, Montana, (406) 794-8747 or TFerris@rdoic.com, for support.



Once the Custom Projection file(s) have been created, these files can be shared with additional users. To copy the Custom Projection file(s), select Browse Folder/Browse User Folder from the Help menu.

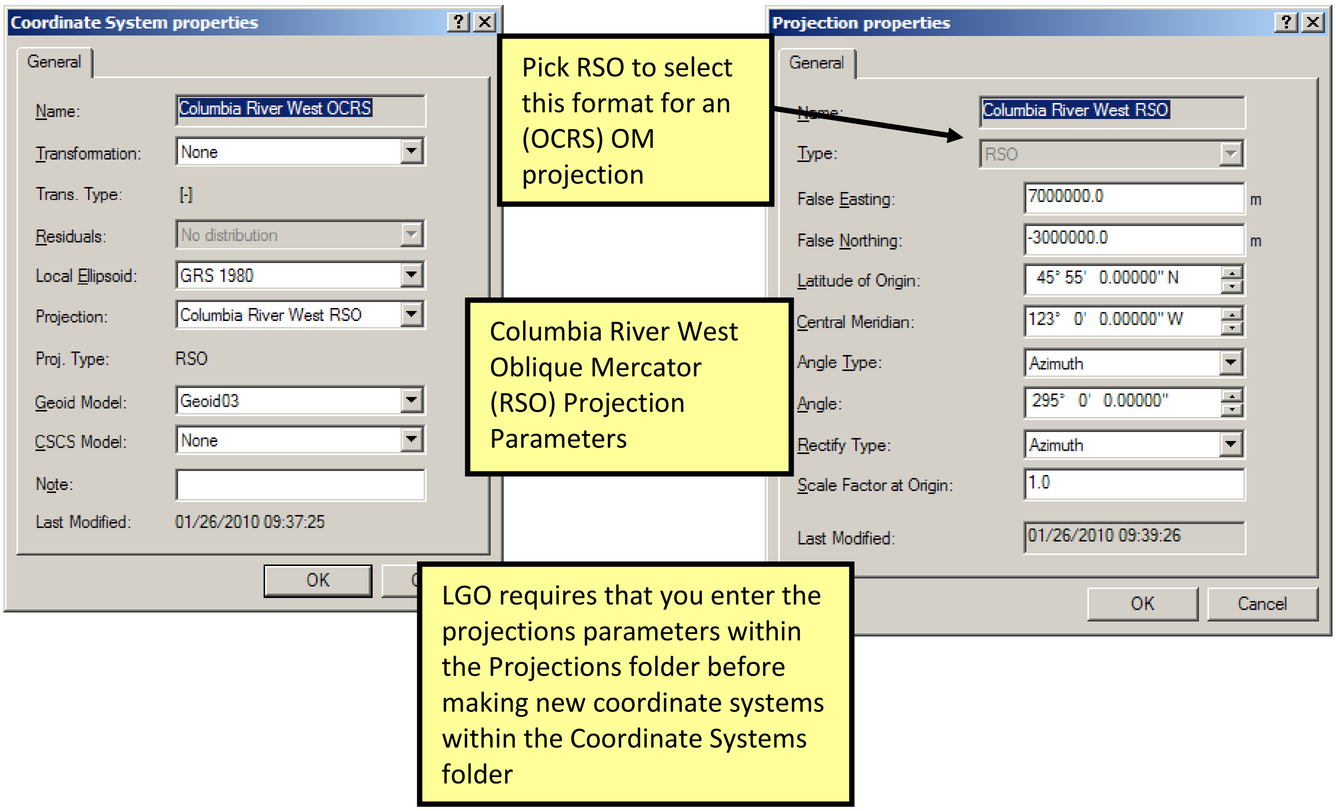


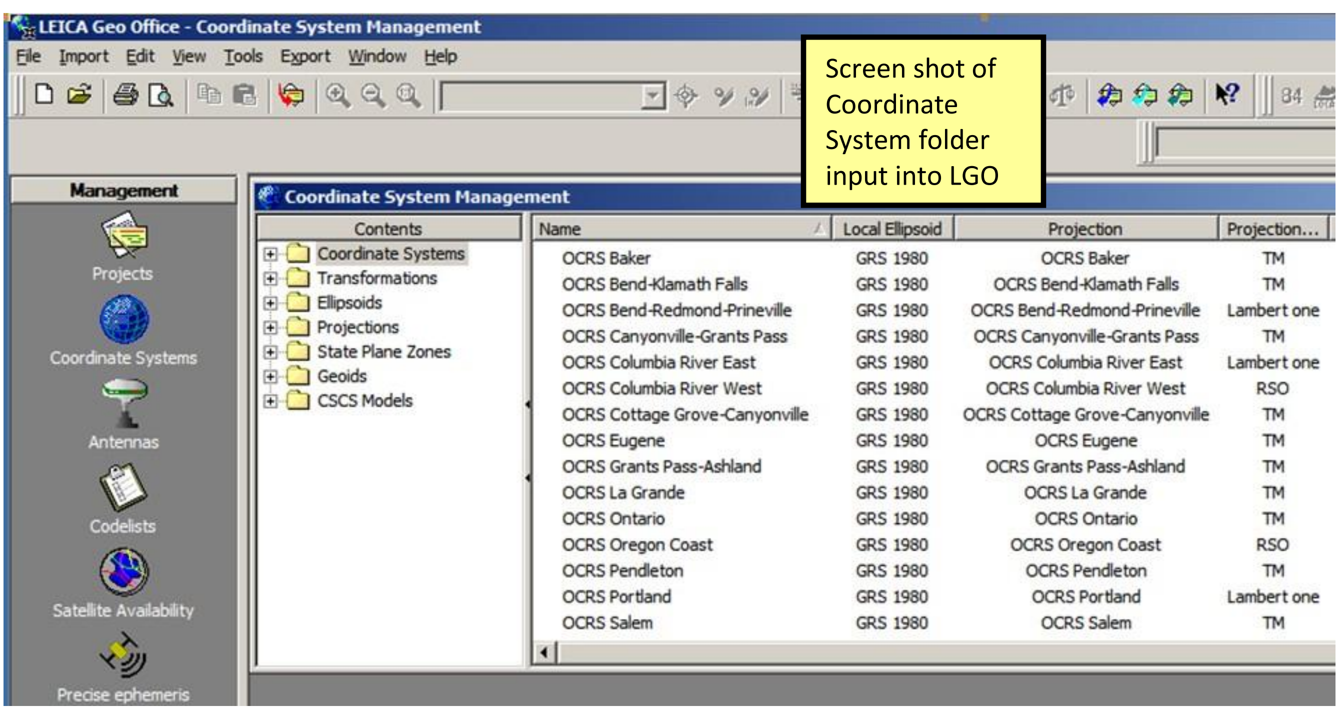
Navigate to the 'Geo' folder and find the file 'userprojections.xml'. This is the file that contains the parameters for the Custom Projection created above. You can then make a copy of this file to distribute to additional users.



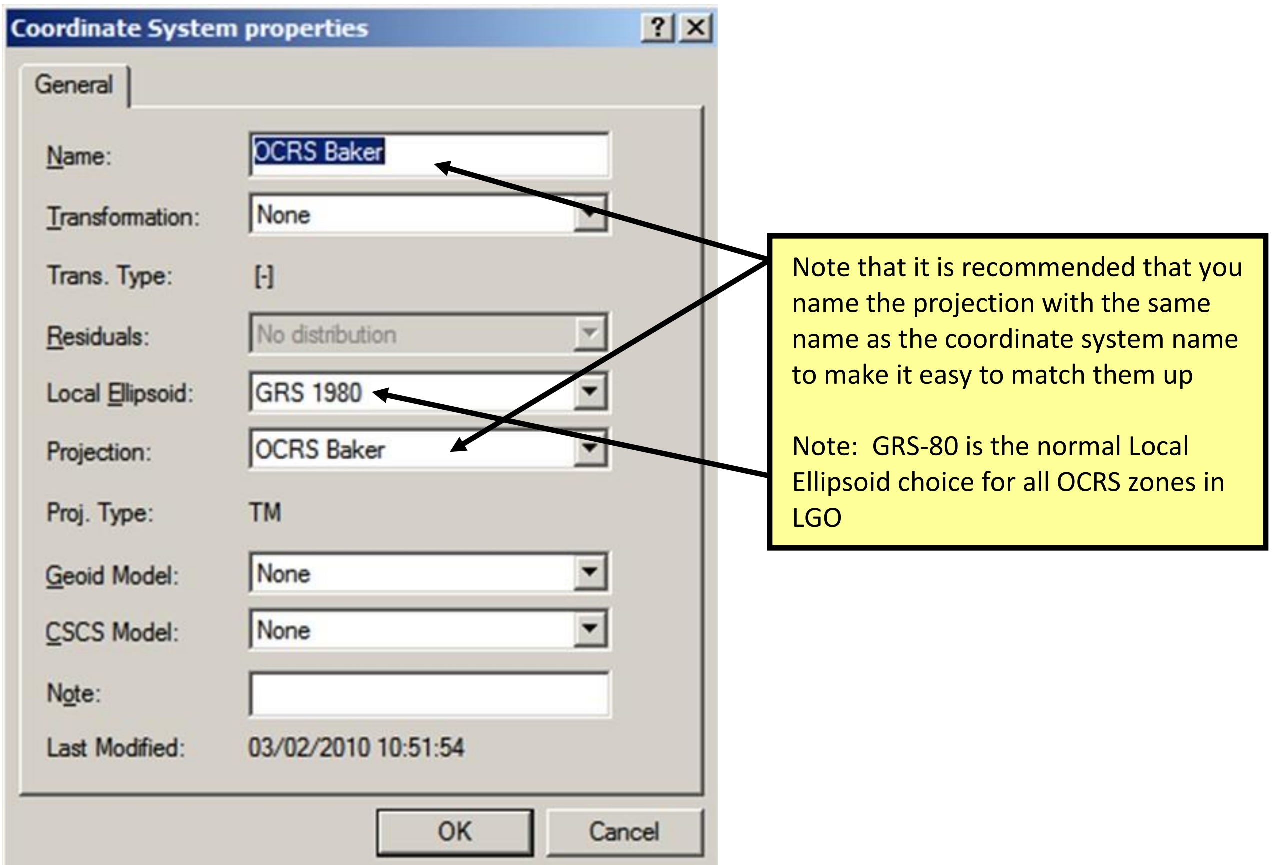
4.1.4 Leica Geomatics Office (LGO)

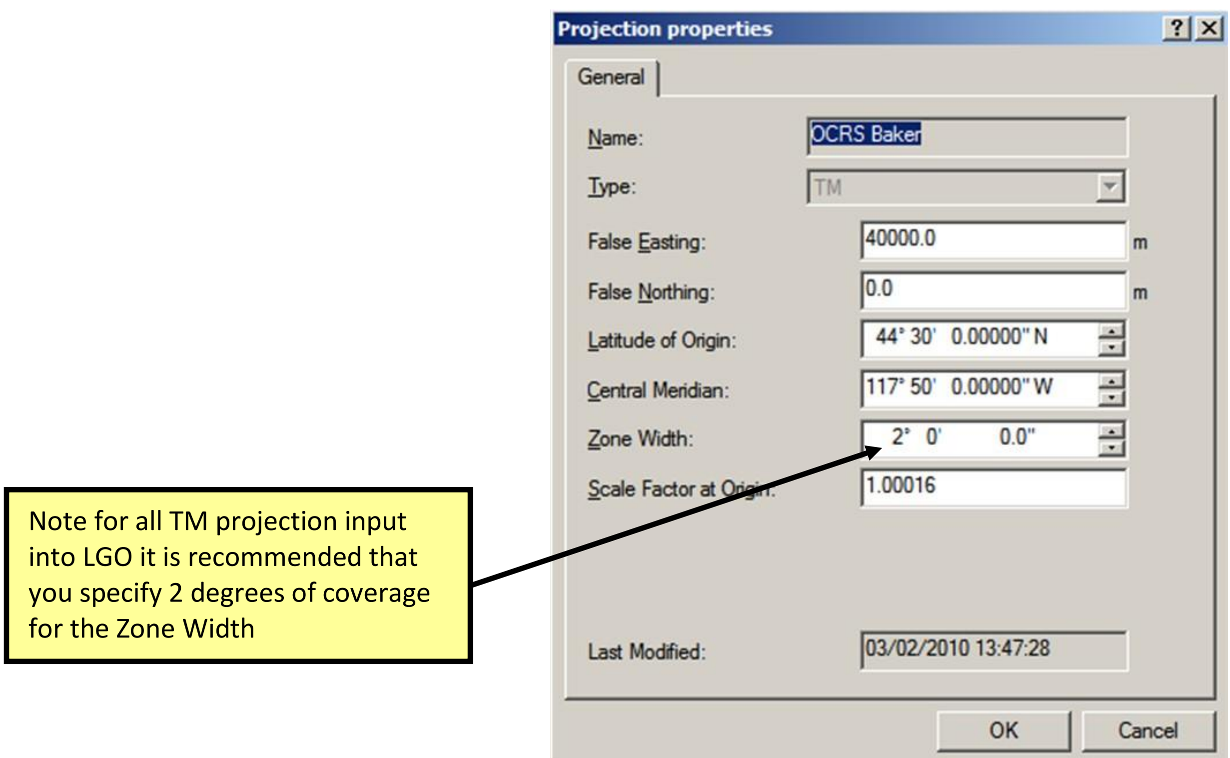
The following outlines the step-by-step procedure to add projections to the LGO. Projection input parameters for RMTCRS zones are provided in Table 3.1.1. Contact Donovan Mosser or Bryce Scala with Selby's at dmosser@selbys.com and bscala@selbys.com for support.





Leica (cont.)


Coordinate System properties
General
Name: OCRS Baker
Transformation: None
Trans. Type: [-]
Residuals: No distribution
Local Ellipsoid: GRS 1980
Projection: OCRS Baker
Proj. Type: TM
Geoid Model: None
CSCS Model: None
Note:
Last Modified: 03/02/2010 10:51:54
OK
Cancel
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


Projection properties
General
Name: OCRS Baker
Type: TM
False Easting: 40000.0 m
False Northing: 0.0 m
Latitude of Origin: 44° 30' 0.00000" N
Central Meridian: 117° 50' 0.00000" W
Zone Width: 2° 0' 0.0"
Scale Factor at Origin: 1.00016
Last Modified: 03/02/2010 13:47:28
OK
Cancel
Note for all TM projection input into LGO it is recommended that you specify 2 degrees of coverage for the Zone Width

4.1.5 ESRI ArcGIS

RMTCRS projections have been available through drop down menus in both feet and meters since ArcGIS Version 10.4.1. The Montana State Library, Geographic Information Department worked with ESRI on the projection input and assisted with the quality control process. *.prj files may be downloaded at www.MARLS.com

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

Table 4.2 provides the correct grid northing and easting for points in each RMTCRS zone. If you have entered the RMTCRS 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 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 RMTCRS zone parameter input.

It is important for users to understand that the (local) coordinates shown in Table 4.2 are datum dependent and are shown for NAD 83(2011) or NAD(CORS). If the datum (datum realization) changes the northings and eastings will also change. Table 4.2 simply provides a coordinate check that the particular zone parameters were entered into the user's software correctly. The latitude and longitude values in the green columns represent the datum shown and the corresponding grid coordinates are shown in the output columns as metric northing and eastings.

The *.xls files for Table 4.2 may be downloaded from www.MARLS.com

Table 4.2

RMCRS Zone	NGS PID	Designation	Latitude (DMS)	Longitude (DMS)	Latitude (dec deg)	Longitude (dec deg)	Ellipsoid height (m)	Northing (m)	Easting (m)	Northing (ft)	Easting (ft)	Foot type	Distortion (ppm)	Combined scale factor	Convergence angle
Big Timber 83	AA9698	J 128 RESET	45° 54' 27.43373" N	110° 37' 05.25130" W	45.907 620 481	-110.618 125 361	1470.883	212,225.6966	127,028.3517	696,278.5320	416,759.6841	International	6.6816	1.000006682	-0° 26' 38.25"
Big Timber 83	DG6502	BZN A	45° 46' 41.95996" N	111° 09' 22.80421" W	45.778 322 211	-111.156 334 503	1344.769	198,316.0843	85,050.8411	650,643.3212	279,038.1927	International	97.5643	1.000097564	-0° 49' 43.46"
Big Timber 83	DG6503	BZN B	45° 47' 10.41663" N	111° 10' 02.09200" W	45.786 226 842	-111.167 247 778	1339.280	199,207.1775	84,214.7526	653,566.8553	276,295.1200	International	100.2810	1.000100281	-0° 50' 12.02"
Big Timber 83	DG6504	BZN C	45° 46' 11.51489" N	111° 08' 39.98310" W	45.769 865 247	-111.144 439 750	1349.416	197,362.6119	85,962.6505	647,515.1309	282,029.6931	International	94.8311	1.000094831	-0° 49' 12.34"
Big Timber 83	PY0138	C 157	44° 58' 12.29242" N	110° 42' 06.93838" W	44.970 081 228	-110.701 927 328	1928.624	108,059.3940	119,614.8796	354,525.5710	392,437.2690	International	-55.6710	0.999944329	-0° 29' 45.93"
Big Timber 83	PY0164	R 161	44° 57' 50.04457" N	111° 04' 30.71985" W	44.963 901 269	-111.075 199 958	2145.577	107,695.3047	90,152.9263	353,331.0522	295,777.3172	International	-38.9191	0.999961081	-0° 45' 35.45"
Big Timber 83	QW0340	J 489	45° 42' 33.38532" N	109° 35' 40.73456" W	45.709 273 700	-109.594 648 489	1143.227	190,069.4095	206,570.5014	623,587.3014	677,724.7423	International	42.0107	1.000042011	+0° 17' 24.56"
Big Timber 83	QX0019	W 494	45° 41' 43.22839" N	110° 17' 44.71301" W	45.695 341 219	-110.295 753 614	1293.714	188,483.1700	151,959.7251	618,383.1036	498,555.5285	International	12.6994	1.000012699	-0° 12' 41.95"
Big Timber 83	QX0098	A 162	45° 06' 08.07010" N	110° 47' 13.92315" W	45.102 241 694	-110.787 200 875	1573.650	122,811.5836	113,029.2425	402,925.1430	370,830.8480	International	9.4650	1.000009465	-0° 33' 27.52"
Big Timber 83	QX0473	Q 563	45° 44' 20.41996" N	111° 06' 26.56753" W	45.739 005 544	-111.107 379 869	1376.434	193,891.3590	88,798.3935	636,126.5060	291,333.3120	International	84.4916	1.000084492	-0° 47' 35.23"
Big Timber 83	QX0749	BOZEMAN GPS	45° 39' 47.00763" N	111° 02' 46.14415" W	45.663 057 675	-111.046 151 153	1490.522	185,384.2089	93,454.2536	608,215.9084	306,608.4434	International	57.0140	1.000057014	-0° 44' 53.85"
Big Timber 83	RW0081	J 127	46° 16' 58.10476" N	110° 46' 19.60324" W	46.282 806 878	-110.772 112 011	1619.150	254,041.5711	115,482.7471	833,469.7213	378,880.4038	International	-1.3058	0.999998694	-0° 33' 29.04"
Billings	AA5458	BIL A	45° 48' 23.07163" N	108° 32' 36.25565" W	45.806 408 786	-108.543 404 347	1077.013	52,572.9735	190,146.8097	172,483.5090	623,841.2393	International	-17.2613	0.999 982 739	-0° 05' 27.00"
Billings	AD9804	BIL C	45° 48' 38.88648" N	108° 33' 26.78002" W	45.810 801 800	-108.557 438 894	1090.496	53,063.1452	189,056.5583	174,091.6838	620,264.2988	International	-19.3409	0.999 980 659	-0° 06' 03.21"
Billings	AI8210	BIL1 A	45° 58' 22.40423" N	107° 59' 43.84583" W	45.972 890 064	-107.995 512 731	870.373	71,158.2491	232,644.8748	233,458.8226	763,270.5866	International	20.5120	1.000 020 512	+0° 18' 06.64"
Billings	AI8211	BIL1 B	45° 58' 40.65678" N	107° 59' 46.50363" W	45.977 960 217	-107.996 251 008	868.598	71,721.5804	232,584.6851	235,307.0223	763,073.1139	International	21.0866	1.000 021 087	+0° 18' 04.73"
Billings	AJ8894	BIL D	45° 48' 09.74558" N	108° 31' 19.34825" W	45.802 707 106	-108.522 041 181	1053.900	52,159.0678	191,807.1405	171,125.5507	629,288.5186	International	-13.6625	0.999 986 338	-0° 04' 31.88"
Billings	DE5402	6S8 C	45° 42' 12.75295" N	108° 45' 45.43118" W	45.703 542 486	-108.762 619 772	1050.874	41,188.4989	173,054.5477	135,132.8705	567,764.2640	International	-12.2810	0.999 987 719	-0° 14' 52.61"
Billings	DE5419	6S8 E	45° 42' 28.97897" N	108° 45' 14.52750" W	45.708 049 714	-108.754 035 417	1043.062	41,686.6717	173,725.2728	136,767.2956	569,964.8058	International	-11.1625	0.999 988 838	-0° 14' 30.46"
Billings	DF5242	QC2	45° 47' 29.07590" N	108° 37' 54.87054" W	45.791 409 972	-108.631 908 483	997.594	50,920.3651	183,261.6011	167,061.5653	601,251.9722	International	-4.8841	0.999 995 116	-0° 09' 15.36"
Billings	DO7252	00U A	45° 44' 43.39107" N	107° 39' 41.47537" W	45.745 386 408	-107.661 520 936	903.306	46,059.2677	258,771.8495	151,113.0829	848,989.0076	International	10.1034	1.000 010 103	+0° 32' 28.39"
Billings	DO7257	00U B	45° 44' 43.40241" N	107° 39' 12.68014" W	45.745 389 558	-107.653 522 261	899.159	46,065.5293	259,394.3521	151,133.6265	851,031.3390	International	10.7534	1.000 010 753	+0° 32' 49.03"
Billings	DO7258	00U C	45° 44' 43.77719" N	107° 40' 00.59064" W	45.745 493 664	-107.666 830 733	906.586	46,067.3001	258,358.4964	151,139.4361	847,632.8621	International	9.5880	1.000 009 588	+0° 32' 14.69"
Billings	QV0262	N 487	45° 43' 20.14115" N	107° 37' 18.63354" W	45.722 261 431	-107.621 842 650	874.665	43,518.6895	261,885.4092	142,777.8528	859,204.0983	International	14.9400	1.000 014 940	+0° 34' 10.76"
Billings	QV0271	S 487	45° 43' 01.90270" N	107° 32' 29.92081" W	45.717 195 194	-107.541 644 669	877.456	43,020.7613	268,135.5916	141,144.2300	879,709.9464	International	14.6002	1.000 014 600	+0° 37' 37.69"
Billings	QW0003	D 484	45° 48' 09.97591" N	108° 27' 00.79858" W	45.802 771 086	-108.450 221 828	935.491	52,161.3281	197,391.0914	171,132.9663	647,608.5675	International	4.8981	1.000 004 898	-0° 01' 26.58"
Billings	QW0140	T 44	45° 42' 42.70680" N	108° 38' 48.41318" W	45.711 863 000	-108.646 781 439	966.868	42,080.9170	182,079.5470	138,060.7515	597,373.8420	International	0.6960	1.000 000 696	-0° 09' 53.73"
Billings	QW0149	G 483	45° 45' 19.73425" N	108° 33' 24.32548" W	45.755 481 736	-108.556 757 078	953.398	46,913.4661	189,098.7853	153,915.5713	620,402.8389	International	2.1508	1.000 002 151	-0° 06' 01.45"
Billings	QW0189	K 44	45° 48' 51.86007" N	108° 41' 07.75931" W	45.814 405 575	-108.685 488 697	1055.635	53,489.2559	179,103.5163	175,489.6849	587,609.9615	International	-13.8446	0.999 986 155	-0° 11' 33.60"
Billings	QW0201	P 44	45° 44' 26.07004" N	108° 42' 35.41023" W	45.740 575 011	-108.709 836 175	1002.429	45,288.6762	177,180.8112	148,584.8957	581,301.8740	International	-5.3753	0.999 994 625	-0° 12' 36.42"
Billings	QW0203	Q 44	45° 42' 36.22243" N	108° 42' 33.58557" W	45.710 061 786	-108.709 329 325	994.143	41,896.6174	177,207.8448	137,456.0938	581,390.5669	International	-3.5399	0.999 996 460	-0° 12' 35.11"
Billings	QW0389	Y 538	45° 42' 49.76774" N	108° 47' 23.97113" W	45.713 824 372	-108.789 991 981	1099.157	42,341.0383	170,927.9449	138,914.1675	560,787.2206	International	-20.0818	0.999 979 918	-0° 16' 03.23"
Billings	QW0402	AIRPORT 2	45° 48' 05.78682" N	108° 32' 13.75160" W	45.801 607 450	-108.537 153 222	1068.009	52,038.4853	190,631.9971	170,729.9388	625,433.0614	International	-15.8803	0.999 984 120	-0° 05' 10.87"
Billings	QW0442	N 560	45° 30' 03.78388" N	108° 51' 48.56965" W	45.501 051 078	-108.863 491 569	1060.035	18,718.6603	165,072.1499	61,412.9275	541,575.2950	International	-2.6108	0.999 997 389	-0° 19' 12.87"
Billings	RU0361	G 394	46° 07' 33.19257" N	107° 34' 40.70018" W	46.125 886 825	-107.577 972 272	824.202	88,421.0389	264,830.3289	290,095.2719	868,865.9083	International	40.1422	1.000 040 142	+0° 36' 03.96"
Billings	RU0372	H 120	46° 14' 43.78666" N	107° 37' 53.57647" W	46.245 496 294	-107.631 549 019	1005.493	101,675.8652	260,558.4393	333,582.2351	854,850.5226	International	26.3943	1.000 026 394	+0° 33' 45.72"
Billings	RU0378	Q 120	46° 22' 19.59955" N	107° 49' 18.43104" W	46.372 110 986	-107.821 786 400	991.093	115,625.7062	245,780.4339	379,349.4299	806,366.2530	International	48.9536	1.000 048 954	+0° 25' 34.88"
Billings	RV0039	3512	46° 11' 30.21218" N	108° 27' 10.54956" W	46.191 725 606	-108.452 930 433	1057.826	95,401.1360	197,200.1121	312,995.8530	646,981.9952	International	11.0556	1.000 011 056	-0° 01' 33.57"
Billings	RV0099	Z 122	46° 17' 36.85046" N	108° 54' 21.13411" W	46.293 569 572	-108.905 870 586	1030.412	106,838.5106	162,298.5940	350,520.0478	532,475.7022	International	29.6180	1.000 029 618	-0° 21' 02.22"
Blackfeet	AB3811	PIEGAN	48° 56' 23.68774" N	113° 22' 21.02986" W	48.939 913 261	-113.372 508 294	1299.508	104,904.7550	36,068.4321	344,175.7053	118,334.7510	International	36.5220	1.000 036 522	-0° 39' 28.48"
Blackfeet	AI7863	SHERBURNE 2	48° 51' 07.53055" N	113° 24' 59.52878" W	48.852 091 819	-113.416 535 772	1352.441	95,174.6245	32,724.6778	312,252.7051	107,364.4286	International	33.6124	1.000 033 612	-0° 41' 24.68"
Blackfeet	DI6635	CTB B	48° 36' 05.20086" N	112° 22' 15.55349" W	48.601 444 683	-112.370 987 081	1155.064	66,899.0884	109,517.0046	219,485.1983	359,307.7580	International	10.0881	1.000 010 088	+0° 05' 48.39"
Blackfeet	DI6636	CTB C	48° 36' 48.15722" N	112° 22' 45.78726" W	48.613 377 006	-112.379 385 350	1159.133	68,225.2274	108,895.3866	223,836.0480	357,268.3288	International	9.3103	1.000 009 310	+0° 05' 25.78"
Blackfeet	TL0318	U 427	48° 10' 34.06436" N	111° 56' 06.16750" W	48.176 128 989	-111.935 046 528	1052.070	19,742.2579	142,024.0575	64,771.1874	465,958.1940	International	46.7892	1.000 046 789	+0° 25' 15.63"
Blackfeet	TM0650	A 423	48° 37' 39.90489" N	112° 22' 12.96322" W	48.627 751 358	-112.370 267 561	1129.602	69,825.0950	109,565.1114	229,084.9575	359,465.5885	International	14.0897	1.000 014 090	+0° 05' 50.48"
Blackfeet	TM0651	C 423	48° 37' 28.40078" N	112° 23' 27.33002" W	48.624 555 772	-112.390 925 006	1166.028	69,467.2886	108,042.5558	227,911.0518	354,470.3273	International	8.0528	1.000 008 053	+0° 04' 54.66"
Blackfeet	TM1045	79 A	48° 14' 17.30421" N	112° 31' 58.51019" W	48.238 140 058	-112.532 919 497	1207.366	26,484.9765	97,554.2335	86,892.9676	320,059.8212	International	0.8463	1.000 000 846	-0° 01' 28.40"
Bobcat	AA9698	J 128 RESET	45° 54' 27.43373" N	110° 37' 05.25130" W	45.907 620 481	-110.618 125 361	1470.883	62,131.6019	149,037.9103	203,843.8381	488,969.5220	International	-27.8206	0.999 972 179	+0° 27' 23.20"
Bobcat	AB2998	15JS	46° 05' 11.91609" N	111° 53' 15.01557" W	46.086 643 358	-111.887 504 325	1381.539	82,036.9561	50,685.1589	269,150.1185	166,289.8913	International	-27.5250	0.999 972 475	-0° 27' 37.84"
Bobcat	DG6502	BZN A	45° 46' 41.95996" N	111° 09' 22.80421" W	45.778 322 211	-111.156 334 503	1344.769	47,566.2753	107,286.1503	156,057.3337	351,988.6821	International	7.8625	1.000 007 862	+0° 04' 03.58"

Table 4.2, cont.

