Project Report

The Kansas Regional Coordinate System

A Statewide Multiple-Zone Low-Distortion Projection Coordinate System for the State of Kansas

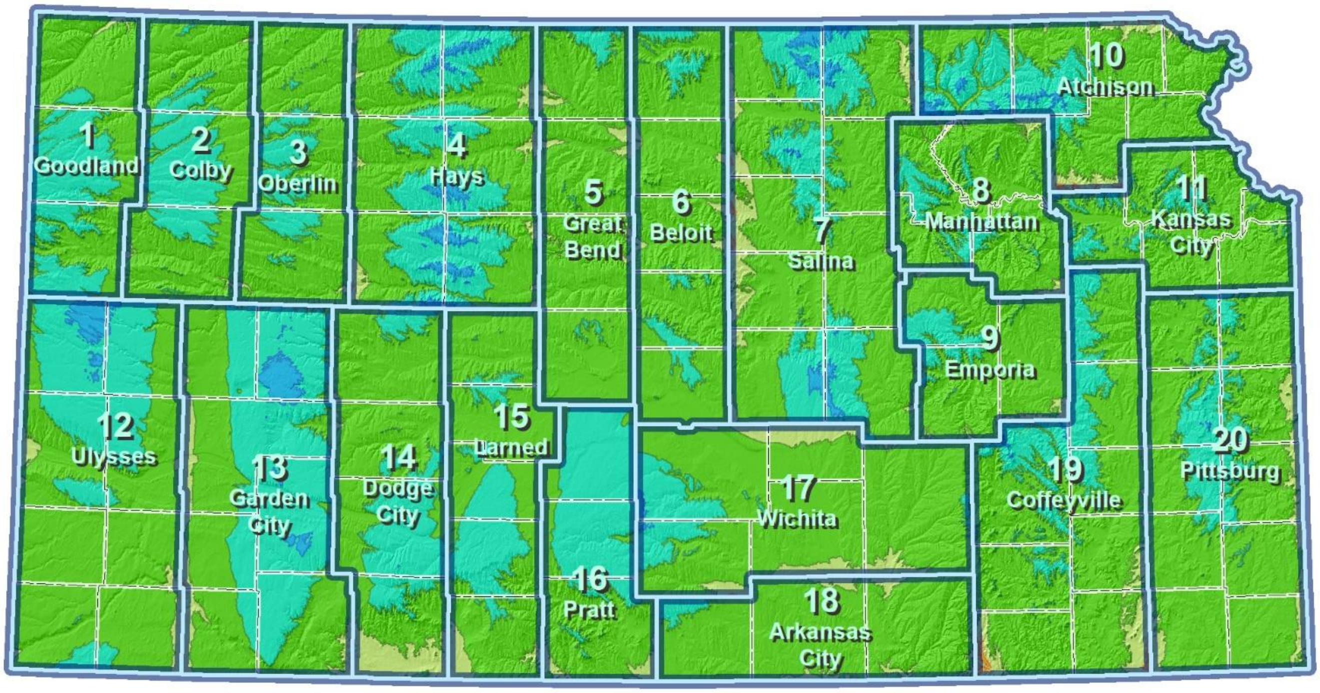

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Table of Contents

List of Figures

List of Tables

Introduction

Purpose and Scope of Project

The purpose of this project was to design the Kansas Regional Coordinate System (KRCS) for the Kansas Department of Transportation (KDOT). The KRCS is a 20-zone statewide system of low-distortion projections (LDPs) referenced to the North American Datum of 1983 (NAD 83). LDPs are conformal map projections designed to optimally minimize linear distortion at the topographic surface of the Earth over large areas. Minimizing linear distortion throughout the state was the intent of the project, by creating a system where LDP zone boundaries coincided with aggregated county boundaries. The main objective was to design a system with linear distortion not exceeding about ±20 parts per million (±0.1 ft per mile or 1:50,000) in nearly the entire state, yet consisting of the minimum number of zones possible. Additional details about design criteria are given in the following section.

Kansas is a large state, about 400 miles long east-west and 200 miles wide north-south, with 105 counties. It is large enough that it requires two State Plane Coordinate System of 1983 (SPCS 83) zones. Although topographic relief is mild, the range in NAD 83 ellipsoid height of topography is significant across the state, approximately 3400 feet. The lowest ellipsoid height is about 580 feet where the Verdigris River crosses the Oklahoma border near the southeast corner of the state, and the highest is 3964 feet at Mount Sunflower, near the Colorado border.

Analysis and design of the LDPs was performed with software and digital topographic height models created by Geodetic Analysis, LLC, as a subconsultant to Professional Engineering Consultants, PA (PEC). LDP design alternatives were limited to the following two conformal projections: Lambert Conformal Conic (LCC) and Transverse Mercator (TM). Design parameters were defined such that all zones of the final selected coordinate system are compatible with a wide range of commonly used commercial surveying, engineering, and GIS software.

The final KRCS design was selected after extensive review and comments from PEC, KDOT, and other stakeholders throughout the design process. Stakeholders invited to participate consisted of representatives from various professional organizations; local, state, and federal government agencies; and private companies. Initial input was obtained in a stakeholder meeting held on January 26, 2017. The final design was presented at a stakeholder meeting held at KDOT headquarters in Topeka on August 28, 2017. The Microsoft *PowerPoint* presentation files and posters from both of those meetings are included as part of this project, in the “Project Deliverables” section of this report.

Although this report goes into some detail on the design of the KRCS, it does not provide detailed background information on map projections, the State Plane or Universal Transverse Mercator coordinate systems, conformality, general design methods for LDPs, or the geodetic concepts that underlie these topics. For additional information, the references of this report lists a variety of documents, many that are available online. For details on the concepts, analysis, design, and design of LDPs, see Dennis (2016 and 2017a).

Project Justification

KDOT elected to design a statewide system of LDPs to improve efficiency, simplify data management, and facilitate data transferability between internal groups and outside organizations. Prior to the KRCS, the method used to create coordinate systems was to "scale" State Plane Coordinate System (SPCS) coordinates to "ground" (the topographic surface). While this approach reduced linear distortion at ground, it had some liabilities:

- A new coordinate system was created for nearly every project, resulting in hundreds of coordinate systems that had to be managed between the various groups within (and outside of) KDOT. The number of systems continued to increase with time.
- Each system was based on a scale factor that was not always consistently documented. Its effect on the coordinates also depended on the point about which the scaling was performed.
- The systems were not rigorously defined (i.e., were not based on standard projection parameters), reducing transferability between geospatial platforms.
- The systems did not optimally minimize distortion, especially for projects of large extent. This was particularly a problem for projects long in the north-south direction, since Kansas SPCS is based on the Lambert Conformal Conic projection and distortion changes more rapidly north-south.

A decision was made to design a system of LDPs to replace the scaled SPCS approach of creating and managing spatial data. The system of LDPs designed for the KRCS has the following advantages:

- Reduces the number of coordinate systems to 20 from hundreds (and growing), thereby simplifying data management.
- LDPs are based on rigorously defined projected coordinate systems supported across a broad spectrum of geospatial platforms, greatly facilitating data transferability and management, and eliminating guesswork in determining the coordinate system of a dataset.
- Simplifies surveying workflows by eliminating the need to perform vendor-specific methods of scaling, rotating, and translating spatial data, such as horizontal "calibrations" or "localizations."
- Optimally minimizes linear distortion over the largest areas possible, so that coordinates "at ground" can be obtained without any additional scaling or modification.
- Generates coordinates that are unique to every LDP zone, are distinct from other coordinate systems (such as SPCS), and are self-identifying (i.e., the LDP zone can be determined from the coordinates).

