Rocky Mountain Tribal Transportation Association

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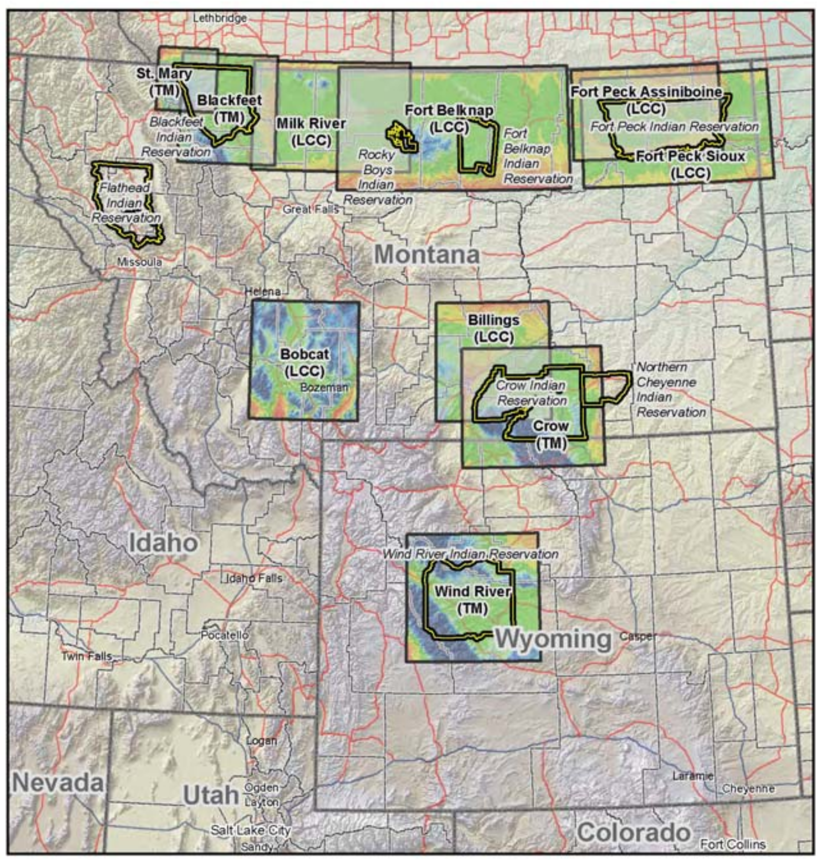
Rocky Mountain Tribal Coordinate Reference System

Handbook and User Guide

For the
Blackfeet
Crow
Fort Belknap
Fort Peck
& Wind River Reservations



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30 September 2014

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

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
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Robert Stewart	Crow DOT
Michael Stewart	Crow DOT
Titus Takes Gun	Crow MR&I Project
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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

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:

Ken Bays, PLS	ODOT Lead Geodetic Surveyor
Mark Armstrong, PLS	NGS Oregon Advisor
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Jim Griffis, PLS	David Evans and Associates
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Ken Crossley	Marion County Survey Technician 2

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

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Document Review History

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

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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.

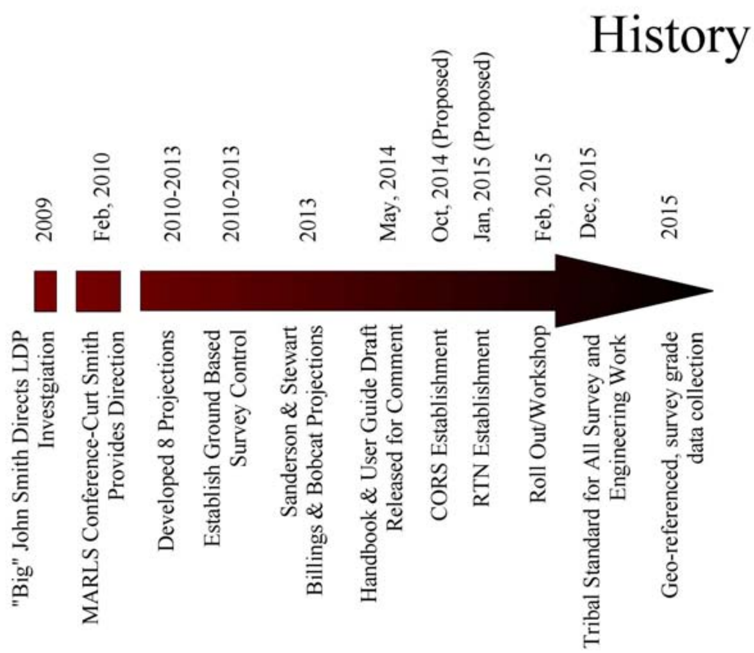


Figure 1.2: Historical Timeline for the RMTCRS

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.

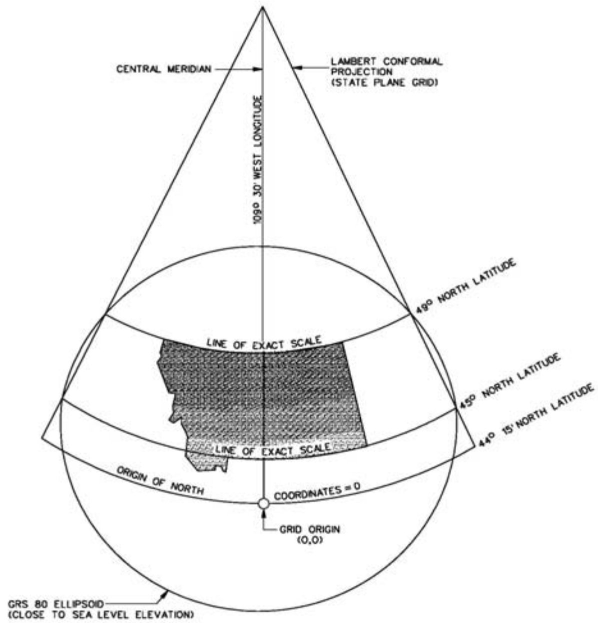


Figure 1.4.1: Montana State Plane Two parallel Lambert Conformal Conic Projection layout

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.

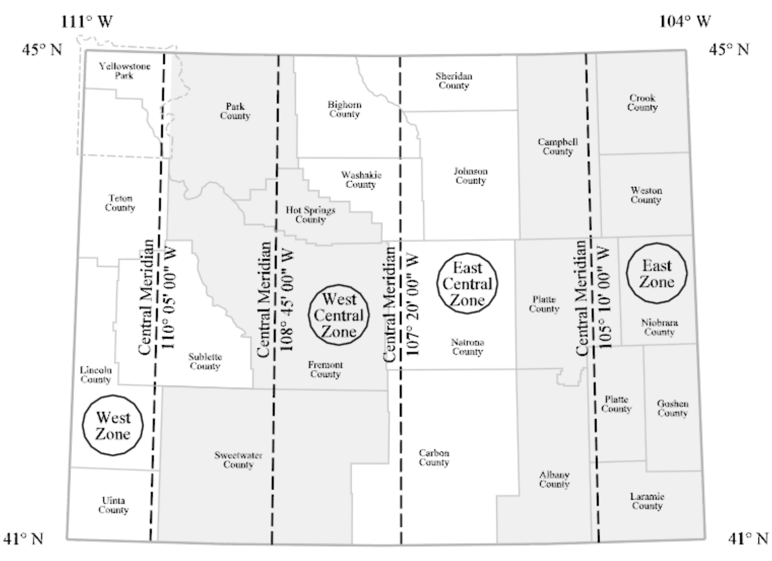
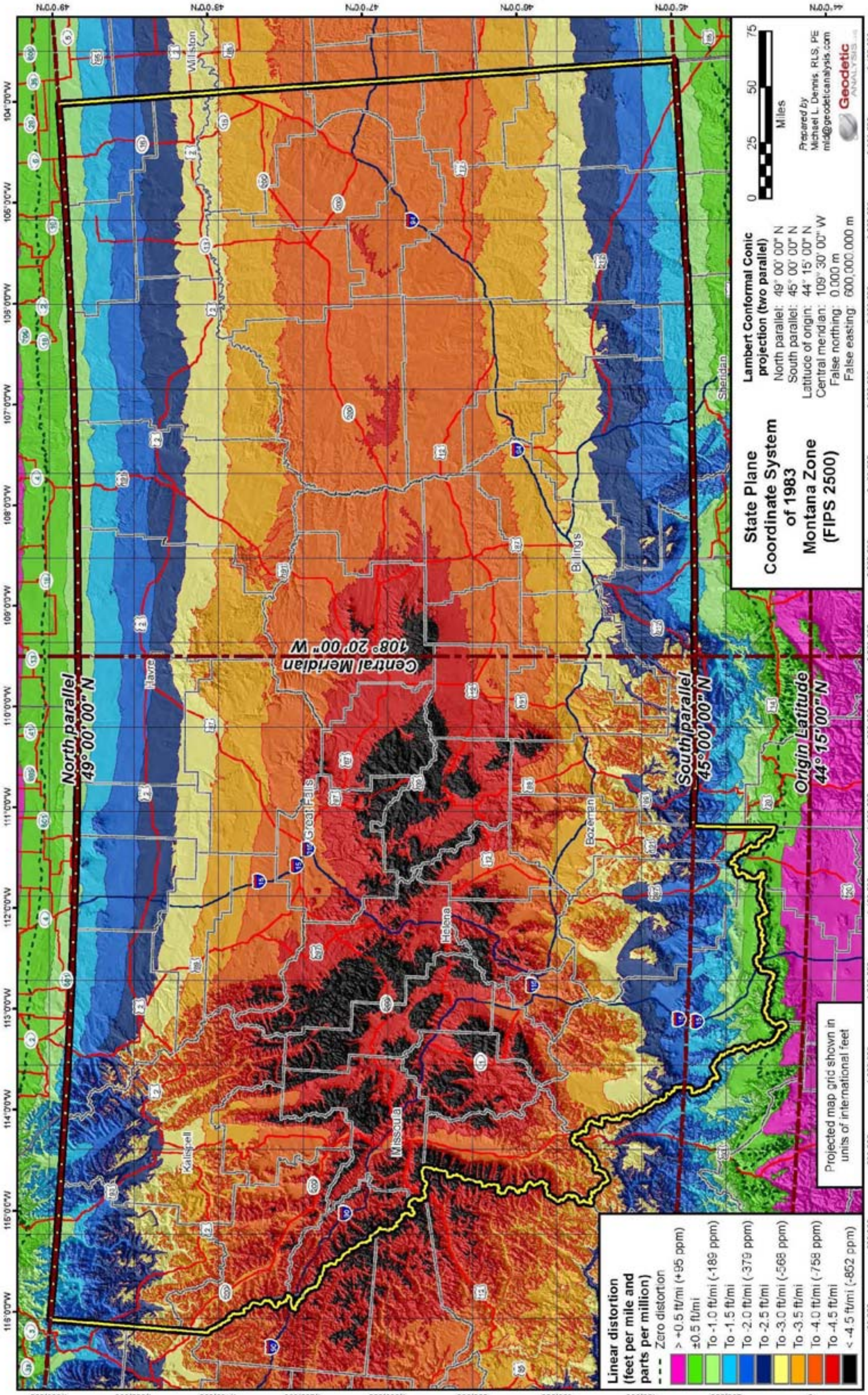


Figure 1.4.2: Wyoming Transverse Mercator State Plane Coordinate System Zones

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
Prepared by Michael L. Dennis, RLS, PE
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Geodetic
North parallel 49° 00' 00" N
South parallel 45° 00' 00" N
Origin Latitude 44° 15' 00" N
Central Meridian 109° 30' 00" W
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
Havre
Bozeman
Billings
Sheridan
Williston

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).

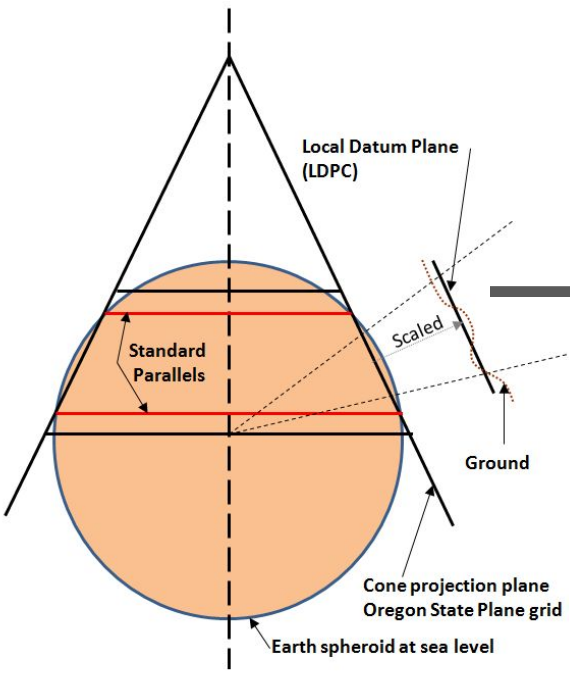


Figure 1.7: Local Datum Plane Coordinate System scaled from State Plane [mla]

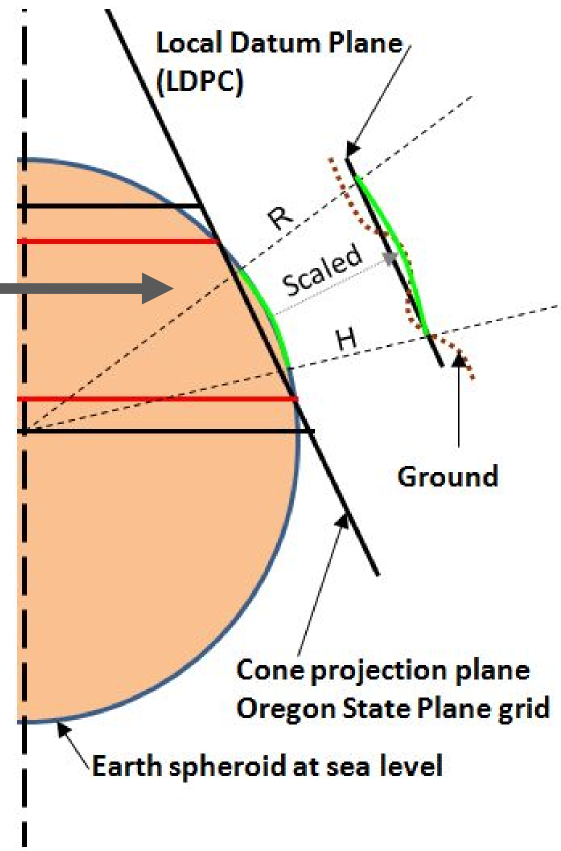


Figure 1.7.1: Local Datum Plane Coordinate System enlarged to show spheroid to LDPC plane

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).

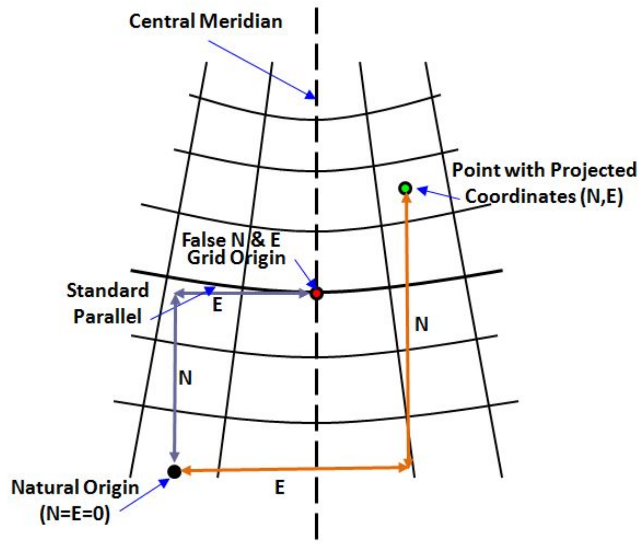


Figure 2.1.1: Diagram for Lambert Conical Conformal Projection with one standard parallel

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.

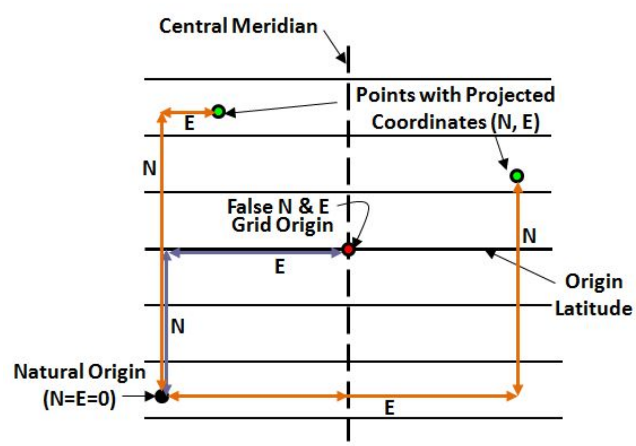


Figure 2.1.2: Diagram Transverse Mercator Projection [mla]

2.1.3 Oblique Mercator (RSO) Projection

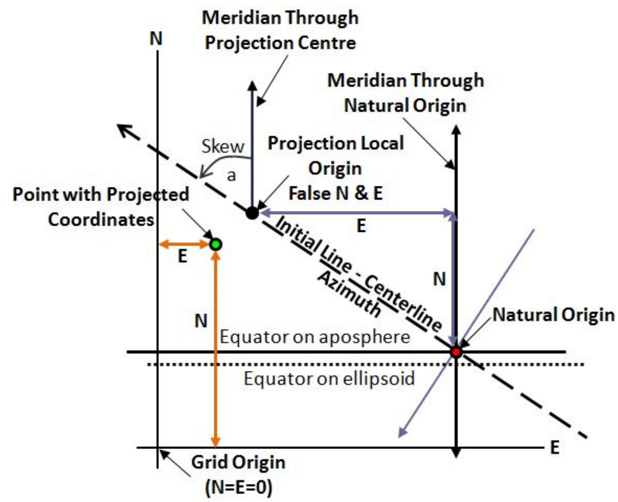


Figure 2.1.3: Diagram for Oblique Mercator (RSO) Projection [mla]

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

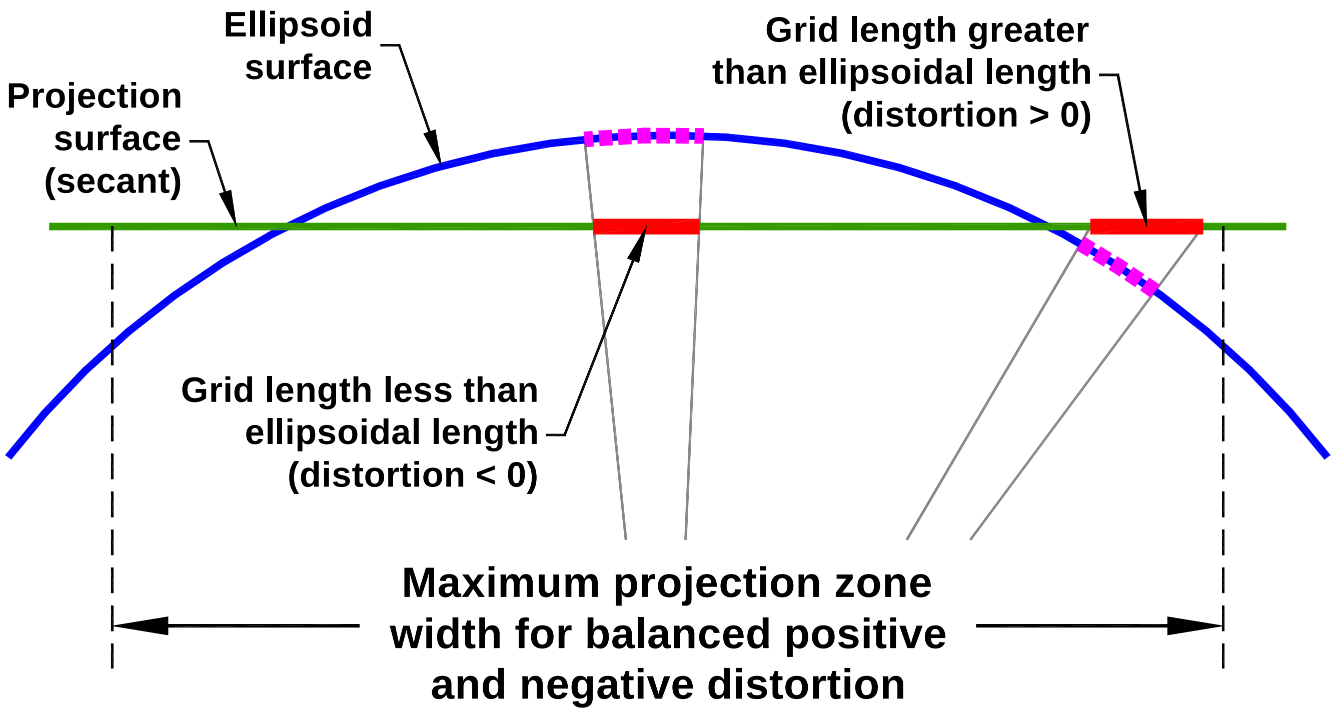


Table 2.2.2.1

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

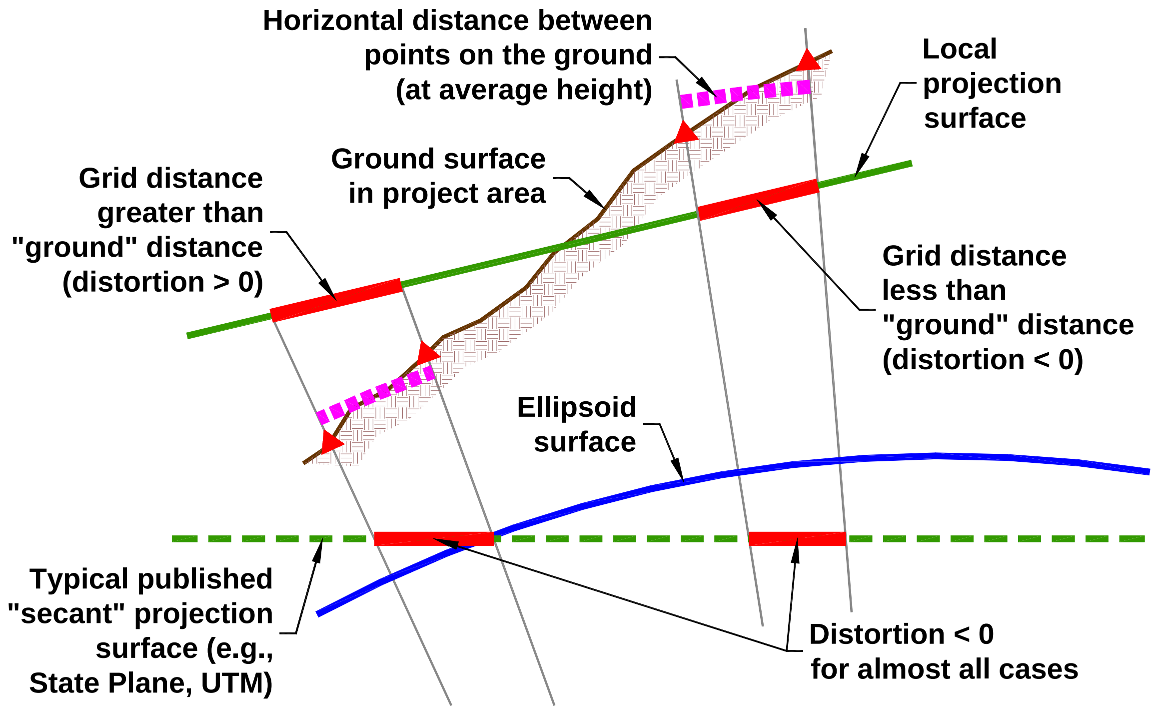


Table 2.2.2.2

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 (not 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.

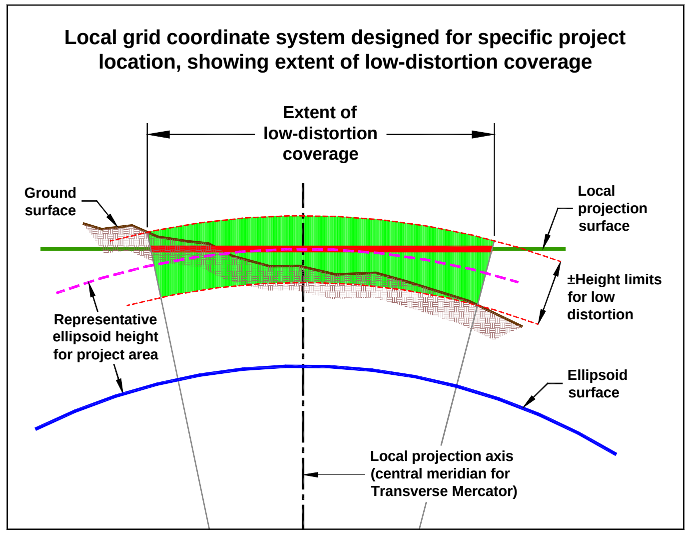


Figure 2.2.3: Diagram shows the effect of scaling the projection to a representative height above the ellipsoid [md]

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 <u>no more</u> 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
Rotation X- Rotation about the X-axis
Rotation Y- Rotation about the Y-axis
Rotation Z- Rotation about the Z-axis
Scale Factor

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

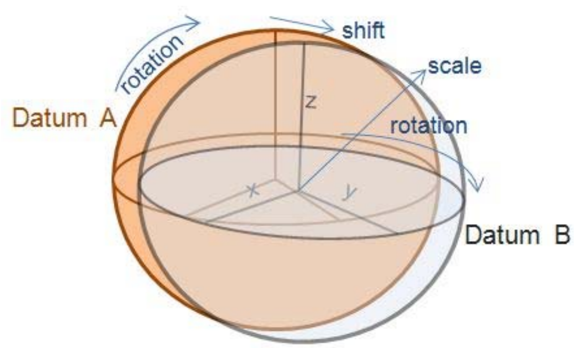


Fig. 2.3.2 [mla]

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).