RMCRS Zone	NGS PID	Designation	Latitude (DMS)	Longitude (DMS)	Latitude (dec deg)	Longitude (dec deg)	Ellipsoid height (m)	Northing (m)	Easting (m)	Northing (ft)	Easting (ft)	Foot type	Distortion (ppm)	Combined scale factor	Convergence angle
Bobcat	DG6503	BZN B	45° 47' 10.41663" N	111° 10' 02.09200" W	45.786 226 842	-111.167 247 778	1339.280	48,444.0989	106,436.3005	158,937.3322	349,200.4609	International	7.6052	1.000 007 605	+0° 03' 35.20"
Bobcat	DG6504	BZN C	45° 46' 11.51489" N	111° 08' 39.98310" W	45.769 865 247	-111.144 439 750	1349.416	46,627.2667	108,212.6826	152,976.5968	355,028.4861	International	8.3507	1.000 008 351	+0° 04' 34.51"
Bobcat	QX0192	Z 493	45° 52' 18.69131" N	111° 21' 37.36675" W	45.871 858 697	-111.360 379 653	1273.434	57,966.5305	91,428.1431	190,178.9058	299,961.0994	International	7.0247	1.000 007 025	-0° 04' 47.04"
Bobcat	QX0254	C 160	45° 37' 53.43892" N	111° 11' 49.46208" W	45.631 510 811	-111.197 072 800	1456.561	31,242.1594	104,128.0483	102,500.5228	341,627.4551	International	14.5141	1.000 014 514	+0° 02' 17.64"
Bobcat	QX0338	H 146	45° 13' 56.79458" N	111° 40' 45.15990" W	45.232 442 939	-111.679 211 083	1606.328	-13,033.2618	66,283.8385	-42,760.0452	217,466.6617	International	89.4091	1.000 089 409	-0° 18' 36.17"
Bobcat	QX0352	Z 145	45° 21' 33.38200" N	111° 43' 54.26773" W	45.359 272 778	-111.731 741 036	1497.331	1,090.2808	62,243.0971	3,577.0367	204,209.6362	International	70.0665	1.000 070 067	-0° 20' 52.77"
Bobcat	QX0397	G 498	45° 47' 36.42596" N	111° 44' 29.70158" W	45.793 451 656	-111.741 583 772	1262.692	49,362.4005	61,770.8242	161,950.1330	202,660.1843	International	18.6047	1.000 018 605	-0° 21' 18.37"
Bobcat	QX0473	Q 563	45° 44' 20.41996" N	111° 06' 26.56753" W	45.739 005 544	-111.107 379 869	1376.434	43,201.0724	111,102.1407	141,735.8019	364,508.3358	International	8.7377	1.000 008 738	+0° 06' 10.89"
Bobcat	QX0478	J 562	45° 53' 30.49015" N	111° 35' 16.10914" W	45.891 802 819	-111.587 808 094	1233.372	60,233.6347	73,776.0318	197,616.9116	242,047.3483	International	11.0824	1.000 011 082	-0° 14' 38.47"
Bobcat	QX0488	R 562	45° 54' 55.37349" N	111° 43' 26.51846" W	45.915 381 525	-111.724 032 906	1380.400	62,909.0002	63,216.7033	206,394.3577	207,403.8821	International	-14.4340	0.999 985 566	-0° 20' 32.73"
Bobcat	QX0749	BOZEMAN GPS	45° 39' 47.00763" N	111° 02' 46.14415" W	45.663 057 675	-111.046 151 153	1490.522	34,768.3008	115,890.1278	114,069.2284	380,216.9547	International	3.4501	1.000 003 450	+0° 08' 50.11"
Bobcat	RW0081	J 127	46° 16' 58.10476" N	110° 46' 19.60324" W	46.282 806 878	-110.772 112 011	1619.150	103,758.3437	136,836.3232	340,414.5134	448,938.0684	International	-68.6418	0.999 931 358	+0° 20' 42.75"
Bobcat	RW0206	D 82	46° 09' 23.11149" N	111° 25' 52.40777" W	46.156 419 858	-111.431 224 381	1190.987	89,612.1385	85,998.7761	294,003.0791	282,148.2155	International	-0.3763	0.999 999 624	-0° 07' 51.28"
Bobcat	RW0582	TOWNSEND GPS	46° 18' 33.94932" N	111° 30' 52.80912" W	46.309 430 367	-111.514 669 200	1155.587	106,641.3330	79,608.6922	349,873.1399	261,183.3734	International	4.3831	1.000 004 383	-0° 11' 28.27"
Butte 83	AJ4422	BTM A	45° 57' 13.54487" N	112° 29' 56.44384" W	45.953 762 464	-112.499 012 178	1673.318	200,551.7403	223,340.8000	657,978.1507	732,745.4067	International	-3.6305	0.999 996 370	+0° 12' 58.84"
Butte 83	AJ4436	BTM B	45° 57' 57.41771" N	112° 30' 10.50448" W	45.965 949 364	-112.502 917 911	1665.627	201,905.5253	223,032.8706	662,419.7025	731,735.1399	International	-2.6001	0.999 997 400	+0° 12' 48.89"
Butte 83	QY0009	S 495	45° 57' 38.00393" N	112° 29' 51.78993" W	45.960 556 647	-112.497 719 425	1669.313	201,307.4864	223,438.1848	660,457.6325	733,064.9108	International	-2.9466	0.999 997 053	+0° 13' 02.28"
Butte 83	QY0075	Z 116	45° 30' 19.09073" N	112° 16' 53.99723" W	45.505 302 981	-112.281 665 897	1450.435	150,781.3564	240,518.3859	494,689.4896	789,102.3158	International	44.7659	1.000 044 766	+0° 22' 11.07"
Butte 83	QY0202	MELROSE	45° 38' 20.10486" N	112° 41' 10.49890" W	45.638 918 017	-112.686 249 694	1572.479	165,511.0282	208,870.8492	543,015.1845	685,271.8151	International	6.4402	1.000 006 440	+0° 04' 52.77"
Butte 83	QY0292	M 67	45° 20' 18.17074" N	113° 20' 53.75787" W	45.338 380 761	-113.348 266 075	2005.762	132,240.4888	157,015.3371	433,859.8715	515,142.1822	International	-39.7490	0.999 960 251	-0° 23' 23.90"
Butte 83	QY0367	L 70	45° 37' 45.13855" N	113° 31' 55.17322" W	45.629 205 153	-113.531 992 561	1879.468	164,685.6451	142,905.5252	540,307.2345	468,850.1483	International	-2.6025	0.999 997 398	-0° 31' 23.75"
Butte 83	QY0638	BUTTE GPS	45° 58' 04.59752" N	112° 31' 03.25535" W	45.967 943 756	-112.517 570 931	1667.217	202,123.1286	221,896.0318	663,133.6241	728,005.3537	International	-3.4766	0.999 996 523	+0° 12' 10.99"
Butte 83	QY0639	DILLON GPS	45° 13' 54.11353" N	112° 36' 52.49024" W	45.231 698 203	-112.614 580 622	1532.769	120,251.5327	214,564.3579	394,526.0261	703,951.3055	International	14.2920	1.000 014 292	+0° 07' 53.91"
Butte 83	QY0663	DILLPORT	45° 15' 17.05653" N	112° 33' 03.58947" W	45.254 737 925	-112.550 997 075	1579.274	122,826.1750	219,550.8267	402,973.0152	720,311.1114	International	9.0929	1.000 009 093	+0° 10' 36.67"
Butte 83	QY0664	DILLPORT B	45° 14' 57.59442" N	112° 33' 00.74780" W	45.249 331 783	-112.550 207 722	1587.438	122,225.3945	219,614.6647	401,001.9505	720,520.5536	International	7.8438	1.000 007 844	+0° 10' 38.63"
Butte 83	QY0669	JACKSON AZ MK	45° 18' 54.10120" N	113° 26' 32.74896" W	45.315 028 111	-113.442 430 267	2016.623	129,699.0299	149,612.0636	425,521.7515	490,853.2271	International	-32.9610	0.999 967 039	-0° 27' 24.36"
Butte 83	RX0377	WARM SPRINGS S BASE	46° 11' 03.25887" N	112° 47' 15.63536" W	46.184 238 575	-112.787 676 489	1455.104	226,132.2376	200,951.6862	741,903.6668	659,290.3091	International	23.8967	1.000 023 897	+0° 00' 32.01"
Canyon Ferry 83	AB2998	15JS	46° 05' 11.91609" N	111° 53' 15.01557" W	46.086 643 358	-111.887 504 325	1381.539	65,219.7958	193,230.9420	213,975.7079	633,959.7834	International	-28.0101	0.999 971 990	-0° 03' 46.93"
Canyon Ferry 83	AI7860	HELENA CBL 0	46° 32' 25.76744" N	111° 44' 13.62985" W	46.540 490 956	-111.737 119 403	1269.289	115,676.0164	204,824.2000	379,514.4895	671,995.4070	International	-10.6834	0.999 989 317	+0° 02' 44.31"
Canyon Ferry 83	AJ4436	BTM B	45° 57' 57.41771" N	112° 30' 10.50448" W	45.965 949 364	-112.502 917 911	1665.627	52,038.5145	145,506.0696	170,730.0345	477,382.1181	International	-36.6244	0.999 963 376	-0° 30' 19.23"
Canyon Ferry 83	AJ8554	HLN F	46° 36' 25.15746" N	111° 59' 57.65501" W	46.606 988 183	-111.999 348 614	1168.242	123,086.7942	184,724.6560	403,828.0651	606,052.0209	International	7.7348	1.000 007 735	-0° 08' 41.49"
Canyon Ferry 83	AJ8555	HLN G	46° 36' 13.23106" N	111° 58' 20.33269" W	46.603 675 294	-111.972 314 636	1159.189	122,713.5718	186,795.3640	402,603.5819	612,845.6824	International	8.4293	1.000 008 429	-0° 07' 30.75"
Canyon Ferry 83	AJ8556	HLN H	46° 36' 08.68451" N	111° 57' 49.55879" W	46.602 412 364	-111.963 766 331	1157.580	122,571.7581	187,450.1371	402,138.3141	614,993.8882	International	8.4744	1.000 008 474	-0° 07' 08.38"
Canyon Ferry 83	DH4417	MONTANA CENTER OF POP	46° 48' 07.65648" N	111° 10' 51.21273" W	46.802 126 800	-111.180 892 425	1331.641	144,950.3380	247,269.2295	475,558.8516	811,250.7530	International	6.7055	1.000 006 706	+0° 27' 04.80"
Canyon Ferry 83	DQ3133	HLN J	46° 36' 32.51518" N	111° 58' 58.11781" W	46.609 031 994	-111.982 810 503	1153.195	123,310.9624	185,992.4366	404,563.5250	610,211.4063	International	9.6372	1.000 009 637	-0° 07' 58.24"
Canyon Ferry 83	DQ3134	HLN K	46° 36' 05.75024" N	111° 57' 55.13169" W	46.601 597 289	-111.965 314 358	1160.516	122,481.3824	187,331.3175	401,841.8058	614,604.0602	International	8.0510	1.000 008 051	-0° 07' 12.42"
Canyon Ferry 83	DQ3135	HLN L	46° 36' 23.21203" N	111° 59' 54.02617" W	46.606 447 786	-111.998 340 603	1166.803	123,026.5159	184,801.7450	403,630.3016	606,304.9376	International	7.9315	1.000 007 932	-0° 08' 38.85"
Canyon Ferry 83	QY0638	BUTTE GPS	45° 58' 04.59752" N	112° 31' 03.25535" W	45.967 943 756	-112.517 570 931	1667.217	52,270.3579	144,372.0880	171,490.6754	473,661.7061	International	-35.3397	0.999 964 660	-0° 30' 57.28"
Canyon Ferry 83	RW0081	J 127	46° 16' 58.10476" N	110° 46' 19.60324" W	46.282 806 878	-110.772 112 011	1619.150	87,538.4122	279,231.6687	287,199.5150	916,114.3985	International	11.2964	1.000 011 296	+0° 44' 34.64"
Canyon Ferry 83	RW0129	J 129	46° 45' 04.90158" N	110° 51' 50.87288" W	46.751 361 550	-110.864 131 356	1752.119	139,545.1855	271,521.2029	457,825.4116	890,817.5947	International	-23.8107	0.999 976 189	+0° 40' 54.13"
Canyon Ferry 83	RW0197	B 80 RESET	46° 35' 31.30188" N	111° 02' 30.54412" W	46.592 028 300	-111.041 817 811	1461.016	121,683.5215	258,112.5922	399,224.1520	846,826.0900	International	0.4597	1.000 000 460	+0° 33' 02.95"
Canyon Ferry 83	RW0206	D 82	46° 09' 23.11149" N	111° 25' 52.40777" W	46.156 419 858	-111.431 224 381	1190.987	73,039.5762	228,491.3196	239,631.1556	749,643.4371	International	11.2653	1.000 011 265	+0° 15' 57.51"
Canyon Ferry 83	RW0336	A 461	46° 37' 02.07655" N	111° 54' 53.31445" W	46.617 243 486	-111.914 809 569	1143.797	124,214.1163	191,204.2288	407,526.6284	627,310.4619	International	9.6507	1.000 009 651	-0° 05' 00.39"
Canyon Ferry 83	RW0581	HELENA GPS	46° 35' 11.16614" N	111° 59' 29.67744" W	46.586 435 039	-111.991 577 067	1221.379	120,800.1406	185,314.6093	396,325.9204	607,987.5633	International	-0.8108	0.999 999 189	-0° 08' 20.99"
Canyon Ferry 83	RW0582	TOWNSEND GPS	46° 18' 33.94932" N	111° 30' 52.80912" W	46.309 430 367	-111.514 669 200	1155.587	90,024.2394	221,983.2615	295,355.1160	728,291.5403	International	12.7819	1.000 012 782	+0° 12' 22.75"
Canyon Ferry 83	RX0014	B 468	46° 36' 36.80977" N	112° 03' 25.68090" W	46.610 224 936	-112.057 133 583	1183.207	123,459.4868	180,297.9834	405,050.8097	591,528.8170	International	7.2911	1.000 007 291	-0° 11' 12.69"
Canyon Ferry 83	RX0088	Z 456	46° 43' 44.97417" N	112° 01' 15.02930" W	46.729 159 492	-112.020 841 472	1171.966	136,674.8260	183,115.8226	448,408.2217	600,773.6962	International	7.7892	1.000 007 789	-0° 09' 38.88"
Canyon Ferry 83	SS0149	M 190	47° 01' 55.13457" N	110° 25' 37.07188" W	47.031 981 825	-110.426 964 411	1614.471	171,237.0579	304,384.1890	561,801.3711	998,635.7906	International	68.7529	1.000 068 753	+1° 00' 17.23"
Crow	AA5458	BIL A	45° 48' 23.07163" N	108° 32' 36.25565" W	45.806 408 786	-108.543 404 347	1077.013	117,729.9245	138,317.2187	386,253.0333	453,796.6491	International	25.8995	1.000 025 899	-0° 34' 07.97"
Crow	AD9804	BIL C	45° 48' 38.88648" N	108° 33' 26.78002" W	45.810 801 800	-108.557 438 894	1090.496	118,229.1980	137,231.0473	387,891.0694	450,233.0947	International	25.4467	1.000 025 447	-0° 34' 44.35"
Crow	AI8210	BIL1A	45° 58' 22.40423" N	107° 59' 43.84583" W	45.972 890 064	-107.995 512 731	870.373	135,960.0149	180,969.6737	446,063.0411	593,732.5254	International	16.0002	1.000 016 000	-0° 10' 35.50"

Table 4.2, cont.

RMCRS Zone	NGS PID	Designation	Latitude (DMS)	Longitude (DMS)	Latitude (dec deg)	Longitude (dec deg)	Ellipsoid height (m)	Northing (m)	Easting (m)	Northing (ft)	Easting (ft)	Foot type	Distortion (ppm)	Combined scale factor	Convergence angle
Crow	AI8211	BIL1B	45° 58' 40.65678" N	107° 59' 46.50363" W	45.977 960 217	-107.996 251 008	868.598	136,523.8265	180,914.1898	447,912.8166	593,550.4914	International	16.3045	1.000 016 305	-0° 10' 37.46"
Crow	AJ8894	BIL D	45° 48' 09.74558" N	108° 31' 19.34825" W	45.802 707 106	-108.522 041 181	1053.900	117,302.1632	139,974.1079	384,849.6167	459,232.6374	International	27.0450	1.000 027 045	-0° 33' 12.69"
Crow	AJ9016	SHR D	44° 46' 13.74356" N	106° 58' 57.07057" W	44.770 484 322	-106.982 519 603	1204.510	2,563.3217	260,763.5109	8,409.8481	855,523.3299	International	4.5201	1.000 004 520	+0° 32' 25.90"
Crow	AJ9020	SHR E	44° 45' 45.94312" N	106° 58' 38.44399" W	44.762 761 978	-106.977 345 553	1197.665	1,708.9090	261,181.3062	5,606.6568	856,894.0492	International	6.2191	1.000 006 219	+0° 32' 38.76"
Crow	AJ9021	SHR ARP	44° 46' 26.66483" N	106° 58' 40.30028" W	44.774 073 564	-106.977 861 189	1195.095	2,965.7340	261,128.5440	9,730.0985	856,720.9447	International	6.5428	1.000 006 543	+0° 32' 37.84"
Crow	DE5402	6S8 C	45° 42' 12.75295" N	108° 45' 45.43118" W	45.703 542 486	-108.762 619 772	1050.874	106,487.6457	121,129.6907	349,368.9162	397,407.1217	International	59.6744	1.000 059 674	-0° 43' 29.30"
Crow	DE5419	6S8 E	45° 42' 28.97897" N	108° 45' 14.52750" W	45.708 049 714	-108.754 035 417	1043.062	106,980.2537	121,804.5871	350,985.0844	399,621.3489	International	59.5967	1.000 059 597	-0° 43' 07.38"
Crow	DF5242	QC2	45° 47' 29.07590" N	108° 37' 54.87054" W	45.791 409 972	-108.631 908 483	997.594	116,134.7345	131,418.1276	381,019.4701	431,161.8361	International	49.3892	1.000 049 389	-0° 37' 55.85"
Crow	DO7252	00U A	45° 44' 43.39107" N	107° 39' 41.47537" W	45.745 386 408	-107.661 520 936	903.306	110,644.0597	206,886.2684	363,005.4451	678,760.7231	International	6.9679	1.000 006 968	+0° 03' 48.14"
Crow	DO7257	00U B	45° 44' 43.40241" N	107° 39' 12.68014" W	45.745 389 558	-107.653 522 261	899.159	110,645.1295	207,508.7997	363,008.9551	680,803.1485	International	7.7280	1.000 007 728	+0° 04' 08.77"
Crow	DO7258	00U C	45° 44' 43.77719" N	107° 40' 00.59064" W	45.745 493 664	-107.666 830 733	906.586	110,655.5391	206,472.9979	363,043.1074	677,404.8488	International	6.3859	1.000 006 386	+0° 03' 34.45"
Crow	PW0132	SHERIDAN AIRPORT	44° 46' 21.66272" N	106° 58' 05.73995" W	44.772 684 089	-106.968 261 097	1188.327	2,818.5614	261,890.0468	9,247.2488	859,219.3136	International	8.7549	1.000 008 755	+0° 33' 02.13"
Crow	PX0523	POWELL MUN APT AP STA A	44° 52' 32.98570" N	108° 47' 58.62181" W	44.875 829 361	-108.799 617 169	1509.669	14,521.3678	117,050.1496	47,642.2826	384,022.8005	International	-4.1367	0.999 995 863	-0° 44' 26.24"
Crow	QV0153	Z 487	45° 37' 48.73543" N	107° 28' 06.11234" W	45.630 204 286	-107.468 364 539	904.356	97,875.0039	221,964.5385	321,112.2176	728,230.1132	International	12.1459	1.000 012 146	+0° 12' 04.77"
Crow	QV0262	N 487	45° 43' 20.14115" N	107° 37' 18.63354" W	45.722 261 431	-107.621 842 650	874.665	108,077.6095	209,978.5212	354,585.3330	688,905.9095	International	12.0977	1.000 012 098	+0° 05' 30.32"
Crow	QV0271	S 487	45° 43' 01.90270" N	107° 32' 29.92081" W	45.717 195 194	-107.541 644 669	877.456	107,527.5640	216,224.3205	352,780.7218	709,397.3771	International	13.6708	1.000 013 671	+0° 08' 56.98"
Crow	QW0003	D 484	45° 48' 09.97591" N	108° 27' 00.79858" W	45.802 771 086	-108.450 221 828	935.491	117,257.8379	145,558.0883	384,704.1925	477,552.7832	International	37.7534	1.000 037 753	-0° 30' 07.32"
Crow	QW0140	T 44	45° 42' 42.70680" N	108° 38' 48.41318" W	45.711 863 000	-108.646 781 439	966.868	107,304.9575	130,162.3809	352,050.3856	427,041.9322	International	56.3408	1.000 056 341	-0° 38' 31.11"
Crow	QW0149	G 483	45° 45' 19.73425" N	108° 33' 24.32548" W	45.755 481 736	-108.556 757 078	953.398	112,079.1046	137,221.9873	367,713.5979	450,203.3706	International	46.9507	1.000 046 951	-0° 34' 40.64"
Crow	QW0189	K 44	45° 48' 51.86007" N	108° 41' 07.75931" W	45.814 405 575	-108.685 488 697	1055.635	118,738.3791	127,281.3819	389,561.6112	417,589.8357	International	47.4721	1.000 047 472	-0° 40' 15.08"
Crow	QW0201	P 44	45° 44' 26.07004" N	108° 42' 35.41023" W	45.740 575 011	-108.709 836 175	1002.429	110,553.5998	125,290.2374	362,708.6607	411,057.2092	International	59.4185	1.000 059 418	-0° 41' 14.83"
Crow	QW0203	Q 44	45° 42' 36.22243" N	108° 42' 33.58557" W	45.710 061 786	-108.709 329 325	994.143	107,161.2145	125,289.0212	351,578.7877	411,053.2193	International	60.7195	1.000 060 720	-0° 41' 12.24"
Crow	QW0389	Y 538	45° 42' 49.76774" N	108° 47' 23.97113" W	45.713 824 372	-108.789 991 981	1099.157	107,657.9328	119,012.5978	353,208.4408	390,461.2789	International	56.2635	1.000 056 264	-0° 44' 40.31"
Crow	QW0402	AIRPORT 2	45° 48' 05.78682" N	108° 32' 13.75160" W	45.801 607 450	-108.537 153 222	1068.009	117,191.3840	138,797.9505	384,486.1680	455,373.8535	International	26.5851	1.000 026 585	-0° 33' 51.66"
Crow	QW0442	N 560	45° 30' 03.78388" N	108° 51' 48.56965" W	45.501 051 078	-108.863 491 569	1060.035	84,083.1293	112,960.4815	275,863.2852	370,605.2544	International	74.8899	1.000 074 890	-0° 47' 39.34"
Crow	QW0468	N 564	45° 08' 45.65953" N	108° 47' 50.45403" W	45.146 016 536	-108.797 348 342	1245.903	44,549.9411	117,617.7390	146,161.2241	385,884.9705	International	36.0585	1.000 036 058	-0° 44' 33.05"
Crow	QW0479	B 565	45° 00' 26.97063" N	108° 37' 27.61190" W	45.007 491 842	-108.624 336 639	1297.963	28,991.1616	131,060.1025	95,115.3596	429,987.2128	International	2.9039	1.000 002 904	-0° 37' 06.08"
Flathead 83	AA9693	CAROLE	47° 51' 06.81273" N	113° 49' 22.88737" W	47.851 892 425	-113.823 024 269	957.440	89,237.2568	196,928.9664	292,773.1524	646,092.4095	International	-7.9418	0.999 992 058	+0° 28' 01.31"
Flathead 83	AB3811	PIEGAN	48° 56' 23.68774" N	113° 22' 21.02986" W	48.939 913 261	-113.372 508 294	1299.508	210,607.6703	228,949.8479	690,970.0471	751,147.7950	International	59.7529	1.000 059 753	+0° 48' 31.77"
Flathead 83	AB7735	LOFTON	48° 24' 50.15904" N	114° 03' 01.66217" W	48.413 933 067	-114.050 461 714	946.007	151,626.6360	179,580.5305	497,462.7165	589,174.9690	International	0.6385	1.000 000 639	+0° 17' 54.64"
Flathead 83	AD9850	FCA ARP	48° 18' 48.97607" N	114° 15' 14.38294" W	48.313 604 464	-114.253 995 261	889.140	140,410.2728	164,540.1073	460,663.6247	539,829.7482	International	2.9523	1.000 002 952	+0° 08' 47.10"
Flathead 83	AD9851	AP STA A2 FCA	48° 19' 09.32035" N	114° 14' 48.98593" W	48.319 255 653	-114.246 940 536	890.453	141,040.1138	165,061.7789	462,730.0321	541,541.2693	International	2.8529	1.000 002 853	+0° 09' 06.07"
Flathead 83	AD9852	STA C2 FCA	48° 18' 03.82376" N	114° 15' 50.00451" W	48.301 062 156	-114.263 890 142	885.734	139,013.5919	163,809.4670	456,081.3383	537,432.6346	International	3.3339	1.000 003 334	+0° 08' 20.48"
Flathead 83	AI7863	SHERBURNE 2	48° 51' 07.53055" N	113° 24' 59.52878" W	48.852 091 819	-113.416 535 772	1352.441	200,795.0827	225,856.0751	658,776.5181	740,997.6218	International	31.1948	1.000 031 195	+0° 46' 29.68"
Flathead 83	DL7171	6 JJH	48° 13' 34.71499" N	114° 23' 41.81604" W	48.226 309 719	-114.394 948 900	920.761	130,684.9859	154,090.8090	428,756.5153	505,547.2736	International	-1.2503	0.999 998 750	+0° 02' 28.41"
Flathead 83	DL7172	15 JJH	48° 16' 09.48179" N	114° 09' 51.63439" W	48.269 300 497	-114.164 342 886	917.378	135,504.0582	171,209.0577	444,567.1202	561,709.5069	International	-1.1877	0.999 998 812	+0° 12' 47.80"
Flathead 83	DL7173	A H SMALL	48° 13' 31.73788" N	114° 09' 53.81610" W	48.225 482 744	-114.164 948 917	892.147	130,630.9101	171,182.1617	428,579.1013	561,621.2653	International	2.3510	1.000 002 351	+0° 12' 46.07"
Flathead 83	DL7175	HEIDI	48° 15' 24.05580" N	114° 19' 42.44364" W	48.256 682 167	-114.328 456 567	904.891	134,068.4217	159,026.4286	439,857.0266	521,740.2512	International	0.3152	1.000 000 315	+0° 05' 26.99"
Flathead 83	DL7176	JMS 53	48° 03' 56.95192" N	114° 04' 57.64496" W	48.065 819 978	-114.082 679 156	905.400	112,901.1586	177,380.5210	370,410.6252	581,957.0900	International	0.1981	1.000 000 198	+0° 16' 26.63"
Flathead 83	DL7177	R D ALTENBURG	48° 05' 46.31604" N	114° 14' 06.79518" W	48.096 198 900	-114.235 220 883	870.655	116,236.3964	166,000.5259	381,353.0066	544,621.1480	International	6.6375	1.000 006 638	+0° 09' 37.71"
Flathead 83	DL7178	RAY KUHNS	48° 19' 39.76464" N	114° 25' 12.87138" W	48.327 712 400	-114.420 242 050	919.733	141,961.0940	152,206.9117	465,751.6206	499,366.5081	International	-1.9968	0.999 998 003	+0° 01' 20.13"
Flathead 83	DL7179	SMITH LAKE	48° 08' 08.91434" N	114° 27' 29.43133" W	48.135 809 539	-114.458 175 369	947.410	120,619.0161	149,391.4751	395,731.6802	490,129.5115	International	-1.8875	0.999 998 113	-0° 00' 20.88"
Flathead 83	DL7180	STUMPTOWN	48° 24' 36.47958" N	114° 18' 30.39606" W	48.410 133 217	-114.308 443 350	913.668	151,136.6363	160,481.2002	495,855.1059	526,513.1241	International	-0.2514	0.999 999 749	+0° 06' 20.98"
Flathead 83	DL7181	STV 192	48° 16' 58.67168" N	114° 19' 51.75804" W	48.282 964 356	-114.331 043 900	908.076	136,990.9950	158,829.7457	449,445.5216	521,094.9660	International	-0.2879	0.999 999 712	+0° 05' 20.01"
Flathead 83	DL8524	88M B	48° 58' 06.50531" N	115° 04' 40.16772" W	48.968 473 697	-115.077 824 367	794.520	213,414.1486	104,025.0993	700,177.6529	341,289.6960	International	17.8607	1.000 017 861	-0° 28' 16.50"
Flathead 83	DL8526	88M C	48° 57' 50.05526" N	115° 04' 49.40073" W	48.963 904 239	-115.080 389 092	793.230	212,907.4762	103,833.0977	698,515.3419	340,659.7694	International	18.0012	1.000 018 001	-0° 28' 23.48"
Flathead 83	SU0290	Y 382	47° 49' 59.35731" N	114° 35' 04.74604" W	47.833 154 808	-114.584 651 678	877.775	86,970.2155	139,918.0479	285,335.3528	459,048.7135	International	32.9933	1.000 032 993	-0° 05' 55.79"
Flathead 83	TN0137	V 115	48° 11' 02.95747" N	114° 06' 41.98878" W	48.184 154 853	-114.111 663 550	882.715	126,050.9530	175,162.0281	413,552.9953	574,678.5699	International	3.8383	1.000 003 838	+0° 15' 08.97"
Flathead 83	TN0140	Y 115	48° 12' 40.19413" N	114° 13' 46.70049" W	48.211 165 036	-114.229 639 025	878.514	129,022.8089	166,379.6300	423,303.1787	545,864.9279	International	4.3229	1.000 004 323	+0° 09' 52.42"
Flathead 83	TN0148	C 381	48° 11' 20.54531" N	114° 23' 43.01530" W	48.189 040 364	-114.395 282 028	929.781	126,540.2328	154,069.0205	415,158.2440	505,475.7890	International	-1.9651	0.999 998 035	+0° 02' 27.69"
Flathead 83	TN0420	A 499	48° 21' 55.24759" N	114° 10' 05.87265" W	48.365 346 553	-114.168 297 958	903.867	146,184.4157	170,876.1881	479,607.6629	560,617.4151	International	2.5923	1.000 002 592	+0° 12' 37.60"

Table 4.2, cont.