Project Deliverables

Deliverables for this project consist of:

1. Distortion maps: One for each of the 20 zones plus two of the entire state showing all zones, in PDF and PNG format, tabloid size (11" × 17") at 300 dots per inch (dpi) resolution. Also maps of the entire state showing distortion for KRCS, SPCS 83, each of the two statewide LCC projections, and UTM Zone 14, in PNG format, standard slide size (7.5" × 10") at 200 dpi resolution. All of these maps are also included as figures in this report.

2. ArcMap (versions 10.4 and 10.5) documents (*.mxd files) corresponding to all maps in the previous item. There are also two *.mxd files for a slide-size index map, one with and one without zone centroids (labeled with KRCS coordinates).

3. GIS raster datasets of linear distortion, topographic height, geoid height, and hillshade, in IMG format and referenced to NAD 83 (2011) epoch 2010.00. The linear distortion rasters are in units of parts per million (ppm). The KRCS distortion rasters are at 3 and 9 arc-second resolution for each zone, and for the entire state. Also included are distortion rasters for SPCS 83, the two statewide LCC systems, and UTM, all at 15 arc-second resolution. The topographic and geoid height rasters are at 3 arc-sec resolution in US survey feet and consist of NAD 83 ellipsoid height, NAVD 88 orthometric height, and GEOID12B geoid height. The hillshade rasters are provided at 1 and 9 arc-second resolution.

4. GIS vector feature dataset corresponding to the ArcMap documents and consisting of Esri shapefiles, referenced to NAD 83 (2011) epoch 2010.00. Includes KRCS distortion contours, zone polygons (with zone parameter attributes), projection axes, and zone centroid points (with coordinates and distortion), as well as various features for boundaries, cities, roads, and Public Land Survey System (PLSS) township lines.

5. Esri projection (*.prj) files and Oracle Spatial scripts in PL (Procedural Language) SQL format for each of the 20 zones of the final KRCS definitions.

6. Microsoft *PowerPoint* presentation files and posters (in PDF and Microsoft *Publisher* format) from the two stakeholder meetings, as well as *PowerPoint* and PDF files created as part of reviewing design alternatives with PEC, KDOT, and other stakeholders.

7. Microsoft *Excel* spreadsheets of KRCS projection parameters, 6-mile buffer bounding coordinates, and centroid coordinates (for calculation checks).

8. This project report, describing the intent, purpose, characteristics, and design methodology of the KRCS.

All deliverables are provided as digital files; no hard copies are included. The folder structure of the electronic deliverables is given in Appendix A.

Additional information and data for the KRCS is available at a website hosted by the Kansas Data Access & Support Center (DASC) at https://www.kansasgis.org/initiatives/kdot_ldp/index.cfm.

The Kansas Regional Coordinate System

Design Criteria and Final Design Parameters

The following criteria were used for design of the Kansas Regional Coordinate System (KRCS):

1. Distortion criteria. The intent was to limit linear distortion to ±20 parts per million (ppm) ±0.1 ft per mile or 1:50,000) for 99% of the state, with no locations exceeding about ±25 ppm. "Linear distortion" is the difference in distance between a pair of projected (map grid) coordinates as

compared to the actual horizontal distance on the ground (i.e., at the topographic surface of the Earth).

2. Projection types. Designs were limited to two commonly used conformal projection types: Lambert Conformal Conic (LCC) and Transverse Mercator (TM). Conformal projections are required because linear distortion (scale error) is the same in every direction from a point; no other projection type is appropriate for minimizing linear distortion.

3. Linear unit. The US survey foot (sft) was selected as the defining unit for the false northings and eastings, and it is also the intended working (output) unit of the projected coordinates.

4. Geodetic reference system. The North American Datum of 1983 (NAD 83) is the defining datum for the KRCS. It is not associated with a specific realization, such as NAD 83 (2011) epoch 2010.00, since all realizations have the same defining parameters, including use of the Geodetic Reference System of 1980 (GRS-80) as the reference ellipsoid. This is discussed later in the report, including compatibility with the new terrestrial reference frame scheduled for release by the National Geodetic Survey (NGS) in 2022.

5. Zone configuration. The layout, number, extent, distribution, overlap, numbering, and naming of zones were specified as follows:

    a. Each zone consists of aggregated counties, where the zone boundary corresponds to county boundaries.
    b. Number of zones minimized (25 or less).
    c. Avoid having zone boundaries pass through cities.
    d. Designed such that there is several miles of low-distortion overlap between zones, to the extent possible.
    e. Zones numbered from left-to-right, then top-to-bottom (like reading a book).
    f. Zone name is the same as the largest city in the zone.

6. Uniqueness with respect to existing coordinate systems. KRCS coordinates were specified such that the numeric values differ substantially from those of six existing coordinate systems, for coordinates in the units as shown below:

    a. State Plane Coordinate System of 1983, Kansas North and South zones (SPCS 83 KS N and S), US survey feet.
    b. State Plane Coordinate System of 1927, Kansas North and South zones (SPCS 27 KS N and S), US survey feet.
    c. Universal Transverse Mercator of 1983, Zone 14 and 15 North (UTM 83 14N and 15N), US survey feet.
    d. Universal Transverse Mercator of 1983, Zone 14 and 15 North (UTM 83 14N and 15N), meters.
    e. New (2011) Statewide Lambert Conformal Conic (LCC) coordinate system, US survey feet.
    f. Old Statewide Lambert Conformal Conic (LCC) coordinate system, US survey feet and meters.

7. Projected coordinate values. KRCS coordinates were further specified such that northings and eastings are not equal anywhere within a zone, and coordinate values are always positive in a zone. In addition:
   a. Easting coordinates are greater than 1 million in all zones.
      i. Eastings are unique for each zone.
      ii. The zone false easting = zone number × 1 million + 500,000.
      iii. Zone can be identified from its easting coordinates; easting in millions of feet (truncated) equals the zone number.
   b. Northing coordinates are less than 1 million in all zones.
      i. Northings are *not* unique for each zone.
      ii. Northings similar in north and south zone "tiers" (north tier is zones 1-11; south tier is zones 12-20).
      iii. Within a tier, northings are approximately the same for all zones. But south tier northings are *greater* than north tier northings by ~300,000 sft at any point within a zone.

Parameters of the final design for the 20 zones of the KRCS are given in Table 1. All projections are referenced to NAD 83 as the geometric reference system (also known as a "geodetic datum" or "geographic coordinate system"). Table 1 also includes the number of counties in each zone. To provide a cross-reference, the zone corresponding to each of the 105 Kansas counties is given in Table 2.

Figure 1 is a map showing the linear map projection distortion for all KRCS zones, along with overall statewide performance statistics. Although the minimum and maximum distortion values of -26.9 and +26.0 ppm exceed the target limit of ±25 ppm, the overage is minor; for 99.998% of the state, distortion is within ±25 ppm. Distortion is within ±20 ppm for 98.802% of the state, and over two thirds (68.330%) of the state has distortion within ±10 ppm. The mean distortion is biased slightly negative, -4.0 ppm. The reason for the bias is that negative distortion is associated with large, broad high areas, whereas maximum positive distortion usually occurs in the bottom of relatively narrow valleys and drainages.

Distortion maps for each of the 20 KRCS zones are given in Appendix B (figures B-1 through B-20). Each map includes the projection parameters for its zone, and it shows distortion outside the zone boundary (along with a line indicating the 6-mile buffer around the zone). Note that figures 1 and B-1 through B-20 are formatted for printing on tabloid-size (11" × 17") sheets. Because of this, they will be at a smaller numeric scale than shown if printed on letter-size paper from this document. However, the maps in these figures are also available in their original size for printing on tabloid sheets, as part of the digital deliverables. All of the maps in this report are 60% of their original size, and their numeric scale is given in the figure captions if printed on letter-size paper from this report.