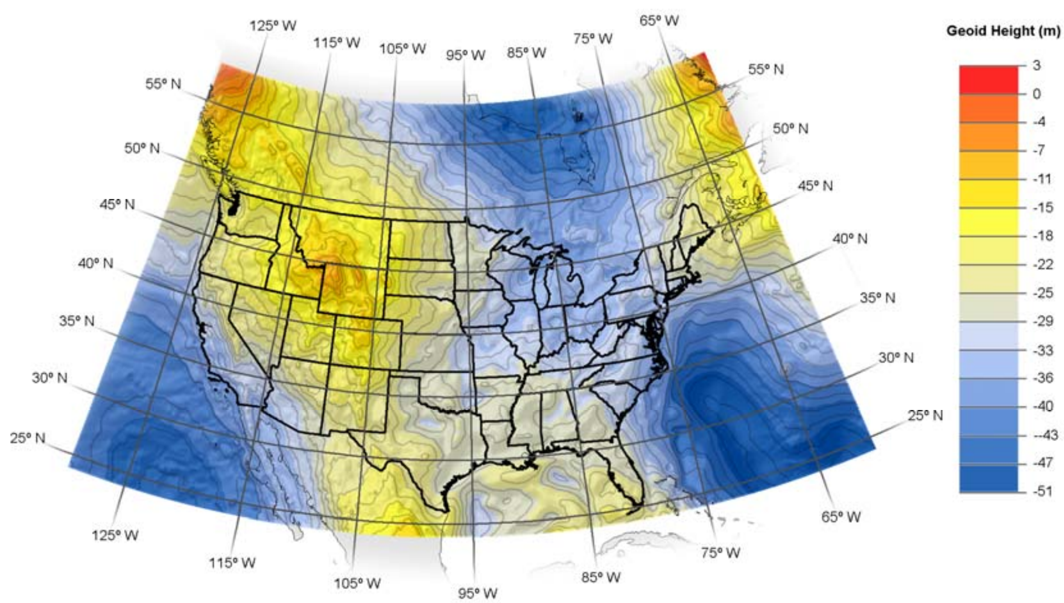
2.3.4 Vertical Reference Datum

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

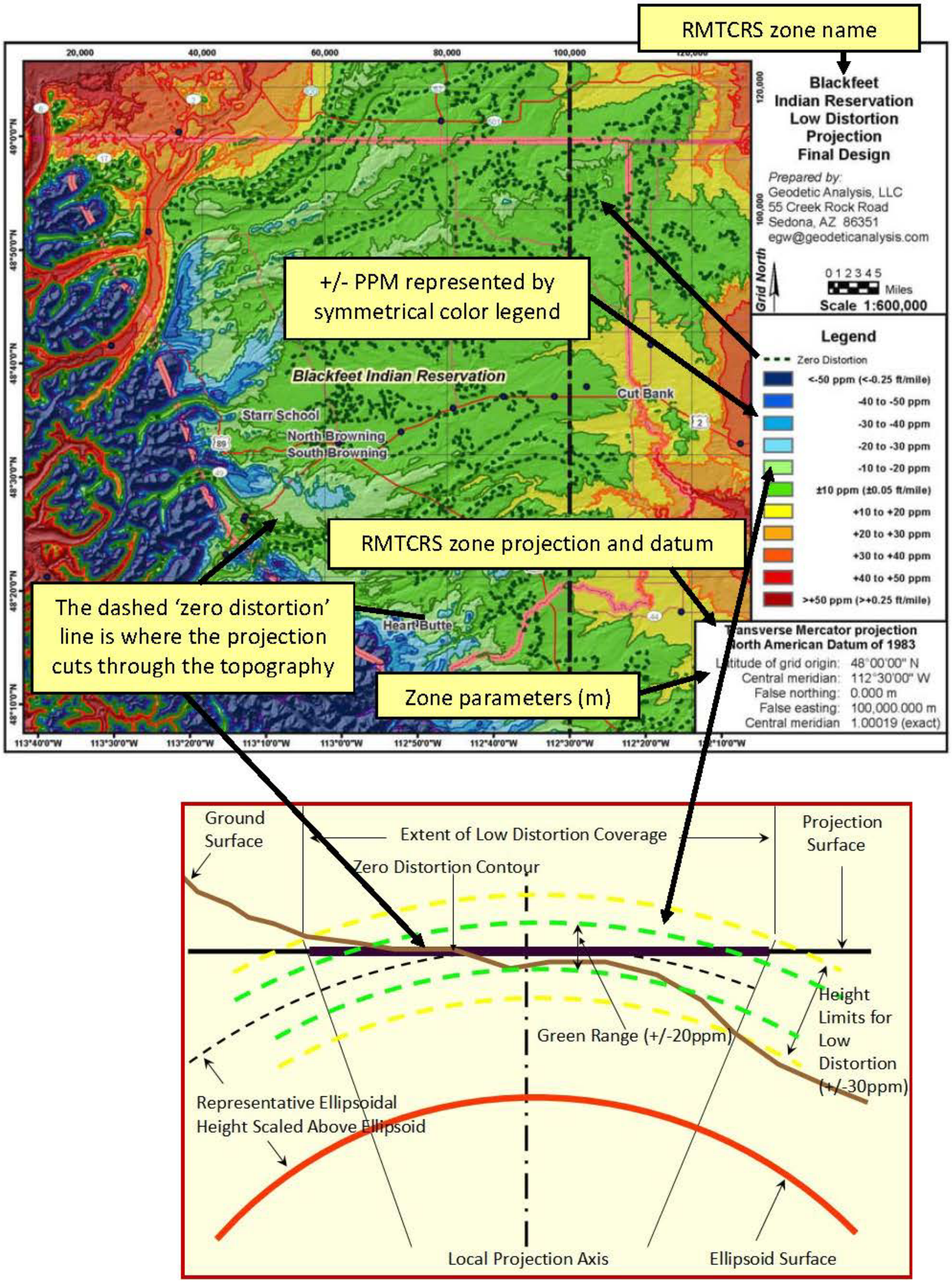
Zone Name*	Projection	Latitude of Grid Origin	Central Meridian	False Northing (m)	False Easting (m)	Scale (exact)
St. Mary's Valley (Blackfeet)	TM	48°30'00"N	112°30'00"W	0	150 000	1.000 160
Blackfeet Indian Reservation	TM	48°00'00"N	112°30'00"W	0	100 000	1.000 190
Fort Belknap Indian Reservation	LCC	48°30'00"N	108°30'00"W	150 000	200 000	1.000 120
Milk River	LCC	48°30'00"N	111°00'00"W	200 000	150 000	1.000145
Fort Peck Indian Reservation-Sioux	LCC	48°20'00"N	105°30'00"W	50 000	100 000	1.000 090
Fort Peck Indian Reservation-Assiniboine	LCC	48°20'00"N	105°30'00"W	100 000	200 000	1.000 120
Wind River Indian Reservation	TM	42°40'00"N	108°20'00"W	0	100 000	1.000 240
Crow Indian Reservation	TM	44°45'00"N	107°45'00"W	0	200 000	1.000 148
Billings	LCC	45°47'00"N	108°25'00"W	50 000	200 000	1.000 1515
Bobcat	LCC	46°15'00"N	111°15'00"W	100 000	100 000	1.000 185

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

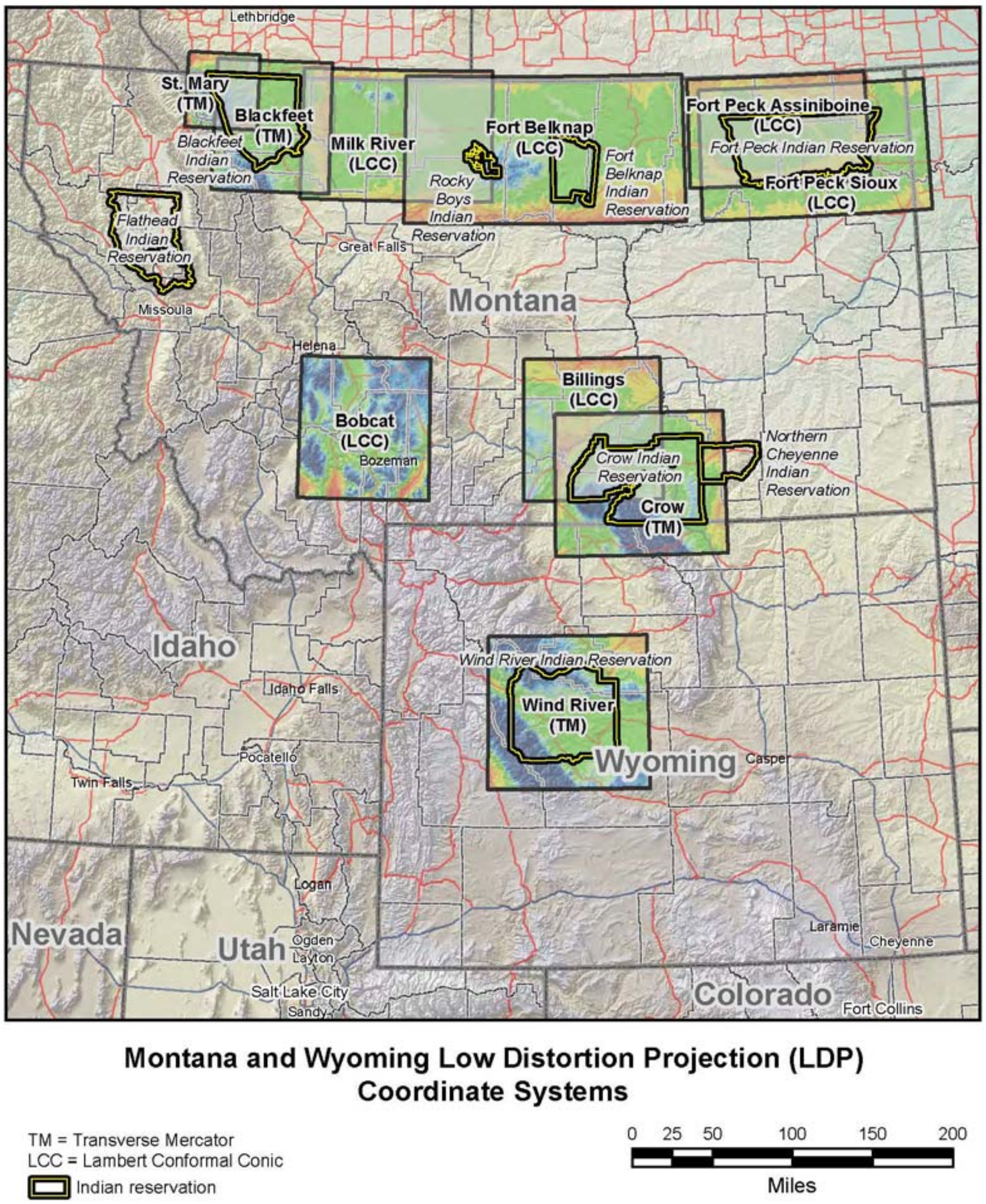


3.1.3 Picking a Zone to Use for a Survey/Engineering/GIS/Mapping Project

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

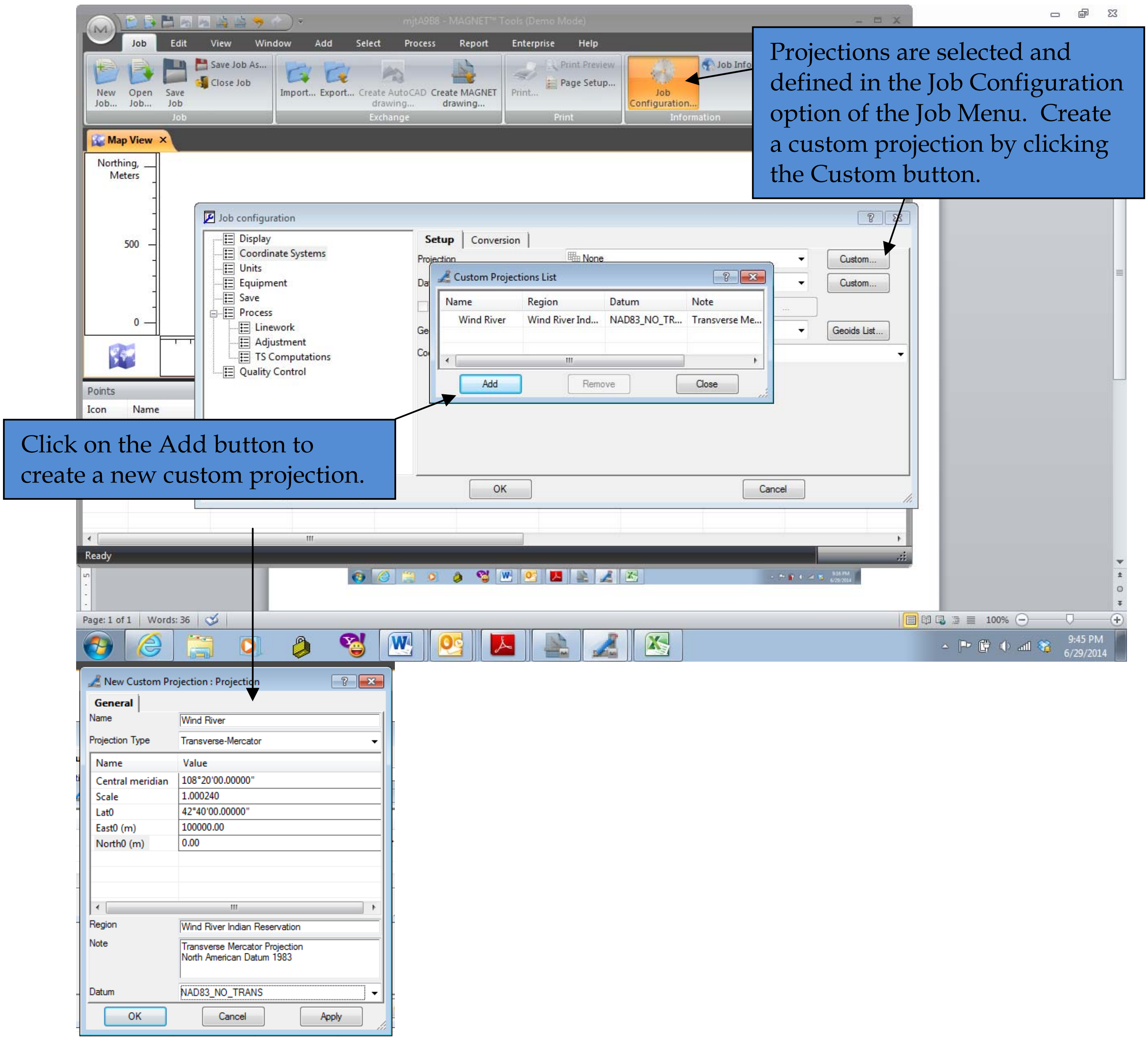
Trimble has created *.csd projection files to use with field and office software. The files and an Operation and Procedure Guide can be downloaded at www.axium.com. Contact Amy Darlinton at Amy.Darlinton@neciusa.com for an access code. The *.csd projection files and the Operation and Procedure Guide may also be obtained by contacting Kevin McKenzie with Frontier Precision at kmckenenzie@frontierprecision.com.

4.1.2 Carlson

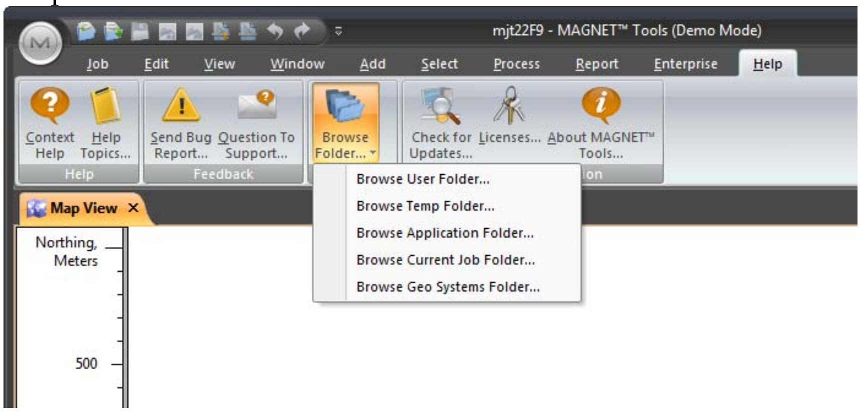
Carlson is working to add the projections to the software drop down menus. In the meantime Jim Reinbold has created *.csl files available upon request. The *.csl files can also be downloaded at www.axium.com along with a procedure on how to upload the files into Carlson data collectors. Contact Amy.Darlinton@neciusa.com for the access code to www.axium.com.

4.1.3 Topcon Magnet Office Tools (version 2.6)

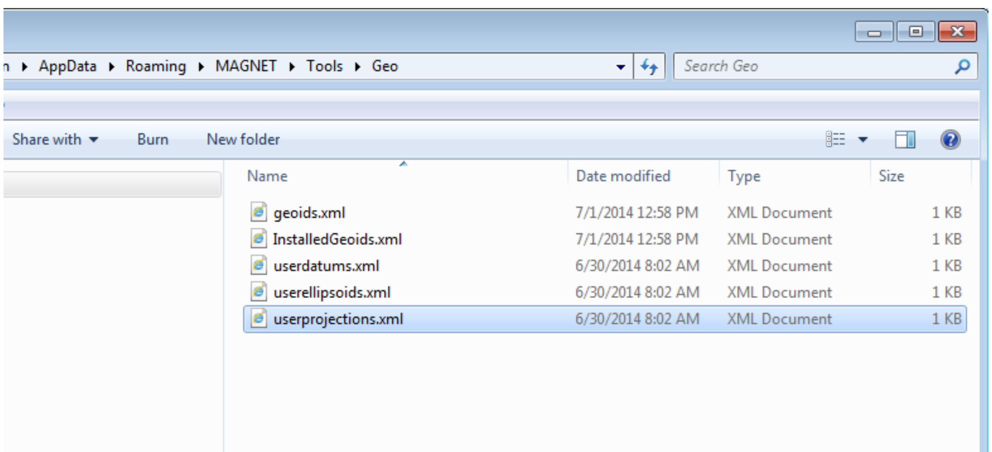
As shown below, Topcon has developed a procedure to define the RMTCRS zones in Magnet Office Tools Software. Projection input parameters for RMTCRS zones are provided in Table 3.1.1. Contact Todd Ferris at RDO Integrated Controls in Billings, Montana, (406) 794-8747 or TFerris@rdoic.com, for support.



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.

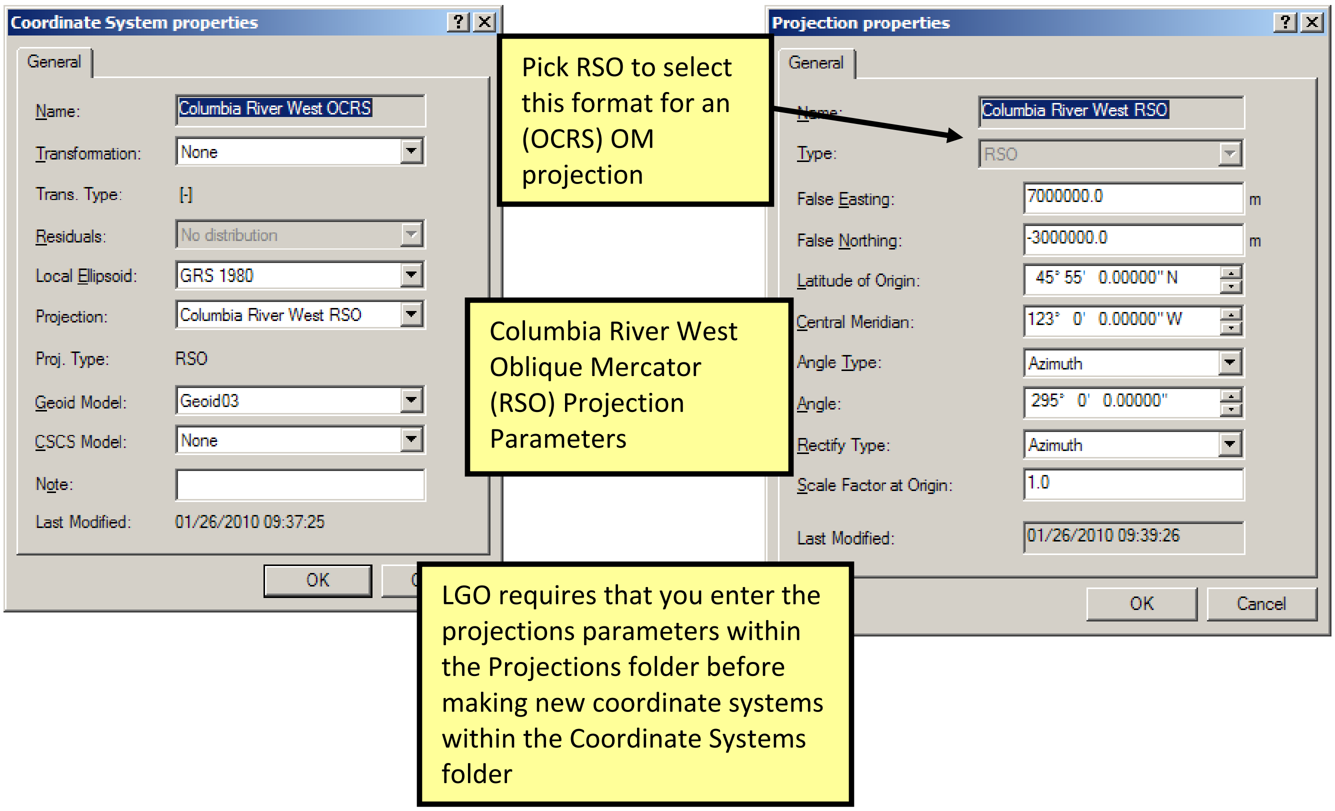


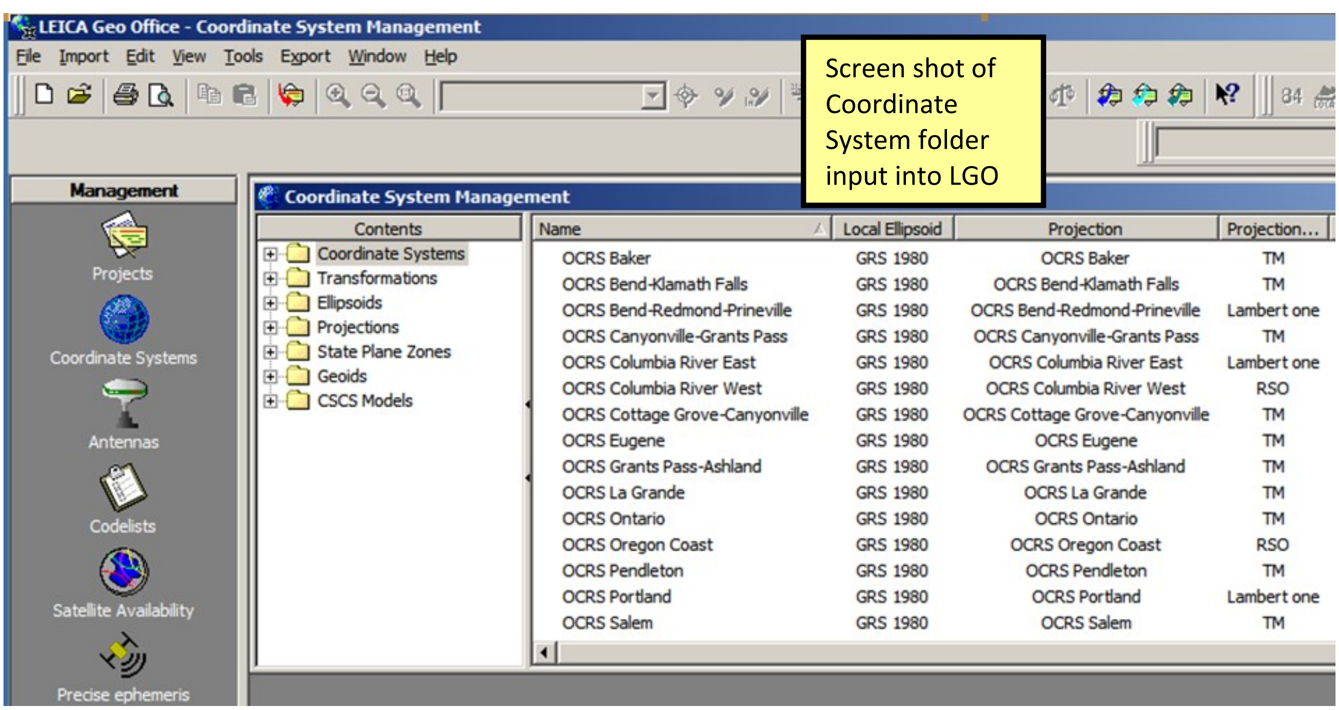
Navigate to the 'Geo' folder and find the file 'userprojections.xml'. This is the file that contains the parameters for the Custom Projection created above. You can then make a copy of this file to distribute to additional users.