RMCRS Zone	NGS PID	Designation	Latitude (DMS)	Longitude (DMS)	Latitude (dec deg)	Longitude (dec deg)	Ellipsoid height (m)	Northing (m)	Easting (m)	Northing (ft)	Easting (ft)	Foot type	Distortion (ppm)	Combined scale factor	Convergence angle
Flathead 83	TN0426	C 428	48° 20' 30.13078" N	114° 13' 46.97478" W	48.341 702 994	-114.229 715 217	894.168	143,540.0569	166,332.2809	470,931.9453	545,709.5830	International	2.7189	1.000 002 719	+0° 09' 52.43"
Flathead 83	TN0428	A 507	48° 18' 30.35478" N	114° 15' 04.90086" W	48.308 431 883	-114.251 361 350	888.341	139,835.5234	164,736.9865	458,777.9638	540,475.6775	International	3.0513	1.000 003 051	+0° 08' 54.16"
Flathead 83	TN0442	A 442	48° 09' 31.33880" N	114° 18' 32.42069" W	48.158 705 222	-114.309 005 747	878.927	123,174.8774	160,490.9802	404,117.0520	526,545.2107	International	5.2873	1.000 005 287	+0° 06' 19.49"
Flathead 83	TN0482	P 501	48° 25' 58.13451" N	114° 28' 29.79806" W	48.432 815 142	-114.474 943 906	911.157	153,649.8105	148,153.9132	504,100.4281	486,069.2692	International	-0.7890	0.999 999 211	-0° 01' 07.16"
Flathead 83	TN0509	M 502	48° 40' 32.29458" N	114° 46' 16.09328" W	48.675 637 383	-114.771 137 022	993.110	180,705.0782	126,346.2326	592,864.4297	414,521.7604	International	-13.6053	0.999 986 395	-0° 14' 26.21"
Flathead 83	TN0543	H 503	48° 57' 48.95679" N	115° 03' 29.68150" W	48.963 599 108	-115.058 244 861	813.257	212,860.3822	105,454.5085	698,360.8340	345,979.3585	International	15.0319	1.000 015 032	-0° 27' 23.38"
Flathead 83	TN0810	MONTFORD	48° 13' 33.00709" N	114° 10' 06.07926" W	48.225 835 303	-114.168 355 350	892.409	130,669.1835	170,928.8869	428,704.6703	560,790.3115	International	2.2946	1.000 002 295	+0° 12' 36.93"
Flathead 83	TN0877	AIRP	48° 55' 08.78401" N	115° 05' 14.82819" W	48.919 106 669	-115.087 452 275	802.113	207,929.3627	103,274.2298	682,182.9486	338,826.2131	International	16.3190	1.000 016 319	-0° 28' 42.71"
Fort Belknap	AB7733	Q 93 RESET	48° 14' 51.62144" N	110° 03' 21.79456" W	48.247 672 622	-110.056 054 044	798.669	123,113.7657	84,428.7975	403,916.5543	276,997.3671	International	4.4803	1.000 004 480	-1° 09' 55.50"
Fort Belknap	AB7734	U 95 RESET	47° 54' 36.62343" N	110° 32' 43.99931" W	47.910 173 175	-110.545 555 364	778.985	86,450.2190	47,076.7293	283,629.3274	154,451.2117	International	50.5354	1.000 050 535	-1° 31' 55.31"
Fort Belknap	SR0914	K 526	47° 55' 25.80011" N	108° 21' 16.24148" W	47.923 833 364	-108.354 511 522	916.925	85,935.0515	210,874.9450	281,939.1453	691,846.9326	International	26.5129	1.000 026 513	+0° 06' 32.27"
Fort Belknap	SR1099	LEROY	47° 53' 07.15674" N	109° 22' 28.12876" W	47.885 321 317	-109.374 480 211	1077.282	82,015.7433	134,586.9478	269,080.5225	441,558.2275	International	8.3064	1.000 008 306	-0° 39' 17.81"
Fort Belknap	TJ0451	A 439	48° 57' 29.66092" N	107° 49' 05.01870" W	48.958 239 144	-107.818 060 750	798.624	201,187.5266	249,947.3507	660,064.0637	820,037.2398	International	26.8316	1.000 026 832	+0° 30' 38.67"
Fort Belknap	TK0168	C 280	48° 17' 09.63500" N	109° 06' 03.81547" W	48.286 009 722	-109.101 059 853	1024.026	126,377.0598	155,388.9775	414,622.8995	509,806.3568	International	-33.5414	0.999 966 459	-0° 27' 00.60"
Fort Belknap	TK0350	S 512	48° 34' 12.15668" N	108° 56' 03.11230" W	48.570 043 522	-108.934 197 861	705.988	157,880.7727	167,952.6999	517,981.5379	551,025.9183	International	10.1012	1.000 010 101	-0° 19' 30.70"
Fort Belknap	TK0356	L 512	48° 31' 25.93183" N	108° 44' 35.25025" W	48.523 869 953	-108.743 125 069	700.675	152,683.2045	182,039.0252	500,929.1485	597,240.8964	International	10.2743	1.000 010 274	-0° 10' 55.52"
Fort Belknap	TK0386	A 513	48° 22' 17.85410" N	108° 06' 12.93131" W	48.371 626 139	-108.103 592 031	674.123	135,799.3571	229,372.4706	445,535.9485	752,534.3523	International	16.8473	1.000 016 847	+0° 17' 48.81"
Fort Belknap	TL0016	T 369	48° 33' 29.31751" N	110° 25' 28.11391" W	48.558 143 753	-110.424 476 086	909.146	158,253.3521	57,939.0906	519,203.9110	190,088.8799	International	-21.9657	0.999 978 034	-1° 26' 28.85"
Ft Peck Assiniboine	AD9826	GGW ARP	48° 12' 47.91642" N	106° 37' 08.77049" W	48.213 310 117	-106.619 102 914	681.268	87,259.1472	116,824.1914	286,283.2912	383,281.4680	International	15.4110	1.000 015 411	-0° 50' 09.59"
Ft Peck Assiniboine	AD9828	GGW AP STA A	48° 13' 07.63480" N	106° 37' 29.35560" W	48.218 787 444	-106.624 821 000	679.804	87,874.4217	116,408.1656	288,301.9084	381,916.5538	International	15.4456	1.000 015 446	-0° 50' 24.97"
Ft Peck Assiniboine	DL6483	OLF A	48° 05' 41.88510" N	105° 34' 25.05804" W	48.094 968 083	-105.573 627 233	587.917	73,494.4744	194,514.9288	241,123.6036	638,172.3385	International	36.4683	1.000 036 468	-0° 03' 18.01"
Ft Peck Assiniboine	DL6484	OLF B	48° 05' 46.09279" N	105° 34' 54.18687" W	48.096 136 886	-105.581 718 575	587.453	73,625.0632	193,912.2799	241,552.0446	636,195.1439	International	36.4568	1.000 036 457	-0° 03' 39.76"
Ft Peck Assiniboine	DL6485	OLF C	48° 05' 28.68054" N	105° 33' 48.36248" W	48.091 300 150	-105.563 434 022	587.035	73,085.8982	195,273.9636	239,783.1305	640,662.6104	International	36.8734	1.000 036 873	-0° 02' 50.59"
Ft Peck Assiniboine	TH0151	Z 63	48° 47' 30.71489" N	104° 46' 30.38803" W	48.791 865 247	-104.775 107 786	612.910	151,247.7191	253,269.6274	496,219.5507	830,937.0978	International	55.9715	1.000 055 971	+0° 32' 29.45"
Ft Peck Assiniboine	TH0213	X 46	48° 31' 10.92849" N	105° 25' 48.93004" W	48.519 702 358	-105.430 258 344	720.473	120,728.8431	205,152.6539	396,092.0048	673,073.0113	International	12.3663	1.000 012 366	+0° 03' 07.56"
Ft Peck Assiniboine	TH0255	T 272	48° 28' 34.27623" N	105° 02' 23.82054" W	48.476 187 842	-105.039 950 150	781.404	115,989.1090	234,018.2369	380,541.6963	767,776.3677	International	0.6385	1.000 000 638	+0° 20' 37.21"
Ft Peck Assiniboine	TH0302	Q 360	48° 27' 02.61242" N	105° 52' 11.82274" W	48.450 725 672	-105.869 950 761	867.552	113,121.3701	172,630.3945	371,133.1039	566,372.6853	International	-13.8690	0.999 986 131	-0° 16' 34.90"
Ft Peck Assiniboine	TH0306	N 360	48° 27' 01.73833" N	105° 54' 29.93917" W	48.450 482 869	-105.908 316 436	846.168	113,108.7682	169,791.9164	371,091.7593	557,060.0932	International	-10.5268	0.999 989 473	-0° 18' 18.08"
Ft Peck Assiniboine	TH0406	T 541	48° 03' 33.33704" N	105° 59' 59.83429" W	48.059 260 289	-105.999 953 969	616.040	69,642.3858	162,728.8739	228,485.5178	533,887.3814	International	34.8322	1.000 034 832	-0° 22' 24.52"
Ft Peck Assiniboine	TH0424	K 542	48° 06' 02.97312" N	105° 37' 20.96571" W	48.100 825 867	-105.622 490 475	593.319	74,150.5512	190,875.7647	243,276.0865	626,232.8239	International	35.2039	1.000 035 204	-0° 05' 29.41"
Ft Peck Assiniboine	TH0426	M 542	48° 06' 39.81322" N	105° 34' 44.03908" W	48.111 059 228	-105.578 899 744	590.887	75,284.3049	194,123.9789	246,995.7509	636,889.6946	International	34.8799	1.000 034 880	-0° 03' 32.18"
Ft Peck Assiniboine	TH0447	POPLAR W BASE	48° 06' 23.76337" N	105° 12' 02.61195" W	48.106 600 936	-105.200 725 542	578.956	74,828.9787	222,290.2054	245,501.8986	729,298.5741	International	37.0530	1.000 037 053	+0° 13' 24.84"
Ft Peck Assiniboine	TJ0099	P 354	48° 01' 24.27852" N	106° 19' 43.48803" W	48.023 410 700	-106.328 746 675	701.081	65,868.2430	138,175.3570	216,103.1596	453,331.2236	International	24.6744	1.000 024 674	-0° 37' 08.74"
Ft Peck Assiniboine	TJ0152	Q 256	48° 10' 29.59917" N	106° 36' 32.62985" W	48.174 888 658	-106.609 063 847	621.674	82,975.9911	117,508.4971	272,230.9420	385,526.5653	International	26.3724	1.000 026 372	-0° 49' 42.59"
Ft Peck Assiniboine	TJ0232	E 91	48° 31' 20.48872" N	106° 33' 45.74979" W	48.522 357 978	-106.562 708 275	812.860	121,565.7445	121,491.5676	398,837.7445	398,594.3820	International	-1.9594	0.999 998 041	-0° 47' 37.93"
Ft Peck Assiniboine	TJ0528	B 540	48° 12' 26.95629" N	106° 37' 37.59739" W	48.207 487 858	-106.627 110 386	675.517	86,620.4501	116,219.5750	284,187.8283	381,297.8182	International	16.5293	1.000 016 529	-0° 50' 31.13"
Ft Peck Assiniboine	TJ0590	KINTYRE	48° 09' 40.89729" N	106° 11' 19.41779" W	48.161 360 358	-106.188 727 164	689.177	81,105.1871	148,758.2812	266,093.1336	488,052.1035	International	16.4711	1.000 016 471	-0° 30' 52.19"
Ft Peck Assiniboine	TJ0615	GLASGOW 2	48° 12' 57.73956" N	106° 36' 51.19599" W	48.216 038 767	-106.614 221 108	685.426	87,557.2805	117,191.4076	287,261.4191	384,486.2453	International	14.6612	1.000 014 661	-0° 49' 56.46"
Fort Peck Sioux	AD9826	GGW ARP	48° 12' 47.91642" N	106° 37' 08.77049" W	48.213 310 117	-106.619 102 914	681.268	37,259.5293	16,826.6864	122,242.5503	55,205.6641	International	-14.5859	0.999 985 414	-0° 50' 09.59"
Fort Peck Sioux	AD9828	GGW AP STA A	48° 13' 07.63480" N	106° 37' 29.35560" W	48.218 787 444	-106.624 821 000	679.804	37,874.7854	16,410.6730	124,261.1069	53,840.7908	International	-14.5512	0.999 985 449	-0° 50' 24.97"
Fort Peck Sioux	DJ5119	CULBERTSON DISCOVERY II	48° 08' 57.18252" N	104° 29' 53.24903" W	48.149 217 367	-104.498 124 731	568.855	30,012.2852	174,554.4124	98,465.5026	572,685.0799	International	5.9855	1.000 005 986	+0° 44' 54.33"
Fort Peck Sioux	DL6483	OLF A	48° 05' 41.88510" N	105° 34' 25.05804" W	48.094 968 083	-105.573 627 233	587.917	23,495.2694	94,515.0933	77,084.2173	310,088.8888	International	6.4708	1.000 006 471	-0° 03' 18.01"
Fort Peck Sioux	DL6484	OLF B	48° 05' 46.09279" N	105° 34' 54.18687" W	48.096 136 886	-105.581 718 575	587.453	23,625.8543	93,912.4625	77,512.6455	308,111.7535	International	6.4593	1.000 006 459	-0° 03' 39.76"
Fort Peck Sioux	DL6485	OLF C	48° 05' 28.68054" N	105° 33' 48.36248" W	48.091 300 150	-105.563 434 022	587.035	23,086.7055	95,274.1054	75,743.7844	312,579.0860	International	6.8759	1.000 006 876	-0° 02' 50.59"
Fort Peck Sioux	TH0013	B 203	48° 52' 46.70211" N	104° 07' 31.26801" W	48.879 639 475	-104.125 352 225	645.647	111,660.4321	200,835.8498	366,340.0005	658,910.2683	International	34.3062	1.000 034 306	+1° 01' 36.83"
Fort Peck Sioux	TH0151	Z 63	48° 47' 30.71489" N	104° 46' 30.38803" W	48.791 865 247	-104.775 107 786	612.910	101,246.1818	153,268.0295	332,172.5125	502,847.8658	International	25.9734	1.000 025 973	+0° 32' 29.45"
Fort Peck Sioux	TH0213	X 46	48° 31' 10.92849" N	105° 25' 48.93004" W	48.519 702 358	-105.430 258 344	720.473	70,728.2213	105,152.4993	232,047.9700	344,988.5147	International	-17.6304	0.999 982 370	+0° 03' 07.56"
Fort Peck Sioux	TH0255	T 272	48° 28' 34.27623" N	105° 02' 23.82054" W	48.476 187 842	-105.039 950 150	781.404	65,988.6294	134,017.2165	216,498.1280	439,689.0304	International	-29.3580	0.999 970 642	+0° 20' 37.21"
Fort Peck Sioux	TH0302	Q 360	48° 27' 02.61242" N	105° 52' 11.82274" W	48.450 725 672	-105.869 950 761	867.552	63,120.9765	72,631.2155	207,089.8179	238,291.3893	International	-43.8650	0.999 956 135	-0° 16' 34.90"
Fort Peck Sioux	TH0306	N 360	48° 27' 01.73833" N	105° 54' 29.93917" W	48.450 482 869	-105.908 316 436	846.168	63,108.3750	69,792.8225	207,048.4745	228,979.0766	International	-40.5229	0.999 959 477	-0° 18' 18.08"
Fort Peck Sioux	TH0406	T 541	48° 03' 33.33704" N	105° 59' 59.83429" W	48.059 260 289	-105.999 953 969	616.040	19,643.2964	62,729.9919	64,446.5106	205,807.0599	International	4.8348	1.000 004 835	-0° 22' 24.52"
Fort Peck Sioux	TH0424	K 542	48° 06' 02.97312" N	105° 37' 20.96571" W	48.100 825 867	-105.622 490 475	593.319	24,151.3265	90,876.0384	79,236.6356	298,149.7324	International	5.2064	1.000 005 206	-0° 05' 29.41"

Table 4.2, cont.

RMCRS Zone	NGS PID	Designation	Latitude (DMS)	Longitude (DMS)	Latitude (dec deg)	Longitude (dec deg)	Ellipsoid height (m)	Northing (m)	Easting (m)	Northing (ft)	Easting (ft)	Foot type	Distortion (ppm)	Combined scale factor	Convergence angle
Fort Peck Sioux	TH0426	M 542	48° 06' 39.81322" N	105° 34' 44.03908" W	48.111 059 228	-105.578 899 744	590.887	25,285.0463	94,124.1552	82,956.1885	308,806.2834	International	4.8825	1.000 004 882	-0° 03' 32.18"
Fort Peck Sioux	TH0447	POPLAR W BASE	48° 06' 23.76337" N	105° 12' 02.61195" W	48.106 600 936	-105.200 725 542	578.956	24,829.7337	122,289.5368	81,462.3810	401,212.3910	International	7.0555	1.000 007 056	+0° 13' 24.84"
Fort Peck Sioux	TH0551	M 548	48° 08' 57.09305" N	104° 29' 38.62173" W	48.149 192 514	-104.494 061 592	568.428	30,013.4793	174,856.7892	98,469.4202	573,677.1300	International	6.0538	1.000 006 054	+0° 45' 05.26"
Fort Peck Sioux	TJ0099	P 354	48° 01' 24.27852" N	106° 19' 43.48803" W	48.023 410 700	-106.328 746 675	701.081	15,869.2669	38,177.2115	52,064.5239	125,253.3185	International	-5.3227	0.999 994 677	-0° 37' 08.74"
Fort Peck Sioux	TJ0152	Q 256	48° 10' 29.59917" N	106° 36' 32.62985" W	48.174 888 658	-106.609 063 847	621.674	32,976.5018	17,510.9716	108,190.6226	57,450.6941	International	-3.6248	0.999 996 375	-0° 49' 42.59"
Fort Peck Sioux	TJ0232	E 91	48° 31' 20.48872" N	106° 33' 45.74979" W	48.522 357 978	-106.562 708 275	812.860	71,565.0976	21,493.9226	234,793.6274	70,518.1188	International	-31.9557	0.999 968 044	-0° 47' 37.93"
Fort Peck Sioux	TJ0528	B 540	48° 12' 26.95629" N	106° 37' 37.59739" W	48.207 487 858	-106.627 110 386	675.517	36,620.8514	16,222.0881	120,147.1502	53,222.0739	International	-13.4676	0.999 986 532	-0° 50' 31.13"
Fort Peck Sioux	TJ0590	KINTYRE	48° 09' 40.89729" N	106° 11' 19.41779" W	48.161 360 358	-106.188 727 164	689.177	31,105.7539	48,759.8182	102,052.9984	159,973.1569	International	-13.5258	0.999 986 474	-0° 30' 52.19"
Fort Peck Sioux	TJ0615	GLASGOW 2	48° 12' 57.73956" N	106° 36' 51.19599" W	48.216 038 767	-106.614 221 108	685.426	37,557.6538	17,193.8915	123,220.6488	56,410.4053	International	-15.3356	0.999 984 664	-0° 49' 56.46"
Interstate 83	AD9833	GDV A	47° 08' 41.32801" N	104° 48' 41.08288" W	47.144 813 336	-104.811 411 911	732.596	235,554.4090	187,755.5718	772,816.3026	615,995.9704	International	-6.7138	0.999 993 286	-0° 07' 05.76"
Interstate 83	AD9870	MLS C	46° 25' 39.39088" N	105° 53' 05.86340" W	46.427 608 578	-105.884 962 056	784.524	156,547.9632	105,068.0051	513,608.8032	344,711.3028	International	8.1449	1.000 008 145	-0° 53' 45.18"
Interstate 83	DH9107	GDV D	47° 08' 23.74760" N	104° 48' 43.80032" W	47.139 929 889	-104.812 166 756	732.544	235,011.5595	187,697.1846	771,035.3002	615,804.4114	International	-6.7949	0.999 993 205	-0° 07' 07.71"
Interstate 83	RT0067	Y 56	46° 24' 17.44756" N	104° 25' 34.32467" W	46.404 846 544	-104.426 201 297	846.504	153,297.1907	217,210.8506	502,943.5391	712,634.0244	International	5.1149	1.000 005 115	+0° 09' 39.74"
Interstate 83	RT0181	W 156	46° 46' 26.87106" N	105° 18' 09.77259" W	46.774 130 850	-105.302 714 608	682.483	194,535.8233	150,143.4953	638,240.8900	492,596.7693	International	7.0025	1.000 007 003	-0° 28' 32.52"
Interstate 83	RT0432	X 569	46° 20' 22.62895" N	105° 46' 31.25874" W	46.339 619 153	-105.775 349 650	726.398	146,641.0399	113,354.0333	481,105.7741	371,896.4346	International	5.2590	1.000 005 259	-0° 48' 58.64"
Interstate 83	RT0434	V 569	46° 18' 50.61676" N	105° 45' 44.79579" W	46.314 060 211	-105.762 443 275	729.863	143,785.8369	114,307.6722	471,738.3102	375,025.1712	International	2.8743	1.000 002 874	-0° 48' 24.71"
Interstate 83	RT0456	DAMON	46° 54' 28.45680" N	104° 02' 45.59489" W	46.907 904 667	-104.045 998 581	857.094	209,378.9064	246,021.6859	686,938.6691	807,157.7622	International	-1.6423	0.999 998 358	+0° 26' 30.96"
Interstate 83	RT0511	MILES CITY GPS	46° 23' 46.99516" N	105° 51' 38.93030" W	46.396 387 544	-105.860 813 972	704.491	153,048.6724	106,870.9441	502,128.1902	350,626.4571	International	17.0348	1.000 017 035	-0° 52' 41.75"
Interstate 83	RT0512	MILES CITY NCMN	46° 23' 47.52964" N	105° 51' 38.97756" W	46.396 536 011	-105.860 827 100	704.110	153,065.1914	106,870.1875	502,182.3866	350,623.9746	International	17.1042	1.000 017 104	-0° 52' 41.79"
Interstate 83	RT0513	AP STA A MLS	46° 25' 57.58765" N	105° 52' 38.06413" W	46.432 663 236	-105.877 240 036	784.090	157,100.5905	105,670.2909	515,421.8847	346,687.3061	International	7.9512	1.000 007 951	-0° 53' 25.22"
Interstate 83	RT0514	MLS D	46° 25' 17.73617" N	105° 53' 45.78586" W	46.421 593 381	-105.896 051 628	784.509	155,892.7002	104,205.0555	511,458.9903	341,880.1033	International	8.6049	1.000 008 605	-0° 54' 13.87"
Interstate 83	RT0515	3U6 D	46° 20' 51.21795" N	104° 15' 40.76936" W	46.347 560 542	-104.261 324 822	889.079	146,977.3500	229,922.2067	482,209.1534	754,337.9486	International	18.8662	1.000 018 866	+0° 16' 49.74"
Interstate 83	RT0516	3U6 B	46° 20' 32.91794" N	104° 15' 12.94622" W	46.342 477 206	-104.253 596 172	890.334	146,415.1552	230,520.0428	480,364.6825	756,299.3529	International	19.9743	1.000 019 974	+0° 17' 09.81"
Interstate 83	RT0517	3U6 A	46° 21' 07.67601" N	104° 15' 58.94239" W	46.352 132 225	-104.266 372 886	886.299	147,483.7138	229,531.1102	483,870.4522	753,054.8234	International	18.3424	1.000 018 342	+0° 16' 36.67"
Interstate 83	RU0003	R 86	46° 35' 16.95392" N	106° 05' 24.69645" W	46.588 042 756	-106.090 193 458	794.150	174,648.9138	89,618.2766	572,995.1240	294,023.2172	International	38.4550	1.000 038 455	-1° 02' 43.38"
Interstate 83	SP0076	U 152	47° 05' 58.09648" N	104° 49' 24.96825" W	47.099 471 244	-104.823 602 292	657.401	230,515.0317	186,819.6430	756,282.9125	612,925.3381	International	4.4087	1.000 004 409	-0° 07' 37.55"
Interstate 83	SP0077	T 164	47° 06' 10.45657" N	104° 50' 38.12089" W	47.102 904 603	-104.843 922 469	661.988	230,900.3904	185,277.8263	757,547.2125	607,866.8841	International	4.2461	1.000 004 246	-0° 08' 31.11"
Interstate 83	SP0192	W 162	47° 22' 12.80183" N	105° 38' 49.93777" W	47.370 222 731	-105.647 204 936	743.765	261,085.9298	124,673.5885	856,581.1344	409,034.0829	International	73.3477	1.000 073 348	-0° 43' 52.86"
Interstate 83	SP0283	M 550	47° 26' 56.54800" N	104° 20' 57.65004" W	47.449 041 111	-104.349 347 233	590.144	269,411.9647	222,676.7016	883,897.5221	730,566.6063	International	12.6430	1.000 012 643	+0° 13' 14.36"
Interstate 83	SP0300	P 157	47° 40' 29.70219" N	104° 10' 28.89230" W	47.674 917 275	-104.174 692 306	570.630	294,592.9805	235,696.6169	966,512.4033	773,282.8639	International	15.8946	1.000 015 895	+0° 20' 57.77"
Interstate 83	SP0338	Q 552	47° 06' 45.36359" N	104° 38' 48.19539" W	47.112 600 997	-104.646 720 942	633.787	231,960.2411	200,248.8944	761,024.4130	656,984.5617	International	5.7944	1.000 005 794	+0° 00' 08.59"
Interstate 83	SP0401	LONE TREE	47° 42' 38.31478" N	104° 11' 05.94607" W	47.710 642 994	-104.184 985 019	583.240	298,560.8077	234,899.9437	979,530.2090	770,669.1068	International	14.3607	1.000 014 361	+0° 20' 30.26"
Milk River	AB5603	7 JFB	48° 41' 48.62668" N	111° 09' 25.98830" W	48.696 840 744	-111.157 218 972	1097.273	221,904.1860	138,424.6110	728,032.1065	454,148.9862	International	-21.0670	0.999 978 933	-0° 07' 03.90"
Milk River	AB5604	13 JFB	48° 44' 26.84193" N	111° 24' 15.08851" W	48.740 789 425	-111.404 191 253	1057.373	226,858.8648	120,266.9967	744,287.6140	394,576.7608	International	-11.8871	0.999 988 113	-0° 18' 09.80"
Milk River	AB7733	Q 93 RESET	48° 14' 51.62144" N	110° 03' 21.79456" W	48.247 672 622	-110.056 054 044	798.669	172,370.2167	220,113.5357	565,519.0835	722,157.2692	International	29.4774	1.000 029 477	+0° 42' 25.11"
Milk River	AB7734	U 95 RESET	47° 54' 36.62343" N	110° 32' 43.99931" W	47.910 173 175	-110.545 555 364	778.985	134,504.8746	183,978.4353	441,288.9585	603,603.7903	International	75.5337	1.000 075 534	+0° 20' 25.29"
Milk River	SS1307	E 429	47° 57' 21.52529" N	111° 45' 08.39708" W	47.955 979 247	-111.752 332 522	1055.089	139,774.4193	93,799.4154	458,577.4911	307,740.8640	International	24.4203	1.000 024 420	-0° 33' 48.47"
Milk River	TL0016	T 369	48° 33' 29.31751" N	110° 25' 28.11391" W	48.558 143 753	-110.424 476 086	909.146	206,626.3849	192,489.1470	677,908.0869	631,526.0727	International	3.0307	1.000 003 031	+0° 25' 51.75"
Milk River	TL0297	A 422	48° 31' 08.85795" N	111° 53' 05.25498" W	48.519 127 208	-111.884 793 050	986.667	202,505.2954	84,629.1250	664,387.4520	277,654.6096	International	-9.5753	0.999 990 425	-0° 39' 45.61"
Milk River	TL0318	U 427	48° 10' 34.06436" N	111° 56' 06.16750" W	48.176 128 989	-111.935 046 528	1052.070	164,406.1845	80,450.2071	539,390.3690	263,944.2492	International	-3.9912	0.999 996 009	-0° 42' 01.11"
Milk River	TL0363	M 432	48° 32' 55.48678" N	111° 51' 36.61447" W	48.548 746 328	-111.860 170 686	1045.856	205,778.4848	86,485.2516	675,126.2624	283,744.2639	International	-18.5440	0.999 981 456	-0° 38' 39.23"
Milk River	TL0453	RAVINE	48° 28' 04.28954" N	111° 18' 26.06139" W	48.467 858 206	-111.307 239 275	961.390	196,470.9524	127,276.9965	644,589.7387	417,575.4477	International	-5.5141	0.999 994 486	-0° 13' 48.39"
Milk River	TL0751	SHELBY	48° 32' 25.61075" N	111° 52' 02.26422" W	48.540 447 431	-111.867 295 617	1030.493	204,861.5051	85,948.7077	672,117.7988	281,983.9491	International	-16.2493	0.999 983 751	-0° 38' 58.44"
Mission 83	AA9693	CAROLE	47° 51' 06.81273" N	113° 49' 22.88737" W	47.851 892 425	-113.823 024 269	957.440	122,851.4045	161,897.3751	403,055.7890	531,159.3672	International	22.9863	1.000 022 986	+0° 36' 47.34"
Mission 83	AI7918	NINEMILE GPS	47° 08' 12.80561" N	114° 31' 00.19739" W	47.136 890 447	-114.516 721 497	1007.845	43,024.5496	110,111.9839	141,156.6587	361,259.7898	International	-30.7161	0.999 969 284	+0° 05' 51.69"
Mission 83	AI7922	CONDON GPS	47° 32' 07.79482" N	113° 43' 01.27252" W	47.535 498 561	-113.717 020 144	1110.439	87,759.7072	170,255.2151	287,925.5484	558,580.1020	International	12.5704	1.000 012 570	+0° 41' 17.82"
Mission 83	DE6282	PLS1 A	47° 39' 48.42527" N	114° 06' 49.86081" W	47.663 451 464	-114.113 850 225	967.766	101,704.9401	140,274.9161	333,677.6252	460,219.5409	International	-5.7625	0.999 994 238	+0° 23' 46.78"
Mission 83	DH7989	7SO A	47° 33' 39.68377" N	114° 06' 08.53004" W	47.561 023 269	-114.102 369 456	922.760	90,321.3305	141,217.7427	296,329.8245	463,312.8040	International	2.2329	1.000 002 233	+0° 24' 14.96"
Mission 83	DH7990	7SO B	47° 34' 03.89378" N	114° 06' 08.44774" W	47.567 748 272	-114.102 346 594	922.661	91,069.1321	141,214.1879	298,783.2416	463,301.1416	International	2.2449	1.000 002 245	+0° 24' 15.18"
Mission 83	DH7991	7SO C	47° 34' 25.18928" N	114° 06' 08.66854" W	47.573 663 689	-114.102 407 928	926.248	91,726.8674	141,204.9320	300,941.1659	463,270.7743	International	1.6734	1.000 001 673	+0° 24' 15.15"
Mission 83	DL7176	JMS 53	48° 03' 56.95192" N	114° 04' 57.64496" W	48.065 819 978	-114.082 679 156	905.400	146,465.4541	142,287.8929	480,529.7052	466,823.7955	International	6.0567	1.000 006 057	+0° 25' 19.36"
Mission 83	DL7177	R D ALTENBURG	48° 05' 46.31604" N	114° 14' 06.79518" W	48.096 198 900	-114.235 220 883	870.655	149,771.2649	130,899.3137	491,375.5409	429,459.6907	International	1.2674	1.000 001 267	+0° 18' 31.35"