Of the 20 KRCS zones, 14 are TM projections, all with a false northing of zero at their origin latitude. The origin latitude is 37°30'00"N for the first seven TM zones (1 through 7), and it is 36°45'00"N for the second seven TM zones (12 through 16, 19, and 20). The remaining six zones are one-parallel LCC projections (zones 8 through 11, 17, and 18); in all cases the origin latitude is also the standard parallel.

Table 1. Defining parameters for the 20 zones of the Kansas Regional Coordinate System (KRCS).

- All zones are referenced to the North American Datum of 1983 (NAD 83), based on the Geodetic Reference System of 1980 (GRS-80) ellipsoid. See section "NAD 83 Realizations, Relationship to WGS 84, and the Vertical Component" for more information.
- "LCC" = Lambert Conformal Conic projection; "TM" = Transverse Mercator projection.
- For LCC projection, origin latitude is the standard parallel (projection axis).
- Linear unit is US survey foot (sft), where 1 sft = 1200 / 3937 meter (exact).
- For latitude and longitude in decimal degrees with repeating digits, recommend representing with minimum of 12 decimal places.

Zone number	Zone name	Projection type	Origin latitude (deg-min)	Central meridian (deg-min)	Origin latitude (dec deg)	Central meridian (dec deg)	Projection axis scale	False northing (sft)	False easting (sft)	Number of counties
1	Goodland	TM	37°30'N	101°36'W	37.5	-101.6	1.000156	0	1,500,000	3
2	Colby	TM	37°30'N	100°57'W	37.5	-100.95	1.000134	0	2,500,000	3
3	Oberlin	TM	37°30'N	100°21'W	37.5	-100.35	1.000116	0	3,500,000	3
4	Hays	TM	37°30'N	99°27'W	37.5	-99.45	1.000082	0	4,500,000	6
5	Great Bend	TM	37°30'N	98°40'W	37.5	-98.666666666667	1.000078	0	5,500,000	4
6	Beloit	TM	37°30'N	98°09'W	37.5	-98.15	1.000068	0	6,500,000	5
7	Salina	TM	37°30'N	97°20'W	37.5	-97.333333333333	1.000049	0	7,500,000	9
8	Manhattan	LCC	39°10'N	96°30'W	39.166666666667	-96.5	1.000044	600,000	8,500,000	4
9	Emporia	LCC	38°30'N	96°30'W	38.5	-96.5	1.000050	300,000	9,500,000	3
10	Atchison	LCC	39°38'N	95°45'W	39.633333333333	-95.75	1.000040	700,000	10,500,000	6
11	Kansas City	LCC	39°06'N	95°15'W	39.1	-95.25	1.000033	600,000	11,500,000	6
12	Ulysses	TM	36°45'N	101°25'W	36.75	-101.416666666667	1.000140	0	12,500,000	8
13	Garden City	TM	36°45'N	100°24'W	36.75	-100.4	1.000109	0	13,500,000	7
14	Dodge City	TM	36°45'N	99°40'W	36.75	-99.666666666667	1.000097	0	14,500,000	4
15	Larned	TM	36°45'N	99°12'W	36.75	-99.2	1.000087	0	15,500,000	5
16	Pratt	TM	36°45'N	98°33'W	36.75	-98.55	1.000069	0	16,500,000	3
17	Wichita	LCC	37°46'N	97°30'W	37.766666666667	-97.5	1.000059	400,000	17,500,000	5
18	Arkansas City	LCC	37°11'N	97°30'W	37.183333333333	-97.5	1.000055	200,000	18,500,000	3
19	Coffeyville	TM	36°45'N	95°58'W	36.75	-95.966666666667	1.000034	0	19,500,000	8
20	Pittsburg	TM	36°45'N	95°05'W	36.75	-95.083333333333	1.000031	0	20,500,000	10

Table 2. List of Kansas counties and corresponding Kansas Regional Coordinate System (KRCS) zone.

County	Zone number	County	Zone number	County	Zone number	County	Zone number	County	Zone number
Allen	20	Doniphan	10	Jackson	10	Morris	9	Saline	7
Anderson	20	Douglas	11	Jefferson	11	Morton	12	Scott	13
Atchison	10	Edwards	15	Jewell	6	Nemaha	10	Sedgwick	17
Barber	16	Elk	19	Johnson	11	Neosho	20	Seward	13
Barton	5	Ellis	4	Kearny	12	Ness	14	Shawnee	11
Bourbon	20	Ellsworth	6	Kingman	17	Norton	4	Sheridan	3
Brown	10	Finney	13	Kiowa	15	Osage	19	Sherman	1
Butler	17	Ford	14	Labette	20	Osborne	5	Smith	5
Chase	9	Franklin	20	Lane	13	Ottawa	7	Stafford	16
Chautauqua	19	Geary	8	Leavenworth	11	Pawnee	15	Stanton	12
Cherokee	20	Gove	3	Lincoln	6	Phillips	4	Stevens	12
Cheyenne	1	Graham	4	Linn	20	Pottawatomie	8	Sumner	18
Clark	14	Grant	12	Logan	2	Pratt	16	Thomas	2
Clay	7	Gray	13	Lyon	9	Rawlins	2	Trego	4
Cloud	7	Greeley	12	Marion	7	Reno	17	Wabaunsee	8
Coffey	19	Greenwood	19	Marshall	10	Republic	7	Wallace	1
Comanche	15	Hamilton	12	McPherson	7	Rice	6	Washington	7
Cowley	18	Harper	18	Meade	13	Riley	8	Wichita	12
Crawford	20	Harvey	17	Miami	20	Rooks	4	Wilson	19
Decatur	3	Haskell	13	Mitchell	6	Rush	15	Woodson	19
Dickinson	7	Hodgeman	14	Montgomery	19	Russell	5	Wyandotte	11