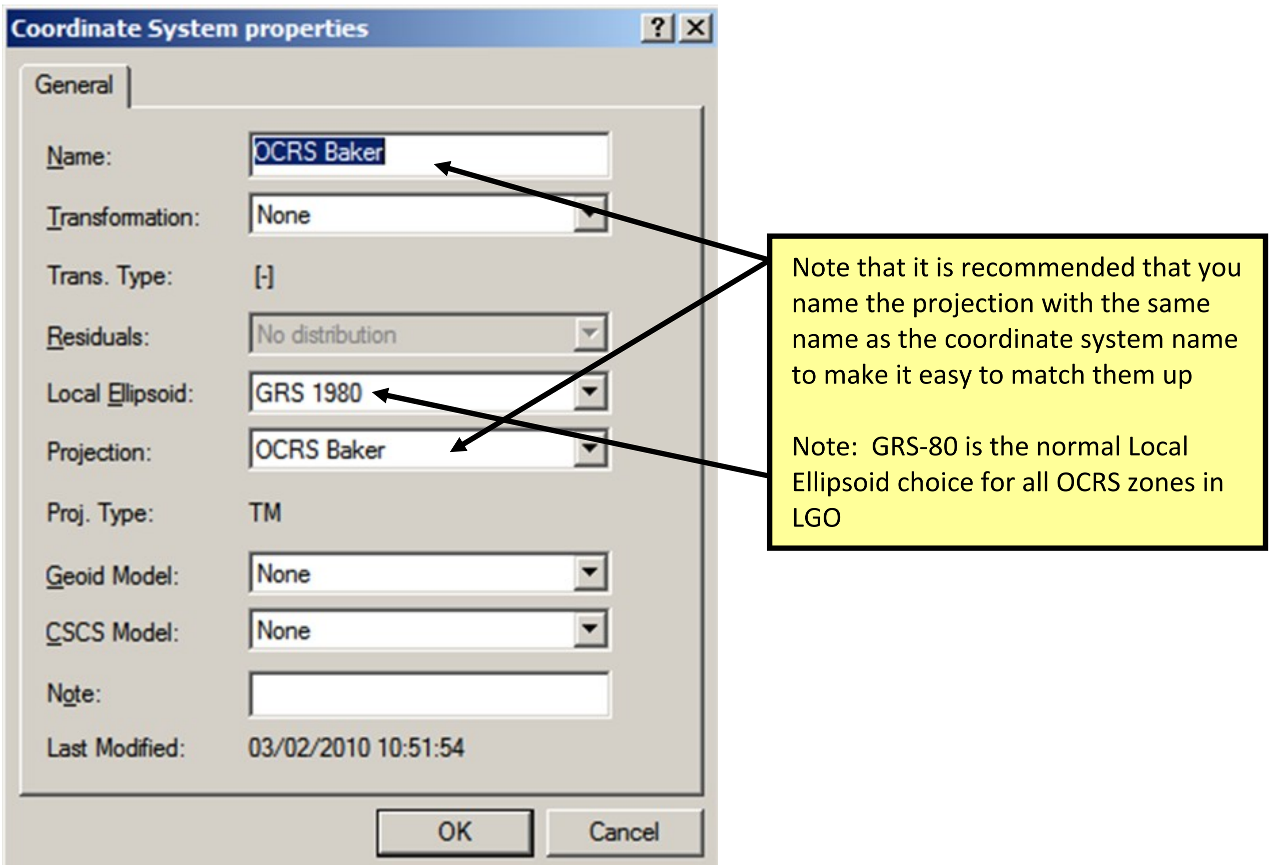
4.1.4 Leica Geomatics Office (LGO)

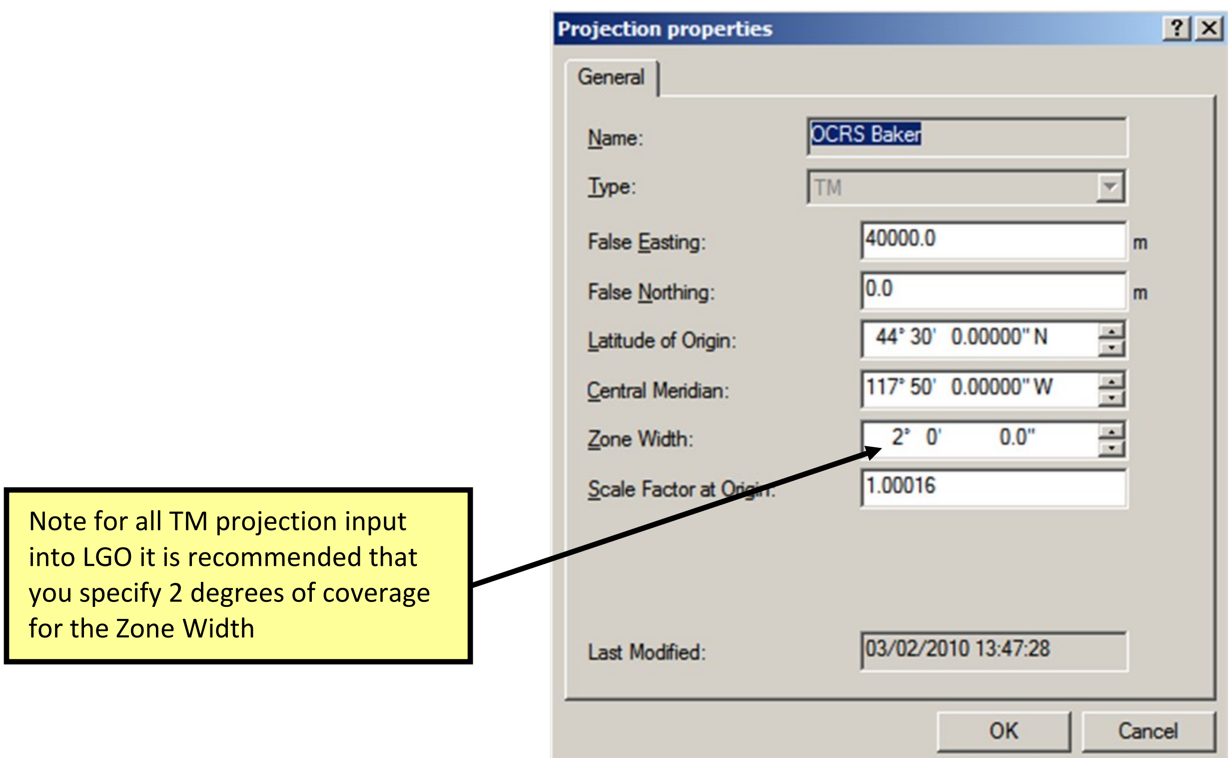
The following outlines the step-by-step procedure to add projections to the LGO. Projection input parameters for RMTCRS zones are provided in Table 3.1.1. Contact Donovan Mosser or Bryce Scala with Selby's at dmosser@selbys.com and bscala@selbys.com for support.





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

The projections will be available through drop down menus in both feet and meters. 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.axium.com. Contact Amy.Darlinton@neciusa.com for an access code.

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.axium.com. Contract Amy.Darlinton@neciusa.com to obtain an access code.

Table 4.2

RMTCRS 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
Billings	RV0039	3512	46°11'30.21218"N	108°27'10.54956"W	46.191725605556	-108.452930433333	1057.826	95,401.1360	197,200.1121	312,995.8530	646,981.9952	International	11.056	1.000011056	−0°01'33.57"
Billings	DO7252	00U A	45°44'43.39107"N	107°39'41.47537"W	45.745386408333	-107.661520936111	903.306	46,059.2677	258,771.8495	151,113.0829	848,989.0076	International	10.103	1.000010103	+0°32'28.39"
Billings	DO7257	00U B	45°44'43.40241"N	107°39'12.68014"W	45.745389558333	-107.653522261111	899.159	46,065.5294	259,394.3521	151,133.6265	851,031.3390	International	10.753	1.000010753	+0°32'49.03"
Billings	DO7258	00U C	45°44'43.77719"N	107°40'00.59064"W	45.745493663889	-107.666830733333	906.586	46,067.3001	258,358.4964	151,139.4361	847,632.8621	International	9.588	1.000009588	+0°32'14.69"
Billings	DE5402	6S8 C	45°42'12.75295"N	108°45'45.43118"W	45.703542486111	-108.762619772222	1050.874	41,188.4989	173,054.5477	135,132.8705	567,764.2640	International	-12.281	0.999987719	−0°14'52.61"
Billings	DE5418	6S8 D	45°42'40.16557"N	108°44'55.71453"W	45.711157102778	-108.748809591667	1039.921	42,030.3898	174,133.6998	137,894.9797	571,304.7894	International	-10.740	0.999989260	−0°14'16.98"
Billings	DE5419	6S8 E	45°42'28.97897"N	108°45'14.52750"W	45.708049713889	-108.754035416667	1043.062	41,686.6717	173,725.2728	136,767.2956	569,964.8058	International	-11.162	0.999988838	−0°14'30.46"
Billings	QW0402	AIRPORT 2	45°48'05.78682"N	108°32'13.75160"W	45.801607450000	-108.537153222222	1068.009	52,038.4853	190,631.9971	170,729.9388	625,433.0614	International	-15.880	0.999984120	−0°05'10.87"
Billings	AA5458	BIL A	45°48'23.07163"N	108°32'36.25565"W	45.806408786111	-108.543404347222	1077.013	52,572.9735	190,146.8097	172,483.5090	623,841.2393	International	-17.261	0.999982739	−0°05'27.00"
Billings	AD9804	BIL C	45°48'38.88648"N	108°33'26.78002"W	45.810801800000	-108.557438894444	1090.496	53,063.1452	189,056.5583	174,091.6838	620,264.2988	International	-19.341	0.999980659	−0°06'3.21"
Billings	AJ8894	BIL D	45°48'09.74558"N	108°31'19.34825"W	45.802707105556	-108.522041180556	1053.900	52,159.0678	191,807.1405	171,125.5507	629,288.5187	International	-13.662	0.999986338	−0°04'31.88"
Billings	AI8210	BIL1 A	45°58'22.40423"N	107°59'43.84583"W	45.972890063889	-107.995512730556	870.373	71,158.2491	232,644.8748	233,458.8226	763,270.5866	International	20.512	1.000020512	+0°18'6.64"
Billings	AI8211	BIL1 B	45°58'40.65678"N	107°59'46.50363"W	45.977960216667	-107.996251008333	868.598	71,721.5804	232,584.6851	235,307.0223	763,073.1139	International	21.087	1.000021087	+0°18'4.73"
Billings	AI7658	BILLINGS 1 CORS ARP	45°58'16.23762"N	107°59'47.29842"W	45.971177116667	-107.996471783333	874.352	70,967.4353	232,571.5374	232,832.7929	763,029.9783	International	19.790	1.000019790	+0°18'4.16"
Billings	AI7660	BILLINGS 2 CORS ARP	45°58'16.25097"N	107°59'48.49939"W	45.971180825000	-107.996805386111	875.145	70,967.7117	232,545.6761	232,833.6997	762,945.1317	International	19.666	1.000019666	+0°18'3.30"
Billings	DI3062	BILLINGS 5 CORS ARP	45°58'16.23782"N	107°59'47.29851"W	45.971177172222	-107.996471808333	874.521	70,967.4415	232,571.5354	232,832.8132	763,029.9718	International	19.763	1.000019763	+0°18'4.16"
Billings	DI3064	BILLINGS 6 CORS ARP	45°58'16.25103"N	107°59'48.49928"W	45.971180841667	-107.996805355556	875.290	70,967.7135	232,545.6785	232,833.7058	762,945.1394	International	19.643	1.000019643	+0°18'3.30"
Billings	DF8970	BILLINGS WAAS 1 CORS	45°48'13.54904"N	108°32'12.74735"W	45.803763622222	-108.536874263889	1100.200	52,278.1418	190,654.0469	171,516.2133	625,505.4033	International	-20.913	0.999979087	−0°05'10.15"
Billings	DL7730	BILLINGSAPMT2005	45°48'23.74196"N	108°32'46.07078"W	45.806594988889	-108.546130772222	1081.750	52,594.0123	189,934.8782	172,552.5337	623,145.9258	International	-18.003	0.999981997	−0°05'34.04"
Billings	DL7728	BILLINGSAPMT2005	45°48'23.74196"N	108°32'46.07078"W	45.806594988889	-108.546130772222	1081.758	52,594.0123	189,934.8782	172,552.5337	623,145.9258	International	-18.004	0.999981996	−0°05'34.04"
Billings	QW0003	D 484	45°48'09.97591"N	108°27'00.79858"W	45.802771086111	-108.450221827778	935.491	52,161.3281	197,391.0914	171,132.9663	647,608.5675	International	4.898	1.000004898	−0°01'26.58"
Billings	DG9745	ENGINC CORS ARP	45°44'47.03567"N	108°36'00.73641"W	45.746398797222	-108.600204558333	970.867	45,910.6226	185,715.5821	150,625.4022	609,303.0909	International	-0.498	0.999999502	−0°07'53.55"
Billings	QW0566	FRITZ	45°38'40.12027"N	108°32'58.84828"W	45.644477852778	-108.549680077778	1240.117	34,573.0812	189,628.9545	113,428.7441	622,142.2392	International	-39.986	0.999960014	−0°05'43.19"
Billings	RU0361	G 394	46°07'33.19257"N	107°34'40.70018"W	46.125886825000	-107.577972272222	824.202	88,421.0389	264,830.3289	290,095.2719	868,865.9083	International	40.142	1.000040142	+0°36'3.96"
Billings	QW0149	G 483	45°45'19.73425"N	108°33'24.32548"W	45.755481736111	-108.556757077778	953.398	46,913.4661	189,098.7853	153,915.5714	620,402.8389	International	2.151	1.000002151	−0°06'1.45"
Billings	RU0372	H 120	46°14'43.78666"N	107°37'53.57647"W	46.245496294444	-107.631549019444	1005.493	101,675.8653	260,558.4393	333,582.2351	854,850.5226	International	26.394	1.000026394	+0°33'45.72"
Billings	QW0184	H 44	45°51'29.93323"N	108°39'11.87738"W	45.858314786111	-108.653299272222	1092.158	58,362.4922	181,620.1542	191,477.9927	595,866.6477	International	-18.861	0.999981139	−0°10'10.55"
Billings	QW0189	K 44	45°48'51.86007"N	108°41'07.75931"W	45.814405575000	-108.685488697222	1055.635	53,489.2559	179,103.5163	175,489.6849	587,609.9615	International	-13.845	0.999986155	−0°11'33.60"
Billings	QW0197	M 44	45°46'44.25938"N	108°41'56.40127"W	45.778960938889	-108.699000352778	1023.765	49,552.7269	178,039.2965	162,574.5632	584,118.4268	International	-8.994	0.999991006	−0°12'8.46"
Billings	QV0262	N 487	45°43'20.14115"N	107°37'18.63354"W	45.722261430556	-107.621842650000	874.665	43,518.6895	261,885.4092	142,777.8528	859,204.0983	International	14.940	1.000014940	+0°34'10.76"
Billings	QW0442	N 560	45°30'03.78388"N	108°51'48.56965"W	45.501051077778	-108.863491569444	1060.035	18,718.6603	165,072.1499	61,412.9275	541,575.2950	International	-2.611	0.999997389	−0°19'12.87"
Billings	QW0201	P 44	45°44'26.07004"N	108°42'35.41023"W	45.740575011111	-108.709836175000	1002.429	45,288.6762	177,180.8112	148,584.8957	581,301.8740	International	-5.375	0.999994625	−0°12'36.42"
Billings	RU0378	Q 120	46°22'19.59955"N	107°49'18.43104"W	46.372110986111	-107.821786400000	991.093	115,625.7062	245,780.4339	379,349.4299	806,366.2530	International	48.954	1.000048954	+0°25'34.88"
Billings	QW0203	Q 44	45°42'36.22243"N	108°42'33.58557"W	45.710061786111	-108.709329325000	994.143	41,896.6174	177,207.8448	137,456.0938	581,390.5669	International	-3.540	0.999996460	−0°12'35.11"
Billings	DF5242	QC2	45°47'29.07590"N	108°37'54.87054"W	45.791409972222	-108.631908483333	997.594	50,920.3651	183,261.6011	167,061.5653	601,251.9722	International	-4.884	0.999995116	−0°09'15.36"
Billings	QW0575	REID	45°52'01.98380"N	108°46'31.70633"W	45.867217722222	-108.775473980556	1285.796	59,387.5230	172,135.0342	194,840.9548	564,747.4876	International	-48.996	0.999951004	−0°15'25.78"
Billings	QV0271	S 487	45°43'01.90270"N	107°32'29.92081"W	45.717195194444	-107.541644669444	877.456	43,020.7613	268,135.5916	141,144.2300	879,709.9463	International	14.600	1.000014600	+0°37'37.69"
Billings	QW0140	T 44	45°42'42.70680"N	108°38'48.41318"W	45.711863000000	-108.646781438889	966.868	42,080.9170	182,079.5470	138,060.7515	597,373.8420	International	0.696	1.000000696	−0°09'53.73"
Billings	QW0389	Y 538	45°42'49.76774"N	108°47'23.97113"W	45.713824372222	-108.789991980556	1099.157	42,341.0383	170,927.9449	138,914.1675	560,787.2207	International	-20.082	0.999979918	−0°16'3.23"
Billings	RV0099	Z 122	46°17'36.85046"N	108°54'21.13411"W	46.293569572222	-108.905870586111	1030.412	106,838.5106	162,298.5940	350,520.0478	532,475.7022	International	29.618	1.000029618	−0°21'2.22"
Blackfeet	AB3812	4220	48°59'54.33032"N	113°08'29.14841"W	48.998425088889	-113.141430113889	1272.775	111,244.3043	53,055.1458	364,974.7517	174,065.4391	International	17.593	1.000017593	−0°29'2.73"
Blackfeet	TM1045	79 A	48°14'17.30421"N	112°31'58.51019"W	48.238140058333	-112.532919497222	1207.366	26,484.9765	97,554.2335	86,892.9676	320,059.8212	International	0.846	1.000000846	−0°01'28.40"
Blackfeet	TM0650	A 423	48°37'39.90489"N	112°22'12.96322"W	48.627751358333	-112.370267561111	1129.602	69,825.0951	109,565.1114	229,084.9575	359,465.5885	International	14.090	1.000014090	+0°05'50.48"
Blackfeet	TM0477	BOUNDARY MON 295	48°59'53.87667"N	113°13'27.69054"W	48.998299075000	-113.224358483333	1413.472	111,284.8837	46,985.7098	365,107.8862	154,152.5913	International	2.995	1.000002995	−0°32'48.04"
Blackfeet	TM0386	BOUNDARY MON 305	48°59'54.57619"N	112°53'22.09976"W	48.998493386111	-112.889472155556	1355.003	111,126.6988	71,495.3798	364,588.9067	234,564.8943	International	-12.369	0.999987631	−0°17'38.16"
Blackfeet	TM0333	BOUNDARY MON 315	48°59'55.40871"N	112°33'51.83988"W	48.998724641667	-112.564399966667	1183.378	111,081.3046	95,286.7234	364,439.9758	312,620.4837	International	4.821	1.000004821	−0°02'54.97"
Blackfeet	TM0191	BOUNDARY MON 324	48°59'55.26435"N	112°16'06.58262"W	48.998684541667	-112.268495172222	1195.427	111,100.6784	116,943.2818	364,503.5379	383,672.1843	International	6.184	1.000006184	+0°10'28.98"
Blackfeet	TL0741	BOUNDARY MON 335	48°59'53.97572"N	111°56'41.46633"W	48.998326588889	-111.944851758333	1069.246	111,183.5824	140,630.1839	364,775.5330	461,385.1177	International	42.695	1.000042695	+0°25'8.29"
Blackfeet	TM0651	C 423	48°37'28.40078"N	112°23'27.33002"W	48.624555772222	-112.390925005556	1166.028	69,467.2886	108,042.5558	227,911.0518	354,470.3273	International	8.053	1.000008053	+0°04'54.66"
Blackfeet	TL0737	CONAIR	48°10'11.44078"N	111°58'22.55324"W	48.169844661111	-111.972931455556	1061.828	19,023.3377	139,210.7876	62,412.5253	456,728.3058	International	42.454	1.000042454	+0°23'33.85"
Blackfeet	TL0738	CONAIR AZ MK	48°10'02.78599"N	111°58'55.43044"W	48.167440552778	-111.982064011111	1063.903	18,751.3499	138,533.1824	61,520.1768	454,505.1916	International	41.482	1.000041482	+0°23'9.30"
Blackfeet	DI6634	CTB A	48°36'42.74587"N	112°21'56.69914"W	48.611873852778	-112.365749761111	1155.075	68,059.7198	109,901.3113	223,293.0441	360,568.6068	International	10.178	1.000010178	+0°06'2.60"
Blackfeet	DI6635	CTB B	48°36'05.20086"N	112°22'15.55349"W	48.601444683333	-112.370987080556	1155.064	66,899.0884	109,517.0046	219,485.1983	359,307.7580	International	10.088	1.000010088	+0°05'48.39"
Blackfeet	DI6636	CTB C	48°36'48.15722"N	112°22'45.78726"W	48.613377005556	-112.379385350000	1159.133	68,225.2274	108,895.3866	223,836.0479	357,268.3288	International	9.310	1.000009310	+0°05'25.78"
Blackfeet	TM0961	CUTAIR 2	48°36'27.46693"N	112°22'03.00654"W	48.607629702778	-112.367501816667	1155.963	67,587.4460	109,772.9116	221,743.5891	360,147.3477	International	10.008	1.000010008	+0°05'57.84"
Blackfeet	TM0962	CUTAIR 2 AZ MK	48°36'00.30398"N	112°22'14.64623"W	48.600084438889	-112.370735063889	1154.701	66,747.8293	109,535.8514	218,988.9412	359,369.5912	International	10.149	1.000010149	+0°05'49.07"
Blackfeet	TM0635	ETHRIDGE	48°34'26.17738"N	112°10'39.12994"W	48.573938161111	-112.177536094444	1122.560	63,881.9154	123,800.3665	209,586.3365	406,169.1815	International	21.023	1.000021023	+0°14'30.44"
Blackfeet	TM0771	MCCORMICK	48°51'24.83220"N	112°07'54.31499"W	48.856897833333	-112.131754163889	1289.996	95,369.3925	127,027.4270	312,891.7077	416,756.6502	International	-3.194	0.999996806	+0°16'38.34"
Blackfeet	TL0320	NIGG	48°12'07.78729"N	111°56'19.11432"W	48.202163136111	-111.938642866667	1059.565	22,635.6742	141,735.4004	74,264.0230	465,011.1563	International	45.318	1.000045318	+0°25'6.59"
Blackfeet	AB3811	PIEGAN	48°56'23.68774"N	113°22'21.02986"W	48.939913261111	-113.372508294444	1299.508	104,904.7550	36,068.4321	344,175.7053	118,334.7509	International	36.522	1.000036522	−0°39'28.48"
Blackfeet	TM0696	R 424	48°28'44.43259"N	113°08'28.14724"W	48.479009052778	-113.141152011111	1499.938	53,472.1341	52,589.5145	175,433.5108	172,537.7773	International	-17.471	0.999982529	−0°28'48.17"
Blackfeet	AI7862	SHERBURNE 1	48°49'42.03861"N	113°31'14.41347"W	48.828344058333	-113.520670408333	1431.261	92,630.5808	25,045.6870	303,906.1051	82,170.8892	International	34.669	1.000034669	−0°46'06.01"
Blackfeet	AI7863	SHERBURNE 2	48°51'07.53055"N	113°24'59.52878"W	48.852091819444	-113.416535772222	1352.441	95,174.6245	32,724.6778	312,252.7051	107,364.4286	International	33.612	1.000033612	−0°41'24.68"
Blackfeet	TM0878	STACK	48°58'04.45876"N	113°08'14.32664"W	48.967905211111	-113.137312955556	1459.365	107,847.0529	53,327.9780	353,828.9136	174,960.5578	International	-11.956	0.999988044	−0°28'50.74"
Blackfeet	TL0318	U 427	48°10'34.06436"N	111°56'06.16750"W	48.176128988889	-111.935046527778	1052.070	19,742.2579	142,024.0575	64,771.1874	465,958.1940	International	46.789	1.000046789	+0°25'15.63"
Blackfeet	TL0414	W 425	48°59'50.06516"N	111°57'35.55140"W	48.997240322222	-111.959875388889	1048.491	111,054.8252	139,531.4987	364,353.1010	457,780.5077	International	44.866	1.000044866	+0°24'27.45"
Bobcat	AB2998	15JS	46°05'11.91609"N	111°53'15.01557"W	46.086643358333	-111.887504325000	1381.539	82,036.9561	50,685.1589	269,150.1185	166,289.8913	International	-27.525	0.999972475	−0°27'37.84"
Bobcat	DK7547	BOZEMAN CORS ARP	45°39'40.37689"N	111°02'42.00898"W	45.661215802778	-111.045002494444	1495.496	34,563.7693	115,980.1953	113,398.1933	380,512.4519	International	2.997	1.000002997	+0°08'53.10"
Bobcat	QX0749	BOZEMAN GPS	45°39'47.00763"N	111°02'46.14415"W	45.663057675000	-111.046151152778	1490.522	34,768.3008	115,890.1278	114,069.2284	380,216.9547	International	3.450	1.000003450	+0°08'50.11"

Table 4.2, cont.