RMCRS Zone	NGS PID	Designation	Latitude (DMS)	Longitude (DMS)	Latitude (dec deg)	Longitude (dec deg)	Ellipsoid height (m)	Northing (m)	Easting (m)	Northing (ft)	Easting (ft)	Foot type	Distortion (ppm)	Combined scale factor	Convergence angle
Mission 83	DL7179	SMITH LAKE	48° 08' 08.91434" N	114° 27' 29.43133" W	48.135 809 539	-114.458 175 369	947.410	154,110.7877	114,279.1655	505,612.8205	374,931.6452	International	-19.9797	0.999 980 020	+0° 08' 34.29"
Mission 83	SU0026	Q 55	47° 36' 07.28501" N	114° 07' 17.86448" W	47.602 023 614	-114.121 629 022	926.145	94,870.3498	139,737.1250	311,254.4285	458,455.1344	International	0.2309	1.000 000 231	+0° 23' 24.71"
Mission 83	SU0091	J 56	47° 08' 33.37622" N	114° 02' 57.98731" W	47.142 604 506	-114.049 440 919	969.988	43,826.2978	145,560.1264	143,787.0663	477,559.4697	International	-0.5459	0.999 999 454	+0° 26' 24.89"
Mission 83	SU0231	PLAINS	47° 27' 43.66398" N	114° 53' 05.63593" W	47.462 128 883	-114.884 898 869	737.654	79,206.1692	82,286.9307	259,862.7598	269,970.2452	International	14.2312	1.000 014 231	-0° 10' 23.09"
Mission 83	SU0290	Y 382	47° 49' 59.35731" N	114° 35' 04.74604" W	47.833 154 808	-114.584 651 678	877.775	120,438.6286	104,892.9612	395,139.8576	344,137.0119	International	-11.2820	0.999 988 718	+0° 02' 54.37"
Mission 83	SU0711	P 444	47° 34' 10.00564" N	114° 06' 48.85134" W	47.569 446 011	-114.113 569 817	915.112	91,252.0153	140,368.2711	299,383.2523	460,525.8238	International	2.5805	1.000 002 580	+0° 23' 45.39"
Mission 83	SU0773	D 509	47° 02' 02.41325" N	114° 19' 40.98858" W	47.034 003 681	-114.328 052 383	904.511	31,626.6232	124,473.5825	103,761.8871	408,377.8955	International	-8.4228	0.999 991 577	+0° 14' 08.12"
Missoula 83	AE2865	MSO D	46° 55' 27.20903" N	114° 06' 26.40853" W	46.924 224 731	-114.107 335 703	957.429	158,336.2519	103,249.9739	519,475.8920	338,746.6334	International	8.0504	1.000 008 050	+0° 01' 52.19"
Missoula 83	AE2866	MSO E	46° 55' 05.23761" N	114° 05' 36.30674" W	46.918 121 558	-114.093 418 539	960.015	157,658.3300	104,310.6102	517,251.7387	342,226.4113	International	7.7435	1.000 007 744	+0° 02' 28.77"
Missoula 83	AI7918	NINEMILE GPS	47° 08' 12.80561" N	114° 31' 00.19739" W	47.136 890 447	-114.516 721 497	1007.845	182,046.7257	72,175.5658	597,266.1605	236,796.4758	International	9.5310	1.000 009 531	-0° 16' 07.69"
Missoula 83	AI7920	POTOMAC GPS	46° 52' 51.60195" N	113° 34' 33.59804" W	46.881 000 542	-113.575 999 456	1093.284	153,689.4242	143,759.8843	504,230.3944	471,653.1638	International	10.1463	1.000 010 146	+0° 25' 08.36"
Missoula 83	AI7922	CONDON GPS	47° 32' 07.79482" N	113° 43' 01.27252" W	47.535 498 561	-113.717 020 144	1110.439	226,395.5548	132,605.3749	742,767.5682	435,057.0043	International	-2.9927	0.999 997 007	+0° 19' 09.88"
Missoula 83	DE6282	PLS1 A	47° 39' 48.42527" N	114° 06' 49.86081" W	47.663 451 464	-114.113 850 225	967.766	240,533.6792	102,715.6174	789,152.4908	336,993.4955	International	6.4043	1.000 006 404	+0° 01' 36.20"
Missoula 83	DH7989	7SO A	47° 33' 39.68377" N	114° 06' 08.53004" W	47.561 023 269	-114.102 369 456	922.760	229,144.0954	103,585.0611	751,785.0899	339,846.0009	International	13.5230	1.000 013 523	+0° 02' 06.54"
Missoula 83	DH7990	7SO B	47° 34' 03.89378" N	114° 06' 08.44774" W	47.567 748 272	-114.102 346 594	922.661	229,891.9128	103,586.3228	754,238.5590	339,850.1403	International	13.5387	1.000 013 539	+0° 02' 06.62"
Missoula 83	DH7991	7SO C	47° 34' 25.18928" N	114° 06' 08.66854" W	47.573 663 689	-114.102 407 928	926.248	230,549.7015	103,581.3036	756,396.6584	339,833.6732	International	12.9762	1.000 012 976	+0° 02' 06.47"
Missoula 83	DH9363	CORPS II TRAVELERS REST	46° 45' 10.02453" N	114° 05' 18.62983" W	46.752 784 592	-114.088 508 286	958.553	139,275.5892	104,699.0839	456,940.9093	343,500.9315	International	8.0128	1.000 008 013	+0° 02' 41.25"
Missoula 83	RX0663	J 310	46° 51' 39.81175" N	113° 51' 45.67749" W	46.861 058 819	-113.862 688 192	990.253	151,352.2722	121,911.8247	496,562.5729	399,973.1783	International	8.6720	1.000 008 672	+0° 12' 34.75"
Missoula 83	RX0726	P 447	46° 41' 49.96210" N	113° 24' 05.40129" W	46.697 211 694	-113.401 500 358	1127.405	133,367.1714	157,257.6440	437,556.3365	515,937.1521	International	21.5426	1.000 021 543	+0° 32' 41.02"
Missoula 83	RX1057	GINA	46° 22' 56.18802" N	113° 21' 49.84697" W	46.382 274 450	-113.363 846 381	1677.703	98,380.8769	160,486.7766	322,771.9058	526,531.4193	International	-60.0356	0.999 939 964	+0° 34' 08.98"
Missoula 83	RY0038	X 72	46° 33' 06.77277" N	114° 04' 20.51692" W	46.551 881 325	-114.072 365 811	980.555	116,939.9303	105,954.6714	383,661.1886	347,620.3131	International	4.7251	1.000 004 725	+0° 03' 22.90"
Missoula 83	RY1013	MISSOULA GPS	46° 55' 27.86732" N	114° 05' 24.64353" W	46.924 407 589	-114.090 178 758	959.945	158,357.4371	104,556.8970	519,545.3974	343,034.4391	International	7.7814	1.000 007 781	+0° 02' 37.31"
Missoula 83	RY1034	MISSOULA BASE A STA RESET	46° 54' 48.22888" N	114° 04' 01.27626" W	46.913 396 911	-114.067 021 183	963.176	157,134.8007	106,322.2256	515,534.1229	348,826.1996	International	7.5107	1.000 007 511	+0° 03' 38.16"
Missoula 83	ST0413	B 100	47° 00' 42.93282" N	113° 22' 18.09018" W	47.011 925 783	-113.371 691 717	1164.622	168,380.7434	159,191.0663	552,430.2606	522,280.4012	International	18.4784	1.000 018 478	+0° 34' 09.64"
Missoula 83	ST0644	SEELEY LAKE GPS	47° 10' 29.50356" N	113° 26' 41.89534" W	47.174 862 100	-113.444 970 928	1260.030	186,444.7990	153,454.8389	611,695.5349	503,460.7577	International	-4.4072	0.999 995 593	+0° 31' 01.57"
Missoula 83	SU0026	Q 55	47° 36' 07.28501" N	114° 07' 17.86448" W	47.602 023 614	-114.121 629 022	926.145	233,702.6136	102,133.7633	766,740.8583	335,084.5252	International	12.8913	1.000 012 891	+0° 01' 15.42"
Missoula 83	SU0091	J 56	47° 08' 33.37622" N	114° 02' 57.98731" W	47.142 604 506	-114.049 440 919	969.988	182,621.7171	107,628.9530	599,152.6152	353,113.3628	International	6.6710	1.000 006 671	+0° 04' 25.37"
Missoula 83	SU0231	PLAINS	47° 27' 43.66398" N	114° 53' 05.63593" W	47.462 128 883	-114.884 898 869	737.654	218,407.9832	44,581.6660	716,561.6247	146,265.3082	International	80.0904	1.000 080 090	-0° 32' 29.43"
Missoula 83	SU0711	P 444	47° 34' 10.00564" N	114° 06' 48.85134" W	47.569 446 011	-114.113 569 817	915.112	230,080.2430	102,741.5915	754,856.4404	337,078.7124	International	14.6562	1.000 014 656	+0° 01' 36.80"
Missoula 83	SU0773	D 509	47° 02' 02.41325" N	114° 19' 40.98858" W	47.034 003 681	-114.328 052 383	904.511	170,556.8598	86,464.5054	559,569.7499	283,676.1988	International	18.4665	1.000 018 466	-0° 07' 49.05"
NECI 83	AB7733	Q 93 RESET	48° 14' 51.62144" N	110° 03' 21.79456" W	48.247 672 622	-110.056 054 044	798.669	101,574.4741	194,361.5969	333,249.5870	637,669.2812	International	11.6976	1.000 011 698	+1° 27' 27.13"
Phillips 83	SR0914	K 526	47° 55' 25.80011" N	108° 21' 16.24148" W	47.923 833 364	-108.354 511 522	916.925	130,758.4088	122,342.5797	428,997.4043	401,386.4162	International	0.3413	1.000 000 341	-0° 31' 22.58"
Phillips 83	SR0940	J 527	47° 41' 10.48880" N	108° 43' 15.77840" W	47.686 246 889	-108.721 049 556	877.238	104,654.6402	94,580.7101	343,355.1188	310,304.1669	International	51.9284	1.000 051 928	-0° 47' 31.38"
Phillips 83	SR1029	CARSON	47° 41' 24.22983" N	108° 03' 03.41901" W	47.690 063 842	-108.050 949 725	850.803	104,601.1097	144,896.9216	343,179.4937	475,383.6010	International	-12.2209	0.999 987 779	-0° 17' 47.44"
Phillips 83	TJ0451	A 439	48° 57' 29.66092" N	107° 49' 05.01870" W	48.958 239 144	-107.818 060 750	798.624	245,569.1509	162,691.0644	805,673.0673	533,763.3346	International	-13.2936	0.999 986 706	-0° 07' 36.32"
Phillips 83	TJ0503	R 540	48° 23' 56.91559" N	107° 06' 21.51820" W	48.399 143 219	-107.105 977 278	647.040	183,518.2980	215,288.0997	602,094.1537	706,325.7863	International	28.5222	1.000 028 522	+0° 24' 24.55"
Phillips 83	TK0350	S 512	48° 34' 12.15668" N	108° 56' 03.11230" W	48.570 043 522	-108.934 197 861	705.988	203,177.8952	80,217.3385	666,594.1444	263,180.2444	International	109.6616	1.000 109 662	-0° 57' 46.51"
Phillips 83	TK0356	L 512	48° 31' 25.93183" N	108° 44' 35.25025" W	48.523 869 953	-108.743 125 069	700.675	197,823.5120	94,246.1632	649,027.2704	309,206.5723	International	80.2581	1.000 080 258	-0° 49' 08.57"
Phillips 83	TK0386	A 513	48° 22' 17.85410" N	108° 06' 12.93131" W	48.371 626 139	-108.103 592 031	674.123	180,414.5347	141,390.6971	591,911.2029	463,880.2399	International	18.2177	1.000 018 218	-0° 20' 20.58"
St. Mary	AB3811	PIEGAN	48° 56' 23.68774" N	113° 22' 21.02986" W	48.939 913 261	-113.372 508 294	1299.508	49,295.1214	86,070.3497	161,729.4010	282,383.0370	International	6.5266	1.000 006 527	-0° 39' 28.48"
St. Mary	AI7863	SHERBURNE 2	48° 51' 07.53055" N	113° 24' 59.52878" W	48.852 091 819	-113.416 535 772	1352.441	39,565.2828	82,726.6957	129,807.3583	271,413.0437	International	3.6171	1.000 003 617	-0° 41' 24.68"
Wind River	AA2121	NWS 5568.70	43° 03' 58.04170" N	108° 28' 41.96397" W	43.066 122 694	-108.478 323 325	1684.437	44,396.4799	88,187.2260	145,657.4510	289,327.5905	US Survey	-22.4354	0.999 977 565	-0° 05' 56.42"
Wind River	DM6045	RIW A	43° 03' 49.67229" N	108° 27' 35.72916" W	43.063 797 858	-108.459 924 767	1652.003	44,135.7166	89,685.8227	144,801.9303	294,244.2366	US Survey	-17.7581	0.999 982 242	-0° 05' 11.18"
Wind River	DM6046	RIW B	43° 04' 12.76557" N	108° 28' 09.33505" W	43.070 212 658	-108.469 259 736	1665.595	44,849.7236	88,926.4004	147,144.4681	291,752.6986	US Survey	-19.6892	0.999 980 311	-0° 05' 34.16"
Wind River	DM6047	RIW C	43° 03' 32.03970" N	108° 26' 46.16286" W	43.058 899 917	-108.446 156 350	1643.019	43,589.8540	90,806.8881	143,011.0460	297,922.2652	US Survey	-16.6185	0.999 983 382	-0° 04' 37.31"
Wind River	DQ9508	LND A	42° 48' 56.49740" N	108° 43' 34.52549" W	42.815 693 722	-108.726 257 081	1687.678	16,633.9523	67,857.2899	54,573.2252	222,628.4585	US Survey	-11.9676	0.999 988 032	-0° 16' 01.38"
Wind River	DQ9510	LND C	42° 49' 05.41484" N	108° 43' 19.91079" W	42.818 170 789	-108.722 197 442	1685.100	16,907.6543	68,190.6544	55,471.1957	223,722.1718	US Survey	-11.8254	0.999 988 175	-0° 15' 51.49"
Wind River	NS0004	P 21	42° 59' 51.39077" N	108° 25' 12.27062" W	42.997 608 547	-108.420 075 172	1495.711	36,776.6327	92,925.0144	120,658.0025	304,871.4848	US Survey	6.0517	1.000 006 052	-0° 03' 32.96"
Wind River	NS0051	X 20	42° 43' 56.86712" N	108° 37' 54.76185" W	42.732 463 089	-108.631 878 292	1660.026	7,354.1076	75,545.1273	24,127.6012	247,850.9718	US Survey	-12.9827	0.999 987 017	-0° 12' 09.31"
Wind River	NS0066	J 21	42° 54' 36.70131" N	108° 34' 13.35403" W	42.910 194 808	-108.570 376 119	1533.344	27,086.9657	80,638.5262	88,867.8199	264,561.5647	US Survey	4.1412	1.000 004 141	-0° 09' 41.01"
Wind River	OW0104	L 49	43° 49' 19.23845" N	108° 32' 34.09736" W	43.822 010 681	-108.542 804 822	1580.636	128,407.9721	83,144.8990	421,285.1551	272,784.5561	US Survey	-4.3636	0.999 995 636	-0° 08' 42.15"
Wind River	OW0192	H 326	43° 45' 11.66538" N	108° 10' 35.11961" W	43.753 240 383	-108.176 422 114	1301.778	120,755.8371	112,640.3278	396,179.7757	369,554.1420	US Survey	37.8252	1.000 037 825	+0° 06' 30.65"
Wind River	OW0207	M 327	43° 35' 08.27329" N	108° 12' 49.40639" W	43.585 631 469	-108.213 723 997	1322.381	102,124.0305	109,662.2423	335,051.9233	359,783.5400	US Survey	33.7748	1.000 033 775	+0° 04' 56.87"

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 the Rocky Mountain Tribal areas 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.

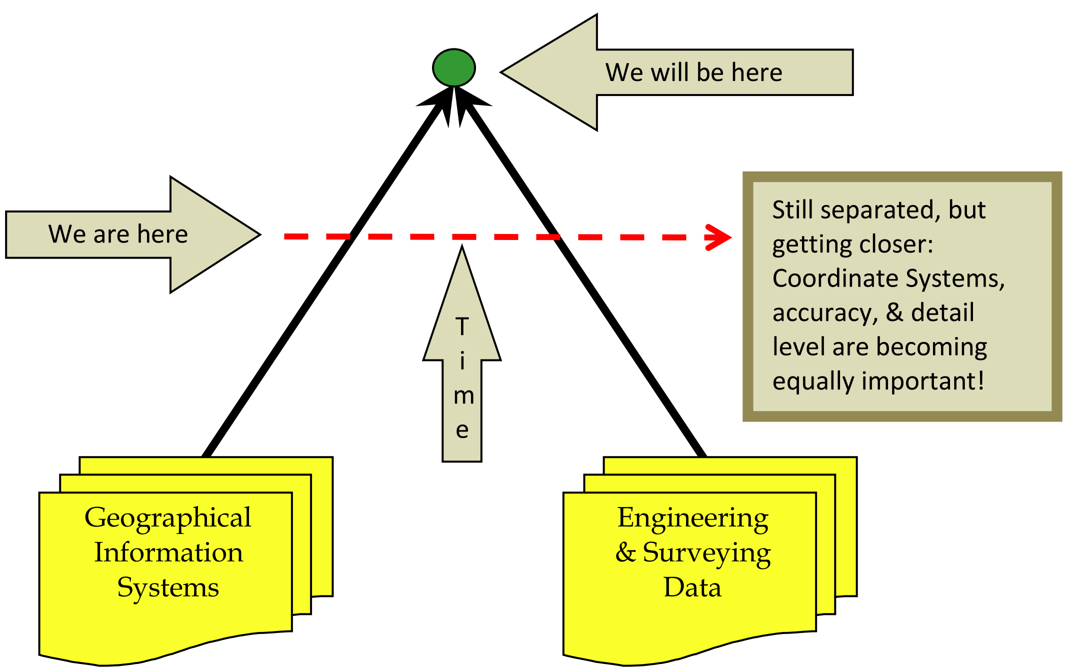


Figure 4.3, [mla,rs]

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 RMTCRS low distortion projections provide another reference system in which 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 RMTCRS Zone

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

1. Field test measurements shall include measurements independent of existing Real-time GPS Networks.
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

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

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

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

{

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

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

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

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

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

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

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

}

$u^2 = \cos^2\alpha.(a^2-b^2)/b^2$
$A = (1+u^2/16384).\{4096+u^2.[-768+u^2.(320-175.u^2)]\}$
$B = (u^2/1024).\{256+u^2.[-128+u^2.(74-47.u^2)]\}$
$\Delta\sigma = B.\sin\sigma.\{\cos 2\sigma_m+B/4.[\cos\sigma.(-1+2.\cos^2 2\sigma_m) - B/6.\cos 2\sigma_m.(-3+4.\sin^2\sigma).(-3+4.\cos^2 2\sigma_m)]\}$
$s = b.A.(\sigma-\Delta\sigma)$

$\alpha_1 = \text{atan}((\cos U_2.\sin\lambda) / (\cos U_1.\sin U_2 - \sin U_1.\cos U_2.\cos\lambda))$
$\alpha_2 = \text{atan}((\cos U_1.\sin\lambda) / (-\sin U_1.\cos U_2 + \cos U_1.\sin U_2.\cos\lambda))$
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 RTN complete software / hardware coordinate results across test projections.
Latest RTCM protocol does support one standard parallel Lambert Projection.
Using the RTN, test 30 to 50 km baseline lengths across zones to prove projection distortion meets predicted tolerances/ppm thresholds (pending).

5.2 RMTCRS Field and Office Test Methods

As part of the development of low distortion projections for the Tribal Coordinate System, field tests and calculations were employed to compare grid distances measured with GPS between two distinct points while working in a project defined by a Tribal LDP 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). For this test two baselines were set (temporary points) and the horizontal ground distance (previously checked) measured with both Trimble and CHC GPS equipment. 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 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 RMTCRS 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 C for samples of the baseline test results.

Chapter 6 The RMTCRS and Rocky Mountain Real-Time GPS Networks

Real Time GPS Networks are not currently available in Montana and Wyoming. This chapter will be updated when Real Time GPS networks are established in Montana and Wyoming.

Chapter 7 Legislative Adoption

7.1 RMTCRS Legislative Adoption

The RMTCRS is substantially complete, thoroughly tested. Coordinate reference systems are very new on the national survey scene and have been generally accepted by Oregon, Minnesota, Wisconsin, and Iowa professional surveyors, engineers, GIS, cartographic, and academic professionals. Montana and Wyoming surveyors are becoming more acquainted with the use of these systems. The next step is for the Rocky Mountain Tribal Department of Transportation's (DOT) initiative is to include the Rocky Mountain Tribal Coordinate Reference System (RMTCRS) into the each participating tribe's Statutes. Legislative adoption will provide fundamental viable acceptance by engineering, surveying, and mapping professionals within the tribes as well as other Federal agencies such as the BLM, NGS and FEMA etc.