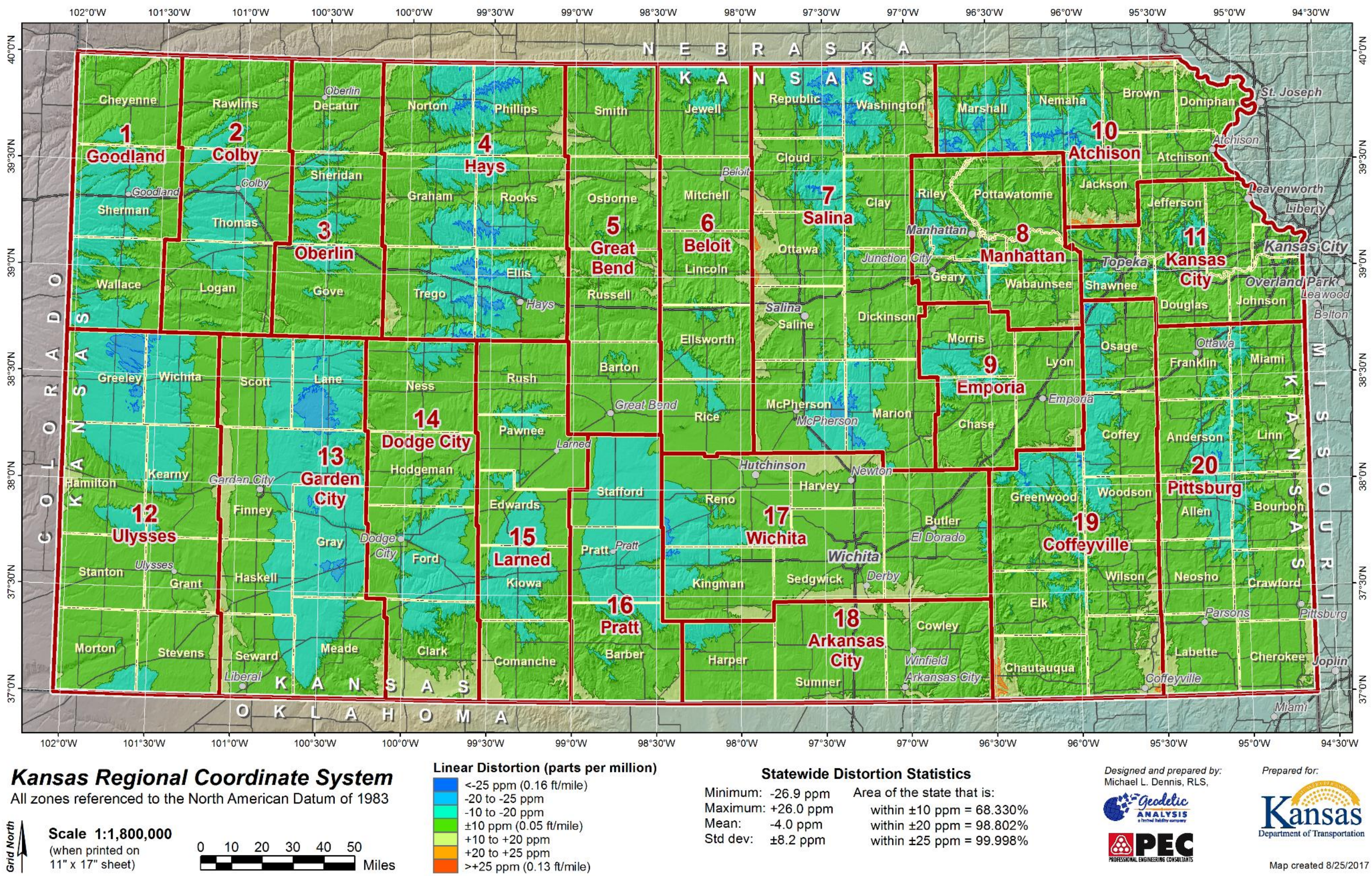

Figure 1. Linear distortion map for all 20 KRCS zones with statewide distortion statistics. Scale when printed on 8-1/2" × 11" sheet is 1:3,000,000 (60% of original size).

KRCS Projected Coordinates Values

Figure 2 shows KRCS coordinates for the centroid point of each zone, in US survey feet rounded to the nearest foot. These centroid points are shown to illustrate the expected magnitude and difference between KRCS coordinates in each zone. They are also given in Table 3, with centroid latitude and longitude values rounded to exactly the nearest whole arc-second. The centroid projected coordinates are given to four decimal places of precision to serve as a check on KRCS coordinate computations in computer software. Note that for each KRCS zone the (truncated) centroid easting in millions of feet (i.e., the digits to the left of the first comma) equals the zone number. This is true for the easting of all points located anywhere within a KRCS zone.

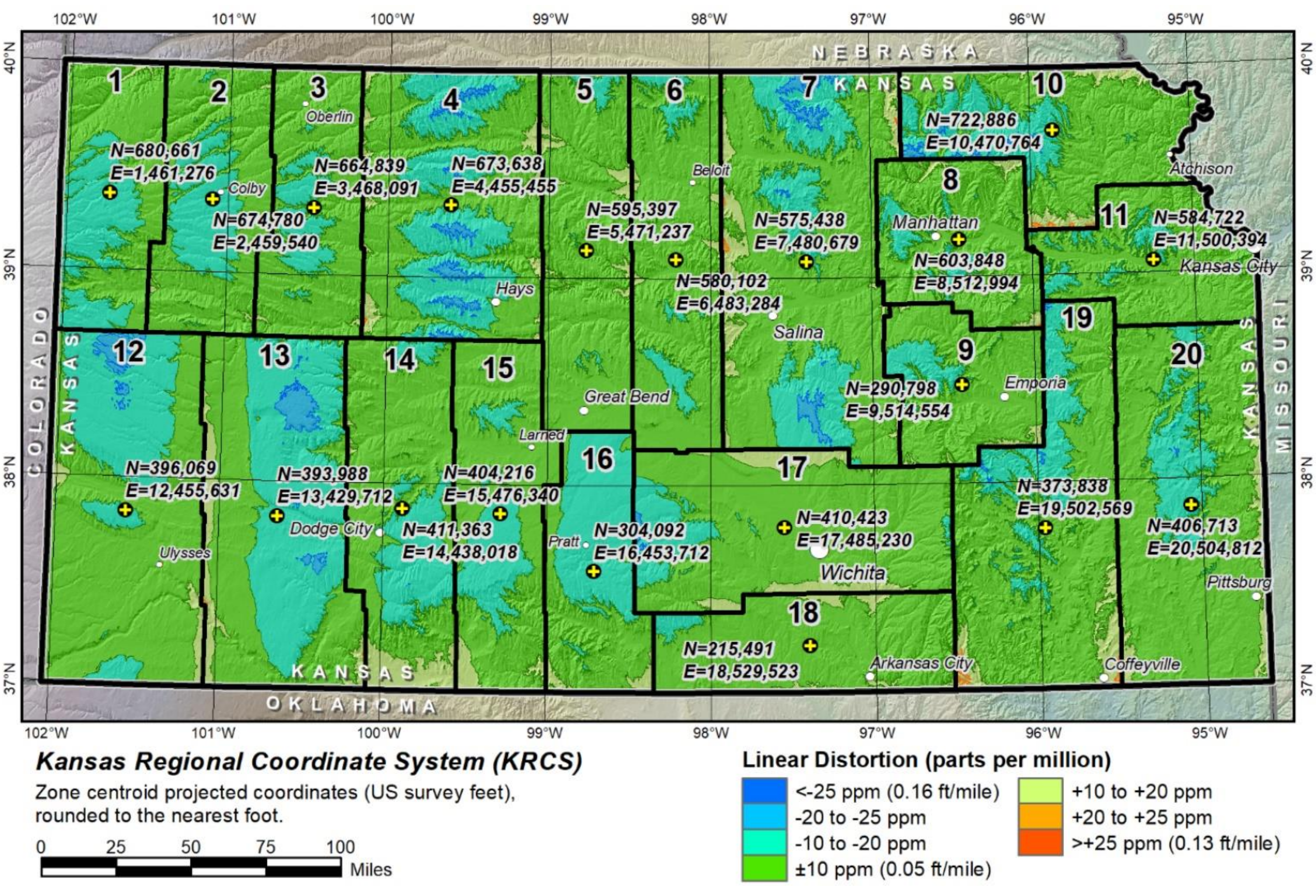

Figure 2. KRCS zone projected centroid coordinates (rounded to the nearest foot).

To serve as a further computation check, Table 4 gives various KRCS distortion values for the zone centroid points, corresponding to the centroid ellipsoid height of topography rounded to the nearest foot (as shown). The grid point scale factor and convergence angles are independent of ellipsoid height, but it affects the height factor and linear distortion. The linear distortion is expressed in four different ways, as the combined factor, parts per million (ppm), feet per mile, and a dimensionless ratio.

Table 3. KRCS zone centroid coordinates for comparison between zones and for computation checks. Latitude and longitude values are to the exact whole arc second and ellipsoid heights are to the exact whole foot.