RMTCRS 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	QX0469	BOZEMAN SOUTHEAST	45°42'26.80575"N	111°02'55.96808"W	45.707446041667	-111.048880022222	1425.299	39,702.4454	115,664.8987	130,257.3667	379,478.0142	International	6.102	1.000006102	+0°08'43.01"
Bobcat	DG6502	BZN A	45°46'41.95996"N	111°09'22.80421"W	45.778322211111	-111.156334502778	1344.769	47,566.2753	107,286.1503	156,057.3337	351,988.6821	International	7.862	1.000007862	+0°04'3.58"
Bobcat	DG6503	BZN B	45°47'10.41663"N	111°10'02.09200"W	45.786226841667	-111.167247777778	1339.280	48,444.0989	106,436.3005	158,937.3322	349,200.4609	International	7.605	1.000007605	+0°03'35.20"
Bobcat	DG6504	BZN C	45°46'11.51489"N	111°08'39.98310"W	45.769865247222	-111.144439750000	1349.416	46,627.2667	108,212.6826	152,976.5968	355,028.4861	International	8.351	1.000008351	+0°04'34.51"
Bobcat	QX0254	C 160	45°37'53.43892"N	111°11'49.46208"W	45.631510811111	-111.197072800000	1456.561	31,242.1594	104,128.0483	102,500.5229	341,627.4551	International	14.514	1.000014514	+0°02'17.64"
Bobcat	AA5542	CWA GPS	45°51'34.11087"N	112°07'59.80333"W	45.859475241667	-112.133278702778	1376.333	56,965.8882	31,392.4569	186,895.9587	102,993.6249	International	-7.664	0.999992336	−0°38'16.98"
Bobcat	RW0206	D 82	46°09'23.11149"N	111°25'52.40777"W	46.156419858333	-111.431224380556	1190.987	89,612.1385	85,998.7761	294,003.0791	282,148.2156	International	-0.376	0.999999624	−0°07'51.28"
Bobcat	QX0439	F 145	45°41'32.92466"N	111°46'59.02467"W	45.692479072222	-111.783062408333	1503.125	38,158.2462	58,469.7461	125,191.0965	191,829.8757	International	-3.610	0.999996390	−0°23'6.23"
Bobcat	QX0615	F 575	45°29'52.89591"N	111°41'47.29309"W	45.498026641667	-111.696470302778	1733.504	16,499.4157	65,094.2723	54,131.9413	213,563.8856	International	-1.297	0.999998703	−0°19'21.05"
Bobcat	QX0397	G 498	45°47'36.42596"N	111°44'29.70158"W	45.793451655556	-111.741583772222	1262.692	49,362.4005	61,770.8242	161,950.1330	202,660.1843	International	18.605	1.000018605	−0°21'18.37"
Bobcat	RX0832	H 440	46°15'33.11182"N	112°06'41.25053"W	46.259197727778	-112.111458480556	1509.099	101,383.3251	33,569.8842	332,622.4576	110,137.4153	International	-51.546	0.999948454	−0°37'20.23"
Bobcat	RW0081	J 127	46°16'58.10476"N	110°46'19.60324"W	46.282806877778	-110.772112011111	1619.150	103,758.3437	136,836.3232	340,414.5134	448,938.0684	International	-68.642	0.999931358	+0°20'42.75"
Bobcat	AA9698	J 128 RESET	45°54'27.43373"N	110°37'05.25130"W	45.907620480556	-110.618125361111	1470.883	62,131.6019	149,037.9103	203,843.8381	488,969.5220	International	-27.821	0.999972179	+0°27'23.20"
Bobcat	QX0478	J 562	45°53'30.49015"N	111°35'16.10914"W	45.891802819444	-111.587808094444	1233.372	60,233.6347	73,776.0318	197,616.9116	242,047.3483	International	11.082	1.000011082	−0°14'38.47"
Bobcat	DL7705	NOMT_EBRY_MT1999 CORS ARP	45°35'48.88902"N	111°37'47.30412"W	45.596913616667	-111.629806700000	1578.635	27,465.5407	70,358.7322	90,110.0417	230,835.7355	International	2.020	1.000002020	−0°16'27.69"
Bobcat	QX0473	Q 563	45°44'20.41996"N	111°06'26.56753"W	45.739005544444	-111.107379869444	1376.434	43,201.0724	111,102.1407	141,735.8019	364,508.3358	International	8.738	1.000008738	+0°06'10.89"
Bobcat	QX0488	R 562	45°54'55.37349"N	111°43'26.51846"W	45.915381525000	-111.724032905556	1380.400	62,909.0002	63,216.7033	206,394.3577	207,403.8821	International	-14.434	0.999985566	−0°20'32.73"
Bobcat	RW0582	TOWNSEND GPS	46°18'33.94932"N	111°30'52.80912"W	46.309430366667	-111.514669200000	1155.587	106,641.3330	79,608.6922	349,873.1399	261,183.3734	International	4.383	1.000004383	−0°11'28.27"
Bobcat	QX0429	Z 139	45°35'50.06410"N	111°43'04.54363"W	45.597240027778	-111.717928786111	1486.198	27,538.5797	63,481.7034	90,349.6709	208,273.3051	International	16.444	1.000016444	−0°20'16.85"
Bobcat	QX0352	Z 145	45°21'33.38200"N	111°43'54.26773"W	45.359272777778	-111.731741036111	1497.331	1,090.2808	62,243.0971	3,577.0367	204,209.6362	International	70.067	1.000070067	−0°20'52.77"
Bobcat	QX0192	Z 493	45°52'18.69131"N	111°21'37.36675"W	45.871858697222	-111.360379652778	1273.434	57,966.5305	91,428.1431	190,178.9058	299,961.0994	International	7.025	1.000007025	−0°04'47.04"
Crow	DO7252	00U A	45°44'43.39107"N	107°39'41.47537"W	45.745386408333	-107.661520936111	903.306	110,644.0597	206,886.2684	363,005.4451	678,760.7231	International	6.968	1.000006968	+0°03'48.14"
Crow	DO7257	00U B	45°44'43.40241"N	107°39'12.68014"W	45.745389558333	-107.653522261111	899.159	110,645.1295	207,508.7997	363,008.9551	680,803.1485	International	7.728	1.000007728	+0°04'8.77"
Crow	DO7258	00U C	45°44'43.77719"N	107°40'00.59064"W	45.745493663889	-107.666830733333	906.586	110,655.5391	206,472.9979	363,043.1074	677,404.8488	International	6.386	1.000006386	+0°03'34.45"
Crow	DE5402	6S8 C	45°42'12.75295"N	108°45'45.43118"W	45.703542486111	-108.762619772222	1050.874	106,487.6457	121,129.6907	349,368.9162	397,407.1217	International	59.674	1.000059674	−0°43'29.30"
Crow	DE5418	6S8 D	45°42'40.16557"N	108°44'55.71453"W	45.711157102778	-108.748809591667	1039.921	107,320.5841	122,215.8901	352,101.6539	400,970.7680	International	59.301	1.000059301	−0°42'54.04"
Crow	DE5419	6S8 E	45°42'28.97897"N	108°45'14.52750"W	45.708049713889	-108.754035416667	1043.062	106,980.2537	121,804.5871	350,985.0844	399,621.3489	International	59.597	1.000059597	−0°43'7.38"
Crow	QW0402	AIRPORT 2	45°48'05.78682"N	108°32'13.75160"W	45.801607450000	-108.537153222222	1068.009	117,191.3840	138,797.9505	384,486.1680	455,373.8535	International	26.585	1.000026585	−0°33'51.66"
Crow	QW0479	B 565	45°00'26.97063"N	108°37'27.61190"W	45.007491841667	-108.624336638889	1297.963	28,991.1616	131,060.1025	95,115.3596	429,987.2128	International	2.904	1.000002904	−0°37'6.08"
Crow	AA5458	BIL A	45°48'23.07163"N	108°32'36.25565"W	45.806408786111	-108.543404347222	1077.013	117,729.9245	138,317.2187	386,253.0333	453,796.6491	International	25.899	1.000025899	−0°34'7.97"
Crow	AD9804	BIL C	45°48'38.88648"N	108°33'26.78002"W	45.810801800000	-108.557438894444	1090.496	118,229.1980	137,231.0473	387,891.0694	450,233.0947	International	25.447	1.000025447	−0°34'44.35"
Crow	AJ8894	BIL D	45°48'09.74558"N	108°31'19.34825"W	45.802707105556	-108.522041180556	1053.900	117,302.1632	139,974.1079	384,849.6167	459,232.6374	International	27.045	1.000027045	−0°33'12.69"
Crow	AI8210	BIL1 A	45°58'22.40423"N	107°59'43.84583"W	45.972890063889	-107.995512730556	870.373	135,960.0149	180,969.6737	446,063.0411	593,732.5254	International	16.000	1.000016000	−0°10'35.50"
Crow	AI8211	BIL1 B	45°58'40.65678"N	107°59'46.50363"W	45.977960216667	-107.996251008333	868.598	136,523.8265	180,914.1898	447,912.8166	593,550.4914	International	16.305	1.000016305	−0°10'37.46"
Crow	AI7658	BILLINGS 1 CORS ARP	45°58'16.23762"N	107°59'47.29842"W	45.971177116667	-107.996471783333	874.352	135,769.8209	180,894.7461	445,439.0449	593,486.6999	International	15.412	1.000015412	−0°10'37.96"
Crow	AI7660	BILLINGS 2 CORS ARP	45°58'16.25097"N	107°59'48.49939"W	45.971180825000	-107.996805386111	875.145	135,770.3132	180,868.8882	445,440.6600	593,401.8642	International	15.299	1.000015299	−0°10'38.82"
Crow	DI3062	BILLINGS 5 CORS ARP	45°58'16.23782"N	107°59'47.29851"W	45.971177172222	-107.996471808333	874.521	135,769.8271	180,894.7442	445,439.0652	593,486.6936	International	15.385	1.000015385	−0°10'37.96"
Crow	DI3064	BILLINGS 6 CORS ARP	45°58'16.25103"N	107°59'48.49928"W	45.971180841667	-107.996805355556	875.290	135,770.3150	180,868.8906	445,440.6661	593,401.8719	International	15.277	1.000015277	−0°10'38.82"
Crow	DF8970	BILLINGS WAAS 1 CORS	45°48'13.54904"N	108°32'12.74735"W	45.803763622222	-108.536874263889	1100.200	117,430.8583	138,822.0000	385,271.8449	455,452.7558	International	21.503	1.000021503	−0°33'51.02"
Crow	DL7730	BILLINGSAPMT2005	45°48'23.74196"N	108°32'46.07078"W	45.806594988889	-108.546130772222	1081.750	117,752.7318	138,105.4608	386,327.8602	453,101.9057	International	25.478	1.000025478	−0°34'15.01"
Crow	DL7728	BILLINGSAPMT2005	45°48'23.74196"N	108°32'46.07078"W	45.806594988889	-108.546130772222	1081.758	117,752.7318	138,105.4608	386,327.8602	453,101.9057	International	25.477	1.000025477	−0°34'15.01"
Crow	QW0003	D 484	45°48'09.97591"N	108°27'00.79858"W	45.802771086111	-108.450221827778	935.491	117,257.8379	145,558.0883	384,704.1925	477,552.7832	International	37.753	1.000037753	−0°30'7.32"
Crow	DG9745	ENGINC CORS ARP	45°44'47.03567"N	108°36'00.73641"W	45.746398797222	-108.600204558333	970.867	111,104.4447	133,830.3833	364,515.8947	439,076.0607	International	49.585	1.000049585	−0°36'32.36"
Crow	QW0566	FRITZ	45°38'40.12027"N	108°32'58.84828"W	45.644477852778	-108.549680077778	1240.117	99,734.1981	137,649.4196	327,211.9359	451,605.7072	International	1.349	1.000001349	−0°34'18.49"
Crow	QW0149	G 483	45°45'19.73425"N	108°33'24.32548"W	45.755481736111	-108.556757077778	953.398	112,079.1046	137,221.9873	367,713.5979	450,203.3706	International	46.951	1.000046951	−0°34'40.64"
Crow	QW0184	H 44	45°51'29.93323"N	108°39'11.87738"W	45.858314786111	-108.653299272222	1092.158	123,590.7166	129,838.7738	405,481.3537	425,980.2292	International	37.258	1.000037258	−0°38'53.71"
Crow	QW0550	HUNTER	45°02'17.78382"N	108°51'03.49770"W	45.038273283333	-108.850971583333	1601.597	32,630.3431	113,236.8467	107,054.9314	371,511.9641	International	-10.593	0.999989407	−0°46'44.66"
Crow	QW0189	K 44	45°48'51.86007"N	108°41'07.75931"W	45.814405575000	-108.685488697222	1055.635	118,738.3791	127,281.3819	389,561.6112	417,589.8357	International	47.472	1.000047472	−0°40'15.08"
Crow	PX0263	LAKE	44°48'01.54933"N	108°20'42.94345"W	44.800430369444	-108.345262069444	1201.505	5,777.4453	152,895.8482	18,954.8730	501,626.7984	International	-13.113	0.999986887	−0°25'10.03"
Crow	QW0197	M 44	45°46'44.25938"N	108°41'56.40127"W	45.778960938889	-108.699000352778	1023.765	114,810.6200	126,184.2908	376,675.2624	413,990.4553	International	54.443	1.000054443	−0°40'48.49"
Crow	QV0262	N 487	45°43'20.14115"N	107°37'18.63354"W	45.722261430556	-107.621842650000	874.665	108,077.6095	209,978.5212	354,585.3329	688,905.9095	International	12.098	1.000012098	+0°05'30.32"
Crow	QW0442	N 560	45°30'03.78388"N	108°51'48.56965"W	45.501051077778	-108.863491569444	1060.035	84,083.1293	112,960.4815	275,863.2852	370,605.2544	International	74.890	1.000074890	−0°47'39.34"
Crow	QW0468	N 564	45°08'45.65953"N	108°47'50.45403"W	45.146016536111	-108.797348341667	1245.903	44,549.9411	117,617.7390	146,161.2241	385,884.9705	International	36.058	1.000036058	−0°44'33.05"
Crow	QW0201	P 44	45°44'26.07004"N	108°42'35.41023"W	45.740575011111	-108.709836175000	1002.429	110,553.5998	125,290.2374	362,708.6607	411,057.2092	International	59.418	1.000059418	−0°41'14.83"
Crow	PX0523	POWELL MUN APT AP	44°52'32.98570"N	108°47'58.62181"W	44.875829361111	-108.799617169444	1509.669	14,521.3678	117,050.1496	47,642.2827	384,022.8004	International	-4.137	0.999995863	−0°44'26.24"
Crow	PX0520	POWELL MUN APT AP	44°52'02.02705"N	108°47'27.48534"W	44.867229736111	-108.790968150000	1529.208	13,556.7558	117,721.4175	44,477.5454	386,225.1230	International	-8.562	0.999991438	−0°44'3.87"
Crow	QW0203	Q 44	45°42'36.22243"N	108°42'33.58557"W	45.710061786111	-108.709329325000	994.143	107,161.2145	125,289.0212	351,578.7877	411,053.2193	International	60.720	1.000060720	−0°41'12.24"
Crow	DF5242	QC2	45°47'29.07590"N	108°37'54.87054"W	45.791409972222	-108.631908483333	997.594	116,134.7345	131,418.1276	381,019.4701	431,161.8361	International	49.389	1.000049389	−0°37'55.85"
Crow	QW0575	REID	45°52'01.98380"N	108°46'31.70633"W	45.867217722222	-108.775473980556	1285.796	124,695.0408	120,361.9385	409,104.4646	394,888.2497	International	24.346	1.000024346	−0°44'9.78"
Crow	QV0271	S 487	45°43'01.90270"N	107°32'29.92081"W	45.717195194444	-107.541644669444	877.456	107,527.5640	216,224.3205	352,780.7219	709,397.3771	International	13.671	1.000013671	+0°08'56.98"
Crow	PW0138	SHERIDAN	44°48'08.25499"N	106°56'30.30594"W	44.802293052778	-106.941751650000	1173.185	6,129.9361	263,956.0874	20,111.3388	865,997.6620	International	14.324	1.000014324	+0°34'10.42"
Crow	PW0132	SHERIDAN AIRPORT	44°46'21.66272"N	106°58'05.73995"W	44.772684088889	-106.968261097222	1188.327	2,818.5614	261,890.0468	9,247.2488	859,219.3136	International	8.755	1.000008755	+0°33'2.13"
Crow	DM7161	SHERIDAN CORS ARP	44°48'01.76938"N	107°00'35.71572"W	44.800491494444	-107.009921033333	1221.357	5,878.3406	258,563.7150	19,285.8943	848,306.1515	International	-1.346	0.999998654	+0°31'17.42"
Crow	AJ9021	SHR ARP	44°46'26.66483"N	106°58'40.30028"W	44.774073563889	-106.977861188889	1195.095	2,965.7340	261,128.5440	9,730.0985	856,720.9447	International	6.543	1.000006543	+0°32'37.84"
Crow	AJ9016	SHR D	44°46'13.74356"N	106°58'57.07057"W	44.770484322222	-106.982519602778	1204.510	2,563.3217	260,763.5110	8,409.8481	855,523.3299	International	4.520	1.000004520	+0°32'25.90"
Crow	AJ9020	SHR E	44°45'45.94312"N	106°58'38.44399"W	44.762761977778	-106.977345552778	1197.665	1,708.9090	261,181.3062	5,606.6568	856,894.0492	International	6.219	1.000006219	+0°32'38.76"
Crow	DE5169	SHR F	44°46'38.78123"N	106°59'12.65927"W	44.777439230556	-106.986849797222	1209.667	3,333.0921	260,413.4255	10,935.3415	854,374.7557	International	3.191	1.000003191	+0°32'15.16"
Crow	QW0140	T 44	45°42'42.70680"N	108°38'48.41318"W	45.711863000000	-108.646781438889	966.868	107,304.9575	130,162.3809	352,050.3856	427,041.9322	International	56.341	1.000056341	−0°38'31.11"

Table 4.2, cont.