References

Federal and academic documents

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5. 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.
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9. 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.
10. 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

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

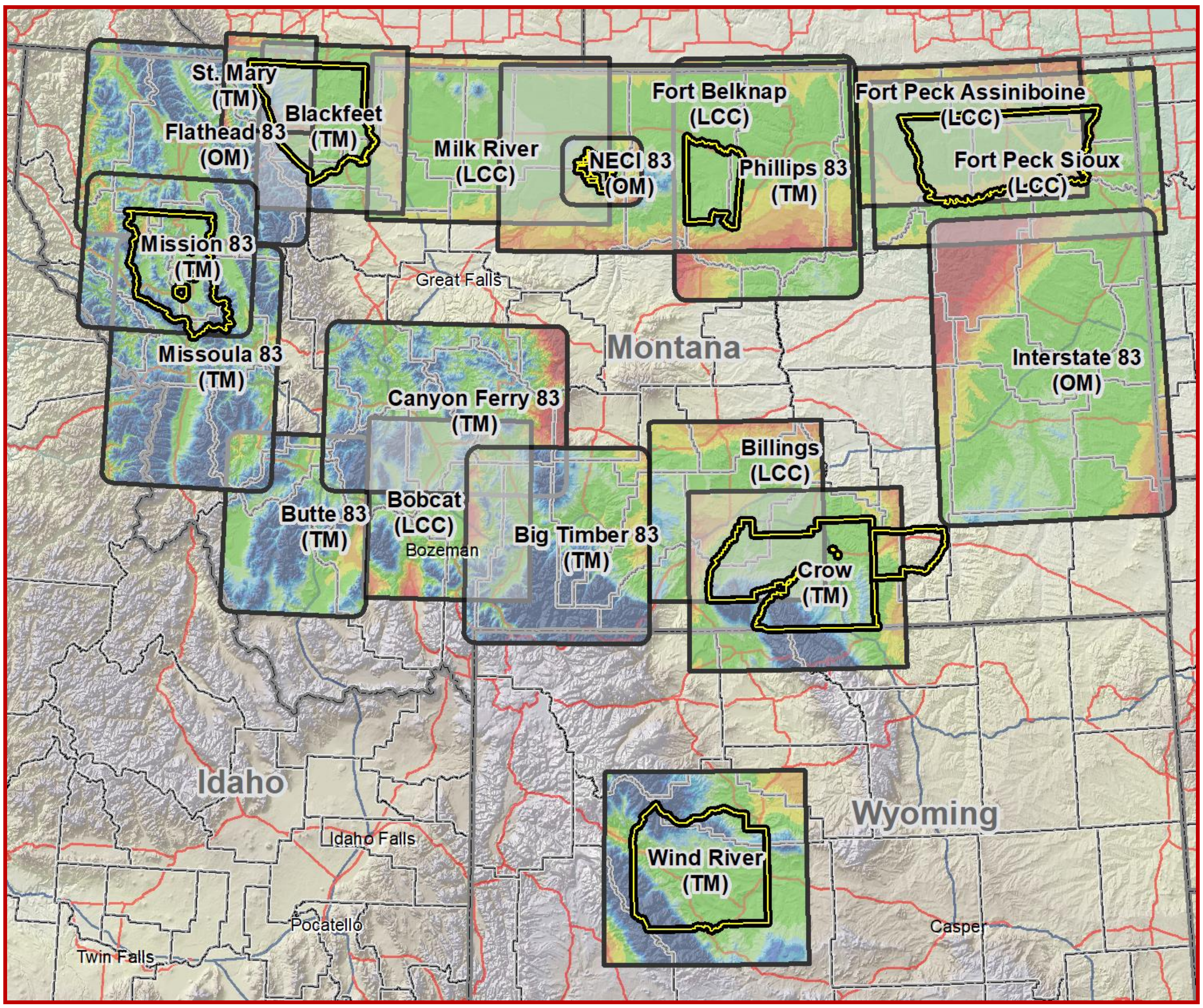
Helmert Transformations: http://earth-info.nga.mil/GandG/coordsys/datums/helmert.html

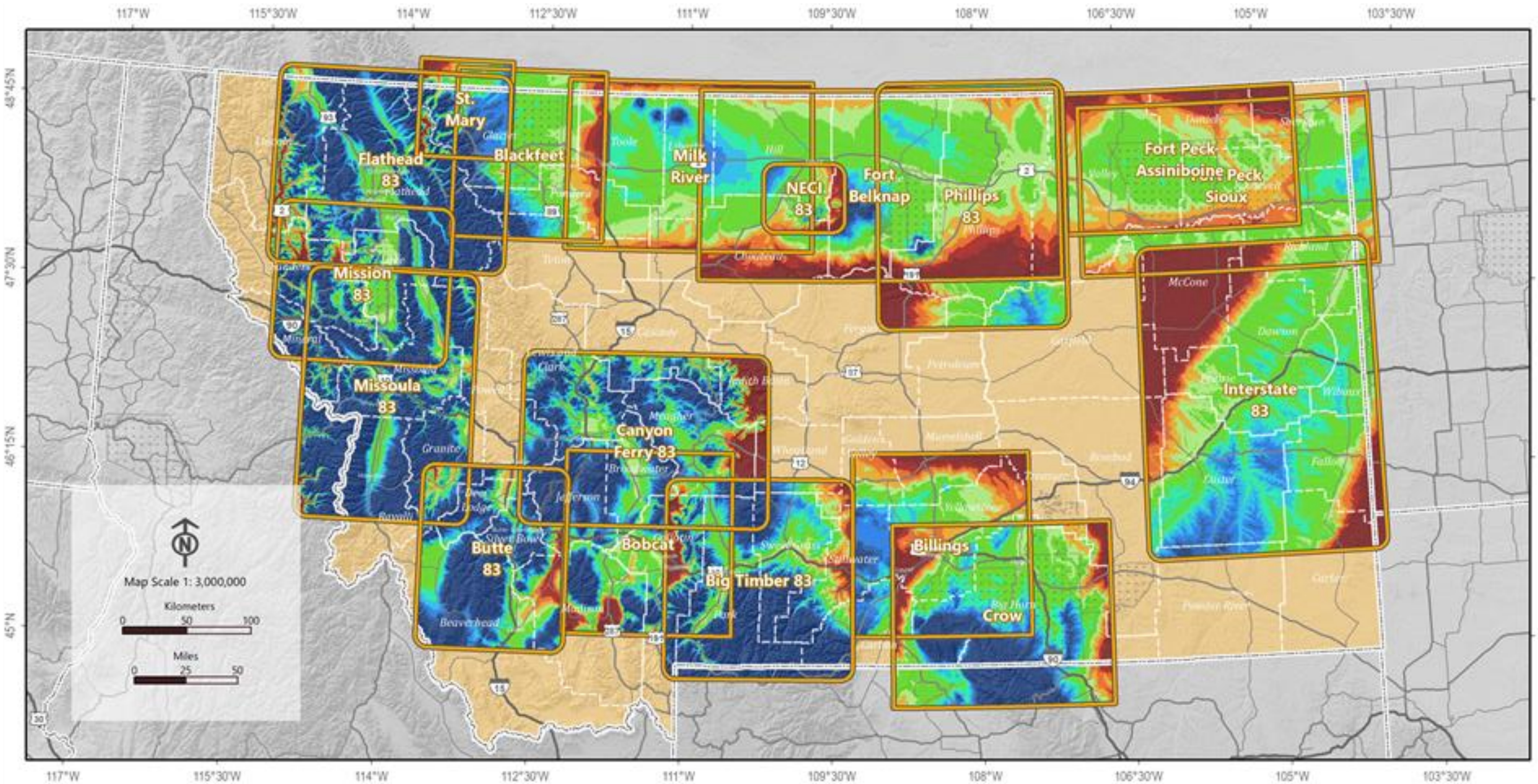
Ordnance Survey:
http://www.ordnancesurvey.co.uk/oswebsite/gps/information/coordinatesystemsinfo/guidecontents/guide6.html

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

Appendix A

RMTCRS Zone Maps





Montana: Rocky Mountain Coordinate System (RMCS)

Funding Partners:

Missoula County

Alpine Surveying & Engineering

Morrison Maierle

DJ&A

Cushing Terrell

C&H

Interstate Engineering

SJW Land Surveying, Inc.

Northern Engineering & Consulting, Inc.

Linear Distortion at the Topographic Surface

in parts per million (ppm)

< -50, to -50, to -40, to -30, to -20, ±10, to +20, to +30, to +40, to +50, > + 50

LDP Zone

Reservation

State

County

Big Timber 83 Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 44°00'00" N
Central meridian: 110°00'00" W
False northing: 0.000 m
False easting: 175,000.000 m
Central meridian scale: 1.000 209 (exact)

Grid North

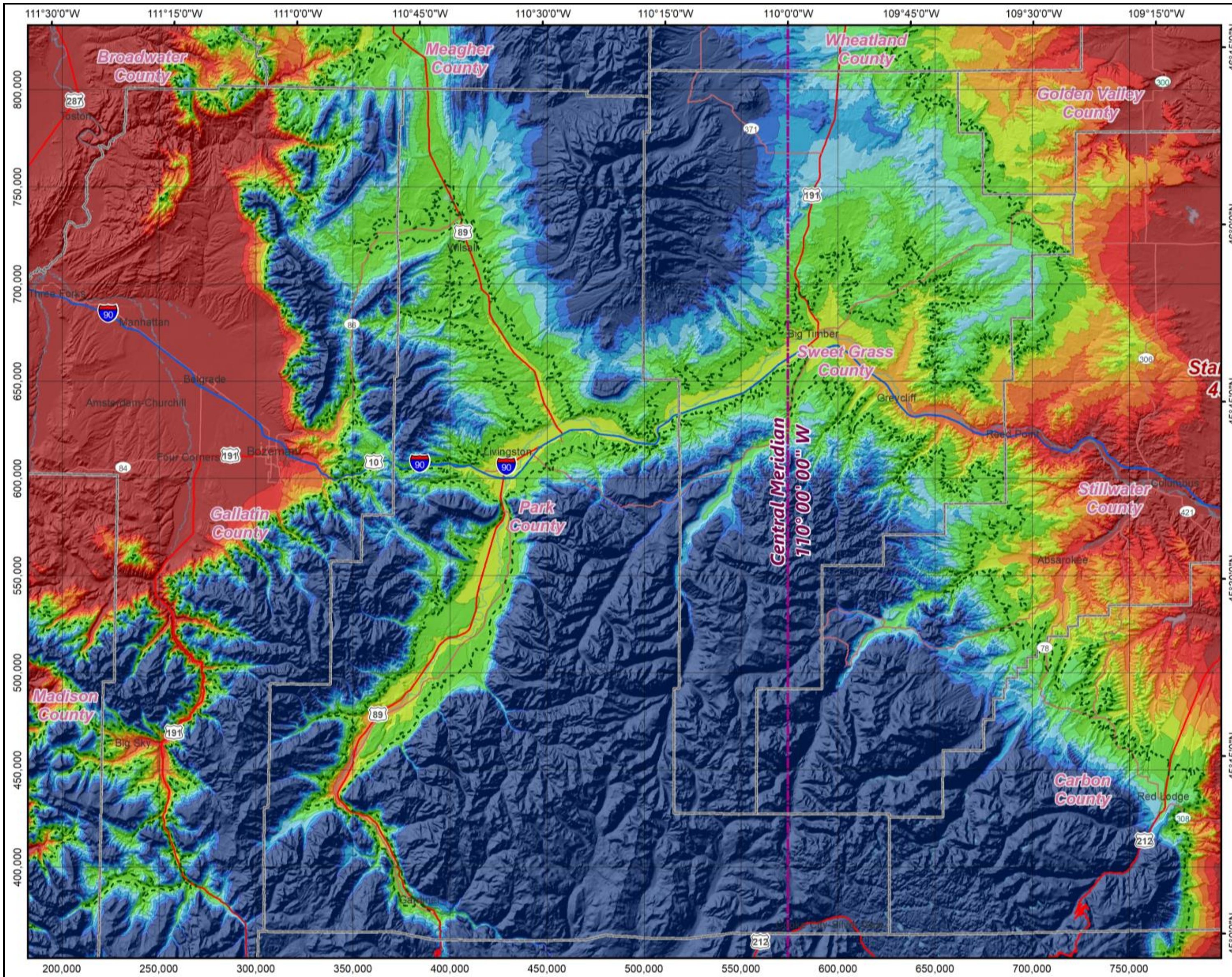
Projected map grid shown in units of international feet

Scale 1:600,000
(when printed on 11" x 17" sheet)

0 5 10 15 20 25
Miles

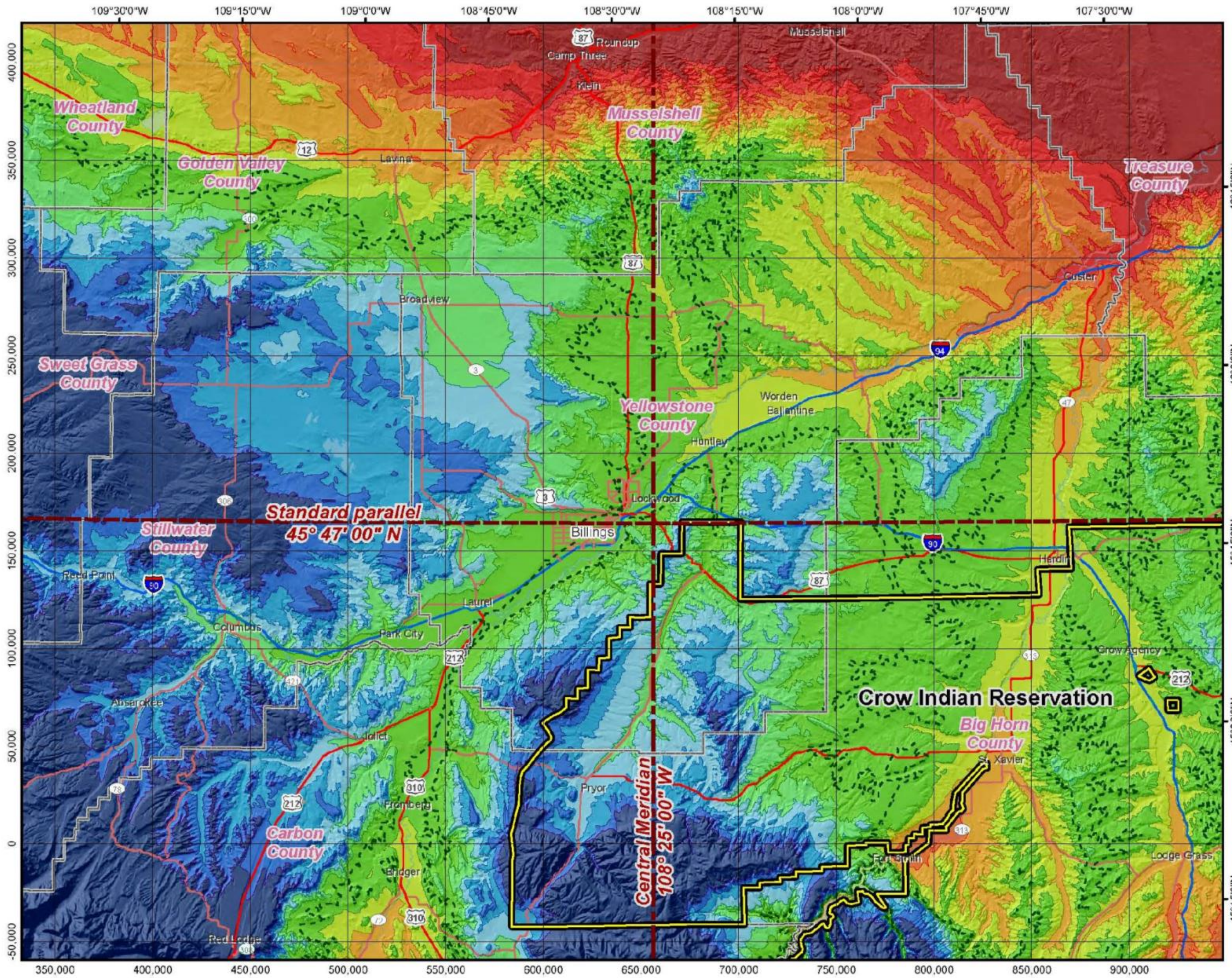
Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)



This Coordinate System and Map are made possible by the generous contributions of Alpine Surveying and Engineering and C&H Engineering and Surveying, Inc

ALPINE SURVEYING & ENGINEERING
Cushing Terrell.



Billings Coordinate System

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

Standard parallel & grid origin: 45°47'00" N
Central meridian: 108°25'00" W
False northing: 50,000.000 m
False easting: 200,000.000 m
Standard parallel scale: 1.000 1515 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:600,000
(when printed on 11" x 17" sheet)

0 5 10 15 20 25
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Indian reservation

Designed by
Rich Jensen, PLS
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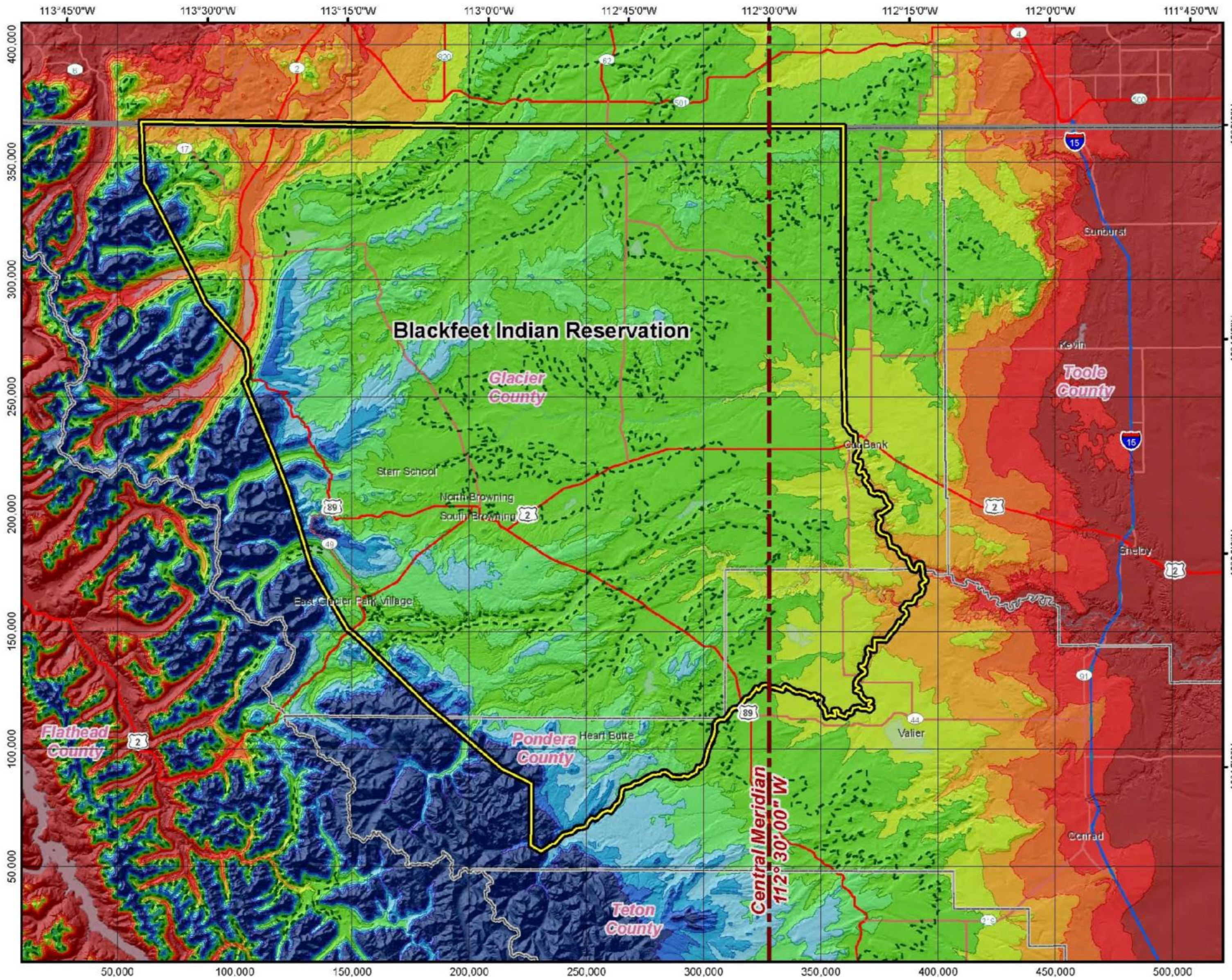
SANDERSON STEWART

Map prepared by
Michael L. Dennis, RLS, PE
mld@geodeticanalysis.com
Geodetic Analysis
and
Northern Engineering & Consulting, Inc.



Blackfeet Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 48°00'00" N
Central meridian: 112°30'00" W
False northing: 0.000 m
False easting: 100,000.000 m
Central meridian scale: 1.000 190 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:500,000
(when printed on 11" x 17" sheet)

0 5 10 15 20
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Indian reservation

Designed and prepared by

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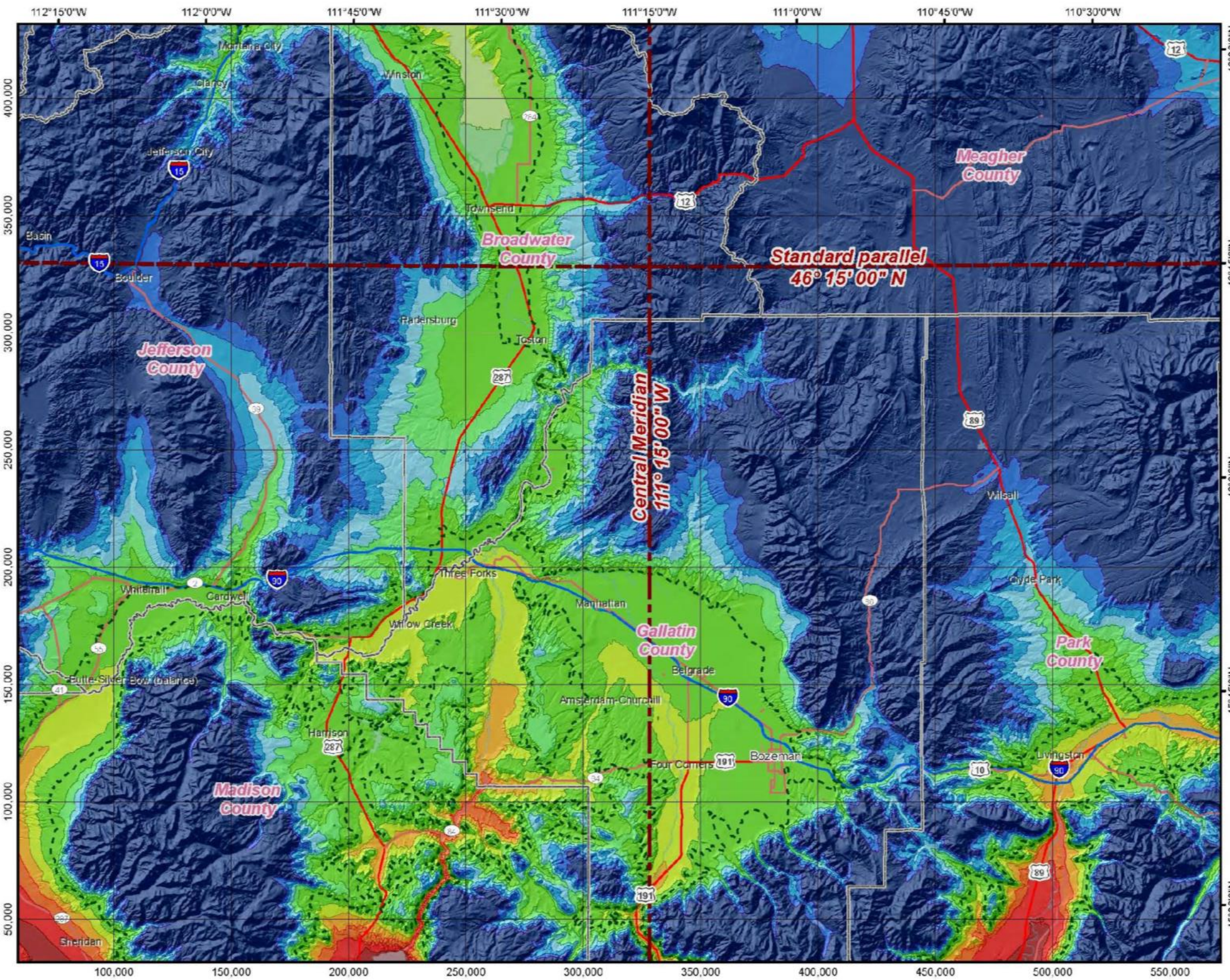
mld@geodeticanalysis.com
Geodetic Analysis
Northern Engineering & Consulting, Inc.



Bobcat Coordinate System

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

Standard parallel & grid origin: 46°15'00" N
Central meridian: 111°15'00" W
False northing: 100,000.000 m
False easting: 100,000.000 m
Standard parallel scale: 1.000 185 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:500,000
(when printed on 11" x 17" sheet)

0 5 10 15 20
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Indian reservation

Designed and prepared by

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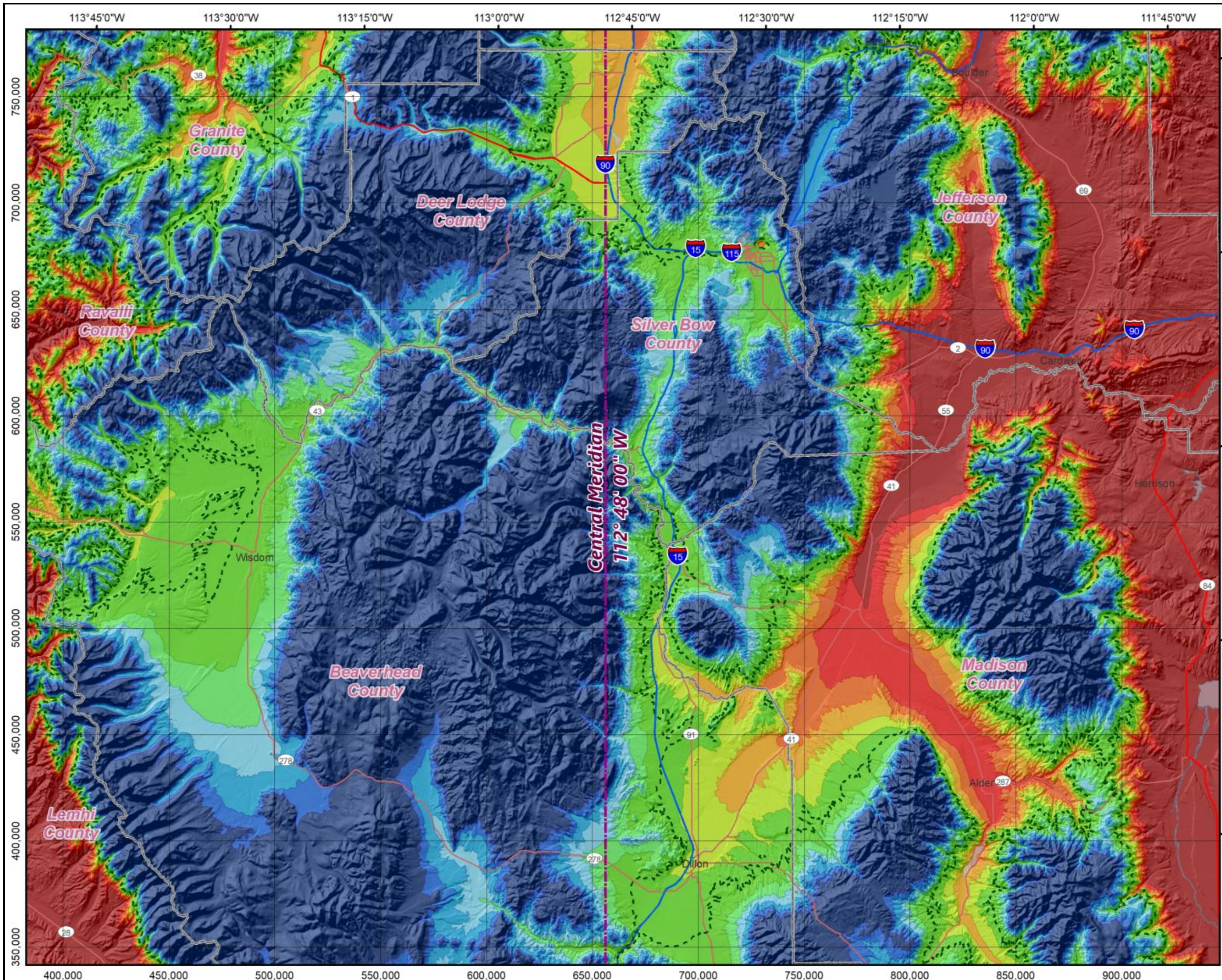


Butte 83 Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 44°09'00" N
Central meridian: 112°48'00" W
False northing: 0.000 m
False easting: 200,000.000 m
Central meridian scale: 1.000 252 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:550,000
(when printed on 11" x 17" sheet)

0 4.5 9 13.5 18 22.5
Miles

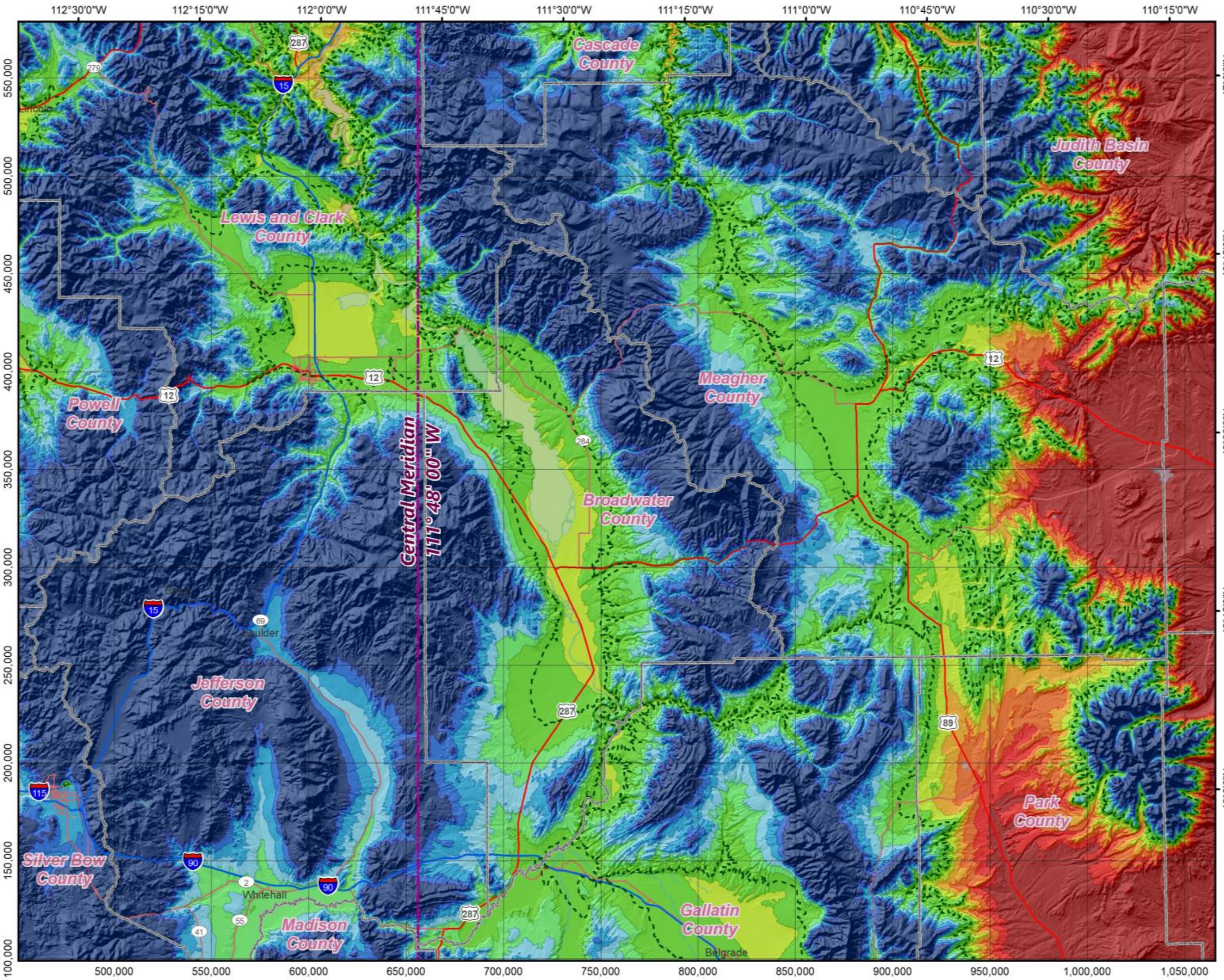
Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

This Coordinate System and Map are made possible by the generous contributions of Morrison-Maierle and NECI.