Zone number	Zone name	Latitude (deg-min-sec)	Longitude (deg-min-sec)	Latitude (dec deg)	Longitude (dec deg)	Ellipsoid height (sft)	Northing (sft)	Easting (sft)
1	Goodland	39°22'07"N	101°44'13"W	39.3686111111	-101.7369444444	3600	680,661.3191	1,461,276.1619
2	Colby	39°21'09"N	101°05'35"W	39.3525000000	-101.0930555556	3132	674,779.8291	2,459,539.7159
3	Oberlin	39°19'31"N	100°27'46"W	39.3252777778	-100.4627777778	2667	664,838.8624	3,468,091.3577
4	Hays	39°20'58"N	099°36'27"W	39.3494444444	-99.6075000000	1960	673,638.4754	4,455,454.7798
5	Great Bend	39°08'05"N	098°46'05"W	39.1347222222	-98.7680555556	1599	595,396.8314	5,471,237.0670
6	Beloit	39°05'34"N	098°12'32"W	39.0927777778	-98.2088888889	1418	580,101.7516	6,483,284.1197
7	Salina	39°04'48"N	097°24'05"W	39.0800000000	-97.4013888889	1298	575,438.2859	7,480,679.0007
8	Manhattan	39°10'38"N	096°27'15"W	39.1772222222	-96.4541666667	895	603,848.1446	8,512,994.1586
9	Emporia	38°28'29"N	096°26'57"W	38.4747222222	-96.4491666667	1239	290,797.6127	9,514,554.1165
10	Atchison	39°41'46"N	095°51'14"W	39.6961111111	-95.8538888889	1053	722,885.5738	10,470,764.3831
11	Kansas City	39°03'29"N	095°14'55"W	39.0580555556	-95.2486111111	756	584,722.1463	11,500,394.4220
12	Ulysses	37°50'15"N	101°34'13"W	37.8375000000	-101.5702777778	3226	396,069.4496	12,455,631.1376
13	Garden City	37°49'54"N	100°38'36"W	37.8316666667	-100.6433333333	2688	393,987.7904	13,429,712.4833
14	Dodge City	37°52'46"N	099°52'53"W	37.8794444444	-99.8813888889	2318	411,362.8917	14,438,017.6546
15	Larned	37°51'36"N	099°16'55"W	37.8600000000	-99.2819444444	2104	404,216.4851	15,476,339.7079
16	Pratt	37°35'06"N	098°42'35"W	37.5850000000	-98.7097222222	1842	304,091.7406	16,453,712.4896
17	Wichita	37°47'43"N	097°33'04"W	37.7952777778	-97.5511111111	1302	410,423.3103	17,485,229.9125
18	Arkansas City	37°13'33"N	097°23'55"W	37.2258333333	-97.3986111111	1104	215,491.3883	18,529,522.6757
19	Coffeyville	37°46'36"N	095°57'28"W	37.7766666667	-95.9577777778	801	373,837.9644	19,502,569.2907
20	Pittsburg	37°52'01"N	095°04'00"W	37.8669444444	-95.0666666667	960	406,712.8120	20,504,811.5414

Table 4. KRCS zone centroid linear distortion and convergence angles for computation checks.

Zone number	Zone name	Projection scale factors (dimensionless)			Linear distortion			Convergence angle	
		Grid point	Height	Combined	(ppm)	(ft/mile)	(ratio)	(deg-min-sec)	(dec deg)
1	Goodland	1.000157714	0.999827878	0.999985565	-14.435	-0.0762	1 : 69,276	-0°05'12.71"	-0.086865
2	Colby	1.000135871	0.999850250	0.999986101	-13.899	-0.0734	1 : 71,949	-0°05'26.56"	-0.090710
3	Oberlin	1.000117164	0.999872480	0.999989629	-10.371	-0.0548	1 : 96,422	-0°04'17.29"	-0.071470
4	Hays	1.000084269	0.999906281	0.999990542	-9.458	-0.0499	1 : 105,732	-0°05'59.51"	-0.099863
5	Great Bend	1.000078946	0.999923540	1.000002480	2.480	0.0131	1 : 403,301	-0°03'50.37"	-0.063991
6	Beloit	1.000068319	0.999932194	1.000000509	0.509	0.0027	1 : 1,966,198	-0°02'13.68"	-0.037134
7	Salina	1.000049427	0.999937931	0.999987355	-12.645	-0.0668	1 : 79,084	-0°02'34.45"	-0.042903
8	Manhattan	1.000044017	0.999957202	1.000001217	1.217	0.0064	1 : 821,661	+0°01'44.21"	+0.028947
9	Emporia	1.000050097	0.999940749	0.999990842	-9.158	-0.0484	1 : 109,200	+0°01'53.92"	+0.031644
10	Atchison	1.000040598	0.999949650	0.999990246	-9.754	-0.0515	1 : 102,523	-0°03'58.56"	-0.066268
11	Kansas City	1.000033267	0.999963848	0.999997114	-2.886	-0.0152	1 : 346,472	+0°00'03.15"	+0.000876
12	Ulysses	1.000142251	0.999845730	0.999987959	-12.041	-0.0636	1 : 83,050	-0°05'39.22"	-0.094229
13	Garden City	1.000114650	0.999871454	0.999986089	-13.911	-0.0734	1 : 71,887	-0°08'57.29"	-0.149248
14	Dodge City	1.000101394	0.999889147	0.999990529	-9.471	-0.0500	1 : 105,588	-0°07'54.62"	-0.131840
15	Larned	1.000087640	0.999899380	0.999987011	-12.989	-0.0686	1 : 76,988	-0°03'01.05"	-0.050292
16	Pratt	1.000071451	0.999911905	0.999983350	-16.650	-0.0879	1 : 60,059	-0°05'50.71"	-0.097421
17	Wichita	1.000059124	0.999937731	0.999996852	-3.148	-0.0166	1 : 317,622	-0°01'52.69"	-0.031303
18	Arkansas City	1.000055274	0.999947197	1.000002468	2.468	0.0130	1 : 405,228	+0°03'40.59"	+0.061276
19	Coffeyville	1.000034008	0.999961691	0.999995697	-4.303	-0.0227	1 : 232,394	+0°00'19.60"	+0.005445
20	Pittsburg	1.000031026	0.999954087	0.999985112	-14.888	-0.0786	1 : 67,169	+0°00'36.83"	+0.010230

Using the KRCS requires that its parameters be entered in software, whether it be done by the software user or manufacturer. It is possible that coordinate system parameters could be entered incorrectly. In addition, not all software performs calculations the same way, and sometimes calculation results are incorrect. If the latitude and longitude values listed in Table 3 for a zone are entered in software, they should produce the KRCS coordinates shown. Conversely, if the KRCS coordinates are entered, they should produce the latitude and longitude values shown. If the software does not produce the value shown in Table 3, check to ensure all parameters have been entered correctly, the units are correct (by definition, 1 US survey foot = 1200 / 3937 meter exactly), and the datum has been properly defined (correct reference ellipsoid, no datum transformation). Datum (geographic) transformations are a common cause of coordinate computation errors. To duplicate the coordinates in Table 3, the latitude and longitude as shown must be used in the projection algorithms; they cannot be transformed before projecting. The reverse is also true – the latitude and longitude generated by de-projecting the KRCS coordinates must not be transformed after de-projection.

To provide an additional means for checking software calculations, KRCS coordinates were computed for all 282 NGS control stations in Kansas with published NAD 83 (2011) epoch 2010.00 coordinates. The coordinates, linear distortion, and convergence angles are given in Appendix C (tables C-1 and C-2, respectively), and their locations are shown in Figure 3. Of the 282 stations, six are currently operating NGS Continuously Operating Reference Stations (CORS), which are labeled in Figure 3 (one near Kansas City, one near Manhattan, and four near Wichita). Except for Zone 3 (Oberlin), there is at least one NGS NAD 83 (2011) station in each KRCS zone, although the vast majority (107) are in the Zone 11 (Kansas City). Although there are no stations in the Oberlin Zone, four stations in Zone 2 (Colby) are within 2000 feet of the border of the Oberlin Zone, and their coordinates and distortion are given for both zones in Appendix C.