RMTCRS 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	QW0389	Y 538	45°42'49.76774"N	108°47'23.97113"W	45.713824372222	-108.789991980556	1099.157	107,657.9328	119,012.5978	**353,208.4408**	**390,461.2789**	International	56.264	1.000056264	−0°44'40.31"
Crow	QV0153	Z 487	45°37'48.73543"N	107°28'06.11234"W	45.630204286111	-107.468364538889	904.356	97,875.0039	221,964.5385	**321,112.2176**	**728,230.1132**	International	12.146	1.000012146	+0°12'4.77"
Fort Belknap	TJ0451	A 439	48°57'29.66092"N	107°49'05.01870"W	48.958239144444	-107.818060750000	798.624	201,187.5266	249,947.3507	**660,064.0637**	**820,037.2398**	International	26.832	1.000026832	+0°30'38.67"
Fort Belknap	TK0386	A 513	48°22'17.85410"N	108°06'12.93131"W	48.371626138889	-108.103592030556	674.123	135,799.3571	229,372.4706	**445,535.9485**	**752,534.3523**	International	16.847	1.000016847	+0°17'48.81"
Fort Belknap	TL0744	BOUNDARY MON 370	48°59'54.14561"N	110°49'34.29236"W	48.998373780556	-110.826192322222	1029.444	208,017.0827	29,782.1596	**682,470.7436**	**97,710.4973**	International	-3.477	0.999996523	−1°44'31.97"
Fort Belknap	TL0745	BOUNDARY MON 380	48°59'56.24091"N	110°29'31.72469"W	48.998955808333	-110.492145747222	875.079	207,391.8831	54,221.5301	**680,419.5640**	**177,892.1593**	International	20.799	1.000020799	−1°29'31.30"
Fort Belknap	TL0746	BOUNDARY MON 388 A	48°59'57.68180"N	110°12'59.09253"W	48.999356055556	-110.216414591667	845.001	206,947.3178	74,395.9419	**678,961.0163**	**244,081.1744**	International	25.573	1.000025573	−1°17'7.87"
Fort Belknap	TK0586	BOUNDARY MON 398	48°59'59.15989"N	109°53'01.96516"W	48.999766636111	-109.883879211111	850.616	206,499.8814	98,728.1212	**677,493.0491**	**323,911.1588**	International	24.756	1.000024756	−1°02'11.27"
Fort Belknap	TK0587	BOUNDARY MON 407	49°00'00.67472"N	109°34'52.13688"W	49.000187422222	-109.581149133333	843.613	206,189.7552	120,880.8004	**676,475.5747**	**396,590.5524**	International	25.918	1.000025918	−0°48'35.04"
Fort Belknap	TK0588	BOUNDARY MON 418	49°00'00.47651"N	109°16'42.04920"W	49.000132363889	-109.278347000000	872.381	205,914.3184	143,039.0826	**675,571.9107**	**469,288.3286**	International	21.402	1.000021402	−0°34'58.61"
Fort Belknap	TK0589	BOUNDARY MON 427	48°59'58.37552"N	108°59'50.52822"W	48.999548755556	-108.997368950000	914.487	205,677.9572	163,600.7984	**674,796.4476**	**536,748.0262**	International	14.715	1.000014715	−0°22'21.03"
Fort Belknap	TK0590	BOUNDARY MON 437	48°59'57.60898"N	108°41'26.62698"W	48.999335827778	-108.690729716667	919.447	205,553.3495	186,041.5884	**674,387.6294**	**610,372.6655**	International	13.905	1.000013905	−0°08'34.25"
Fort Belknap	TK0591	BOUNDARY MON 448	48°59'58.39122"N	108°21'06.70721"W	48.999553116667	-108.351863113889	882.148	205,570.6141	210,841.2448	**674,444.2720**	**691,736.3674**	International	19.783	1.000019783	+0°06'39.41"
Fort Belknap	TK0592	BOUNDARY MON 456	48°59'58.86938"N	108°04'37.27407"W	48.999685938889	-108.077020575000	821.290	205,660.4678	230,955.0917	**674,739.0676**	**757,726.6787**	International	29.339	1.000029339	+0°19'0.45"
Fort Belknap	TJ0726	BOUNDARY MON 465	48°59'59.26947"N	107°46'50.22688"W	48.999797075000	-107.780618577778	864.480	205,834.7852	252,646.1871	**675,310.9752**	**828,891.6901**	International	22.588	1.000022588	+0°32'19.63"
Fort Belknap	TJ0727	BOUNDARY MON 477	48°59'57.78196"N	107°26'29.56970"W	48.999383877778	-107.441547138889	793.391	206,077.1609	277,459.6153	**676,106.1710**	**910,300.5751**	International	33.665	1.000033665	+0°47'33.84"
Fort Belknap	TJ0728	BOUNDARY MON 487	49°00'00.17596"N	107°06'50.43011"W	49.000048877778	-107.114008363889	846.470	206,534.0678	301,425.8798	**677,605.2092**	**988,930.0519**	International	25.449	1.000025449	+1°02'16.97"
Fort Belknap	TK0168	C 280	48°17'09.63500"N	109°06'03.81547"W	48.286009722222	-109.101059852778	1024.026	126,377.0598	155,388.9775	**414,622.8995**	**509,806.3568**	International	-33.541	0.999966459	−0°27'0.60"
Fort Belknap	SR1029	CARSON	47°41'24.22983"N	108°03'03.41901"W	47.690063841667	-108.050949725000	850.803	60,026.6161	233,717.9504	**196,937.7168**	**766,791.1759**	International	85.745	1.000085745	+0°20'10.75"
Fort Belknap	TK0447	CHERRY	48°52'29.69430"N	108°57'19.96652"W	48.874915083333	-108.955546255556	1071.691	191,796.7443	166,578.9447	**629,254.4105**	**546,518.8474**	International	-26.544	0.999973456	−0°20'28.26"
Fort Belknap	TL0498	F 513	48°34'10.92401"N	110°00'56.72162"W	48.569701113889	-110.015756005556	823.975	158,860.0448	88,130.9604	**521,194.3727**	**289,143.5709**	International	-8.395	0.999991605	−1°08'6.84"
Fort Belknap	TK0585	HAVRE CBL 1230	48°32'47.07163"N	109°46'22.74902"W	48.546408786111	-109.772985838889	769.633	155,943.3755	106,003.4843	**511,625.2475**	**347,780.4602**	International	-0.291	0.999999709	−0°57'12.28"
Fort Belknap	SR0914	K 526	47°55'25.80011"N	108°21'16.24148"W	47.923833363889	-108.354511522222	916.925	85,935.0515	210,874.9450	**281,939.1453**	**691,846.9326**	International	26.513	1.000026513	+0°06'32.27"
Fort Belknap	TK0356	L 512	48°31'25.93183"N	108°44'35.25025"W	48.523869952778	-108.743125069444	700.675	152,683.2045	182,039.0252	**500,929.1485**	**597,240.8964**	International	10.274	1.000010274	−0°10'55.52"
Fort Belknap	TJ0643	LAKESIDE	48°25'34.92119"N	107°40'24.88398"W	48.426366997222	-107.673578883333	678.403	142,141.4715	261,168.2886	**466,343.4105**	**856,851.3405**	International	14.500	1.000014500	+0°37'8.23"
Fort Belknap	SR1099	LEROY	47°53'07.15674"N	109°22'28.12876"W	47.885321316667	-109.374480211111	1077.282	82,015.7433	134,586.9478	**269,080.5225**	**441,558.2275**	International	8.306	1.000008306	−0°39'17.81"
Fort Belknap	TJ0634	LONG RESET	48°57'24.31359"N	107°16'52.97861"W	48.956753775000	-107.281382947222	928.410	201,510.6043	289,255.3404	**661,124.0297**	**949,000.4605**	International	6.287	1.000006287	+0°54'45.68"
Fort Belknap	DG9749	MONTANA STATE UNI CORS ARP	48°32'27.42663"N	109°41'11.85806"W	48.540951841667	-109.686627238889	773.920	155,234.0486	112,370.2085	**509,298.0597**	**368,668.6631**	International	-1.035	0.999998965	−0°53'19.43"
Fort Belknap	TJ0660	NELSON	48°30'48.80525"N	107°33'18.18204"W	48.513557013889	-107.555050566667	693.793	151,938.9484	269,821.0771	**498,487.3635**	**885,239.7543**	International	11.294	1.000011294	+0°42'27.81"
Fort Belknap	TK0417	PORTER	48°55'49.63348"N	108°02'23.54169"W	48.930453744444	-108.039872691667	893.805	197,975.8731	233,719.9855	**649,527.1427**	**766,797.8527**	International	8.150	1.000008150	+0°20'40.61"
Fort Belknap	AB7733	Q 93 RESET	48°14'51.62144"N	110°03'21.79456"W	48.247672622222	-110.056054044444	798.669	123,113.7658	84,428.7975	**403,916.5543**	**276,997.3671**	International	4.480	1.000004480	−1°09'55.50"
Fort Belknap	TK0350	S 512	48°34'12.15668"N	108°56'03.11230"W	48.570043522222	-108.934197861111	705.988	157,880.7727	167,952.6999	**517,981.5379**	**551,025.9183**	International	10.101	1.000010101	−0°19'30.70"
Fort Belknap	TK0519	SIGNAL	48°56'42.11645"N	109°48'00.72705"W	48.945032347222	-109.800201958333	909.375	200,305.4430	104,747.5254	**657,170.0886**	**343,659.8601**	International	7.657	1.000007657	−0°58'25.66"
Fort Belknap	TL0016	T 369	48°33'29.31751"N	110°25'28.11391"W	48.558143752778	-110.424476086111	909.146	158,253.3521	57,939.0906	**519,203.9110**	**190,088.8799**	International	-21.966	0.999978034	−1°26'28.85"
Fort Belknap	AB7734	U 95 RESET	47°54'36.62343"N	110°32'43.99931"W	47.910173175000	-110.545555363889	778.985	86,450.2190	47,076.7293	**283,629.3274**	**154,451.2117**	International	50.535	1.000050535	−1°31'55.31"
Fort Belknap	DL7733	WHITEWATERMT2007	48°43'33.86526"N	107°43'31.45670"W	48.726073683333	-107.725404638889	815.593	175,431.5291	256,995.0048	**575,562.7596**	**843,159.4647**	International	-0.044	0.999999956	+0°34'48.50"
Fort Belknap	DL7731	WHITEWATERMT2007 CORS ARP	48°43'33.86526"N	107°43'31.45670"W	48.726073683333	-107.725404638889	815.602	175,431.5291	256,995.0048	**575,562.7596**	**843,159.4647**	International	-0.046	0.999999954	+0°34'48.50"
Fort Belknap	TK0281	Y 513	48°12'13.13478"N	108°03'29.77786"W	48.203648550000	-108.058271627778	745.850	117,137.2664	232,838.3869	**384,308.6170**	**763,905.4687**	International	16.415	1.000016415	+0°19'51.01"
Fort Belknap	TJ0454	Z 441	48°59'58.21670"N	107°49'55.55563"W	48.999504638889	-107.832098786111	846.969	205,768.0997	248,879.1162	**675,092.1905**	**816,532.5333**	International	25.288	1.000025288	+0°30'0.82"
Fort Peck Assiniboine	TJ0528	B 540	48°12'26.95629"N	106°37'37.59739"W	48.207487858333	-106.627110386111	675.517	86,620.4501	116,219.5750	**284,187.8283**	**381,297.8182**	International	16.529	1.000016529	−0°50'31.13"
Fort Peck Assiniboine	DI0389	CORPS II MILK RIVER	48°01'44.31835"N	106°19'09.96035"W	48.028977319444	-106.319433430556	785.226	66,479.7829	138,876.7136	**218,109.5240**	**455,632.2624**	International	10.970	1.000010970	−0°36'43.69"
Fort Peck Assiniboine	TJ0232	E 91	48°31'20.48872"N	106°33'45.74979"W	48.522357977778	-106.562708275000	812.860	121,565.7445	121,491.5676	**398,837.7445**	**398,594.3820**	International	-1.959	0.999998041	−0°47'37.93"
Fort Peck Assiniboine	TJ0022	F 92	48°50'50.97525"N	106°15'04.89233"W	48.847493125000	-106.251358980556	922.895	157,453.2726	144,846.0994	**516,578.9783**	**475,216.8616**	International	15.654	1.000015654	−0°33'40.62"
Fort Peck Assiniboine	TH0751	FIRE	48°58'56.92844"N	105°04'58.83724"W	48.982480122222	-105.083010344444	817.780	172,280.3317	230,528.0556	**565,224.1854**	**756,325.6416**	International	56.115	1.000056115	+0°18'41.41"
Fort Peck Assiniboine	AD9828	GGW AP STA A	48°13'07.63480"N	106°37'29.35560"W	48.218787444444	-106.624821000000	679.804	87,874.4217	116,408.1656	**288,301.9084**	**381,916.5538**	International	15.446	1.000015446	−0°50'24.97"
Fort Peck Assiniboine	AD9826	GGW ARP	48°12'47.91642"N	106°37'08.77049"W	48.213310116667	-106.619102913889	681.268	87,259.1472	116,824.1914	**286,283.2912**	**383,281.4680**	International	15.411	1.000015411	−0°50'9.59"
Fort Peck Assiniboine	TJ0615	GLASGOW 2	48°12'57.73956"N	106°36'51.19599"W	48.216038766667	-106.614221108333	685.426	87,557.2805	117,191.4076	**287,261.4190**	**384,486.2453**	International	14.661	1.000014661	−0°49'56.46"
Fort Peck Assiniboine	TH0424	K 542	48°06'02.97312"N	105°37'20.96571"W	48.100825866667	-105.622490475000	593.319	74,150.5511	190,875.7647	**243,276.0864**	**626,232.8239**	International	35.204	1.000035204	−0°05'29.41"
Fort Peck Assiniboine	TJ0590	KINTYRE	48°09'40.89729"N	106°11'19.41779"W	48.161360358333	-106.188727163889	689.177	81,105.1871	148,758.2812	**266,093.1336**	**488,052.1035**	International	16.471	1.000016471	−0°30'52.19"
Fort Peck Assiniboine	TH0426	M 542	48°06'39.81322"N	105°34'44.03908"W	48.111059227778	-105.578899744444	590.887	75,284.3049	194,123.9789	**246,995.7509**	**636,889.6946**	International	34.880	1.000034880	−0°03'32.18"
Fort Peck Assiniboine	TH0464	M 544	48°08'42.04451"N	104°55'52.05615"W	48.145012363889	-104.931126708333	586.375	79,214.1163	242,338.1829	**259,888.8330**	**795,072.7784**	International	33.475	1.000033475	+0°25'29.87"
Fort Peck Assiniboine	TH0195	MADOC	48°48'27.98858"N	105°19'07.21693"W	48.807774605556	-105.318671369444	836.323	152,781.2184	213,321.1679	**501,250.7165**	**699,872.5982**	International	23.226	1.000023226	+0°08'7.65"
Fort Peck Assiniboine	TH0608	MCCABE	48°15'32.53214"N	104°22'09.66548"W	48.259036705556	-104.369351522222	684.704	92,356.3615	283,958.8949	**303,006.4354**	**931,623.6709**	International	13.525	1.000013525	+0°50'40.64"

Table 4.2, cont.

RMTCRS 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 Assiniboine	TH0306	N 360	48°27'01.73833"N	105°54'29.93917"W	48.450482869444	-105.908316436111	846.168	113,108.7683	169,791.9164	**371,091.7594**	**557,060.0932**	International	-10.527	0.999989473	−0°18'18.08"
Fort Peck Assiniboine	DL6483	OLF A	48°05'41.88510"N	105°34'25.05804"W	48.094968083333	-105.573627233333	587.917	73,494.4744	194,514.9288	**241,123.6036**	**638,172.3385**	International	36.468	1.000036468	−0°03'18.01"
Fort Peck Assiniboine	DL6484	OLF B	48°05'46.09279"N	105°34'54.18687"W	48.096136886111	-105.581718575000	587.453	73,625.0632	193,912.2799	**241,552.0446**	**636,195.1439**	International	36.457	1.000036457	−0°03'39.76"
Fort Peck Assiniboine	DL6485	OLF C	48°05'28.68054"N	105°33'48.36248"W	48.091300150000	-105.563434022222	587.035	73,085.8982	195,273.9636	**239,783.1305**	**640,662.6104**	International	36.873	1.000036873	−0°02'50.59"
Fort Peck Assiniboine	TJ0099	P 354	48°01'24.27852"N	106°19'43.48803"W	48.023410700000	-106.328746675000	701.081	65,868.2430	138,175.3570	**216,103.1596**	**453,331.2236**	International	24.674	1.000024674	−0°37'8.74"
Fort Peck Assiniboine	TH0447	POPLAR W BASE	48°06'23.76337"N	105°12'02.61195"W	48.106600936111	-105.200725541667	578.956	74,828.9787	222,290.2054	**245,501.8986**	**729,298.5741**	International	37.053	1.000037053	+0°13'24.84"
Fort Peck Assiniboine	TJ0152	Q 256	48°10'29.59917"N	106°36'32.62985"W	48.174888658333	-106.609063847222	621.674	82,975.9911	117,508.4971	**272,230.9420**	**385,526.5653**	International	26.372	1.000026372	−0°49'42.59"
Fort Peck Assiniboine	TH0302	Q 360	48°27'02.61242"N	105°52'11.82274"W	48.450725672222	-105.869950761111	867.552	113,121.3701	172,630.3945	**371,133.1039**	**566,372.6853**	International	-13.869	0.999986131	−0°16'34.90"
Fort Peck Assiniboine	TJ0503	R 540	48°23'56.91559"N	107°06'21.51820"W	48.399143219444	-107.105977277778	647.040	108,563.8890	81,075.0995	**356,180.7383**	**265,994.4209**	International	19.249	1.000019249	−1°11'58.94"
Fort Peck Assiniboine	TJ0557	RICHLAND	48°55'05.64685"N	106°01'29.98561"W	48.918235236111	-106.024996002778	929.295	165,183.1881	161,515.9351	**541,939.5936**	**529,907.9236**	International	26.525	1.000026525	−0°23'31.87"
Fort Peck Assiniboine	TH0469	S 544	48°09'54.21114"N	104°49'41.79167"W	48.165058650000	-104.828275463889	649.504	81,505.2294	249,973.1439	**267,405.6082**	**820,121.8631**	International	22.498	1.000022498	+0°30'6.46"
Fort Peck Assiniboine	TH0255	T 272	48°28'34.27623"N	105°02'23.82054"W	48.476187841667	-105.039950150000	781.404	115,989.1090	234,018.2369	**380,541.6963**	**767,776.3677**	International	0.638	1.000000638	+0°20'37.21"
Fort Peck Assiniboine	TH0406	T 541	48°03'33.33704"N	105°59'59.83429"W	48.059260288889	-105.999953969444	616.040	69,642.3858	162,728.8739	**228,485.5178**	**533,887.3814**	International	34.832	1.000034832	−0°22'24.52"
Fort Peck Assiniboine	TH0213	X 46	48°31'10.92849"N	105°25'48.93004"W	48.519702358333	-105.430258344444	720.473	120,728.8431	205,152.6538	**396,092.0048**	**673,073.0113**	International	12.366	1.000012366	+0°03'7.56"
Fort Peck Assiniboine	TH0151	Z 63	48°47'30.71489"N	104°46'30.38803"W	48.791865247222	-104.775107786111	612.910	151,247.7191	253,269.6274	**496,219.5507**	**830,937.0978**	International	55.971	1.000055971	+0°32'29.45"
Fort Peck Sioux	TH0013	B 203	48°52'46.70211"N	104°07'31.26801"W	48.879639475000	-104.125352225000	645.647	111,660.4321	200,835.8498	**366,340.0005**	**658,910.2683**	International	34.306	1.000034306	+1°01'36.83"
Fort Peck Sioux	TJ0528	B 540	48°12'26.95629"N	106°37'37.59739"W	48.207487858333	-106.627110386111	675.517	36,620.8514	16,222.0881	**120,147.1502**	**53,222.0738**	International	-13.468	0.999986532	−0°50'31.13"
Fort Peck Sioux	DJ5118	CONFLUENCE	47°59'06.99085"N	103°59'14.17450"W	47.985275236111	-103.987270694444	559.645	12,408.1576	212,924.9934	**40,709.1784**	**698,572.8128**	International	20.640	1.000020640	+1°07'48.17"
Fort Peck Sioux	DI0389	CORPS II MILK RIVER	48°01'44.31835"N	106°19'09.96035"W	48.028977319444	-106.319433430556	785.226	16,480.7884	38,878.5471	**54,070.8281**	**127,554.2883**	International	-19.027	0.999980973	−0°36'43.69"
Fort Peck Sioux	DJ5119	CULBERTSON	48°08'57.18252"N	104°29'53.24903"W	48.149217366667	-104.498124730556	568.855	30,012.2852	174,554.4124	**98,465.5026**	**572,685.0799**	International	5.986	1.000005986	+0°44'54.33"
Fort Peck Sioux	TJ0232	E 91	48°31'20.48872"N	106°33'45.74979"W	48.522357977778	-106.562708275000	812.860	71,565.0976	21,493.9226	**234,793.6274**	**70,518.1188**	International	-31.956	0.999968044	−0°47'37.93"
Fort Peck Sioux	TJ0022	F 92	48°50'50.97525"N	106°15'04.89233"W	48.847493125000	-106.251358980556	922.895	107,451.5492	44,847.7538	**352,531.3294**	**147,138.3000**	International	-14.343	0.999985657	−0°33'40.62"
Fort Peck Sioux	TH0519	G 547	48°36'27.92569"N	104°26'25.82778"W	48.607757136111	-104.440507716667	594.404	81,058.3355	178,137.3251	**265,939.4210**	**584,440.0429**	International	8.302	1.000008302	+0°47'29.28"
Fort Peck Sioux	AD9828	GGW AP STA A	48°13'07.63480"N	106°37'29.35560"W	48.218787444444	-106.624821000000	679.804	37,874.7854	16,410.6730	**124,261.1070**	**53,840.7908**	International	-14.551	0.999985449	−0°50'24.97"
Fort Peck Sioux	AD9826	GGW ARP	48°12'47.91642"N	106°37'08.77049"W	48.213310116667	-106.619102913889	681.268	37,259.5293	16,826.6864	**122,242.5503**	**55,205.6641**	International	-14.586	0.999985414	−0°50'9.59"
Fort Peck Sioux	TJ0615	GLASGOW 2	48°12'57.73956"N	106°36'51.19599"W	48.216038766667	-106.614221108333	685.426	37,557.6538	17,193.8915	**123,220.6488**	**56,410.4053**	International	-15.336	0.999984664	−0°49'56.46"
Fort Peck Sioux	TH0571	H 549	48°08'15.87479"N	104°02'54.70215"W	48.137742997222	-104.048528375000	663.076	29,271.5991	208,031.8347	**96,035.4303**	**682,519.1428**	International	-8.120	0.999991880	+1°05'3.43"
Fort Peck Sioux	SP0366	JACKSON RESET	47°55'37.00574"N	104°19'45.51738"W	47.926946038889	-104.329310383333	762.409	5,475.9318	187,493.0596	**17,965.6555**	**615,134.7101**	International	-4.479	0.999995521	+0°52'28.32"
Fort Peck Sioux	TH0424	K 542	48°06'02.97312"N	105°37'20.96571"W	48.100825866667	-105.622490475000	593.319	24,151.3265	90,876.0384	**79,236.6356**	**298,149.7324**	International	5.206	1.000005206	−0°05'29.41"
Fort Peck Sioux	TJ0590	KINTYRE	48°09'40.89729"N	106°11'19.41779"W	48.161360358333	-106.188727163889	689.177	31,105.7539	48,759.8182	**102,052.9984**	**159,973.1569**	International	-13.526	0.999986474	−0°30'52.19"
Fort Peck Sioux	TH0530	L 543	48°27'48.82134"N	104°29'52.21772"W	48.463561483333	-104.497838255556	615.952	64,966.6692	174,118.9847	**213,145.2402**	**571,256.5115**	International	-3.956	0.999996044	+0°44'55.10"
Fort Peck Sioux	TH0426	M 542	48°06'39.81322"N	105°34'44.03908"W	48.111059227778	-105.578899744444	590.887	25,285.0463	94,124.1552	**82,956.1885**	**308,806.2834**	International	4.882	1.000004882	−0°03'32.18"
Fort Peck Sioux	TH0464	M 544	48°08'42.04451"N	104°55'52.05615"W	48.145012363889	-104.931126708333	586.375	29,214.7398	142,336.9129	**95,848.8838**	**466,984.6223**	International	3.477	1.000003477	+0°25'29.87"
Fort Peck Sioux	TH0551	M 548	48°08'57.09305"N	104°29'38.62173"W	48.149192513889	-104.494061591667	568.428	30,013.4793	174,856.7892	**98,469.4202**	**573,677.1300**	International	6.054	1.000006054	+0°45'5.26"
Fort Peck Sioux	TH0195	MADOC	48°48'27.98858"N	105°19'07.21693"W	48.807774605556	-105.318671369444	836.323	102,779.6351	113,320.7683	**337,203.5273**	**371,787.2977**	International	-6.771	0.999993229	+0°08'7.65"
Fort Peck Sioux	TH0608	MCCABE	48°15'32.53214"N	104°22'09.66548"W	48.259036705556	-104.369351522222	684.704	42,356.5908	183,956.3764	**138,965.1929**	**603,531.4187**	International	-16.472	0.999983528	+0°50'40.64"
Fort Peck Sioux	TH0306	N 360	48°27'01.73833"N	105°54'29.93917"W	48.450482869444	-105.908316436111	846.168	63,108.3750	69,792.8225	**207,048.4745**	**228,979.0766**	International	-40.523	0.999959477	−0°18'18.08"
Fort Peck Sioux	TH0586	NELSON	48°15'17.39359"N	104°09'17.85802"W	48.254831552778	-104.154960561111	789.154	42,145.9527	199,882.6897	**138,274.1231**	**655,783.1026**	International	-32.742	0.999967258	+1°00'17.20"
Fort Peck Sioux	DL6483	OLF A	48°05'41.88510"N	105°34'25.05804"W	48.094968083333	-105.573627233333	587.917	23,495.2695	94,515.0933	**77,084.2174**	**310,088.8888**	International	6.471	1.000006471	−0°03'18.01"
Fort Peck Sioux	DL6484	OLF B	48°05'46.09279"N	105°34'54.18687"W	48.096136886111	-105.581718575000	587.453	23,625.8543	93,912.4625	**77,512.6455**	**308,111.7535**	International	6.459	1.000006459	−0°03'39.76"
Fort Peck Sioux	DL6485	OLF C	48°05'28.68054"N	105°33'48.36248"W	48.091300150000	-105.563434022222	587.035	23,086.7055	95,274.1054	**75,743.7844**	**312,579.0860**	International	6.876	1.000006876	−0°02'50.59"
Fort Peck Sioux	TJ0099	P 354	48°01'24.27852"N	106°19'43.48803"W	48.023410700000	-106.328746675000	701.081	15,869.2669	38,177.2115	**52,064.5239**	**125,253.3185**	International	-5.323	0.999994677	−0°37'8.74"
Fort Peck Sioux	TH0447	POPLAR W BASE	48°06'23.76337"N	105°12'02.61195"W	48.106600936111	-105.200725541667	578.956	24,829.7337	122,289.5368	**81,462.3810**	**401,212.3910**	International	7.056	1.000007056	+0°13'24.84"
Fort Peck Sioux	TJ0152	Q 256	48°10'29.59917"N	106°36'32.62985"W	48.174888658333	-106.609063847222	621.674	32,976.5018	17,510.9716	**108,190.6226**	**57,450.6941**	International	-3.625	0.999996375	−0°49'42.59"
Fort Peck Sioux	TH0302	Q 360	48°27'02.61242"N	105°52'11.82274"W	48.450725672222	-105.869950761111	867.552	63,120.9765	72,631.2155	**207,089.8179**	**238,291.3893**	International	-43.865	0.999956135	−0°16'34.90"
Fort Peck Sioux	TJ0557	RICHLAND	48°55'05.64685"N	106°01'29.98561"W	48.918235236111	-106.024996002778	929.295	115,181.2329	61,517.0895	**377,891.1839**	**201,827.7215**	International	-3.472	0.999996528	−0°23'31.87"
Fort Peck Sioux	TH0469	S 544	48°09'54.21114"N	104°49'41.79167"W	48.165058650000	-104.828275463889	649.504	31,505.7842	149,971.6449	**103,365.4336**	**492,032.9555**	International	-7.499	0.999992501	+0°30'6.46"
Fort Peck Sioux	TH0255	T 272	48°28'34.27623"N	105°02'23.82054"W	48.476187841667	-105.039950150000	781.404	65,988.6294	134,017.2165	**216,498.1280**	**439,689.0304**	International	-29.358	0.999970642	+0°20'37.21"
Fort Peck Sioux	TH0406	T 541	48°03'33.33704"N	105°59'59.83429"W	48.059260288889	-105.999953969444	616.040	19,643.2964	62,729.9919	**64,446.5106**	**205,807.0599**	International	4.835	1.000004835	−0°22'24.52"
Fort Peck Sioux	TH0213	X 46	48°31'10.92849"N	105°25'48.93004"W	48.519702358333	-105.430258344444	720.473	70,728.2213	105,152.4993	**232,047.9701**	**344,988.5147**	International	-17.630	0.999982370	+0°03'7.56"
Fort Peck Sioux	TH0486	Y 543	48°09'49.60467"N	104°30'43.87438"W	48.163779075000	-104.512187327778	614.452	31,617.8961	173,487.1495	**103,733.2551**	**569,183.5613**	International	-1.941	0.999998059	+0°44'16.51"
Fort Peck Sioux	TH0151	Z 63	48°47'30.71489"N	104°46'30.38803"W	48.791865247222	-104.775107786111	612.910	101,246.1818	153,268.0295	**332,172.5125**	**502,847.8658**	International	25.973	1.000025973	+0°32'29.45"
Milk River	AB5604	13 JFB	48°44'26.84193"N	111°24'15.08851"W	48.740789425000	-111.404191252778	1057.373	226,858.8648	120,266.9967	**744,287.6140**	**394,576.7608**	International	-11.887	0.999988113	−0°18'9.80"
Milk River	AB5603	7 JFB	48°41'48.62668"N	111°09'25.98830"W	48.696840744444	-111.157218972222	1097.273	221,904.1861	138,424.6110	**728,032.1065**	**454,148.9862**	International	-21.067	0.999978933	−0°07'3.90"

Table 4.2, cont.