Morrison Maierle
engineers - surveyors - planners - scientists

NORTHERN ENGINEERING NECI & CONSULTING, INC.



Canyon Ferry 83 Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 45°30'00" N
Central meridian: 111°48'00" W
False northing: 0.000 m
False easting: 200,000.000 m
Central meridian scale: 1.000 188 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:600,000
(when printed on 11" x 17" sheet)

0 5 10 15 20 25
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

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Morrison Maierle
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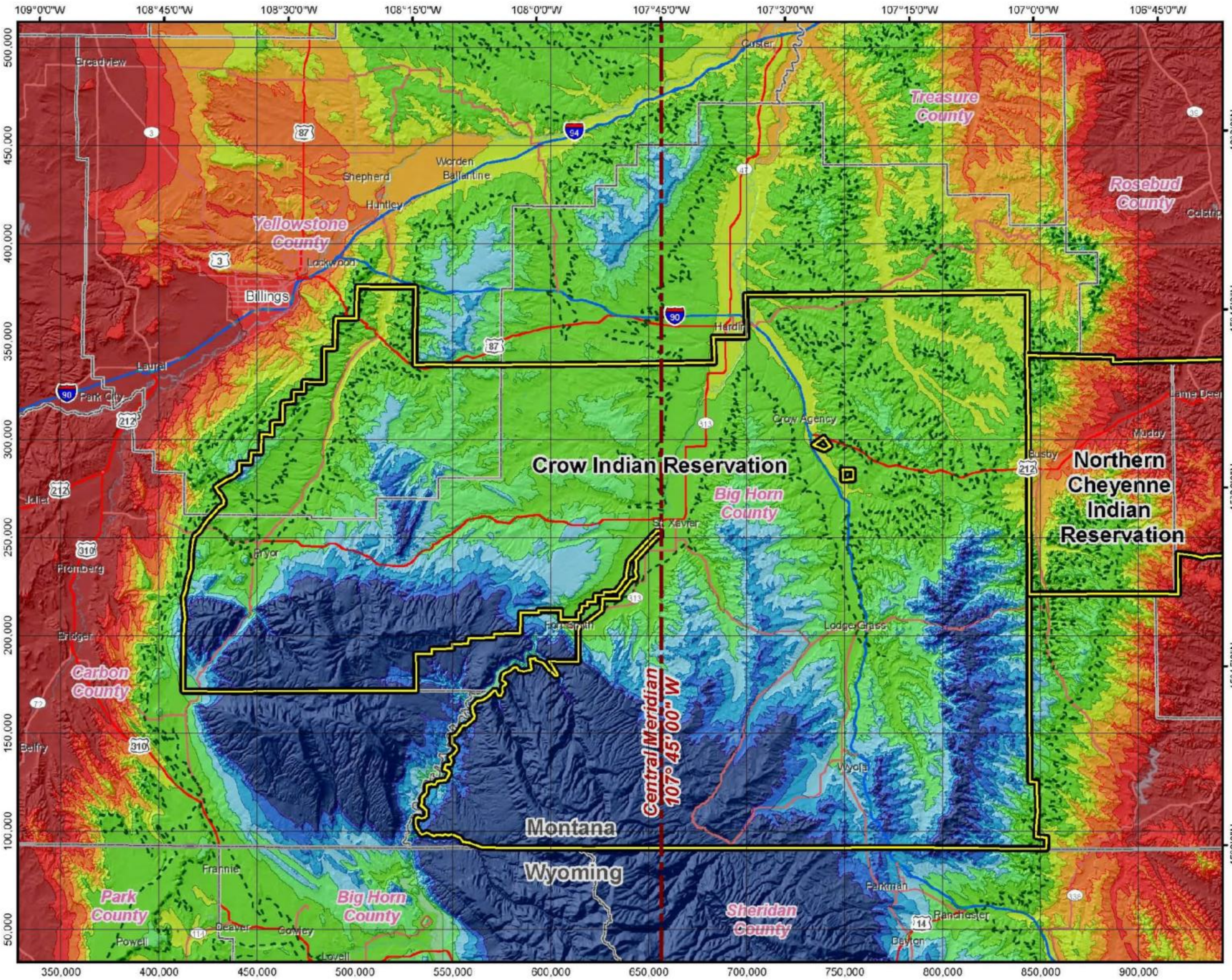

Crow Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 44° 45' 00" N
Central meridian: 107° 45' 00" W
False northing: 0.000 m
False easting: 200,000.000 m
Central meridian scale: 1.000 148 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:600,000
(when printed on 11" x 17" sheet)

0 5 10 15 20 25
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Designed and prepared by

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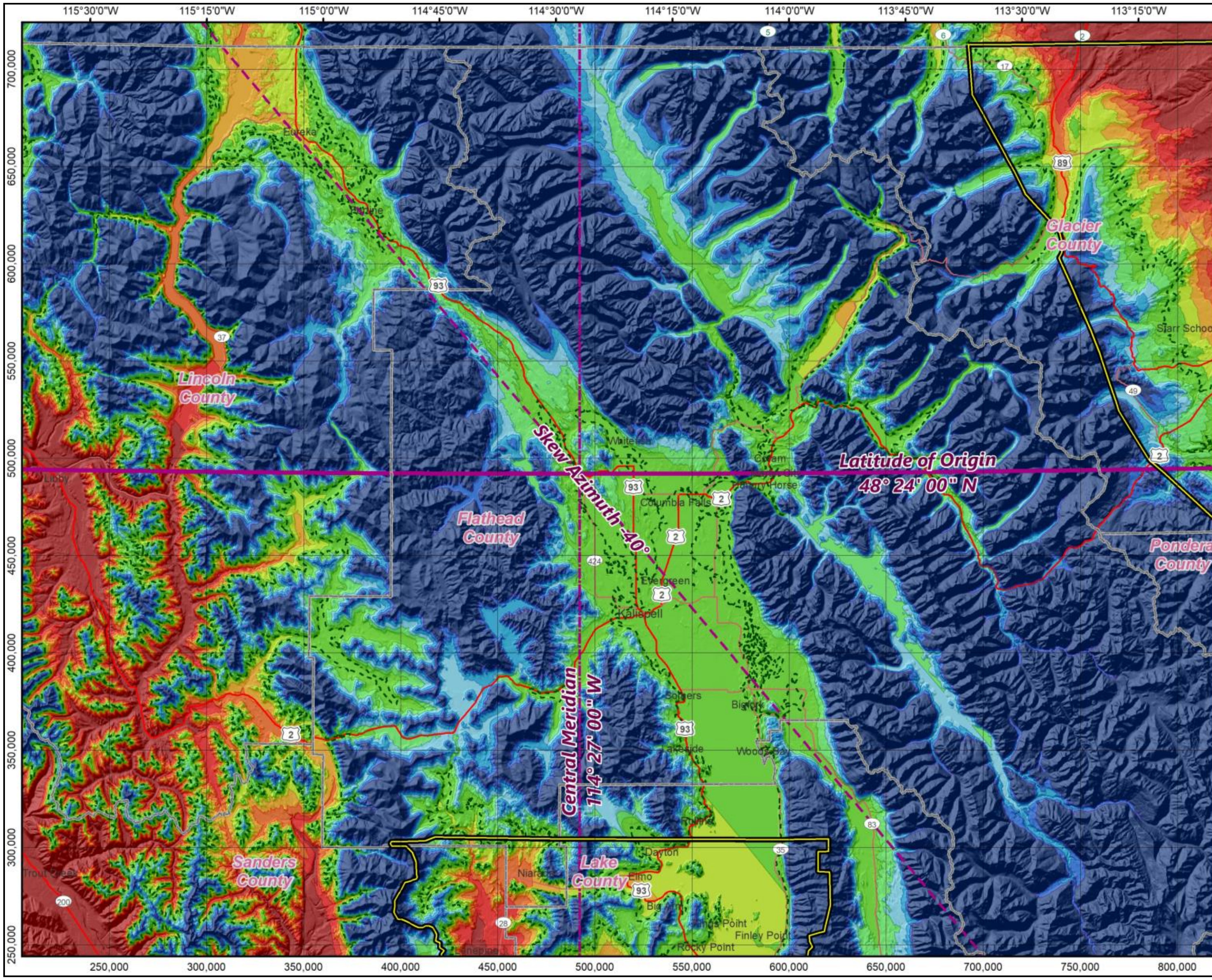


Flathead 83 Coordinate System

Oblique Mercator Projection
North American Datum of 1983

Latitude of grid origin: 48°24'00" N
Central meridian: 114°27'00" W
False northing: 150,000.000 m
False easting: 150,000.000 m
Central meridian scale: 1.000 142 (exact)
Skew Azimuth: -40°

Grid North

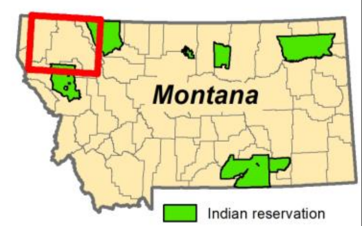
Projected map grid shown in units of international feet

Scale 1:600,000
(when printed on 11" x 17" sheet)

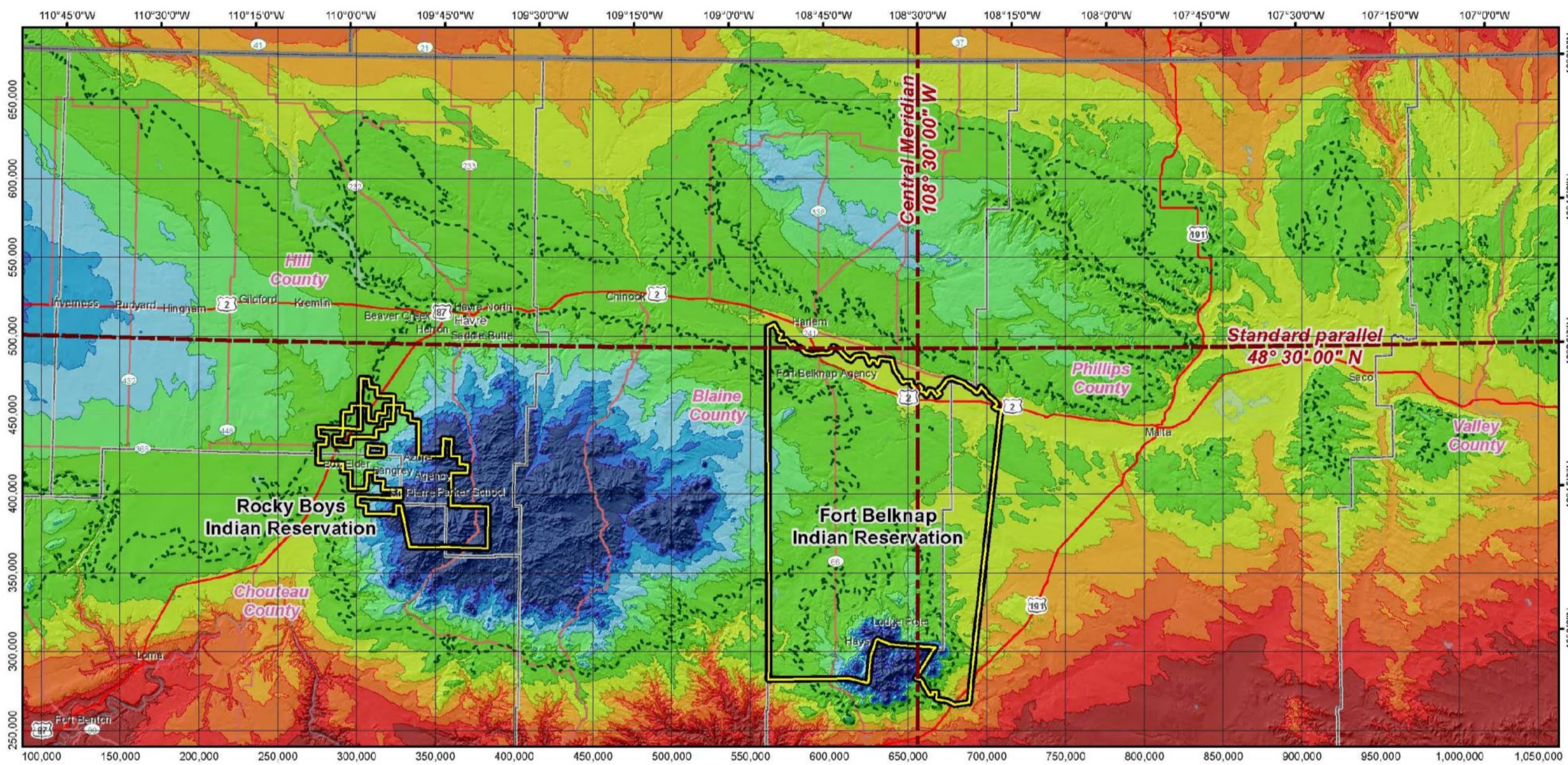
0 5 10 15 20 25
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)



This Coordinate System and Map are made possible by the generous contributions of Sands Surveying, Inc



Fort Belknap Coordinate System

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

Standard parallel & grid origin: 48°30'00" N
Central meridian: 108°30'00" W
False northing: 150,000.000 m
False easting: 200,000.000 m
Standard parallel scale: 1.000 120 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:750,000
(when printed on 11" x 17" sheet)

0 5 10 15 20 25
Miles

Linear distortion (parts per million)

- - - Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Designed and prepared by
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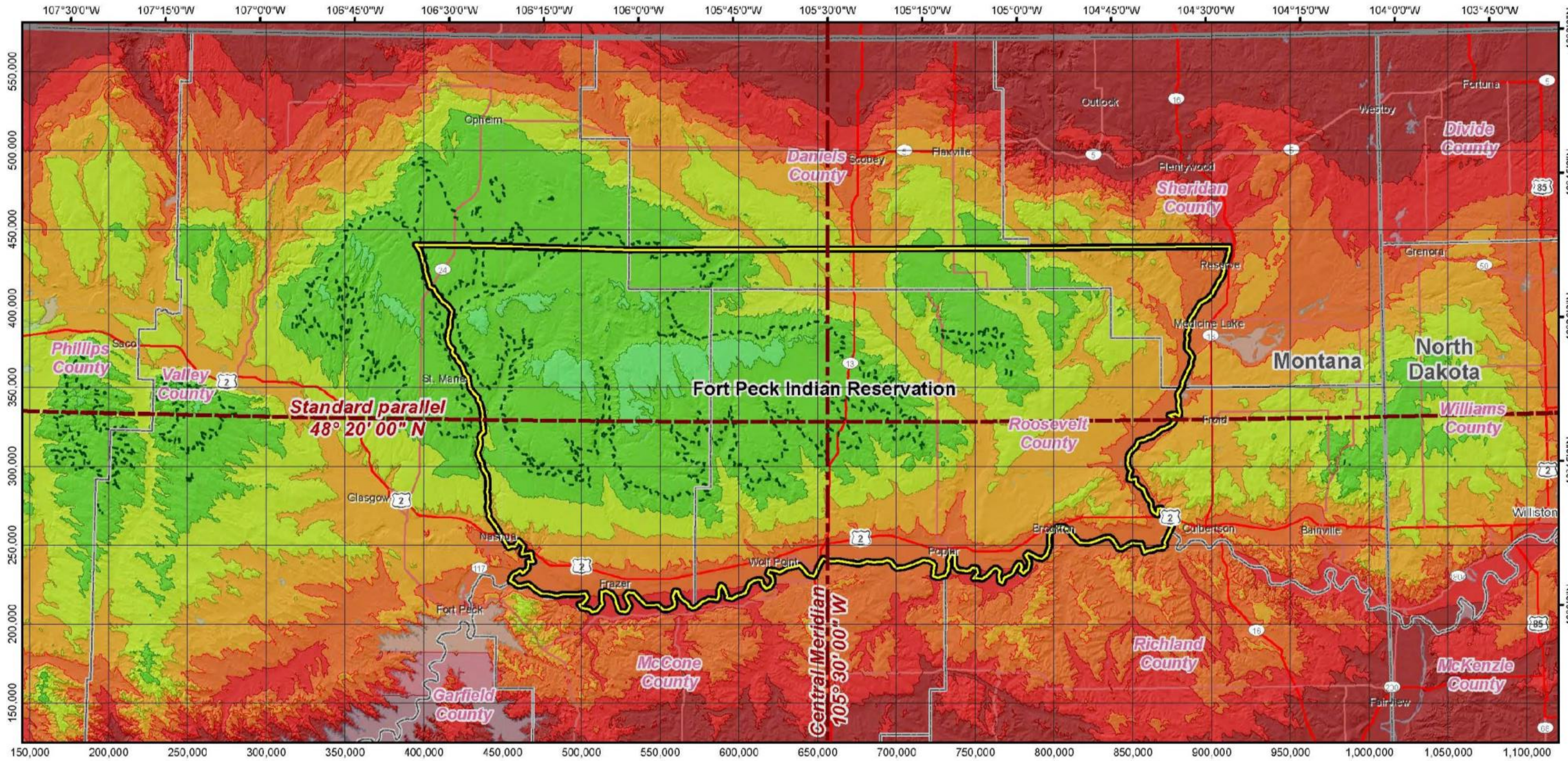
Geodetic Analysis LLC
and
Northern Engineering & Consulting, Inc.



Fort Peck Assiniboine Coordinate System

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

Standard parallel & grid origin: 48°20'00" N
Central meridian: 105°30'00" W
False northing: 100,000.000 m
False easting: 200,000.000 m
Standard parallel scale: 1.000 012 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:750,000
(when printed on 11" x 17" sheet)

0 5 10 15 20 25
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

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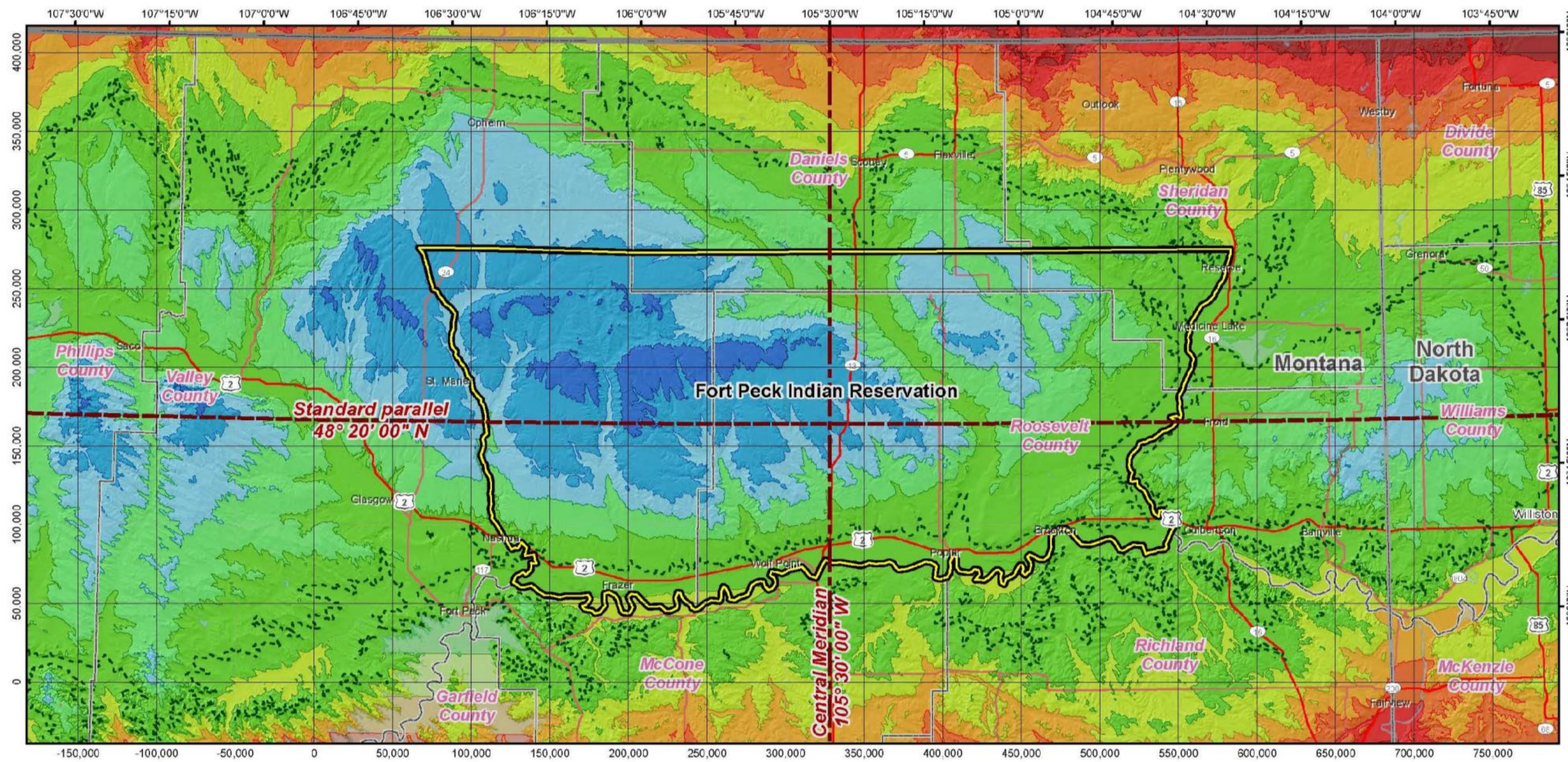


Fort Peck Sioux Coordinate System

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

Standard parallel & grid origin: 48°20'00" N
Central meridian: 105°30'00" W
False northing: 50,000.000 m
False easting: 100,000.000 m
Standard parallel scale: 1.000 090 (exact)

Grid North

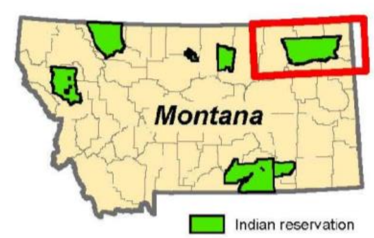
Projected map grid shown in units of international feet

Scale 1:750,000
(when printed on 11" x 17" sheet)

0 5 10 15 20 25
Miles

Linear distortion (parts per million)

- - - Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)



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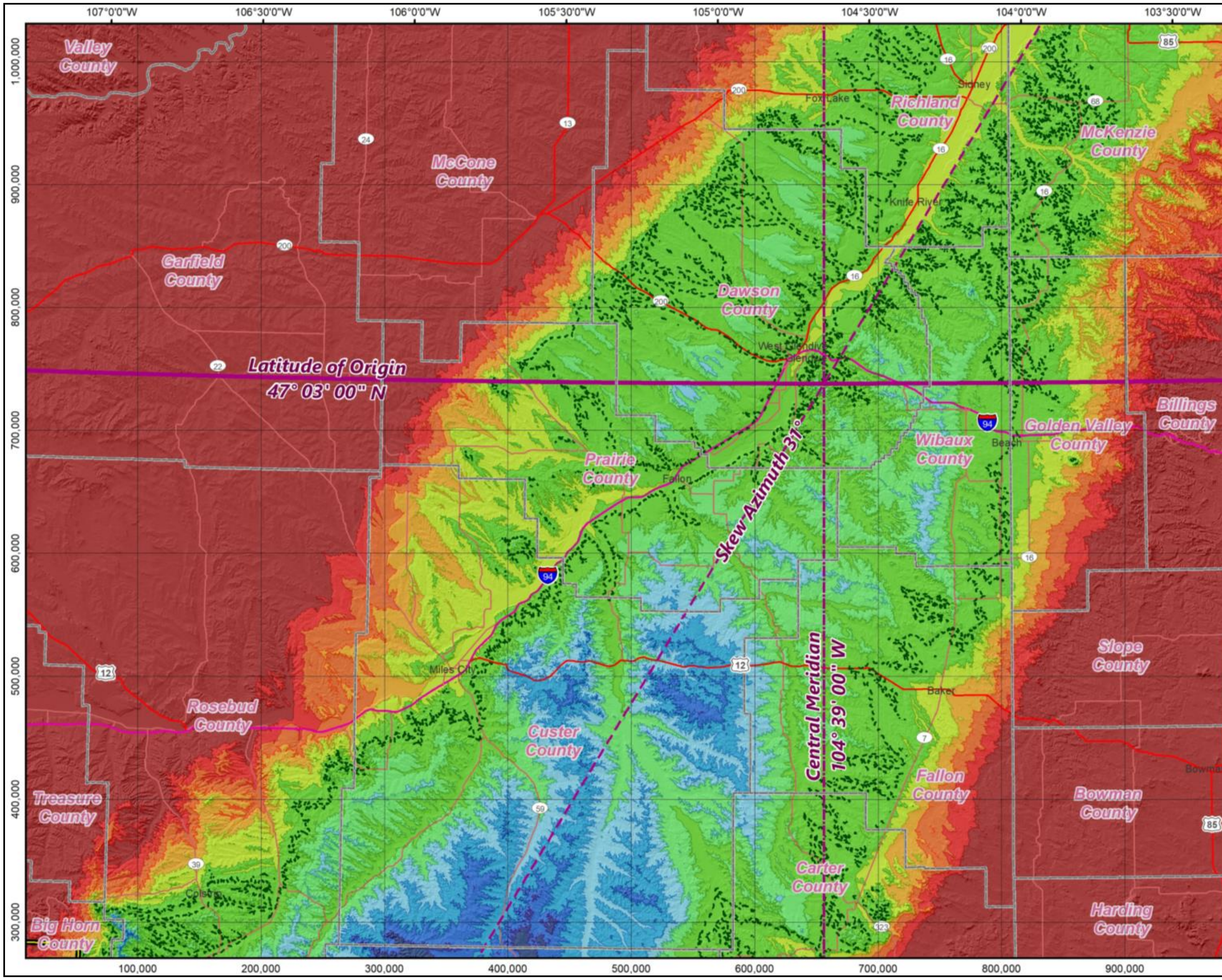


Interstate 83 Coordinate System

Oblique Mercator Projection
North American Datum of 1983

Latitude of grid origin: 47°03'00" N
Central meridian: 104°39'00" W
False northing: 225,000.000 m
False easting: 200,000.000 m
Central meridian scale: 1.000 105 (exact)
Skew Azimuth: 31°

Grid North

Projected map grid shown in units of international feet

Scale 1:950,000
(when printed on 11" x 17" sheet)

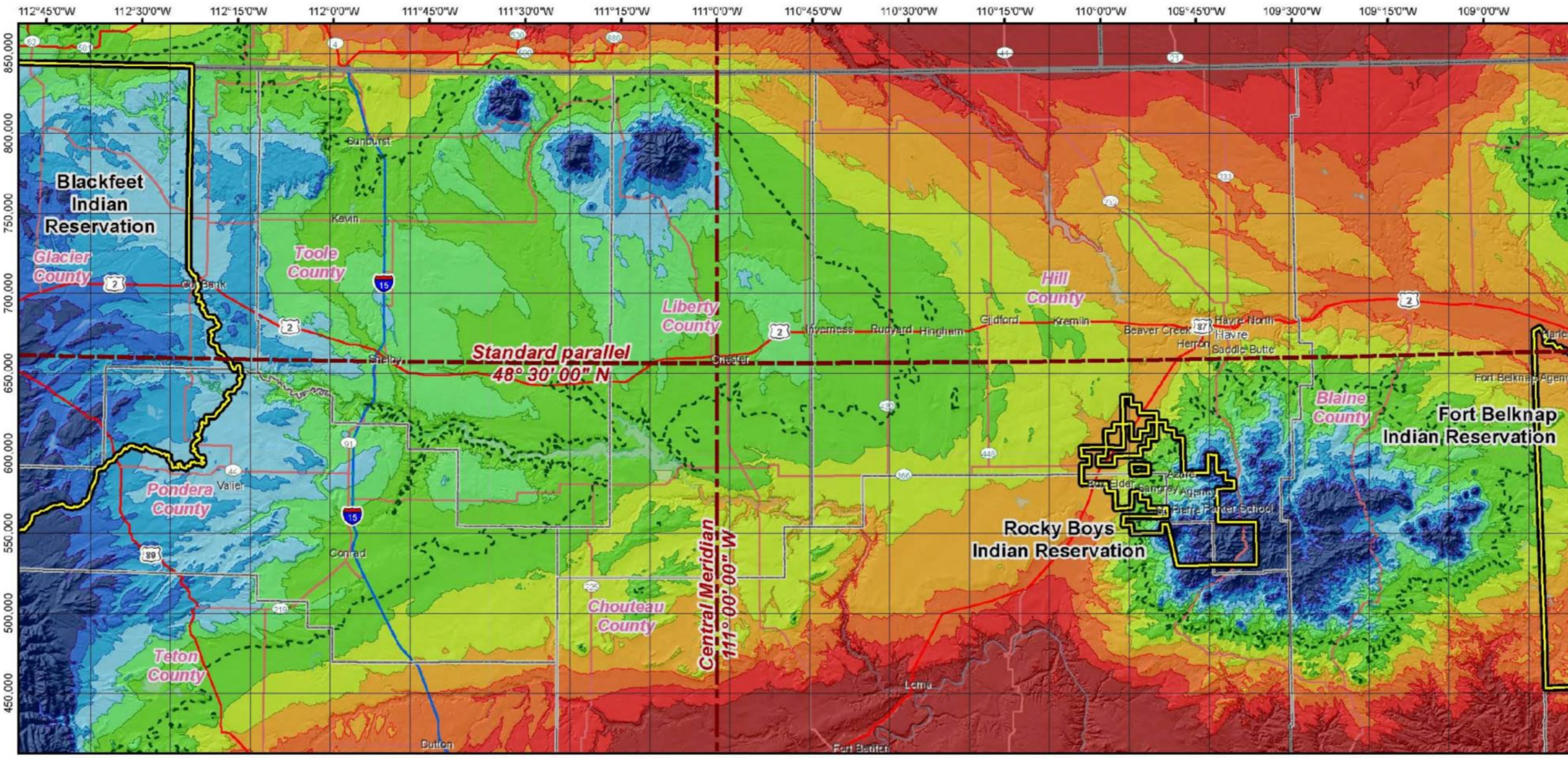
0 8 16 24 32 40
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

This Coordinate System and Map are made possible by the generous contributions of Interstate Engineering.