KRCS projected coordinates are defined such that they differ substantially from other existing coordinate systems defined in Kansas. These systems are: State Plane Kansas North and South zones (based on both NAD 83 and NAD 27); UTM 83 zones 14 North and 15 North (both in sft and meters); and the two Kansas statewide LCC systems, with the old LCC differences given in both sft and meters. Differences between KRCS in sft and in meters for UTM and the old LCC are given because units may not be known when comparing numeric values.

The absolute value of the minimum and maximum KRCS zone centroid coordinate differences with these systems are shown in Table 5. The smallest differences in northings occur in KRCS zones 9 (Emporia), 10 (Atchison), 17 (Wichita), and 18 (Arkansas City). The minimum difference in northing is 1,911 between KRCS Zone 17 (Wichita) and the SPCS 27 KS South Zone (however for this KRCS zone the corresponding difference in easting is 15,210,957). The smallest differences in easting between the KRCS and all other systems always occurs in KRCS Zone 1 (Goodland), with a minimum of 376,393 between it and SPCS 27 KS South Zone.

The maximum difference in northings always occur in KRCS zones 9 (Emporia), 10 (Atchison), and 18 (Arkansas City). The maximum difference in eastings always occurs in KRCS Zone 20 (Pittsburg).

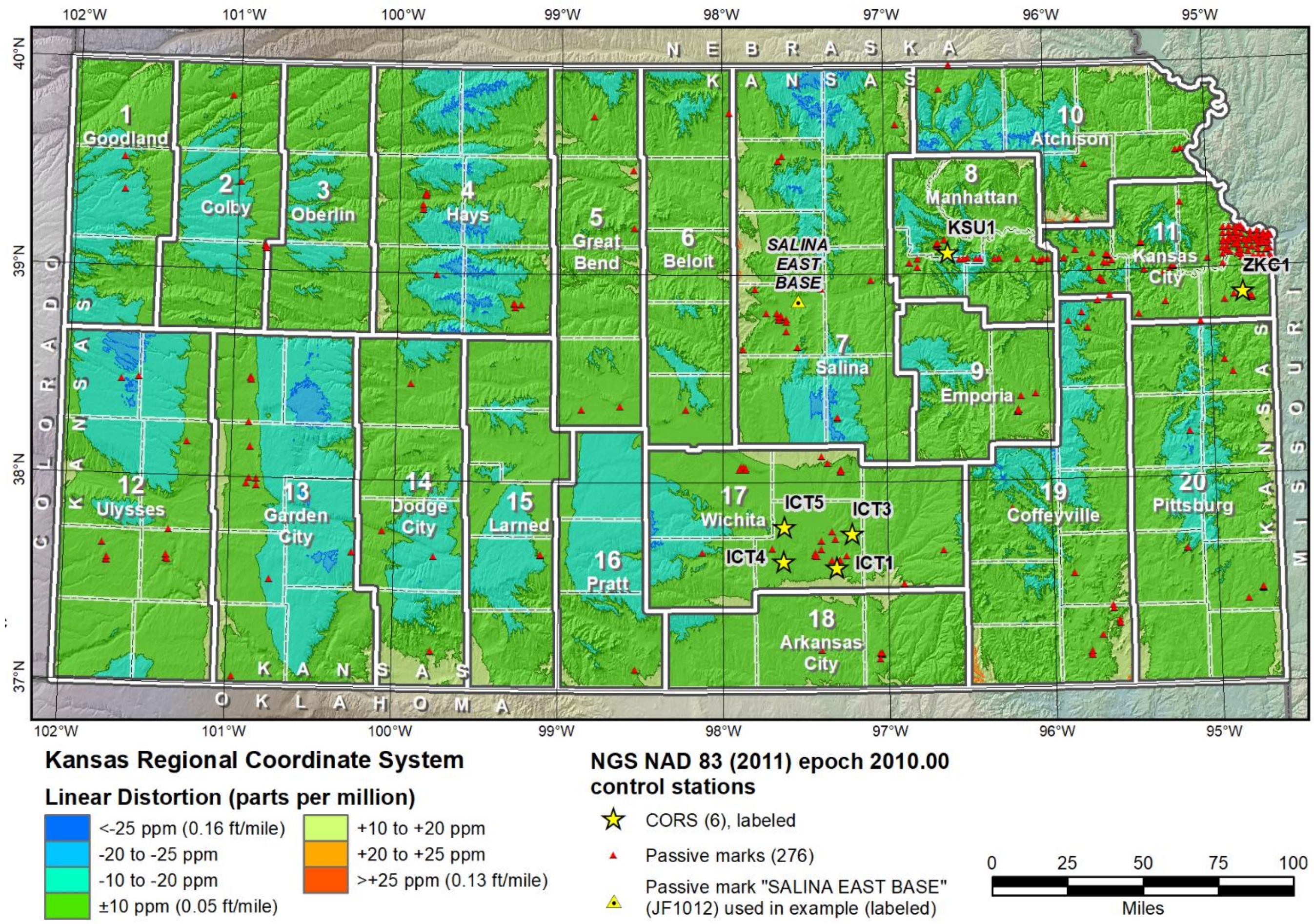

Figure 3. NGS control in Kansas with NAD 83 (2011) epoch 2010.00 coordinates. KRCS coordinates and distortion for the NGS stations are given in Appendix C. Passive station SALINA EAST BASE (PID JF1012) in the Zone 7 (Salina) and labeled is used in the example on NAD 83 realization coordinate differenced in section "NAD 83 Realizations, Relationship to WGS 84, and the Vertical Component."

KRCS Design Methodology and Results

Coordinate system design was done using a digital elevation model (DEM) derived from the USGS National Elevation Dataset (NED) at a resolution of 3 arc-seconds (approximately 300 ft). The NED provides North American Vertical Datum of 1988 (NAVD 88) orthometric heights (elevations). The NAVD 88 heights were converted to NAD 83 ellipsoid heights by adding the NGS hybrid geoid model GEOID12B (interpolated to the same resolution as the DEM). GEOID12B heights in Kansas range from about -74 feet in the northwest corner of the state to -107 feet in the Kansas City area. On average, NAD 83 ellipsoid heights are less than NAVD 88 elevations by an average of about 90 feet in Kansas.

Table 5. Differences in coordinate values between KRCS and other Kansas coordinate systems. Minimum and maximum differences in northing and easting are given as absolute values.

Coordinate system	Absolute value of coordinate differences			
	Minimum		Maximum	
	Delta North	Delta East	Delta North	Delta East
State Plane 1983 KS North Zone (sft)	225,434	1,205,132	624,377	18,345,613
State Plane 1983 KS South Zone (sft)	1,296,290	1,064,164	1,697,272	18,201,619
State Plane 1927 KS North Zone (sft)	225,440	517,365	624,375	17,657,852
State Plane 1927 KS South Zone (sft)	1,911	376,393	384,919	17,513,854
UTM 1983 zones 14N and 15N (sft)	13,299,184	594,414	13,699,914	19,460,801
UTM 1983 zones 14N and 15N (m)	3,668,983	1,197,056	3,970,774	20,186,597
New Kansas statewide LCC (sft)	226,078	1,134,521	625,896	18,273,769
Old Kansas statewide LCC (sft)	286,225	2,517,599	684,984	19,658,131
Old Kansas statewide LCC (m)	292,463	1,783,244	594,001	20,246,743
All coordinate systems	**1,911 (Wichita)**	**376,393 (Goodland)**	**13,699,914 (Atchison)**	**20,246,743 (Pittsburg)**

Topographic ellipsoid height in Kansas generally increases from east to west, as shown in Figure 4. The range is about 3400 feet, from a low of about 600 feet in the southeast corner of the state to a high of nearly 4000 feet along the Colorado border. For the entire state, the topography slopes up by about 0.13% nearly due west. But the increase in slope is substantially greater in the western half of the state, 0.20%. In contrast, the slope is about 0.07% in the eastern half of the state.