RMTCRS 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
Milk River	TL0297	A 422	48°31'08.85795"N	111°53'05.25498"W	48.519127208333	-111.884793050000	986.667	202,505.2954	84,629.1250	**664,387.4520**	**277,654.6096**	International	-9.575	0.999990425	−0°39'45.61"
Milk River	TM0191	BOUNDARY MON 324	48°59'55.26435"N	112°16'06.58262"W	48.998684541667	-112.268495172222	1195.427	256,234.5669	57,166.7665	**840,664.5895**	**187,555.0081**	International	-4.440	0.999995560	−0°57'0.17"
Milk River	TL0741	BOUNDARY MON 335	48°59'53.97572"N	111°56'41.46633"W	48.998326588889	-111.944851758333	1069.246	255,852.1142	80,850.3028	**839,409.8234**	**265,256.8988**	International	15.276	1.000015276	−0°42'27.55"
Milk River	TL0742	BOUNDARY MON 346	48°59'48.48151"N	111°36'12.97536"W	48.996800419444	-111.603604266667	1211.370	255,429.6074	105,822.7568	**838,023.6465**	**347,187.5223**	International	-7.224	0.999992776	−0°27'7.46"
Milk River	TL0743	BOUNDARY MON 361	48°59'51.36658"N	111°06'28.50100"W	48.997601827778	-111.107916944444	1115.284	255,350.0353	142,101.7041	**837,762.5832**	**466,212.9401**	International	7.952	1.000007952	−0°04'50.97"
Milk River	TL0744	BOUNDARY MON 370	48°59'54.14561"N	110°49'34.29236"W	48.998373780556	-110.826192322222	1029.444	255,444.7791	162,720.5481	**838,073.4223**	**533,860.0660**	International	21.520	1.000021520	+0°07'48.63"
Milk River	TL0745	BOUNDARY MON 380	48°59'56.24091"N	110°29'31.72469"W	48.998955808333	-110.492145747222	875.079	255,618.4385	187,167.9085	**838,643.1710**	**614,067.9414**	International	45.797	1.000045797	+0°22'49.30"
Milk River	TL0746	BOUNDARY MON 388 A	48°59'57.68180"N	110°12'59.09253"W	48.999356055556	-110.216414591667	845.001	255,833.2854	207,346.5787	**839,348.0492**	**680,270.9274**	International	50.571	1.000050571	+0°35'12.73"
Milk River	TK0586	BOUNDARY MON 398	48°59'59.15989"N	109°53'01.96516"W	48.999766636111	-109.883879211111	850.616	256,181.1151	231,680.9940	**840,489.2227**	**760,108.2481**	International	49.754	1.000049754	+0°50'9.33"
Milk River	TL0677	CENTER VI RESET	48°59'55.17833"N	110°56'06.24238"W	48.998660647222	-110.935067327778	1083.763	255,464.2538	154,752.2359	**838,137.3155**	**507,717.3094**	International	13.052	1.000013052	+0°02'55.07"
Milk River	TL0737	CONAIR	48°10'11.44078"N	111°58'22.55324"W	48.169844661111	-111.972931455556	1061.828	163,742.4911	77,623.5452	**537,212.8972**	**254,670.4239**	International	-4.898	0.999995102	−0°43'43.26"
Milk River	TL0738	CONAIR AZ MK	48°10'02.78599"N	111°58'55.43044"W	48.167440552778	-111.982064011111	1063.903	163,483.8292	76,940.7786	**536,364.2689**	**252,430.3760**	International	-4.982	0.999995018	−0°44'7.88"
Milk River	SS1307	E 429	47°57'21.52529"N	111°45'08.39708"W	47.955979247222	-111.752332522222	1055.089	139,774.4193	93,799.4154	**458,577.4911**	**307,740.8640**	International	24.420	1.000024420	−0°33'48.47"
Milk River	TM0635	ETHRIDGE	48°34'26.17738"N	112°10'39.12994"W	48.573938161111	-112.177536094444	1122.560	208,892.0214	63,095.8098	**685,341.2775**	**207,007.2498**	International	-30.093	0.999969907	−0°52'54.92"
Milk River	TL0498	F 513	48°34'10.92401"N	110°00'56.72162"W	48.569701113889	-110.015756005556	823.975	208,219.2688	222,645.8277	**683,134.0841**	**730,465.3139**	International	16.602	1.000016602	+0°44'13.76"
Milk River	TK0585	HAVRE CBL 1230	48°32'47.07163"N	109°46'22.74902"W	48.546408786111	-109.772985838889	769.633	205,888.0572	240,604.5558	**675,485.7518**	**789,385.0255**	International	24.706	1.000024706	+0°55'8.33"
Milk River	TL0363	M 432	48°32'55.48678"N	111°51'36.61447"W	48.548746327778	-111.860170686111	1045.856	205,778.4848	86,485.2516	**675,126.2624**	**283,744.2639**	International	-18.544	0.999981456	−0°38'39.23"
Milk River	TM0771	MCCORMICK	48°51'24.83220"N	112°07'54.31499"W	48.856897833333	-112.131754163889	1289.996	240,308.7072	66,939.9104	**788,414.3938**	**219,619.1286**	International	-37.763	0.999962237	−0°50'51.48"
Milk River	TL0320	NIGG	48°12'07.78729"N	111°56'19.11432"W	48.202163136111	-111.938642866667	1059.565	167,304.5456	80,218.2445	**548,899.4277**	**263,183.2168**	International	-7.615	0.999992385	−0°42'10.81"
Milk River	AB7733	Q 93 RESET	48°14'51.62144"N	110°03'21.79456"W	48.247672622222	-110.056054044444	798.669	172,370.2167	220,113.5357	**565,519.0836**	**722,157.2692**	International	29.477	1.000029477	+0°42'25.11"
Milk River	TL0453	RAVINE	48°28'04.28954"N	111°18'26.06139"W	48.467858205556	-111.307239275000	961.390	196,470.9524	127,276.9965	**644,589.7387**	**417,575.4477**	International	-5.514	0.999994486	−0°13'48.39"
Milk River	TL0751	SHELBY	48°32'25.61075"N	111°52'02.26422"W	48.540447430556	-111.867295616667	1030.493	204,861.5051	85,948.7077	**672,117.7988**	**281,983.9491**	International	-16.249	0.999983751	−0°38'58.44"
Milk River	TL0752	SHELBY AZ MK	48°32'17.37852"N	111°52'48.07676"W	48.538160700000	-111.880021322222	1027.253	204,617.9316	85,006.0078	**671,318.6732**	**278,891.1017**	International	-15.769	0.999984231	−0°39'32.75"
Milk River	TK0519	SIGNAL	48°56'42.11645"N	109°48'00.72705"W	48.945032347222	-109.800201958333	909.375	250,186.5095	237,899.7340	**820,821.8815**	**780,510.9383**	International	32.654	1.000032654	+0°53'54.94"
Milk River	TL0016	T 369	48°33'29.31751"N	110°25'28.11391"W	48.558143752778	-110.424476086111	909.146	206,626.3849	192,489.1470	**677,908.0869**	**631,526.0727**	International	3.031	1.000003031	+0°25'51.75"
Milk River	AI7864	TIB1	48°19'02.75135"N	111°06'12.25456"W	48.317430930556	-111.103404044444	907.236	179,700.8417	142,329.7447	**589,569.6908**	**466,961.1047**	International	7.868	1.000007868	−0°04'38.80"
Milk River	AI7865	TIB2	48°19'21.34362"N	111°05'27.97165"W	48.322595450000	-111.091103236111	918.373	180,274.0442	143,242.8717	**591,450.2762**	**469,956.9281**	International	5.841	1.000005841	−0°04'5.64"
Milk River	TL0318	U 427	48°10'34.06436"N	111°56'06.16750"W	48.176128988889	-111.935046527778	1052.070	164,406.1845	80,450.2071	**539,390.3690**	**263,944.2492**	International	-3.991	0.999996009	−0°42'1.11"
Milk River	AB7734	U 95 RESET	47°54'36.62343"N	110°32'43.99931"W	47.910173175000	-110.545555363889	778.985	134,504.8746	183,978.4353	**441,288.9585**	**603,603.7903**	International	75.534	1.000075534	+0°20'25.29"
Milk River	TL0414	W 425	48°59'50.06516"N	111°57'35.55140"W	48.997240322222	-111.959875388889	1048.491	255,744.9861	79,749.3282	**839,058.3535**	**261,644.7774**	International	18.363	1.000018363	−0°43'8.05"
Milk River	DI3422	WICKUMRNCHMT2006 CORS ARP	48°48'34.09693"N	111°14'54.29691"W	48.809471369444	-111.248415808333	1267.430	234,448.9448	131,750.8588	**769,189.4515**	**432,253.4736**	International	-39.043	0.999960957	−0°11'9.79"
Milk River	DI3424	WICKUMRNCHMT2006	48°48'34.09693"N	111°14'54.29691"W	48.809471369444	-111.248415808333	1267.422	234,448.9448	131,750.8588	**769,189.4515**	**432,253.4736**	International	-39.042	0.999960958	−0°11'9.79"
St. Mary	AB3812	4220	48°59'54.33032"N	113°08'29.14841"W	48.998425088889	-113.141430113889	1272.775	55,634.4806	103,056.5539	**182,527.8235**	**338,112.0535**	International	-12.402	0.999987598	−0°29'2.73"
St. Mary	TM0964	BOUNDARY MON 278	48°59'53.58991"N	113°49'29.72764"W	48.998219419444	-113.824924344444	2601.479	56,259.4613	53,035.1339	**184,578.2852**	**173,999.7832**	International	-132.194	0.999867806	−0°59'59.94"
St. Mary	TM0965	BOUNDARY MON 286	48°59'52.23920"N	113°31'36.97042"W	48.997844222222	-113.526936227778	1513.529	55,879.8955	74,842.5232	**183,332.9903**	**245,546.3359**	International	-7.836	0.999992164	−0°46'30.18"
St. Mary	TM0477	BOUNDARY MON 295	48°59'53.87667"N	113°13'27.69054"W	48.998299075000	-113.224358483333	1413.472	55,675.0588	96,987.2999	**182,660.9540**	**318,199.8030**	International	-26.999	0.999973001	−0°32'48.04"
St. Mary	AB3811	PIEGAN	48°56'23.68774"N	113°22'21.02986"W	48.939913261111	-113.372508294444	1299.508	49,295.1214	86,070.3497	**161,729.4010**	**282,383.0370**	International	6.527	1.000006527	−0°39'28.48"
St. Mary	AI7862	SHERBURNE 1	48°49'42.03861"N	113°31'14.41347"W	48.828344058333	-113.520670408333	1431.261	37,021.3154	75,047.9352	**121,461.0087**	**246,220.2600**	International	4.673	1.000004673	−0°46'6.01"
St. Mary	AI7863	SHERBURNE 2	48°51'07.53055"N	113°24'59.52878"W	48.852091819444	-113.416535772222	1352.441	39,565.2828	82,726.6957	**129,807.3583**	**271,413.0436**	International	3.617	1.000003617	−0°41'24.68"
St. Mary	TM0878	STACK	48°58'04.45876"N	113°08'14.32664"W	48.967905211111	-113.137312955556	1459.365	52,237.3311	103,329.3779	**171,382.3197**	**339,007.1454**	International	-41.950	0.999958050	−0°28'50.74"
Wind River	OW0202	D 330	43°39'24.95262"N	108°12'50.57983"W	43.656931283333	-108.214049952778	1381.162	110,047.6498	109,624.5306	**361,047.9978**	**359,659.8140**	US survey	24.552	1.000024552	+0°04'56.45"
Wind River	OW0192	H 326	43°45'11.66538"N	108°10'35.11961"W	43.753240383333	-108.176422113889	1301.778	120,755.8371	112,640.3278	**396,179.7757**	**369,554.1420**	US survey	37.825	1.000037825	+0°06'30.65"
Wind River	AA2122	HART	42°50'16.18787"N	108°43'02.35522"W	42.837829963889	-108.717320894444	1626.906	19,090.2793	68,599.5120	**62,632.0246**	**225,063.5656**	US survey	-3.019	0.999996981	−0°15'39.91"
Wind River	NS0066	J 21	42°54'36.70131"N	108°34'13.35403"W	42.910194808333	-108.570376119444	1533.344	27,086.9657	80,638.5262	**88,867.8199**	**264,561.5647**	US survey	4.141	1.000004141	−0°09'41.01"
Wind River	OW0104	L 49	43°49'19.23845"N	108°32'34.09736"W	43.822010680556	-108.542804822222	1580.636	128,407.9721	83,144.8990	**421,285.1551**	**272,784.5561**	US survey	-4.364	0.999995636	−0°08'42.15"
Wind River	OW0207	M 327	43°35'08.27329"N	108°12'49.40639"W	43.585631469444	-108.213723997222	1322.381	102,124.0305	109,662.2423	**335,051.9233**	**359,783.5400**	US survey	33.775	1.000033775	+0°04'56.87"
Wind River	AA2121	NWS 5568.70	43°03'58.04170"N	108°28'41.96397"W	43.066122694444	-108.478323325000	1684.437	44,396.4799	88,187.2260	**145,657.4510**	**289,327.5905**	US survey	-22.435	0.999977565	−0°05'56.42"
Wind River	NS0004	P 21	42°59'51.39077"N	108°25'12.27062"W	42.997608547222	-108.420075172222	1495.711	36,776.6327	92,925.0144	**120,658.0025**	**304,871.4848**	US survey	6.052	1.000006052	−0°03'32.96"
Wind River	OW0267	PEBBLE	43°04'58.68147"N	108°29'03.07811"W	43.082967075000	-108.484188363889	1705.245	46,269.0846	87,712.7491	**151,801.1551**	**287,770.9110**	US survey	-25.557	0.999974443	−0°06'10.95"
Wind River	DM6045	RIW A	43°03'49.67229"N	108°27'35.72916"W	43.063797858333	-108.459924766667	1652.003	44,135.7166	89,685.8227	**144,801.9303**	**294,244.2367**	US survey	-17.758	0.999982242	−0°05'11.18"
Wind River	DM6046	RIW B	43°04'12.76557"N	108°28'09.33505"W	43.070212658333	-108.469259736111	1665.595	44,849.7236	88,926.4004	**147,144.4681**	**291,752.6986**	US survey	-19.689	0.999980311	−0°05'34.16"
Wind River	DM6047	RIW C	43°03'32.03970"N	108°26'46.16286"W	43.058899916667	-108.446156350000	1643.019	43,589.8540	90,806.8881	**143,011.0460**	**297,922.2652**	US survey	-16.618	0.999983382	−0°04'37.31"
Wind River	OW0260	SHOSHONE	43°10'47.99759"N	108°00'26.84366"W	43.179999330556	-108.007456572222	1662.683	57,092.0214	126,500.9769	**187,309.4069**	**415,028.6217**	US survey	-12.105	0.999987895	+0°13'22.79"

(Shaded) NGS PID contained in two RMCRS's

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.

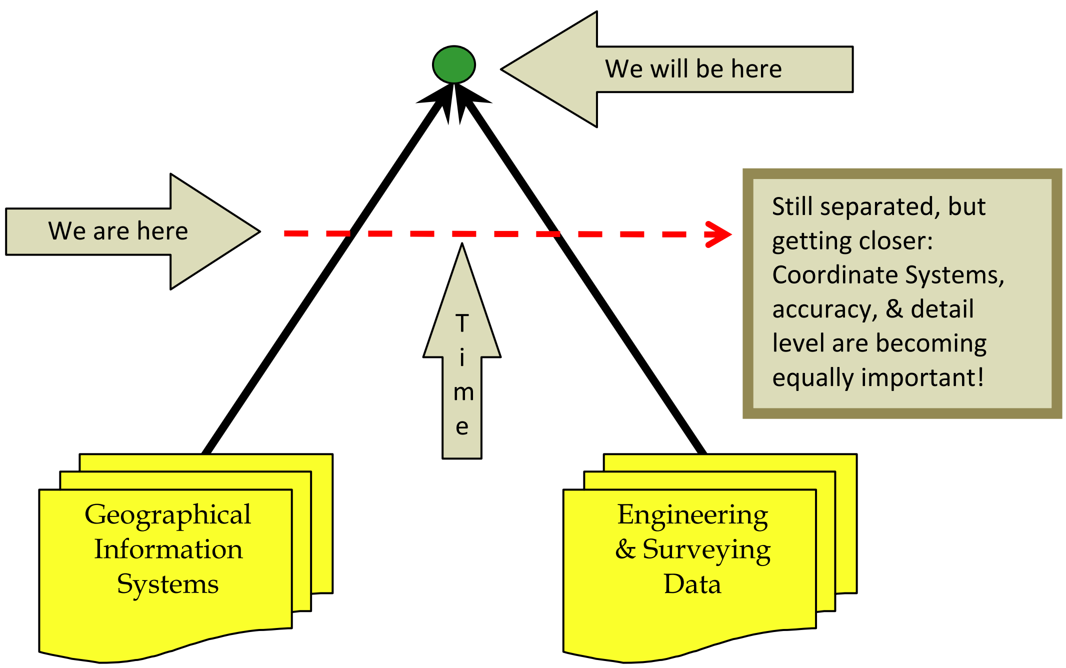


Figure 4.3, [mla,rs]

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} ≈ 0.06 mm)*:
{
$\sin\sigma = \text{sqrt}[(\cos U_2.\sin\lambda)^2 + (\cos U_1.\sin U_2 - \sin U_1.\cos U_2.\cos\lambda)^2]$
$\cos\sigma = \sin U_1.\sin U_2 + \cos U_1.\cos U_2.\cos\lambda$
$\sigma = \text{atan}(\sin\sigma / \cos\sigma)$
$\sin\alpha = \cos U_1.\cos U_2.\sin\lambda / \sin\sigma$
$\cos 2\sigma_m = \cos\sigma - 2.\sin U_1.\sin U_2/\cos^2\alpha$
$C = (f/16).\cos^2\alpha.[4+f.(4-3.\cos^2\alpha)]$
$\lambda' = L + (1-C).f.\sin\alpha.\{\sigma+C.\sin\sigma.[\cos 2\sigma_m+C.\cos\sigma.(-1+2.\cos^2 2\sigma_m)]\}$
}
$u^2 = \cos^2\alpha.(a^2-b^2)/b^2$
$A = (1+u^2/16384).\{4096+u^2.[-768+u^2.(320-175.u^2)]\}$
$B = (u^2/1024).\{256+u^2.[-128+u^2.(74-47.u^2)]\}$
$\Delta\sigma = B.\sin\sigma.\{\cos 2\sigma_m+B/4.[\cos\sigma.(-1+2.\cos^2 2\sigma_m) - B/6.\cos 2\sigma_m.(-3+4.\sin^2\sigma).(-3+4.\cos^2 2\sigma_m)]\}$
$s = b.A.(\sigma-\Delta\sigma)$

α_1 = atan((cosU_2.sinλ) / (cosU_1.sinU_2 − sinU_1.cosU_2.cosλ))
α_2 = atan((cosU_1.sinλ) / (−sinU_1.cosU_2 + cosU_1.sinU_2.cosλ))
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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2. "Wyoming Department of Transportation Survey Manual" https://www.dot.state.wy.us/home/engineering_technical_programs/photos_and_surveys/SurveyManual.html.
3. Federal Geographic Data Committee (1998) *Geospatial Positioning Accuracy Standards*, FGDC-STD-007.2-1998, Federal Geographic Data Committee, Reston, Virginia, USA, 128 pp., http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/, [includes Standards for Geodetic Networks (Part 2), National Standard for Spatial Data Accuracy (Part 3), and Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management (Part 4)].
4. National Geodetic Survey, *User Guidelines for Single Base Real Time GNSS Positioning v3.0,* by William Henning, Lead Author
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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7. "*Transforming Position and Velocities between the International Terrestrial Reference Frame of 2000 and North American Datum of 1983*", by Tomas Soler and Richard Snay.
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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

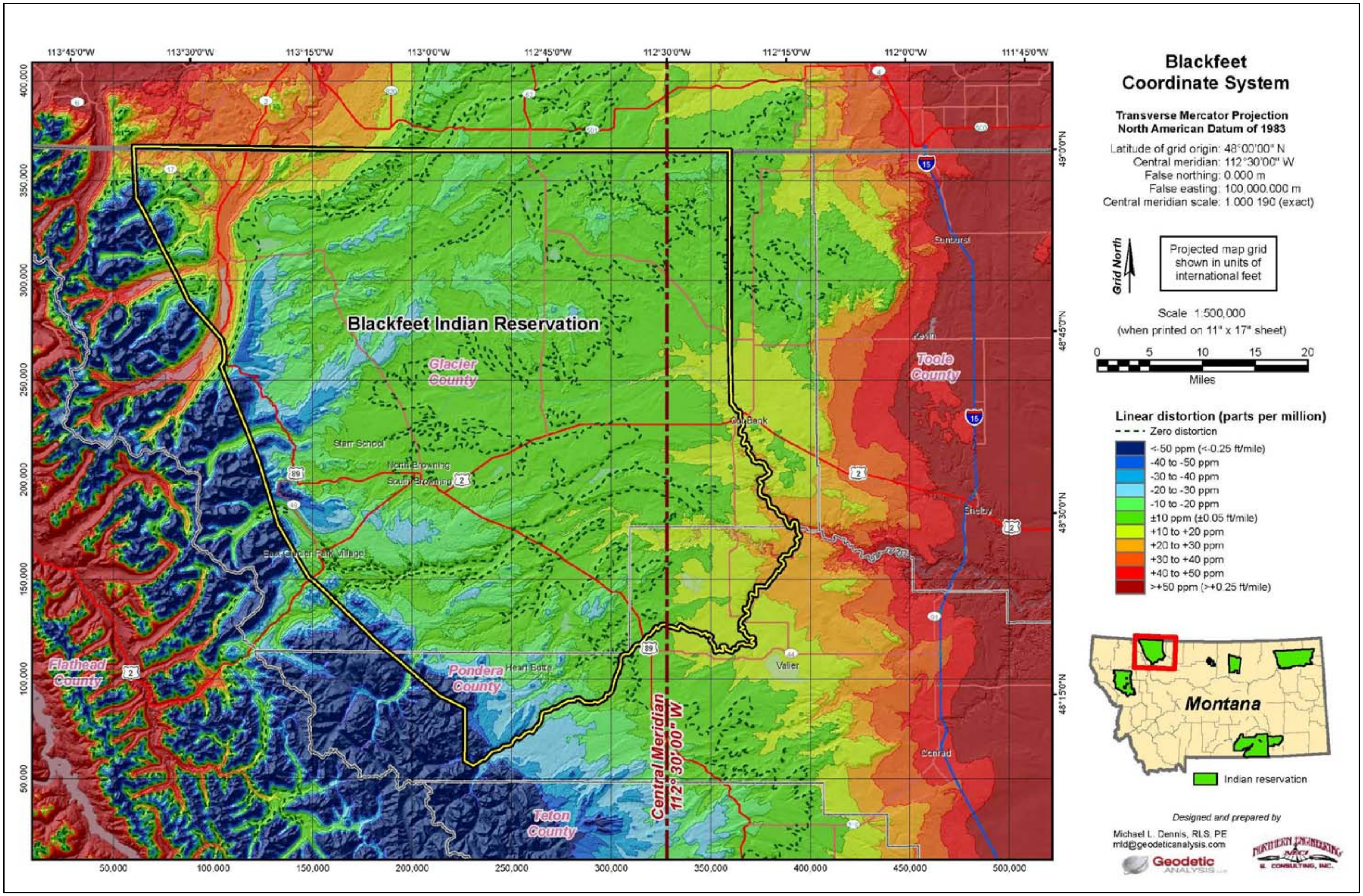
Helmert Transformations: http://earth-info.nga.mil/GandG/coordsys/datums/helmert.html

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


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)
Montana
Indian reservation
Designed and prepared by
Michael L. Dennis, RLS, PE
mld@geodeticanalysis.com
Geodetic Analysis
Northern Engineering & Consulting, Inc.
Blackfeet Indian Reservation
Glacier County
Toole County
Pondera County
Teton County
Flathead County
Central Meridian 112° 30' 00" W
Starr School
North Browning
South Browning
East Glacier Park Village
Heart Butte
Valier
Cut Bank
Sunburst
Kevin
Shelby
Conrad
113°45'0"W
113°30'0"W
113°15'0"W
113°0'0"W
112°45'0"W
112°30'0"W
112°15'0"W
112°0'0"W
111°45'0"W
49°0'0"N
48°45'0"N
48°30'0"N
48°15'0"N
400,000
350,000
300,000
250,000
200,000
150,000
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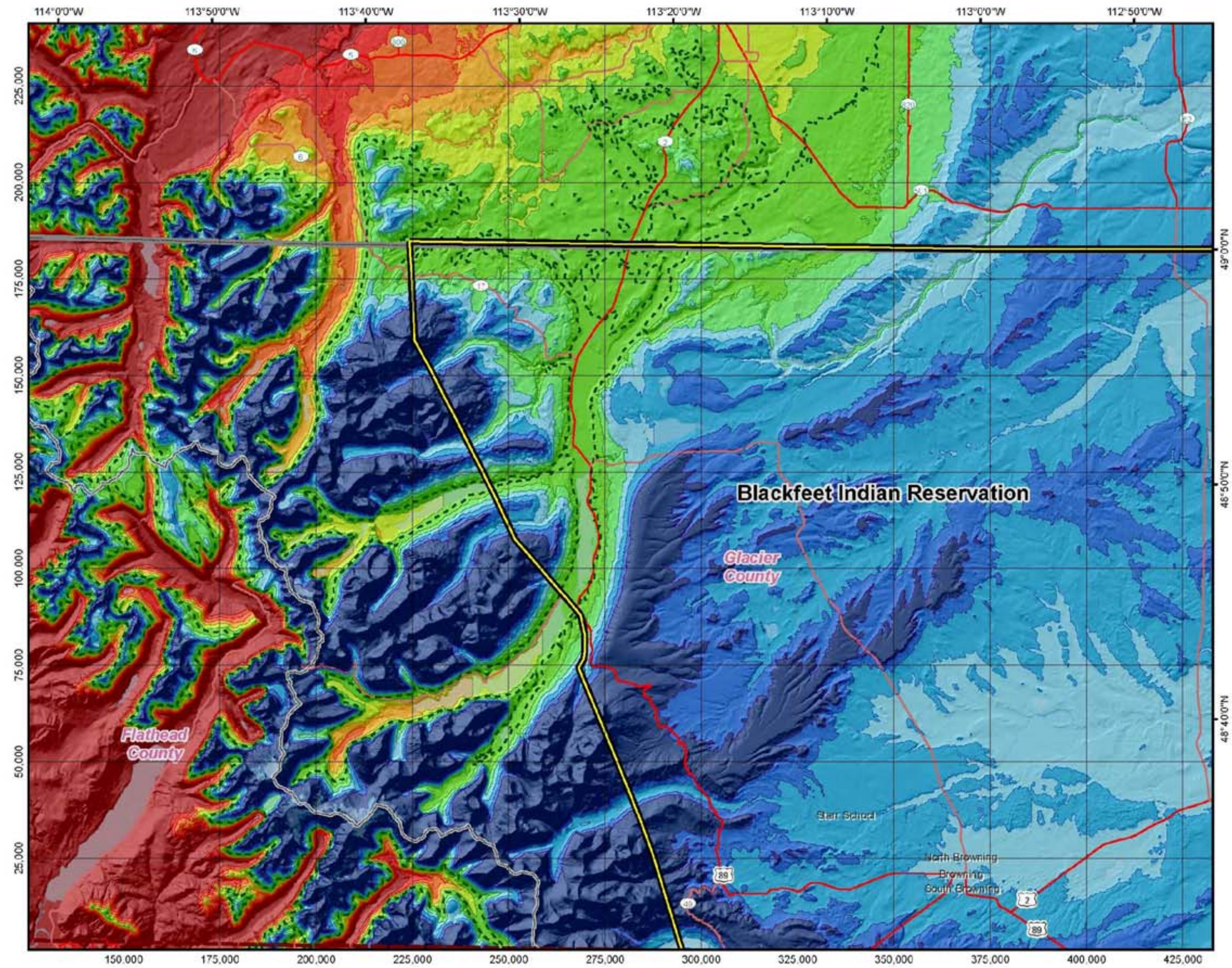
400,000
450,000
500,000