INTERSTATE ENGINEERING



Milk River Coordinate System

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

Standard parallel & grid origin: 48°30'00" N
Central meridian: 111°00'00" W
False northing: 200,000.000 m
False easting: 150,000.000 m
Standard parallel scale: 1.000 145 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:750,000
(when printed on 11" x 17" sheet)

0 5 10 15 20 25
Miles

Linear distortion (parts per million)

- - - Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

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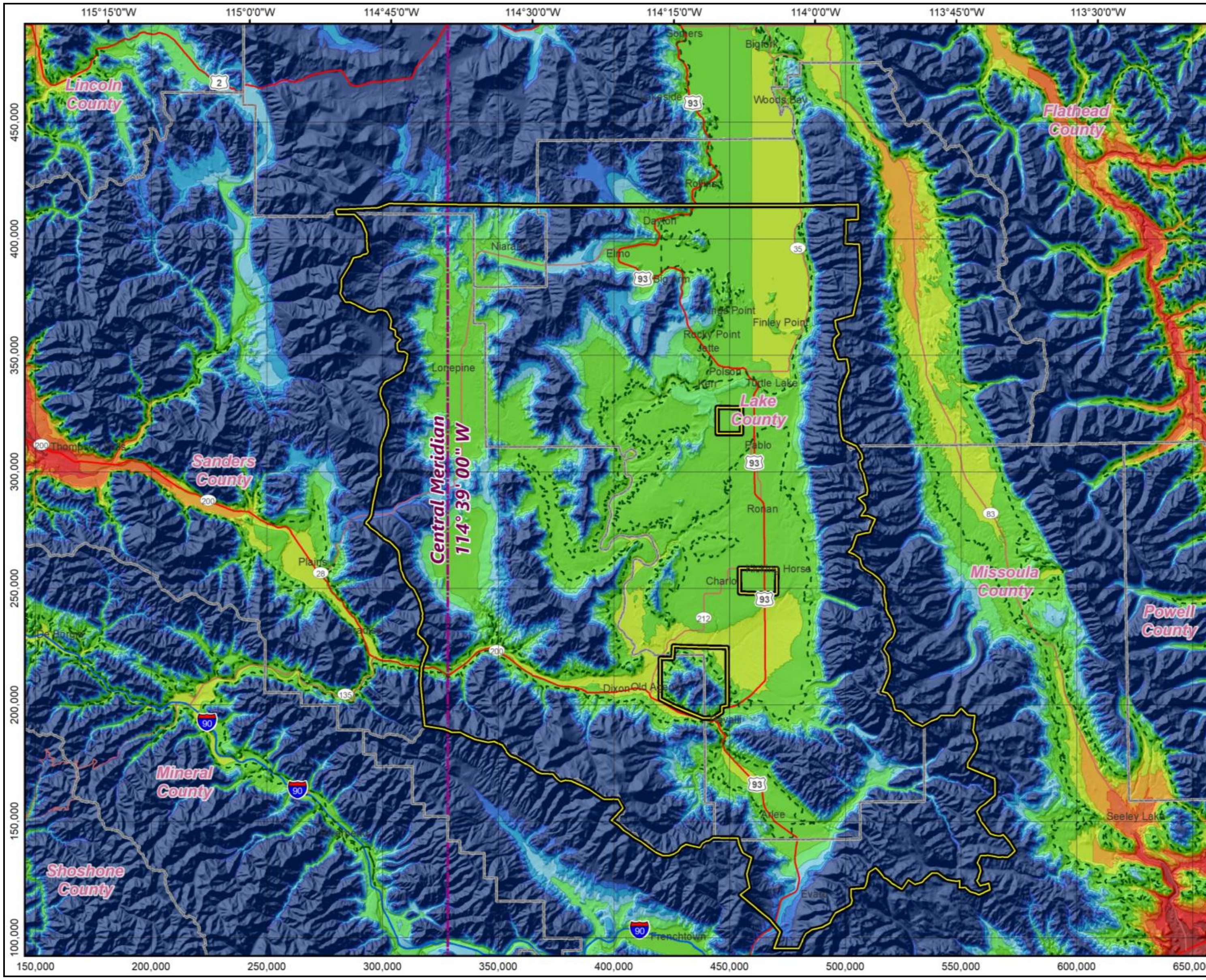


Mission 83 Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 46°45'00" N
Central meridian: 114°39'00" W
False northing: 0.000 m
False easting: 100,000.000 m
Central meridian scale: 1.000 126 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:500,000
(when printed on 11" x 17" sheet)

0 4 8 12 16 20
Miles

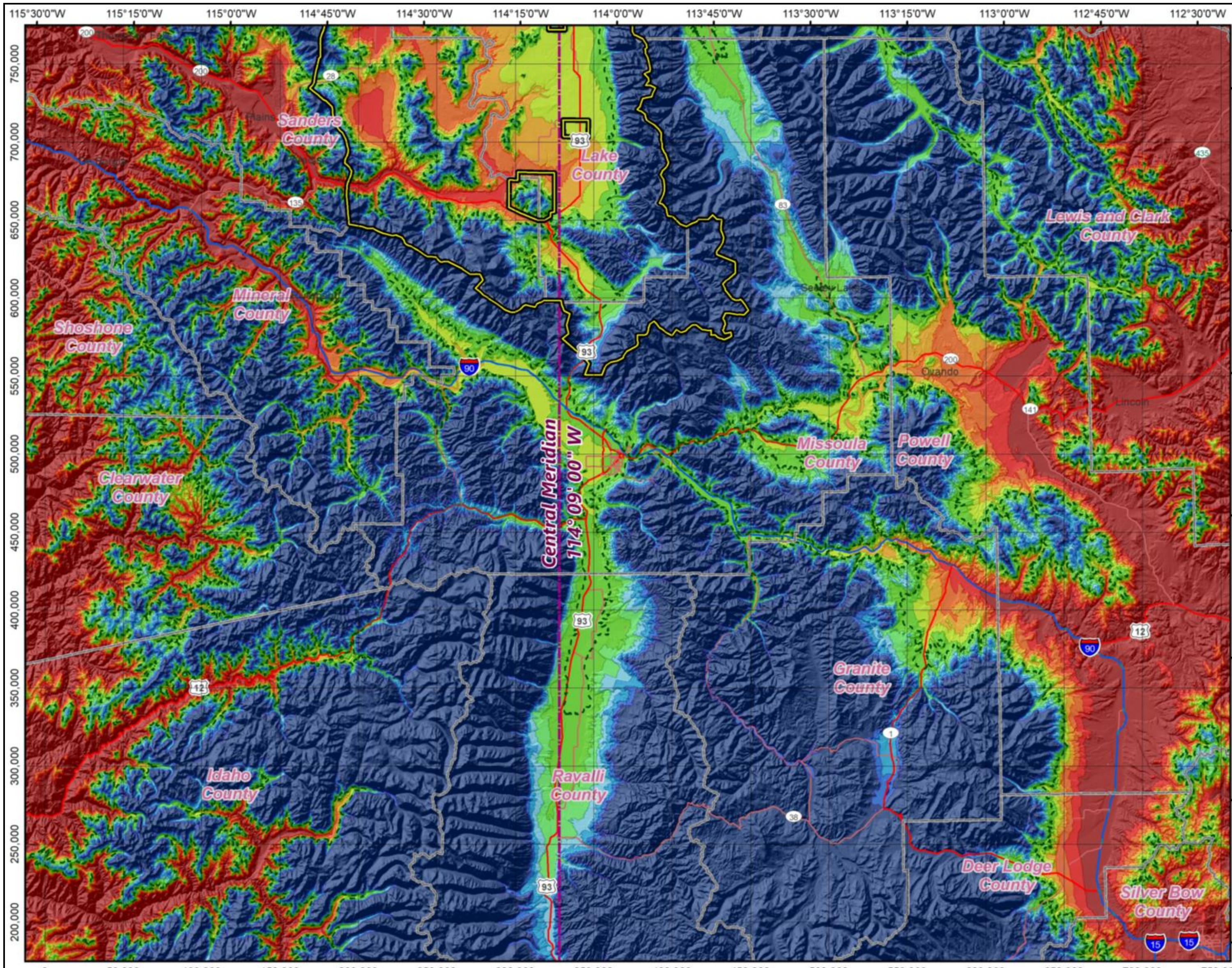
Linear distortion (parts per million)

- - - Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

This Coordinate System and Map are made possible by the generous contributions of SJW Land Surveying, Inc. and DJ&A

SJW LAND SURVEYING, INC.

DJ&A



Missoula 83 Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 45°30'00" N
Central meridian: 114°09'00" W
False northing: 0.000 m
False easting: 100,000.000 m
Central meridian scale: 1.000 158 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:750,000
(when printed on 11" x 17" sheet)

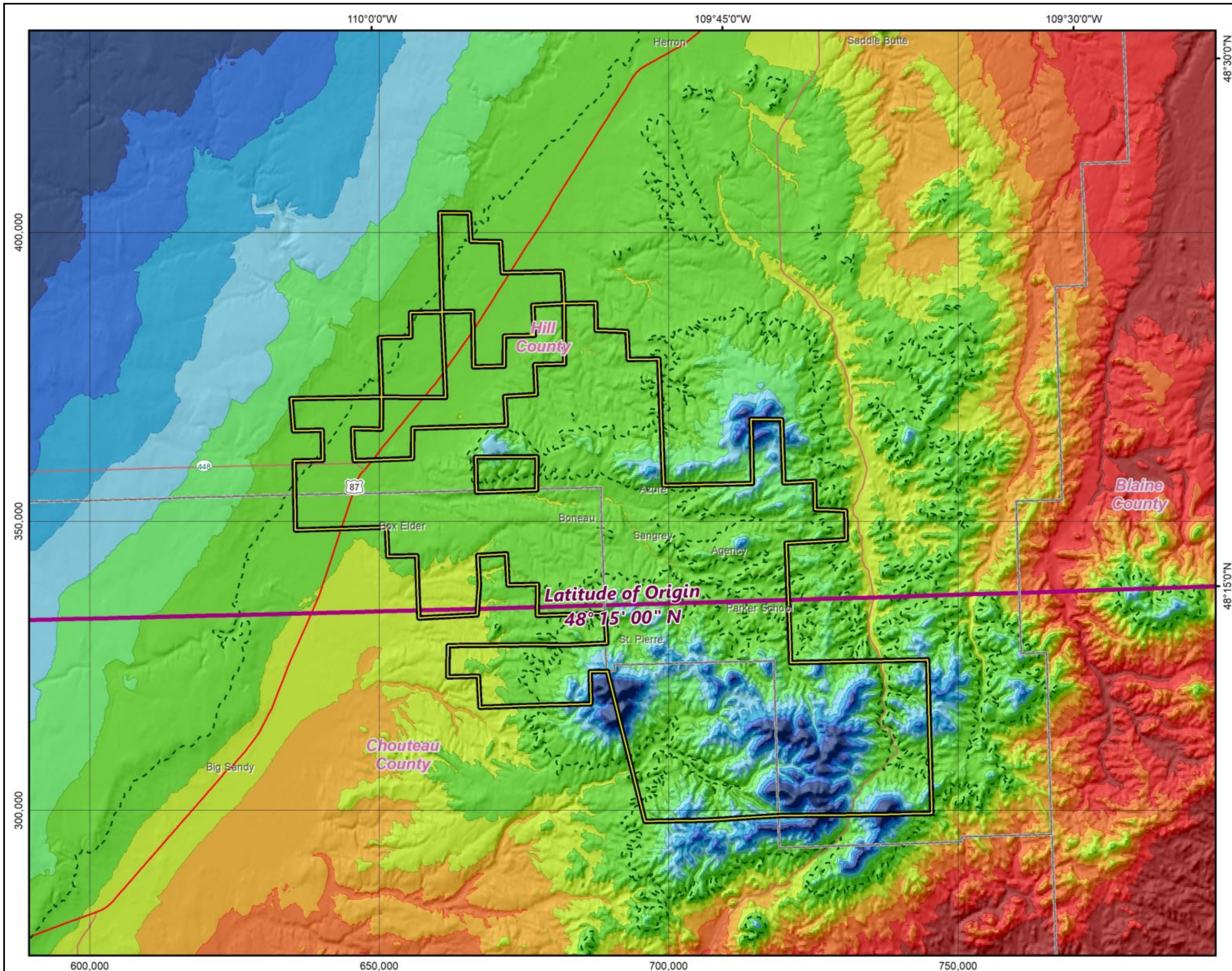
0 6 12 18 24 30
Miles

Linear distortion (parts per million)

- - - Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

This Coordinate System and Map are made possible by the generous contributions of Missoula County and DJ&A.

Missoula County
DJ&A



NECI 83 Coordinate System

Oblique Mercator Projection
North American Datum of 1983

Latitude of grid origin: 48°15'00" N
Central meridian: 112°00'00" W
False northing: 100,000.000 m
False easting: 50,000.000 m
Central meridian scale: 0.999 985 (exact)
Skew Azimuth: 39°

Grid North

Projected map grid shown in units of international feet

Scale 1:200,000
(when printed on 11" x 17" sheet)

0 1.5 3 4.5 6 7.5
Miles

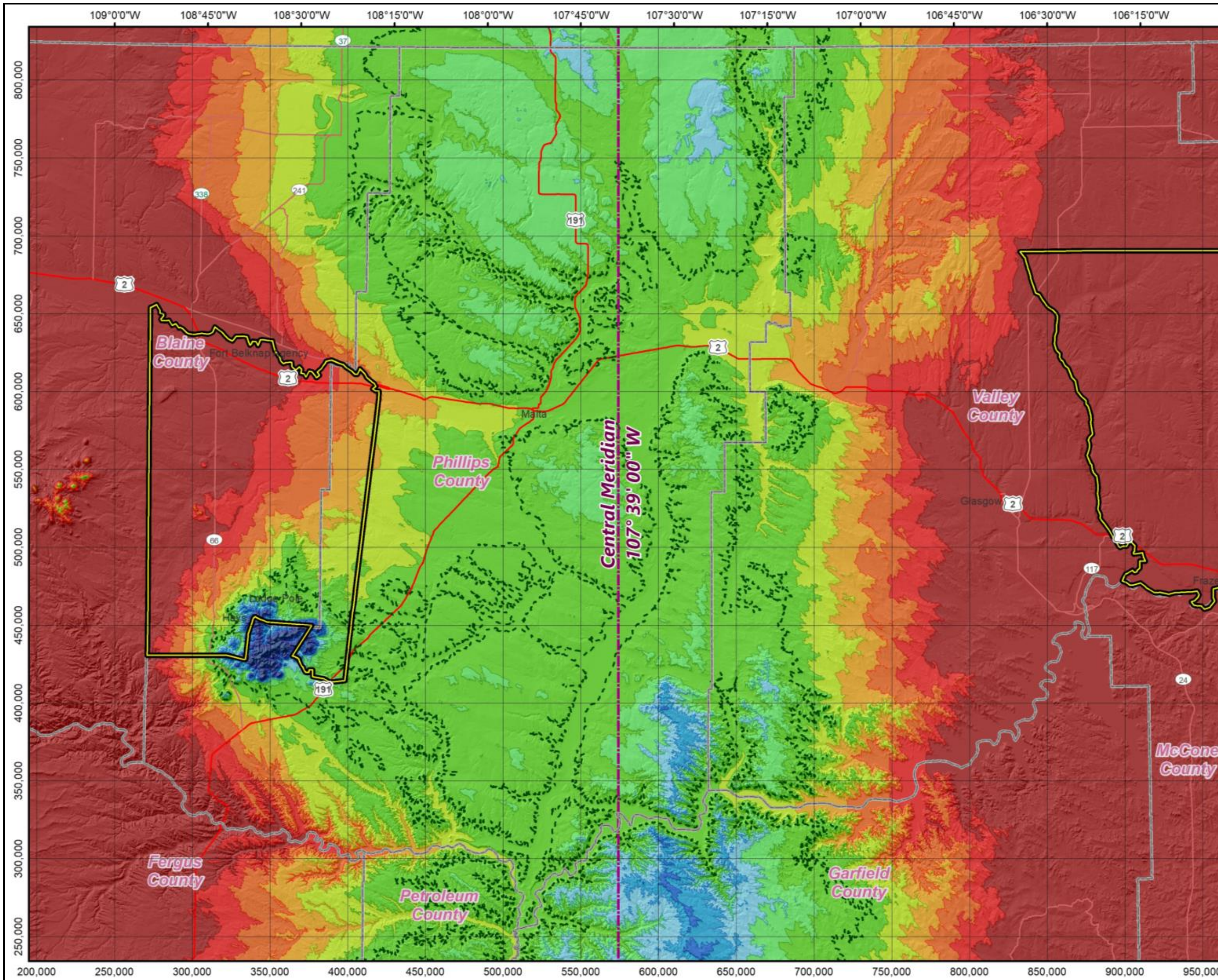
Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Indian reservation

This Coordinate System and Map are made possible by the generous contributions of NECI.

NORTHERN ENGINEERING & CONSULTING, INC.



Phillips 83 Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 46°45'00" N
Central meridian: 107°39'00" W
False northing: 0.000 m
False easting: 175,000.000 m
Central meridian scale: 1.000 110 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:750,000
(when printed on 11" x 17" sheet)

0 6 12 18 24 30
Miles

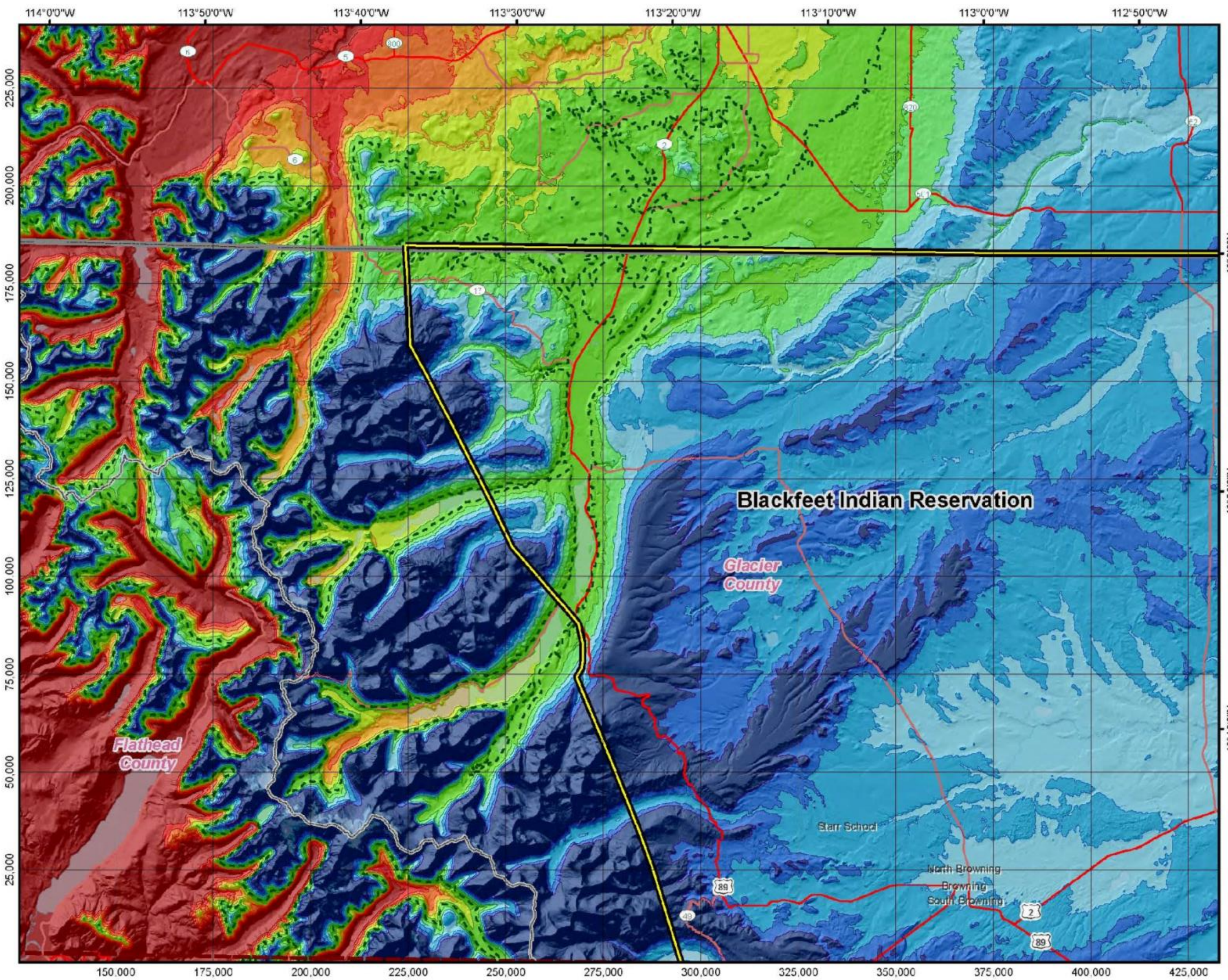
Linear distortion (parts per million)

- - - Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Indian reservation

This Coordinate System and Map are made possible by the generous contributions of Assiniboine and Sioux Tribes and NECI.

St. Mary Coordinate System



Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 48°30'00" N
Central meridian: 112°30'00" W
False northing: 0.000 m
False easting: 150,000.000 m
Central meridian scale: 1.000 160 (exact)

Grid North

Projected map grid shown in units of international feet

Scale 1:300,000
(when printed on 11" x 17" sheet)

0 5 10
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Indian reservation

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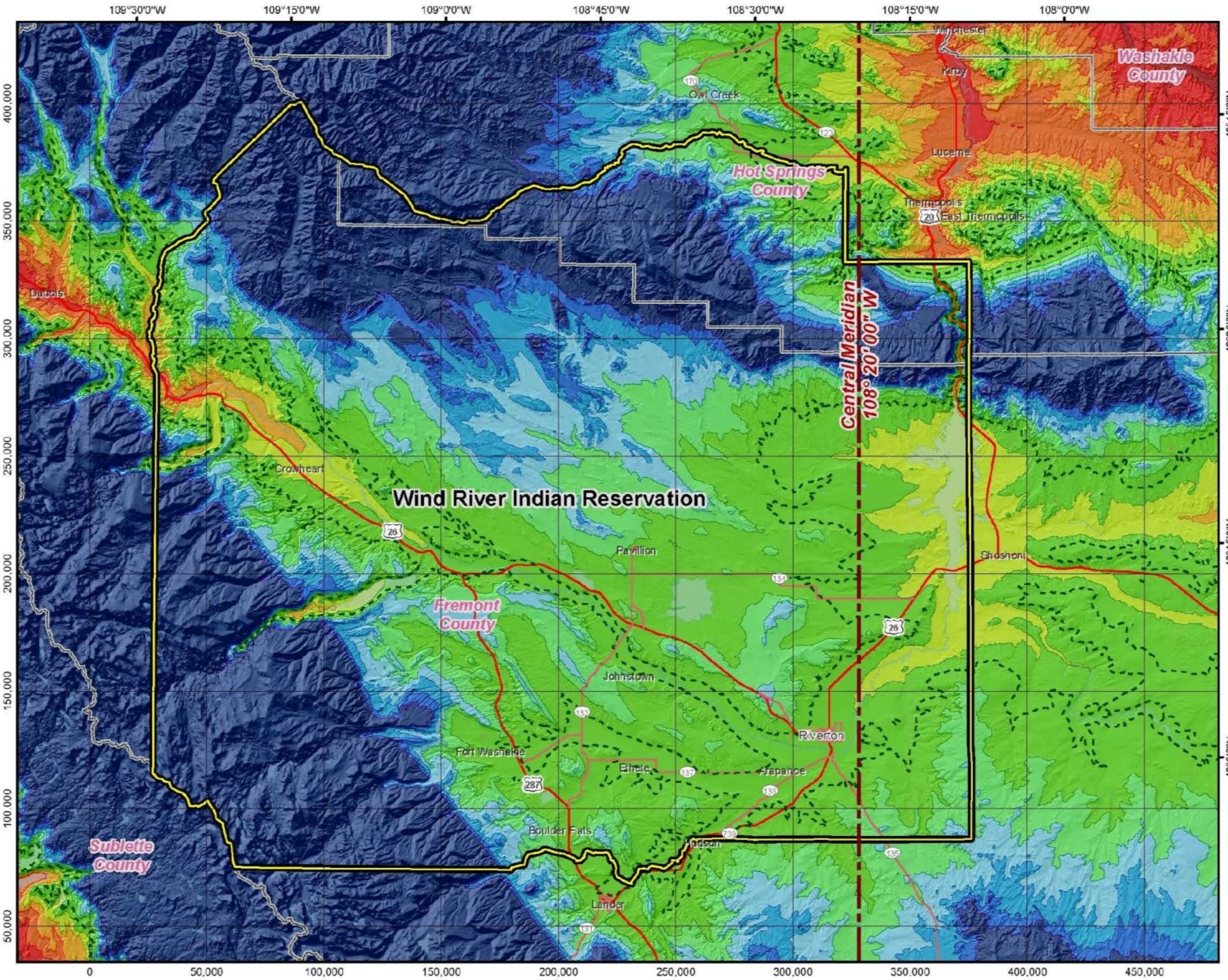
Geodetic Analysis LLC
Northern Engineering & Consulting, Inc.