Map projection linear distortion is caused by change in topographic height and Earth curvature, each for the same reason: both make the projection developable surface depart from the topographic surface. Since total distortion is based on both height and Earth curvature, there is no single design height for large areas. The reason this is particularly true for large areas is that the contribution of Earth curvature to total distortion increases as the size of the area increases. Consequently, topographic ellipsoid height was not used directly as a design parameter for the KRCS.

A ±400-ft change in height (800-ft range) causes about ±20 ppm of distortion. So the 3400-ft range in topographic height in Kansas by itself would require at least five zones. Similarly, a zone width of 70 miles perpendicular to the projection axis will also cause about ±20 ppm of distortion, due to curvature alone. The approximate 400-mile east-west length of the state would require at least six zones. The combined effect of height variation and curvature suggest that about 30 zones are required to achieve ±20 ppm distortion throughout Kansas. However, the general upward east-to-west topographic slope in Kansas can be used to decrease the impact of both height and curvature, especially in the western half of the state.

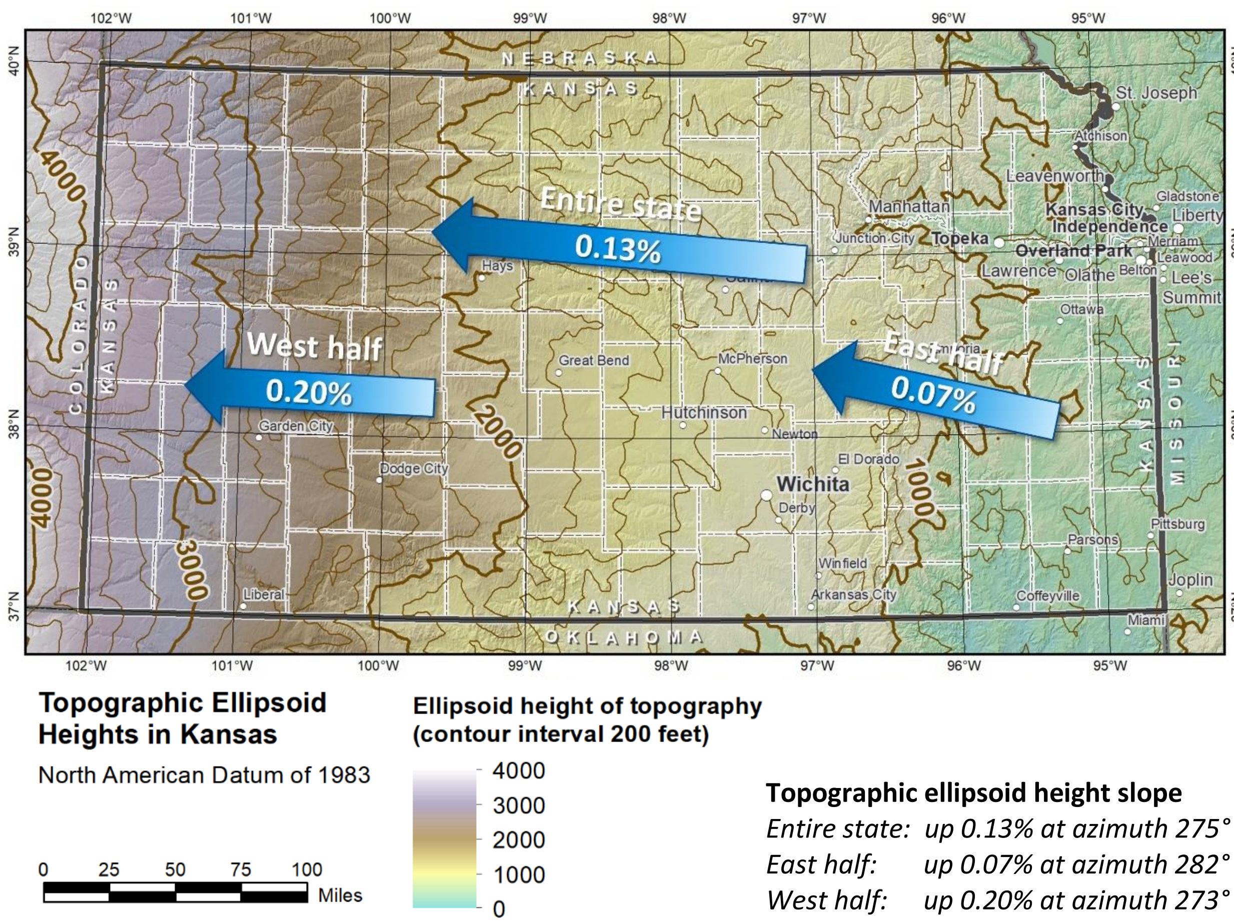

Figure 4. Topographic ellipsoid height and slope in Kansas (slope is given for entire state and for east and west half of state).

The greater east-to-west upward slope in the western half of Kansas is the reason that all KRCS zones in that part of the state use the Transverse Mercator (TM) projection. The developable surface of the TM projection is a cylinder that conforms to Earth curvature in the north-south direction but departs from the Earth's surface in the east-west direction, as shown schematically in Figure 5. Since topography slopes upward to the west, the TM projection axis (central meridian) can be offset to the east so that its developable projection surface coincides with the topographic surface. This design approach was used for all 11 KRCS zones on the western half of Kansas (zones 1-6 and 12-16).

The east-to-west slope in the western half of Kansas makes the Lambert Conformal Conic (LCC) projection a poor choice for that part of the state. The LCC developable surface is a cone that curves with the Earth in the east-west direction. Because of that, the distortion due to height variation cannot be reduced by offsetting its projection axis (its standard parallel). This problem severely limits its east-west extent, even though the developable surface curves with the Earth in that direction.

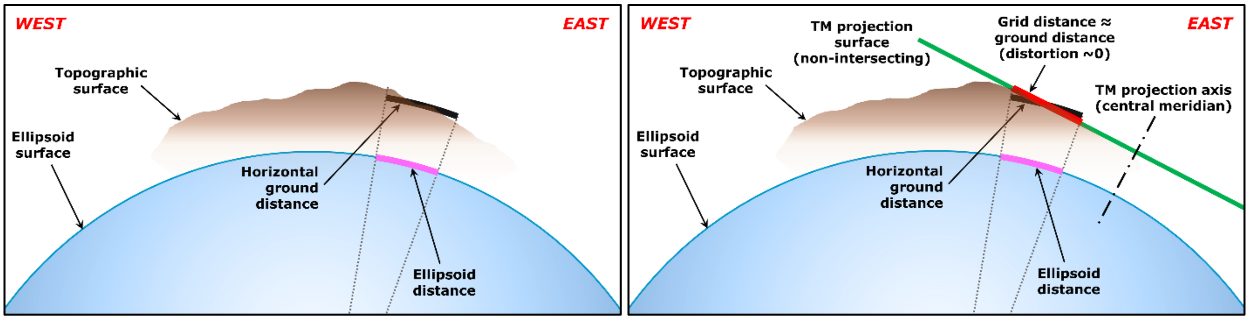

Figure 5. TM axis offset for projection surface to coincide with east-west sloping topographic surface (TM projection axis is the central meridian).

Design of the KRCS was performed in four phases:

1. Initial preliminary design and analysis (preliminary design set #1). Based on the ellipsoid heights of 3621 design points distributed throughout the state. It consisted of 105 county centroids, 1175 city and town points, and 2341 PLSS township centroids. The initial design points are shown in Figure 6, and their use resulted in 23 preliminary design alternatives. Analysis and results for this phase are shown in the "KansasLDPs_PrelimDesigns1.pptx" file included in the electronic deliverables in folder "KRCS\Presentations\Design\".