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)

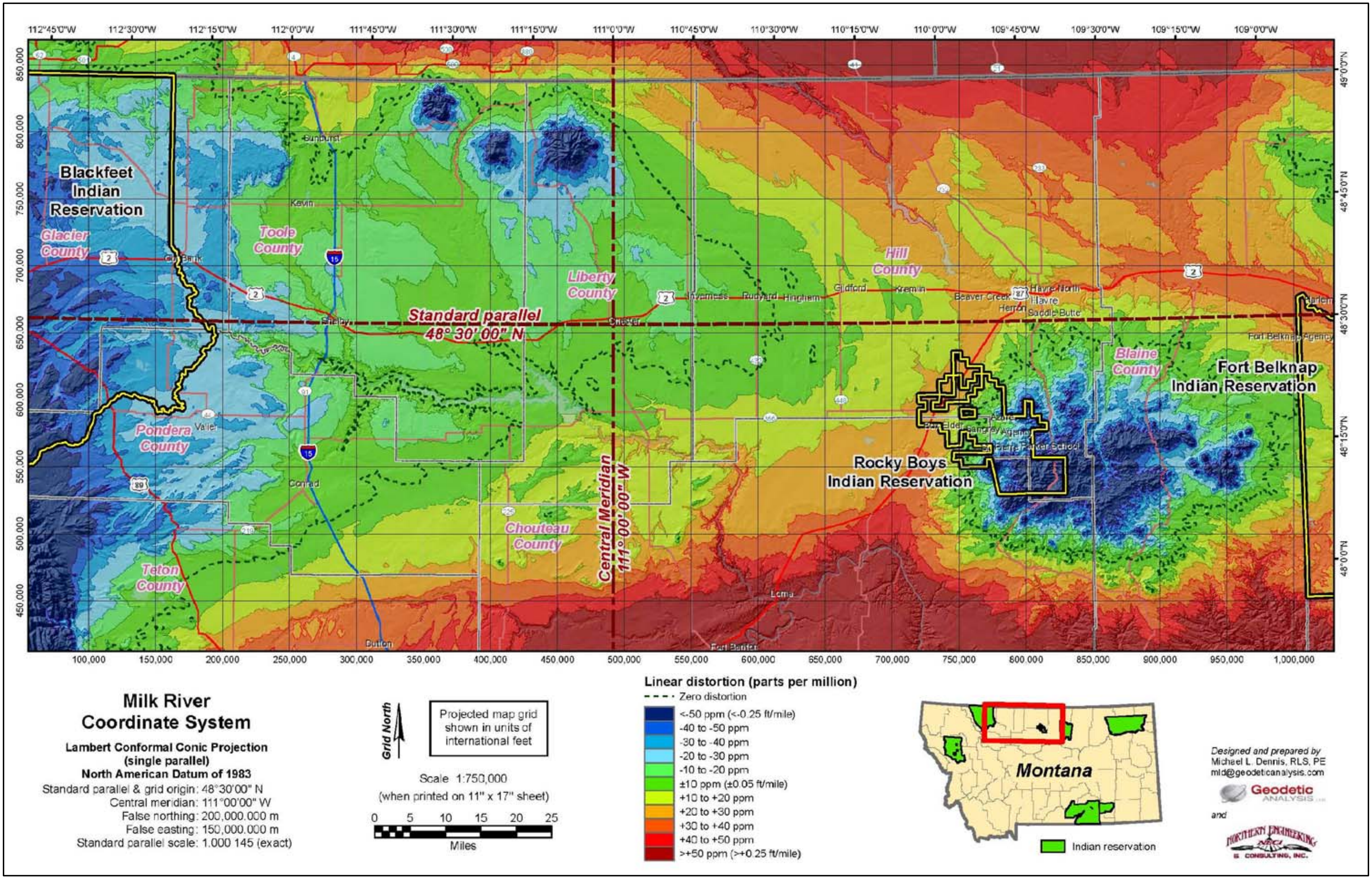
- Zero distortion
- <-50 ppm (<-0.25 ft/mile)
- -40 to -50 ppm
- -30 to -40 ppm
- -20 to -30 ppm
- -10 to -20 ppm
- ±10 ppm (±0.05 ft/mile)
- +10 to +20 ppm
- +20 to +30 ppm
- +30 to +40 ppm
- +40 to +50 ppm
- >+50 ppm (>+0.25 ft/mile)

Indian reservation

Designed and prepared by

Michael L. Dennis, RLS, PE
mld@geodeticanalysis.com

Geodetic Analysis
Northern Engineering & Consulting, Inc.


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)
Montana
Indian reservation
Designed and prepared by
Michael L. Dennis, RLS, PE
mld@geodeticanalysis.com
Geodetic ANALYSIS
and
NORTHERN ENGINEERING & CONSULTING, INC.
Standard parallel
48° 30' 00" N
Central Meridian
111° 00' 00" W
Blackfeet Indian Reservation
Rocky Boys Indian Reservation
Fort Belknap Indian Reservation
Glacier County
Toole County
Liberty County
Hill County
Blaine County
Pondera County
Teton County
Chouteau County
Sunburst
Kevin
Cut Bank
Shelby
Conrad
Valier
Dutton
Chester
Inverness
Rudyard
Hingham
Gildford
Kremlin
Beaver Creek
Havre North
Havre
Herron
Saddle Butte
Box Elder
Agency
Parker School
Fort Belknap Agency
Harlem
Loma
Fort Benton
112°45'0"W
112°30'0"W
112°15'0"W
112°0'0"W
111°45'0"W
111°30'0"W
111°15'0"W
111°0'0"W
110°45'0"W
110°30'0"W
110°15'0"W
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49°0'0"N
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48°30'0"N
48°15'0"N
48°0'0"N
850,000
800,000
750,000
700,000
650,000
600,000
550,000
500,000
450,000
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150,000
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350,000
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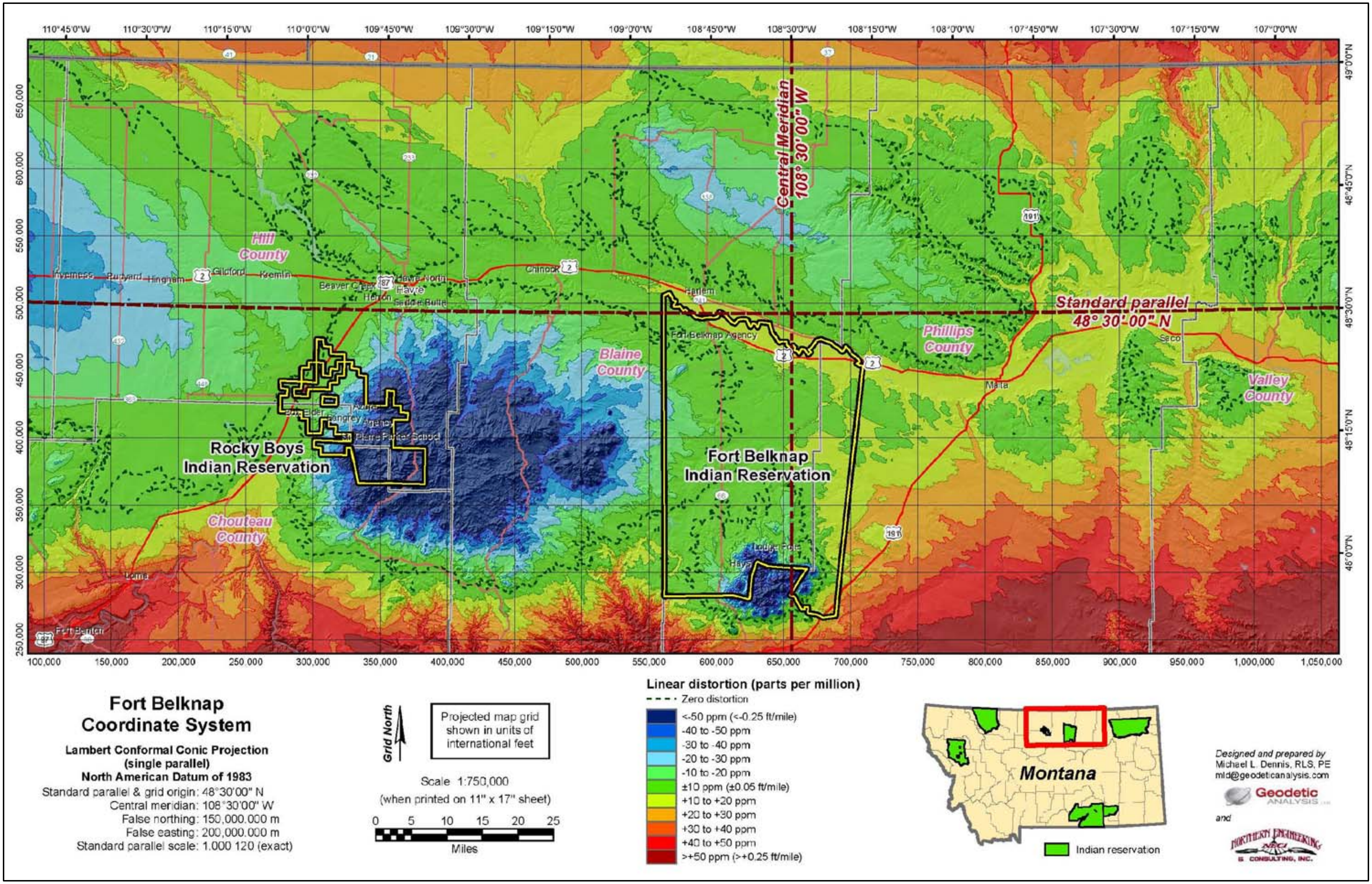
900,000
950,000
1,000,000


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)
Montana
Indian reservation
Designed and prepared by
Michael L. Dennis, RLS, PE
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Geodetic
ANALYSIS
and
Central Meridian
108° 30' 00" W
Standard parallel
48° 30' 00" N
Fort Belknap
Indian Reservation
Rocky Boys
Indian Reservation
Hill County
Blaine County
Phillips County
Valley County
Chouteau County
Fort Belknap Agency
Harlem
Chinook
Havre
Havre North
Beaver Creek
Saddle Butte
Heron
Box Elder
Gilford
Kremlin
Hingham
Rudyard
Inverness
Malta
Saco
Loma
Fort Benton
Hays
Lodge Pole
Agency
Sangrey
Azure
St. Pierre Parker School
110°45'0"W
110°30'0"W
110°15'0"W
110°0'0"W
109°45'0"W
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109°15'0"W
109°0'0"W
108°45'0"W
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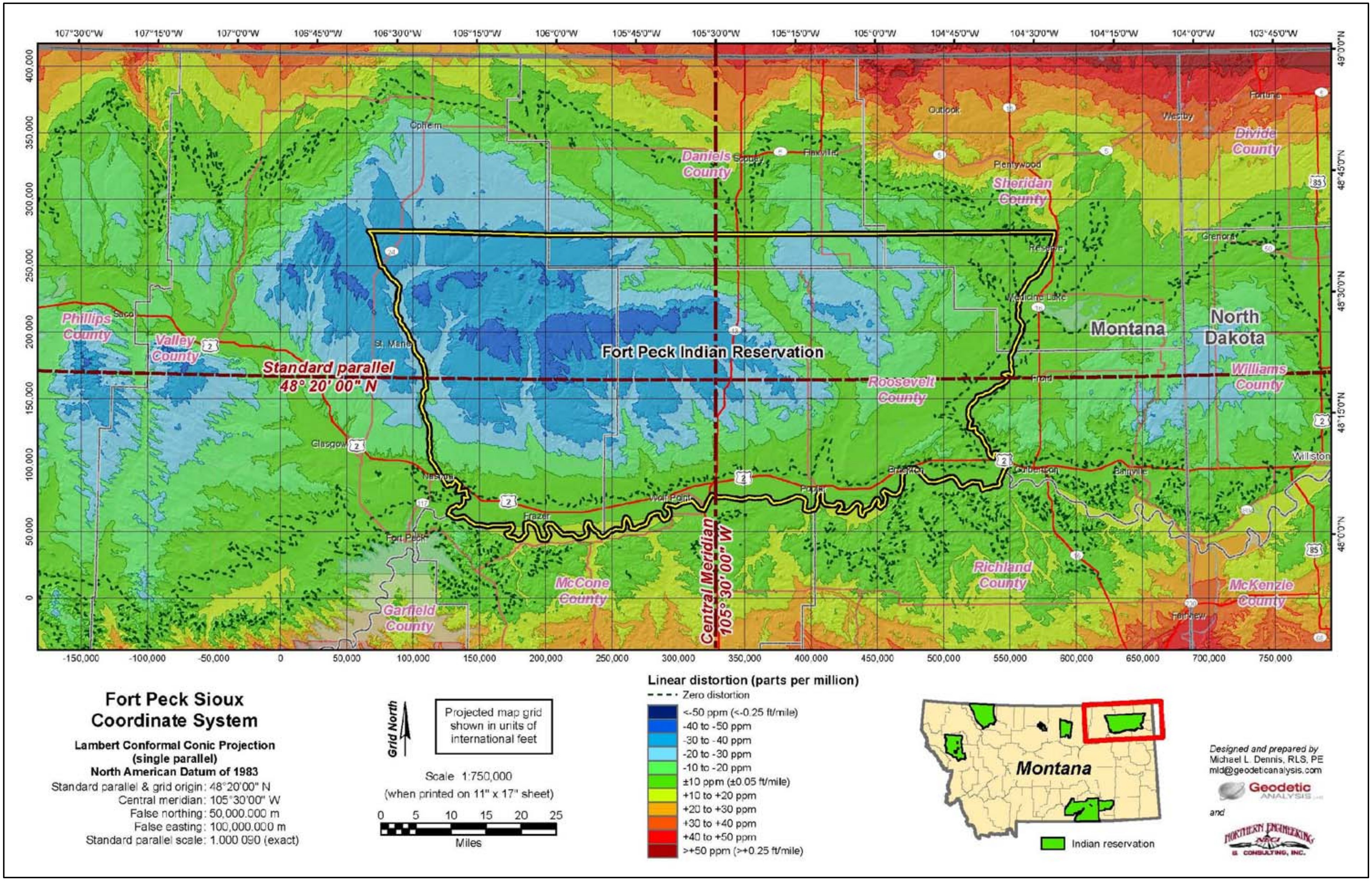
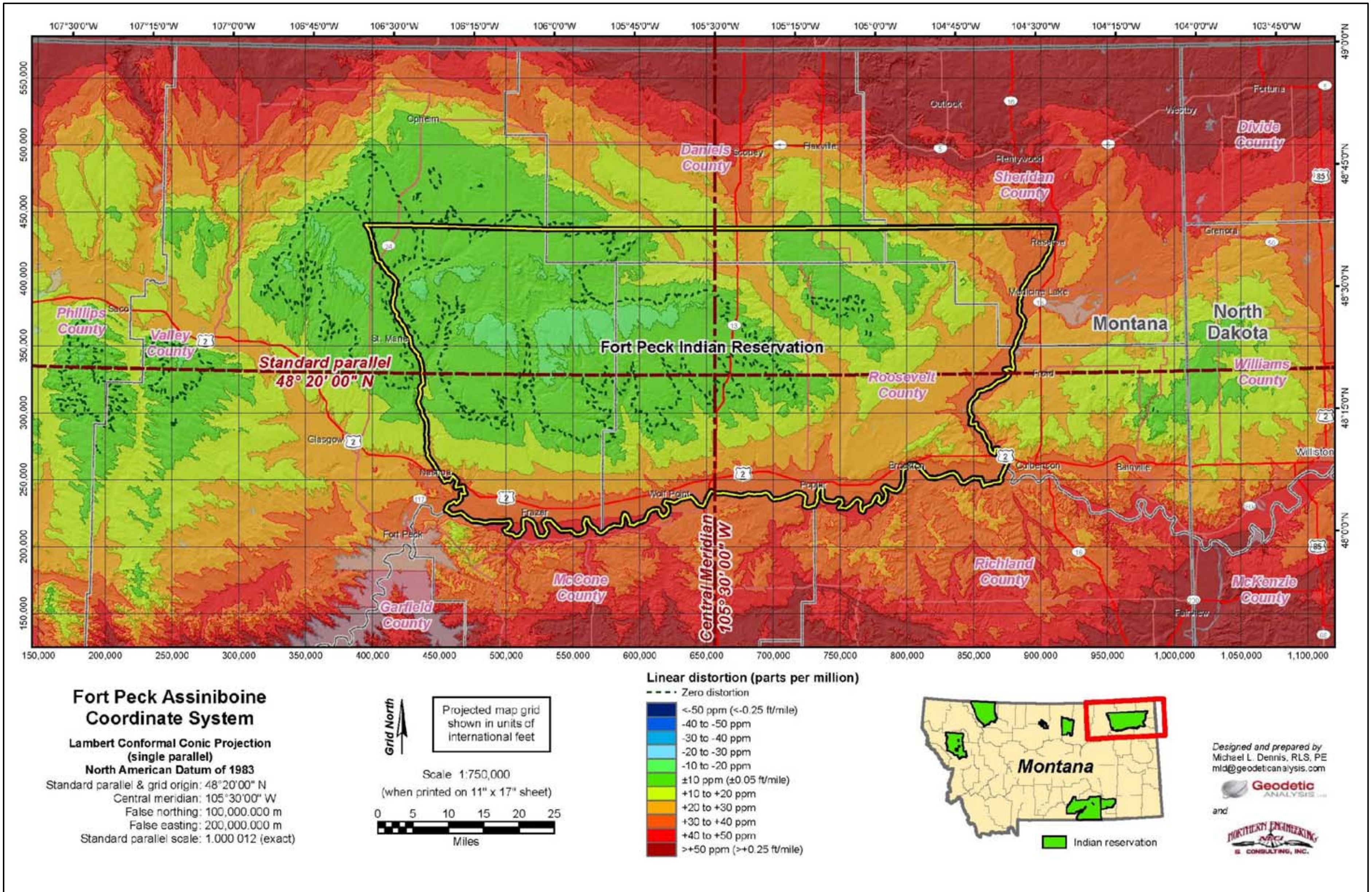
1,000,000
1,050,000


Fort Peck Indian Reservation
Standard parallel 48° 20' 00" N
Central Meridian 105° 30' 00" W
Montana
North Dakota
Phillips County
Valley County
Daniels County
Sheridan County
Roosevelt County
Divide County
Williams County
McKenzie County
Richland County
McCone County
Garfield County
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)
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)
Montana
Indian reservation
Designed and prepared by
Michael L. Dennis, RLS, PE
mld@geodeticanalysis.com
Geodetic Analysis
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)
Montana
Indian reservation
Designed and prepared by
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Geodetic
and
Fort Peck Indian Reservation
Standard parallel
48° 20' 00" N
Central Meridian
105° 30' 00" W
Montana
North
Dakota
Phillips County
Valley County
Daniels County
Sheridan County
Roosevelt County
Richland County
McCone County
Garfield County
Divide County
Williams County
McKenzie County
Saco
Opheim
Glasgow
St. Marie
Nashua
Fort Peck
Frazer
Wolf Point
Poplar
Brockton
Culbertson
Bainville
Froid
Medicine Lake
Reserve
Plentywood
Scobey
Flaxville
Outlook
Westby
Fortuna
Crosby
Grenora
Williston
Fairview
107°30'0"W
107°15'0"W
107°0'0"W
106°45'0"W
106°30'0"W
106°15'0"W
106°0'0"W
105°45'0"W
105°30'0"W
105°15'0"W
105°0'0"W
104°45'0"W
104°30'0"W
104°15'0"W
104°0'0"W
103°45'0"W
49°0'0"N
48°45'0"N
48°30'0"N
48°15'0"N
48°0'0"N
550,000
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
150,000
200,000
250,000
300,000
350,000
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450,000
500,000
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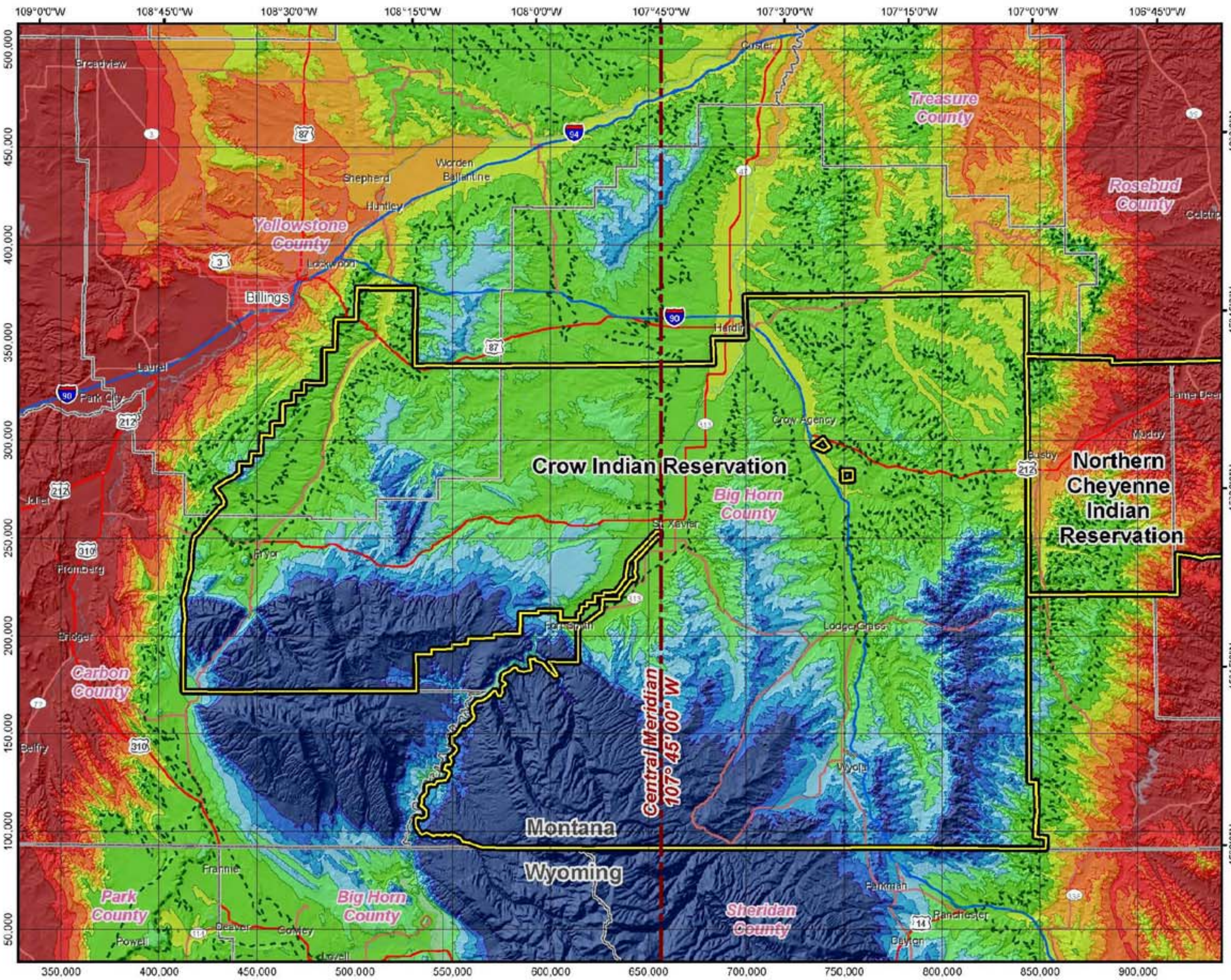
1,050,000
1,100,000



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)

Indian reservation

Designed and prepared by

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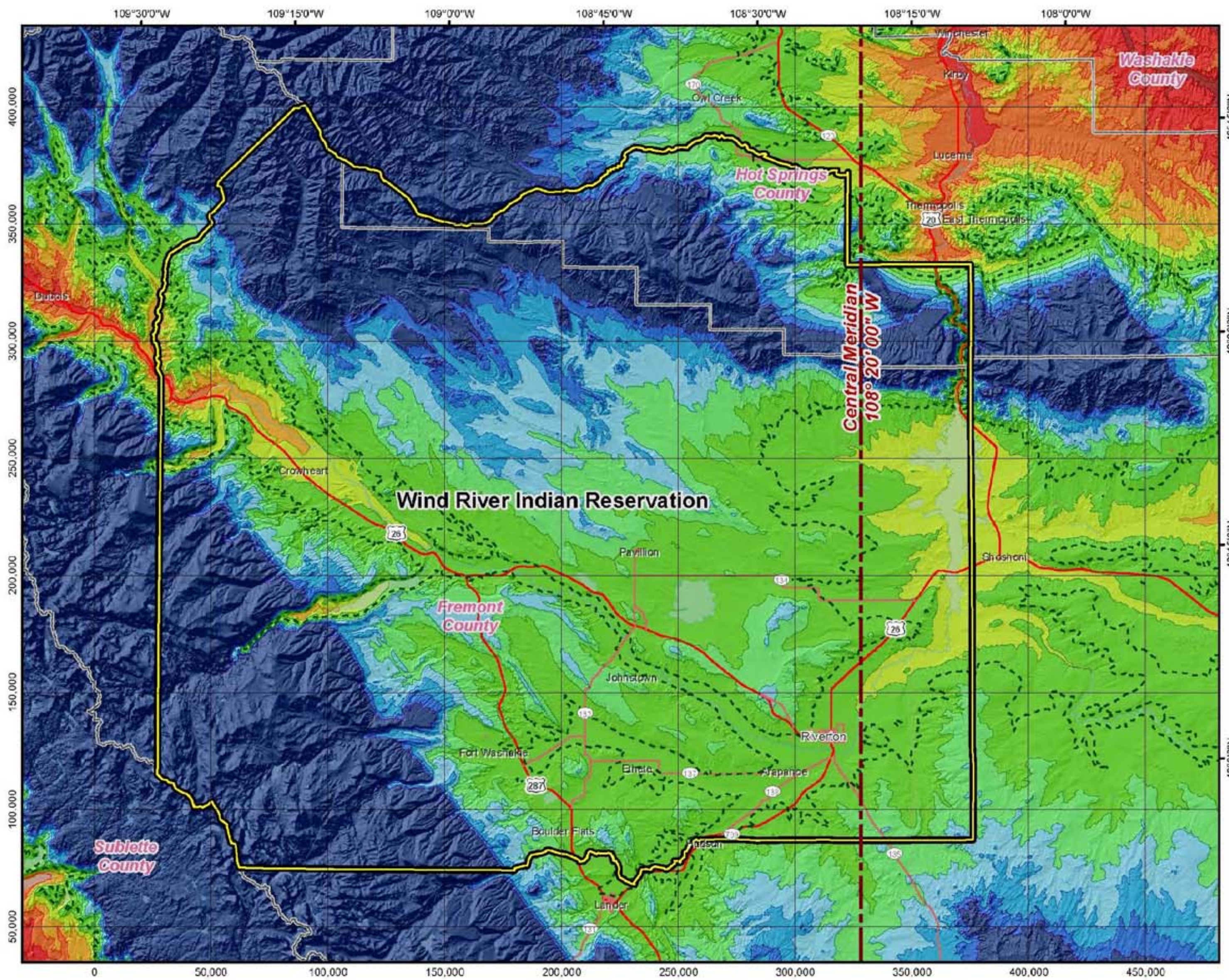
Northern Engineering & Consulting, Inc.