Wind River Coordinate System

Transverse Mercator Projection
North American Datum of 1983

Latitude of grid origin: 42° 40' 00" N
Central meridian: 108° 20' 00" W
False northing: 0.000 m
False easting: 100,000.000 m
Central meridian scale: 1.000 240 (exact)

Grid North

Projected map grid shown in units of US survey feet

Scale 1:500,000
(when printed on 11" x 17" sheet)

0 5 10 15 20
Miles

Linear distortion (parts per million)

- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Designed and prepared by

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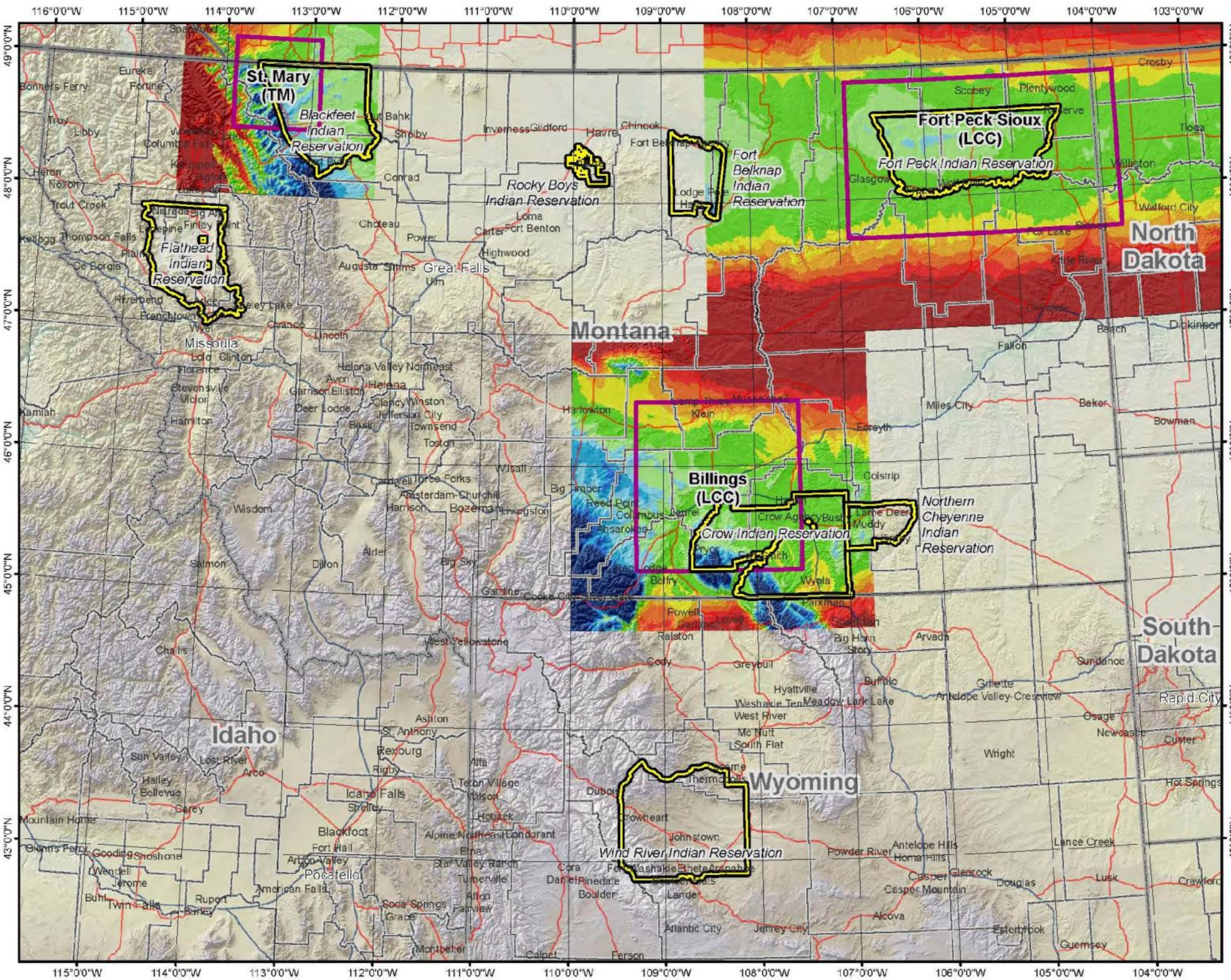
Geodetic Analysis
Northern Engineering & Consulting, Inc.

Appendix B

RMTCRS Distortion Overview Maps



Distortion Overview

Montana and Wyoming Low Distortion Projection (LDP) Coordinate Systems

Distortion displayed for the following zones (extended coverage used to show performance beyond design area):

- **Billings (LCC)**
- **Fort Peck Sioux (LCC)**
- **St. Mary (TM)**

TM = Transverse Mercator projection
LCC = Lambert Conformal Conic projection

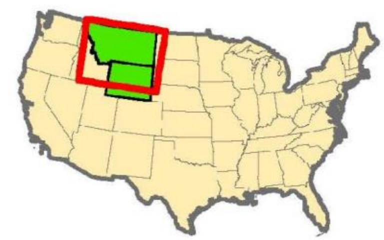
Scale 1:3,250,000
(when printed on 11" x 17" sheet)

0 25 50 75 100
Miles

Indian reservation
LDP design area

Linear distortion (parts per million)

- <-100 ppm (<-0.5 ft/mile)
- -80 to -100 ppm
- -60 to -80 ppm
- -40 to -60 ppm
- -20 to -40 ppm
- ±20 ppm (±0.1 ft/mile)
- +20 to +40 ppm
- +40 to +60 ppm
- +60 to +80 ppm
- +80 to +100 ppm
- >+100 ppm (>+0.5 ft/mile)



Designed and prepared by

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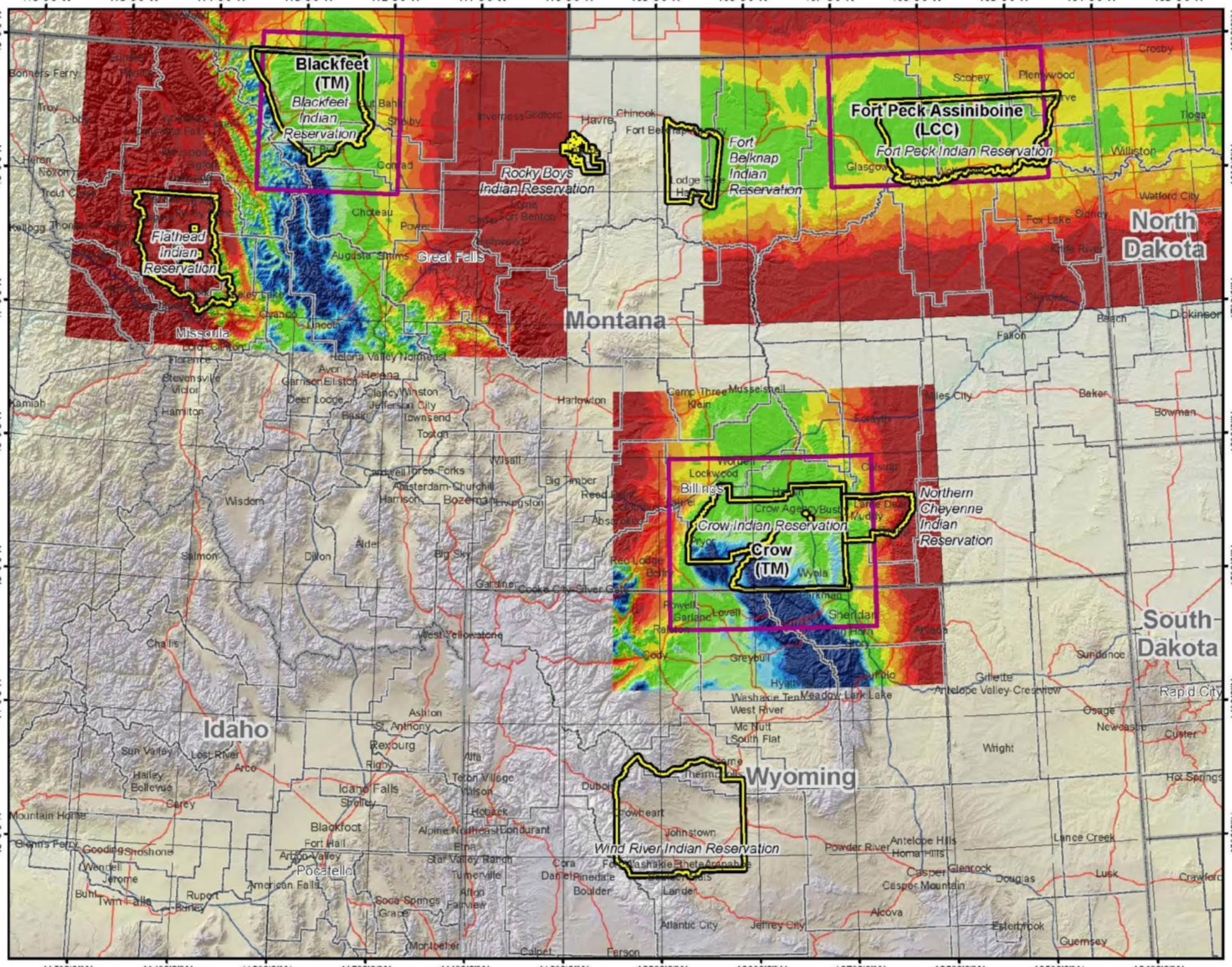
Northern Engineering & Consulting, Inc.



Distortion Overview

Montana and Wyoming Low Distortion Projection (LDP) Coordinate Systems

Distortion displayed for the following zones (extended coverage used to show performance beyond design area):

- **Blackfeet (TM)**
- **Crow (TM)**
- **Fort Peck Assiniboine (LCC)**

TM = Transverse Mercator projection
LCC = Lambert Conformal Conic projection

Scale 1:3,250,000
(when printed on 11" x 17" sheet)

0 25 50 75 100
Miles

Indian reservation
LDP design area

Linear distortion (parts per million)

- <-100 ppm (<-0.5 ft/mile)
- -80 to -100 ppm
- -60 to -80 ppm
- -40 to -60 ppm
- -20 to -40 ppm
- ±20 ppm (±0.1 ft/mile)
- +20 to +40 ppm
- +40 to +60 ppm
- +60 to +80 ppm
- +80 to +100 ppm
- >+100 ppm (>+0.5 ft/mile)

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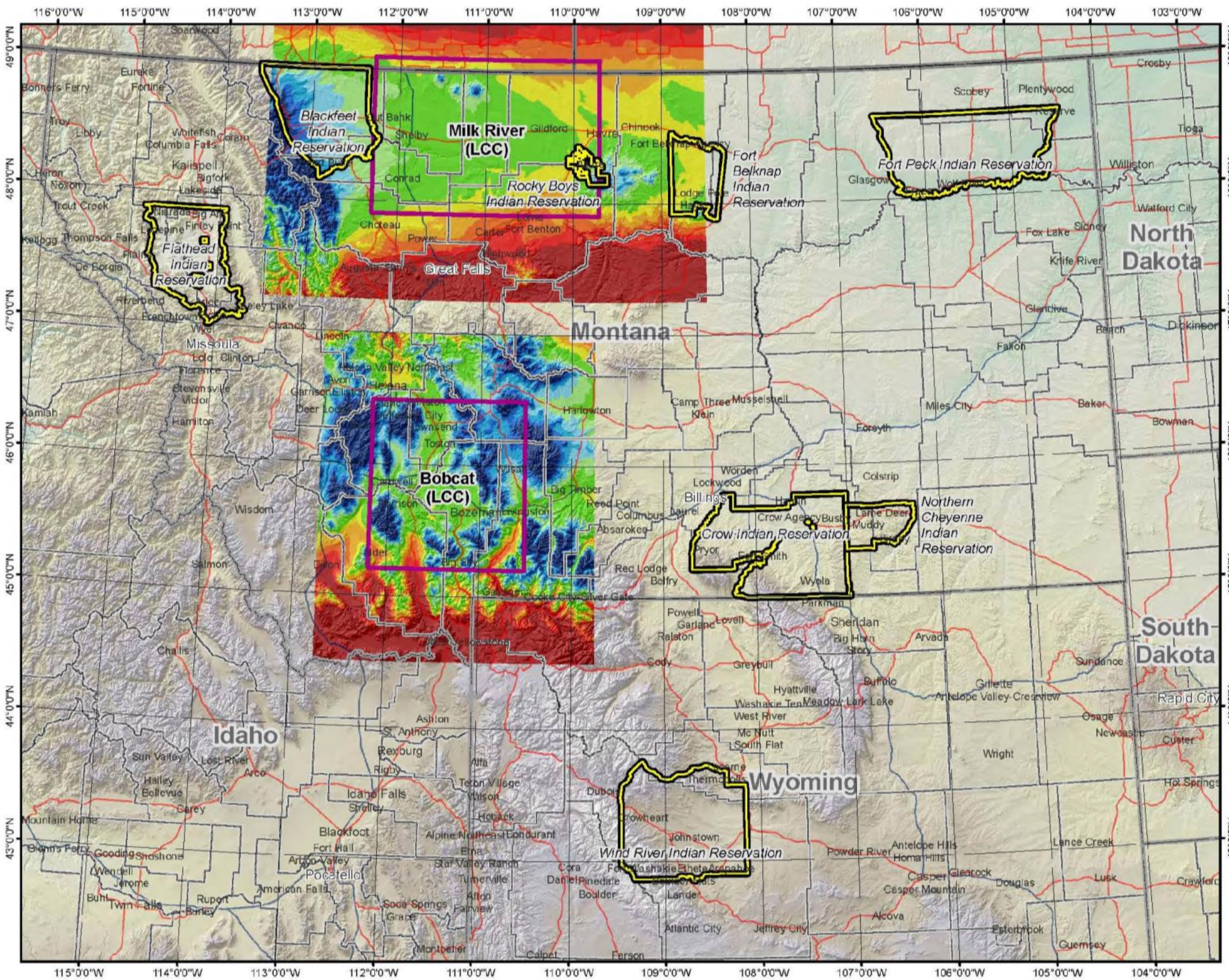
Geodetic Analysis LLC
Northern Engineering & Consulting, Inc.



Distortion Overview

Montana and Wyoming Low Distortion Projection (LDP) Coordinate Systems

Distortion displayed for the following zones (extended coverage used to show performance beyond design area):

- **Bobcat (LCC)**
- **Milk River (LCC)**

TM = Transverse Mercator projection
LCC = Lambert Conformal Conic projection

Scale 1:3,250,000
(when printed on 11" x 17" sheet)

0 25 50 75 100
Miles

Indian reservation
LDP design area

Linear distortion (parts per million)

- <-100 ppm (<-0.5 ft/mile)
- -80 to -100 ppm
- -60 to -80 ppm
- -40 to -60 ppm
- -20 to -40 ppm
- ±20 ppm (±0.1 ft/mile)
- +20 to +40 ppm
- +40 to +60 ppm
- +60 to +80 ppm
- +80 to +100 ppm
- >+100 ppm (>+0.5 ft/mile)

Designed and prepared by

Michael L. Dennis, RLS, PE
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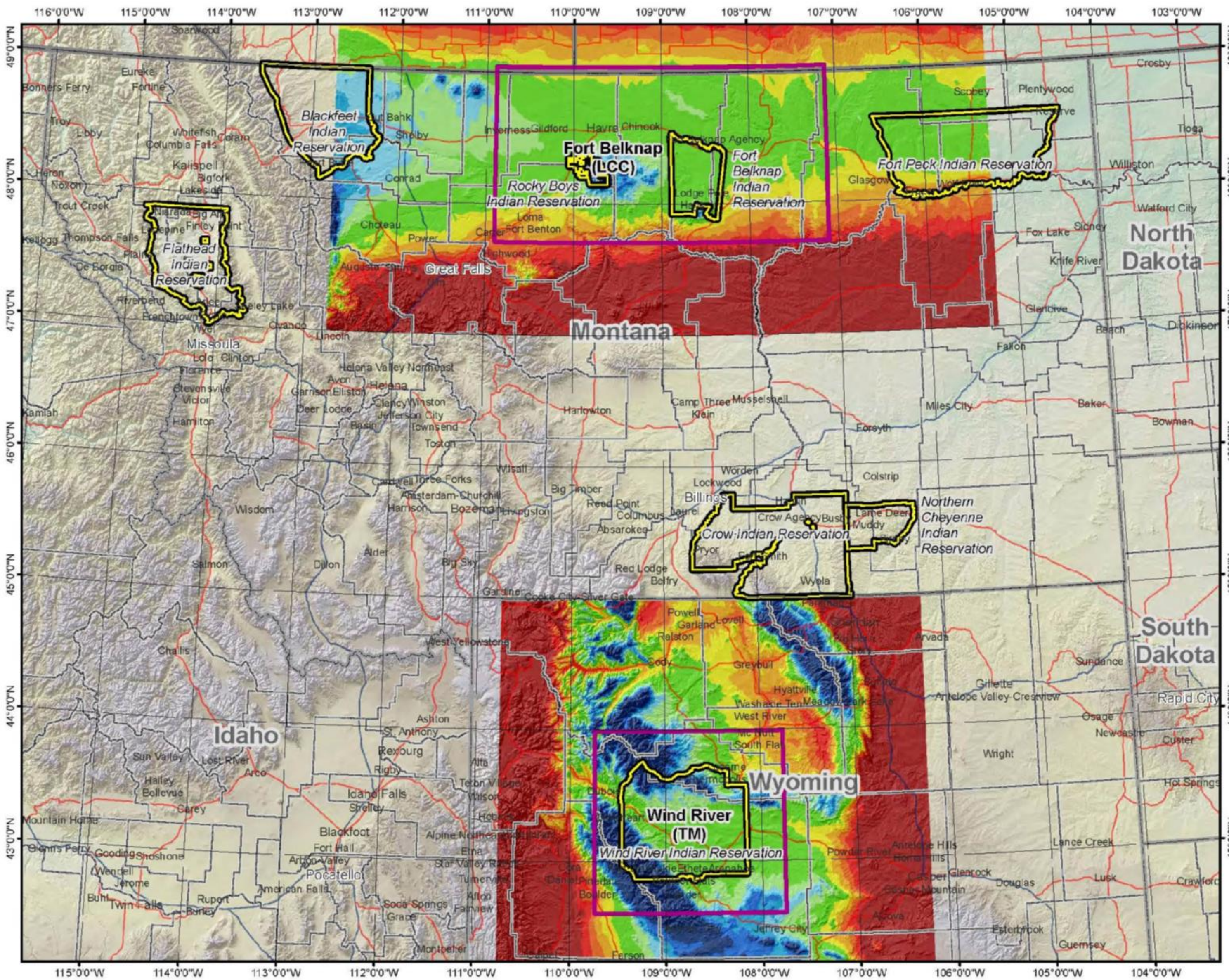
Geodetic Analysis
Northern Engineering & Consulting, Inc.



Distortion Overview

Montana and Wyoming Low Distortion Projection (LDP) Coordinate Systems

Distortion displayed for the following zones (extended coverage used to show performance beyond design area):

- **Fort Balknap (LCC)**
- **Wind River (TM)**

TM = Transverse Mercator projection
LCC = Lambert Conformal Conic projection

Scale 1:3,250,000
(when printed on 11" x 17" sheet)

0 25 50 75 100
Miles

Indian reservation
LDP design area

Linear distortion (parts per million)

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- -80 to -100 ppm
- -60 to -80 ppm
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- +20 to +40 ppm
- +40 to +60 ppm
- +60 to +80 ppm
- +80 to +100 ppm
- >+100 ppm (>+0.5 ft/mile)

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Appendix C

RMTCRS Trial – Field Testing Results

NGS GPS Station Distances

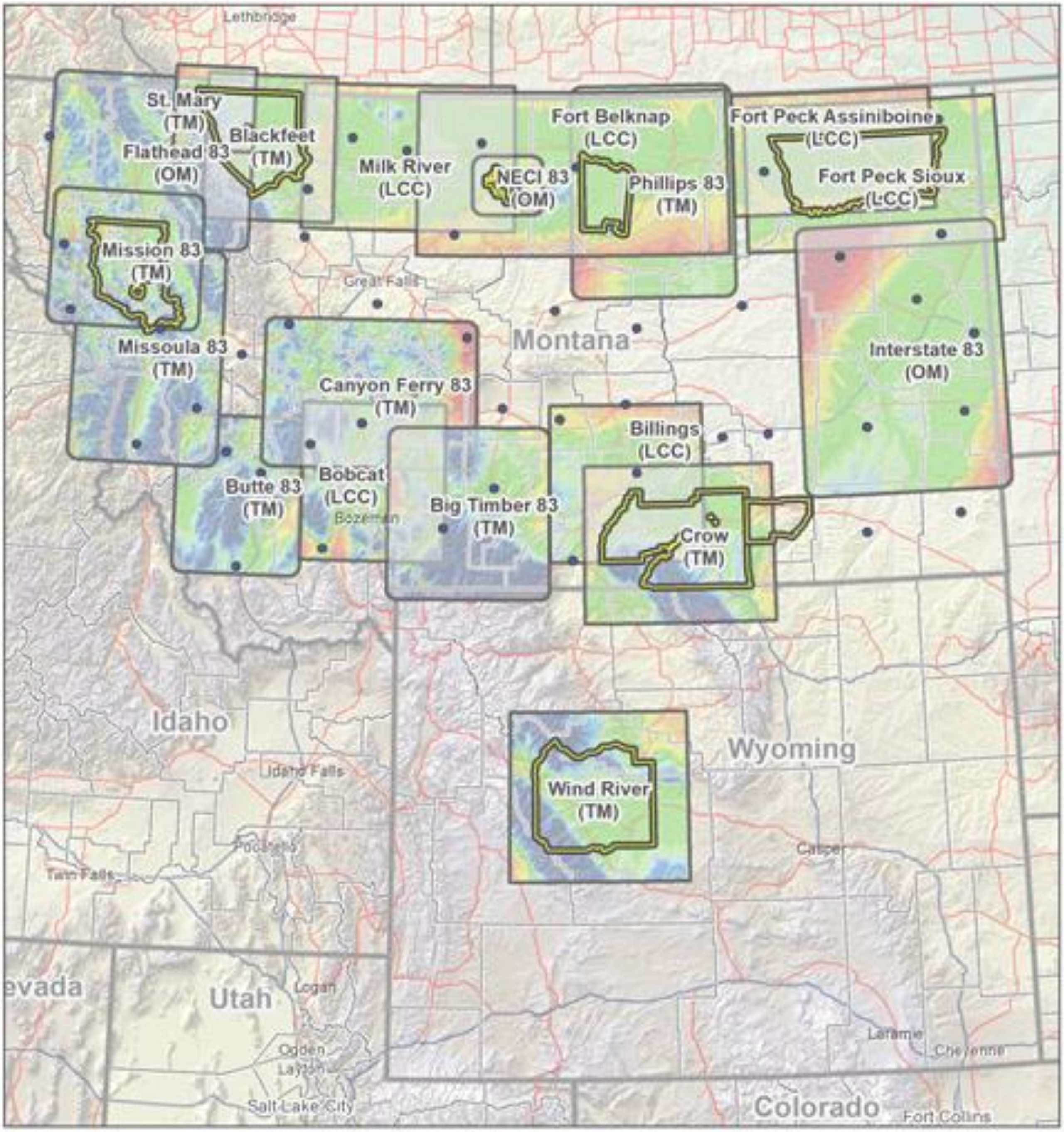
Blackfeet & St. Mary LDP	NGS Dist. To R424		NGS Dist. To Blackfeet		NGS Dist. To Sherburne 2		Observed Dist. To R424		Observed Dist. To Blackfeet		Observed Dist. To Sherburne 2	
	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing
R424	0.00	-	62940.05	N 66° 08' 07.3077" E	151485.66	N 24° 42' 31.2835" W	0.00	-				
W423	77500.02	S 64° 41' 47.2197" W	14665.23	S 58° 30' 34.4540" W	167719.10	N 51° 12' 19.9654" W	77918.13	S 62° 35' 19" W	15041.58	N 56°42' 47" W		
Blackfeet	62940.05	S 66° 08' 07.3077" W	0.00	-	163458.09	N 46° 03' 46.2484" W	62939.20	S 66° 08' 07" W	0.00	-		
Sherburne 1	157003.84	S 33° 03' 21.8294" E	178130.26	S 54° 38' 07.4055" E	26530.97	N 73° 50' 37.6351" E					26553.55	N 71° 39' 17" E
Sherburne 2	151485.66	S 24° 42' 31.2835" E	163458.09	S 46° 03' 46.2484" E	0.00	-						

Ft. Belknap LDP	NGS Dist. To K526		NGS Dist. To Cherry		NGS Dist. To Carson		Observed Dist. To K526		Observed Dist. To Cherry		Observed Dist. To Carson	
	Dist. METERS	Bearing	Dist. METERS	Bearing	Dist. METERS	Bearing	Dist. METERS	Bearing	Dist. METERS	Bearing	Dist. METERS	Bearing
K526	0.00	-	114705.75	N 24° 33' 35.2493" W	34516.25	S 43° 52' 17.9027" E	0.00	-	114755.54	N 22° 42' 22" W	34540.55	S 41° 24' 07" E
Y513	38134.78	S 34° 24' 56.0783" W	99784.68	N 43° 40' 46.9845" W	57080.86	S 02° 23' 38.1260" E	38157.18	S 35°08'31" W	114705.75	N 24° 33' 35.2493" W	57117.42	S 00° 52' 56" E
Cherry	114705.75	S 24° 33' 35.2493" E	0.00	-	147816.50	S 28° 16' 08.1271" E	114755.54	S 22° 42' 22" E	0.00	-	147888.51	S 26° 59' 58" E
Porter	114297.98	S 10° 47' 54.0631" W	67411.11	S 84° 00' 37.0572" W	137883.80	S 01° 16' 38.1850" E	114346.16	S 11° 31' 29" W	67424.81	S 84° 44' 30" E	137949.26	S 00° 00' 03" E
Lakeside	75382.23	S 41° 05' 56.5596" W	106796.63	N 64° 58' 09.3956" W	86530.54	S 17° 45' 50.3205" W	75422.68	S 41° 55' 19" W	106830.66	N 62° 18' 09" W	86581.58	S 18° 29' 04" W
Carson	34516.25	N 43° 52' 17.9027" W	147816.50	N 28° 16' 08.1271" W	0.00	-	34540.55	N 41° 24' 07" W	147888.51	N 26° 59' 58" W	0.00	-

Ft. Peck LDP	NGS Dist. To P354		NGS Dist. To Richland		NGS Dist. To R540		Observed Dist. To P354		Observed Dist. To Richland		Observed Dist. To R540	
	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing
P354	0.00	-	334578.61	N 10° 17' 19.9379" E	233797.03	N 57° 50' 30.1847" W	0.00	-	334703.87	N 13° 13' 31" E	233909.26	N 53° 12' 48" W
MCCabe	485862.20	S 76° 46' 41.8597" W	467235.83	N 63° 49' 19.7255" W	667442.72	N 89° 38' 15.8402" W	486108.68	S 79° 42' 07" W	467387.88	N 59° 25' 24" W	667729.79	N 86° 25' 57" W
Richland	334578.61	S 10° 17' 19.9379" W	0.00	-	322627.52	S 51° 55' 01.6763" W	334703.87	S 13° 13' 31" W	0.00	-	322723.55	S 54° 51' 35" W
Madoc	376789.91	S 37° 54' 57.3588" W	174724.57	N 80° 32' 03.6019"W	457328.51	S 68° 34' 30.7046" W	376939.31	S 40° 50' 49" W	174761.88	N 76° 32' 13"W	457474.61	S 71° 30' 44" W
R540	233797.03	S 57° 50' 30.1847" E	322627.52	N 51° 55' 01.6763" E	0.00	-	233909.26	S 53° 12' 48" E	322723.55	N 54° 51' 35" E	0.00	-

Wind River LDP	NGS Dist. To Fort Washakie		NGS Dist. To Pebble		NGS Dist. to J21		Observed Dist. To Fort Washakie		Observed Dist. To Pebble		Observed Dist. To J21	
	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing	Distance	Bearing
Fort Washakie	0.00	-	110012.37	N 74° 41' 23.8554" E	89888.53	S 68° 12' 42.7071' E						
P21	123374.22	N 00° 55' 45.2359" W	35518.71	N 30° 56' 40.6248" W	51321.81	S 51° 27' 18.7404" W						
Pebble	110012.37	S 74° 41' 23.8554" W	0.00	-	67056.45	S 19° 57' 34.0004" W						
Hart	74649.24	N 36° 00' 51.6898" W	108977.35	N 34° 49' 56.9270" E	47402.71	N 56° 07' 23.3946" E						
J21	89888.53	N 68° 12' 42.7071" W	67056.45	N 19° 57' 34.0004" E	0.00	-						

*NOTE ALL DISTANCES ARE IN FEET UNLESS OTHERWISE NOTED



Rocky Mountain Coordinate Reference System (RMCRS)

TM = Transverse Mercator
LCC = Lambert Conformal Conic
OM = Oblique Mercator

Indian reservation

0 25 50 75 100
Miles