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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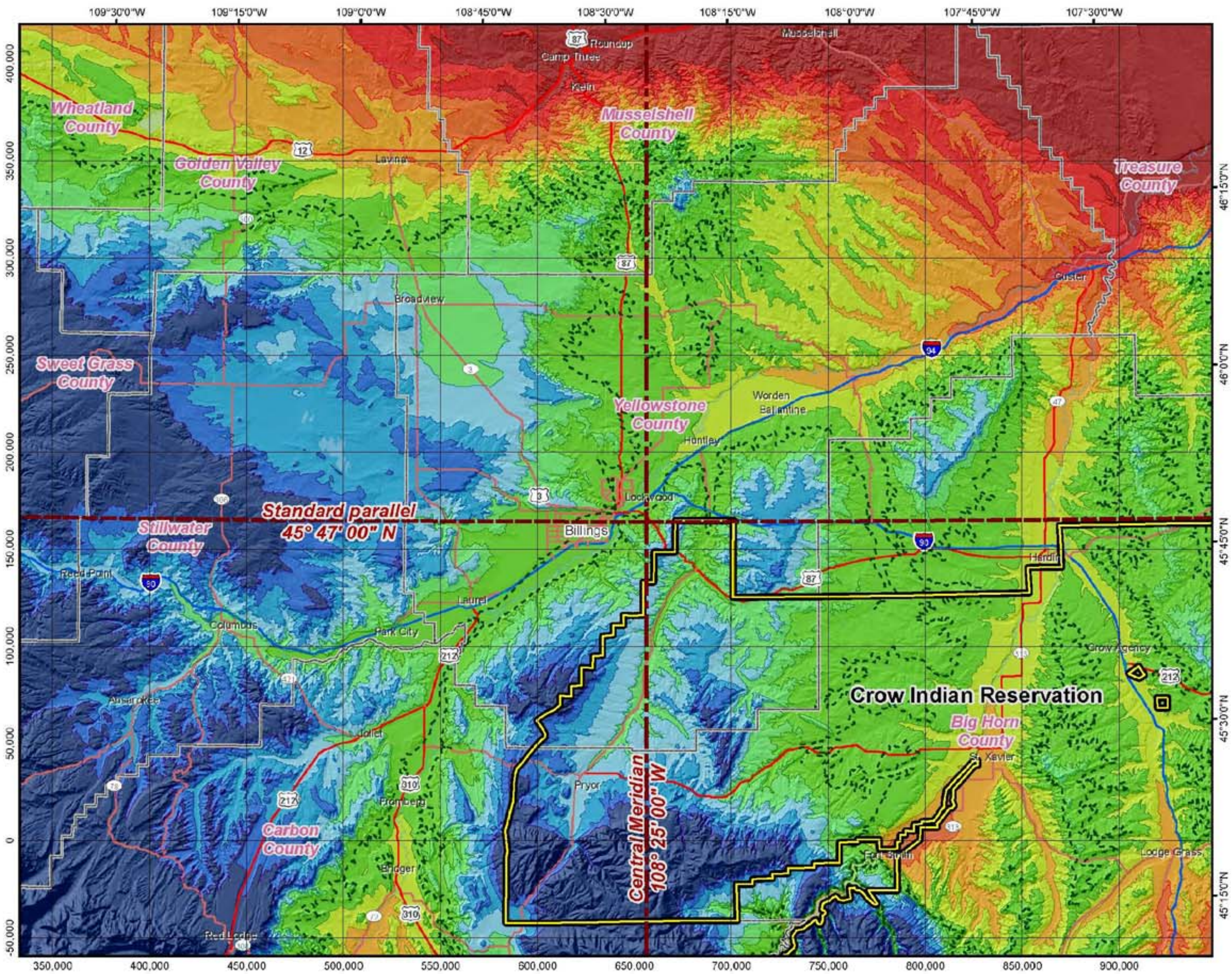
Northern Engineering & Consulting, Inc.



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
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SANDERSON STEWART

Map prepared by
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Geodetic Analysis
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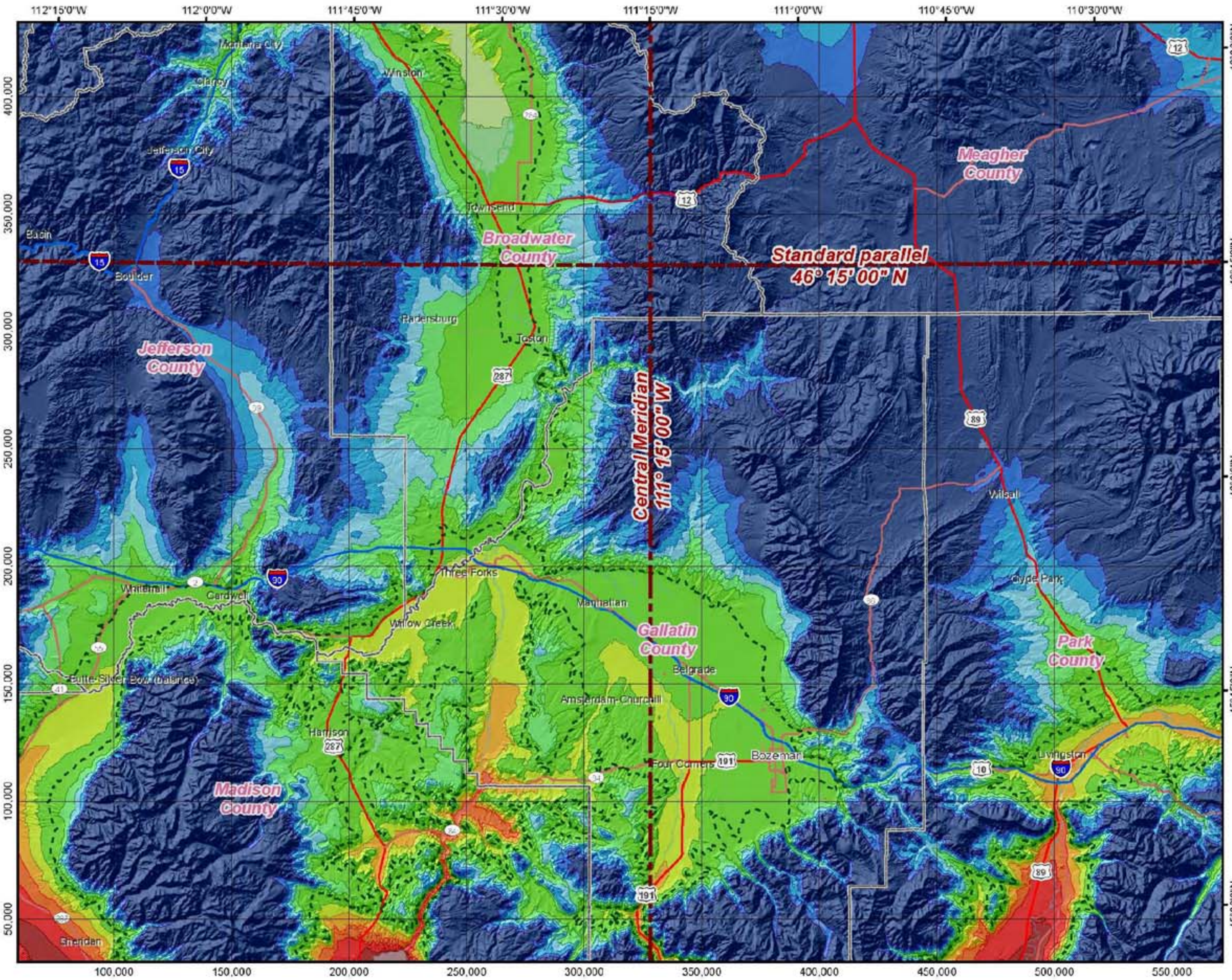

Bobcat Coordinate System

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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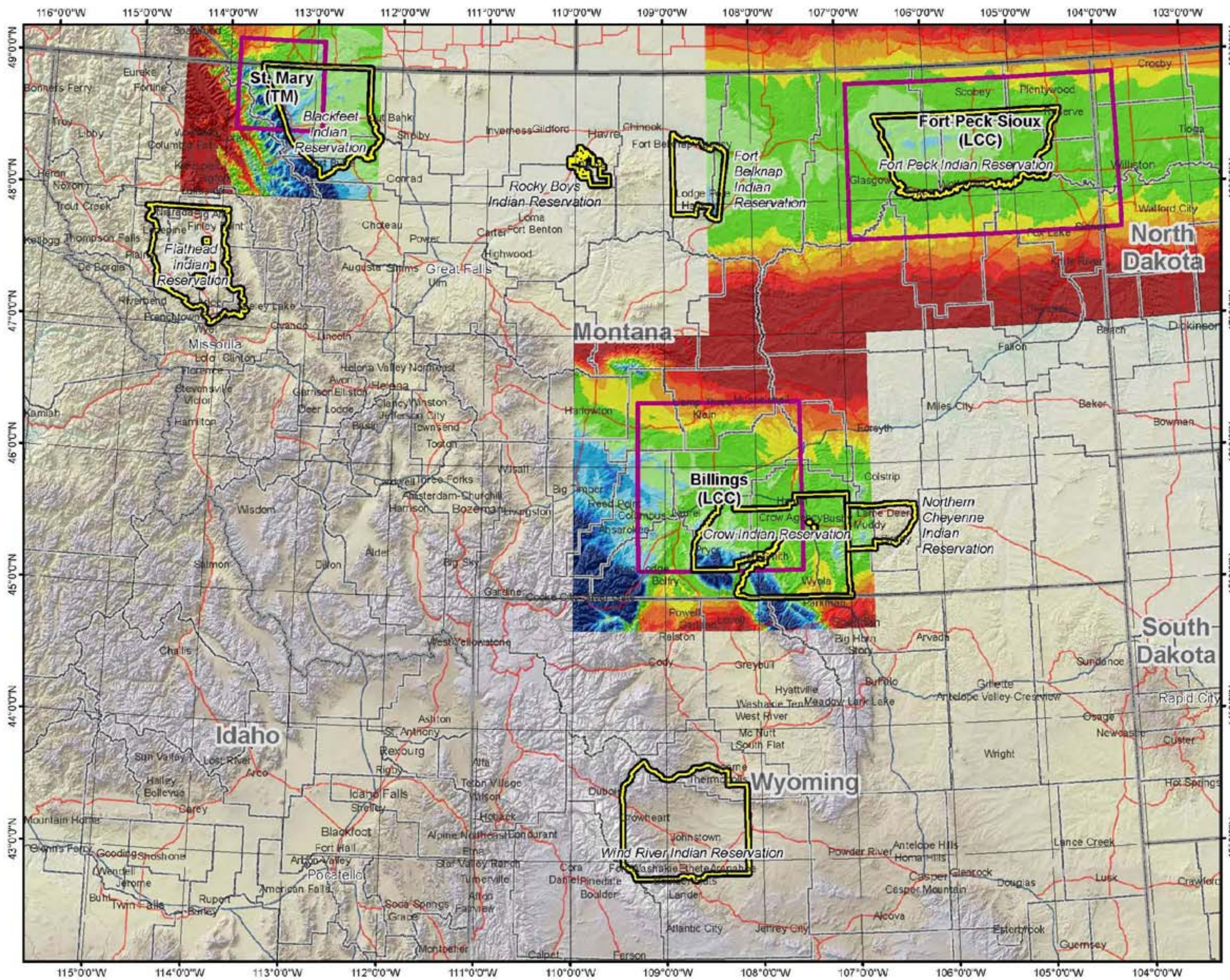
mld@geodeticanalysis.com

SANDERSON STEWART
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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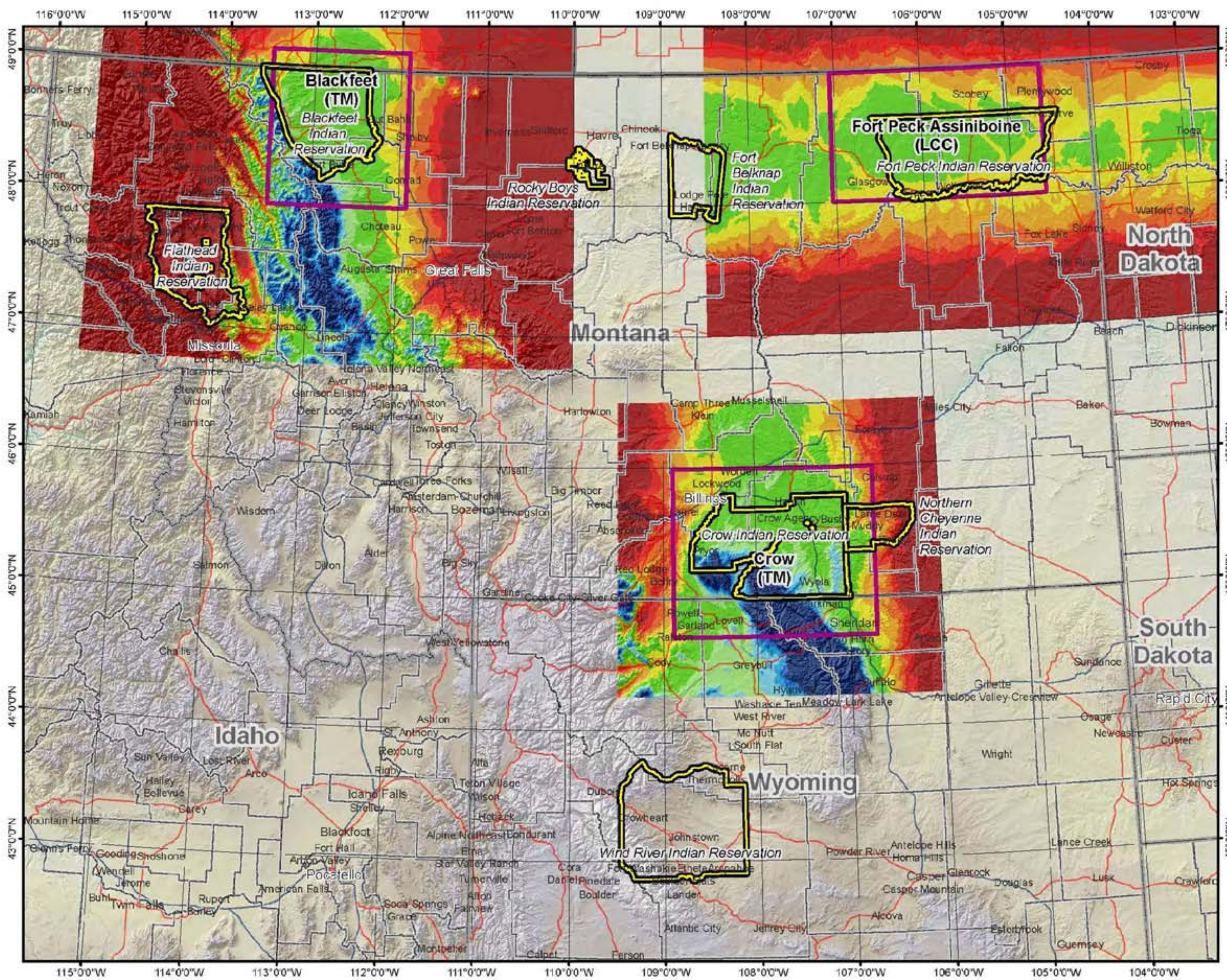
Northern Engineering & Consulting, Inc.



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)

Designed and prepared by

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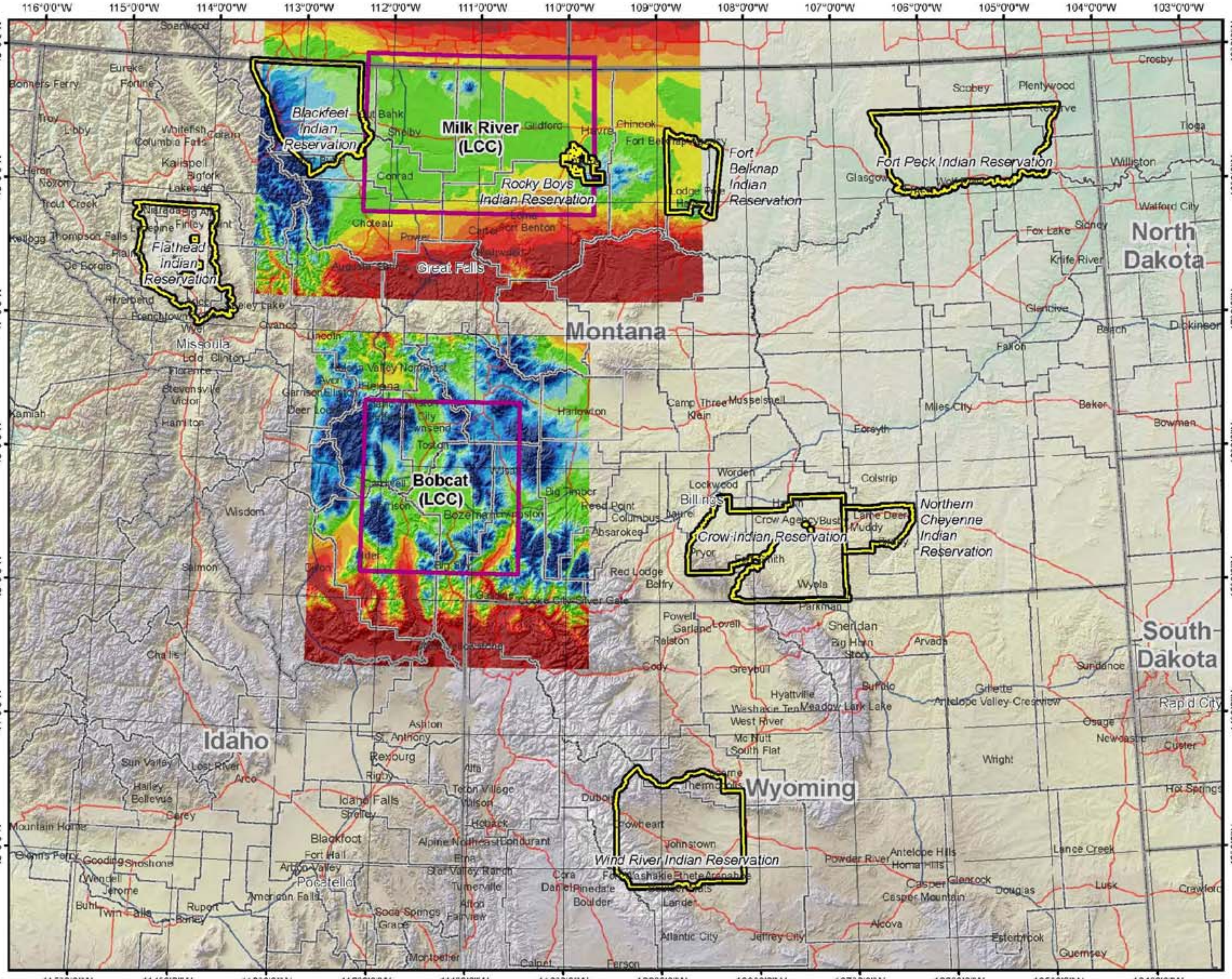
Geodetic Analysis

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):

- **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

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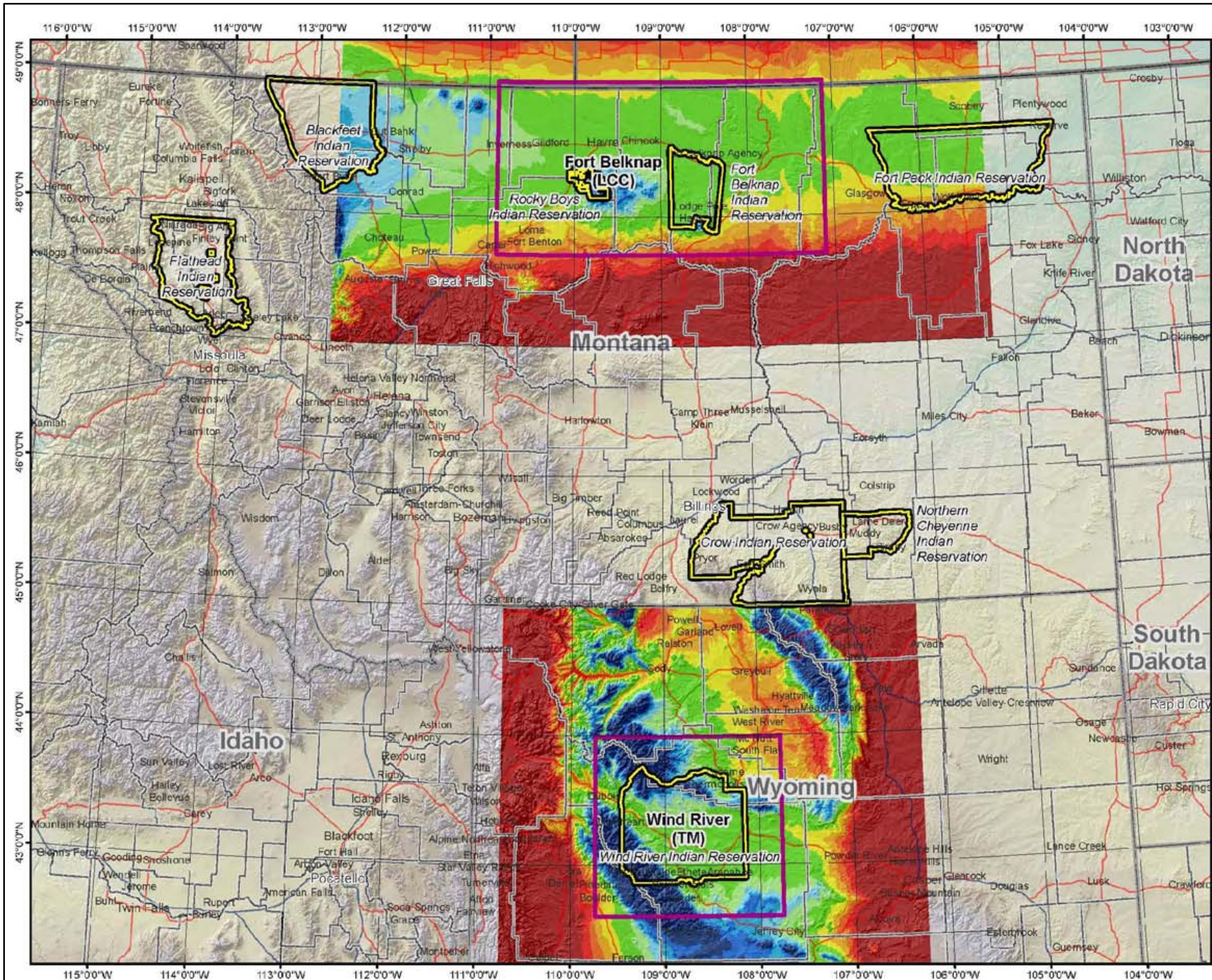
Northern Engineering & Consulting, Inc.



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):

- **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)

- <-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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Northern Engineering & Consulting, Inc.

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