2. Refinement of initial preliminary designs (preliminary design set #2). A 1 arc-minute grid of design points (approximately 1-mile spacing) was generated to refine the preliminary designs. This increased the number of design points from 3621 to 79,457. Design and analysis was performed separately for the east and west half of the state, resulting in 22 permutations of the initial set of eastern zones, and 19 permutations of the initial set of western zones. This resulted in two alternatives for the eastern half of the state and four alternatives in the western half of the state, which were evaluated and further refined in the next design phase. Results of these analyses are provided in the four *PowerPoint* files "KansasLDPs_PrelimDesigns2_East.pptx", "KansasLDPs_PrelimDesigns2_East_alt.pptx", "KansasLDPs_PrelimDesigns2_East_alt3.pptx", and "KansasLDPs_PrelimDesigns2_West.pptx" (these files include some analysis performed in the next phase using 9 arc-second distortion rasters).

3. Proposed final designs. A complete set of defining parameters for the 20 final zones was proposed based on further analysis of preliminary design set #2. Analyses were performed using 9-arc-second distortion rasters for each zone, analogous to using about 3.5 million design points at approximately 900-ft spacing over the entire state. This analysis also included consideration of distortion performance in a 6-mile buffer around the zone boundaries. It was found that the maximum limit of ±25 ppm could not be satisfied within a 6-mile buffer in all directions for most zones. Low distortion was usually achieved in the 6-mile buffer in the north-south direction for TM zones and the east-west direction for the LCC zones, but it was usually not achieved in perpendicular directions. To meet this requirement for a 6-mile buffer for all zones in all directions would require a significant increase in the number of zones, so this requirement was relaxed. Results of these analyses are

provided in the two *PowerPoint* files "KansasLDPs_PrelimDesigns2_Buffer_6miles.pptx" and "KansasLDPs_PrelimDesigns2_def1.pptx", and the phases 2 and 3 of the design process are combined and summarized in "KansasLDPs_PrelimDesigns2_Combined.pdf".

4. Final designs. Minor modifications were made to the proposed final designs based on input from PEC and KDOT, as well as additional analysis using 3 arc-second distortion rasters for each zone (essentially 31.5 million design points at approximately 300-ft spacing over the entire state). Small (approximately 1 ppm) changes to parameters affecting distortion were made to seven zones (2, 9, 10, 11, 17, 18, and 20). Maps showing these final designs, parameters, and projected grid coordinates are shown in the maps in Appendix B. A summary of the entire design process is given in the *PowerPoint* file "KRCS_2017-08-28.pptx" from the final stakeholder meeting, in electronic deliverable folder "KRCS\Presentations\". This presentation also includes background information on LDPs in general and the new 2022 terrestrial reference frames and geopotential datum.

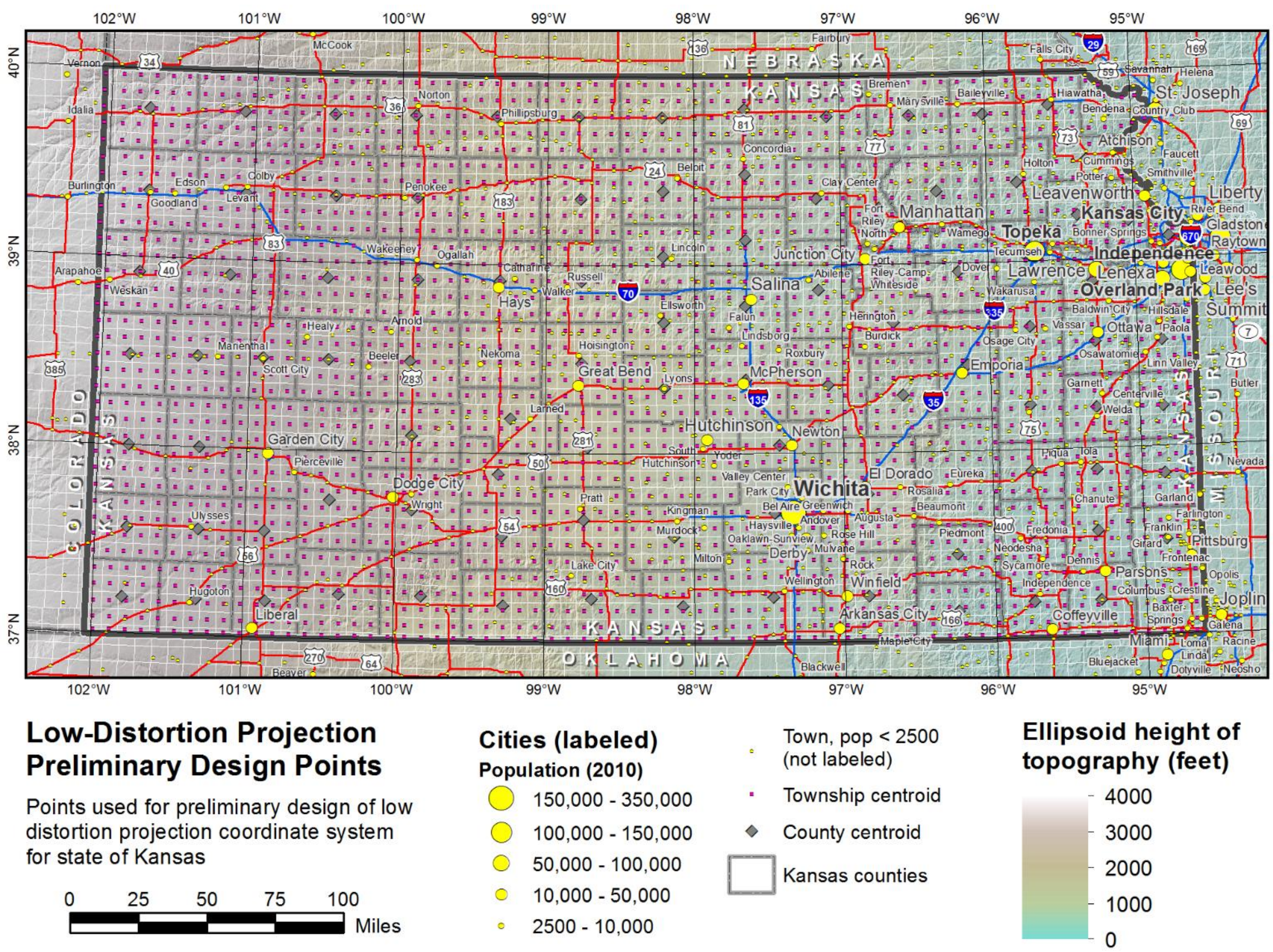

Figure 6. Set of 3621 points used for initial preliminary design and analysis of the KRCS (105 county centroids, 1175 cities and towns, and 2341 PLSS township centroids).

Final KRCS distortion and ellipsoid height statistics for each zone and the entire state are given in Table 6. The distortion and ellipsoid height statistics were computed from the 3 arc-second distortion and ellipsoid height rasters. The table gives minimum, maximum, and range for distortion and ellipsoid height, as well as mean, standard deviation, and "balance" for distortion. Balance is the sum of the minimum and maximum distortion and indicates how well their magnitudes match. The extremes of all 20 zones are balanced within ±2 ppm, and most (13) are balanced within ±1 ppm. This value was a more useful statistic for designing well-centered systems than the mean, since the objective was to keep distortion within ±25 ppm everywhere. Note than the mean is negative for all zones other than Zone 1 (Arkansas City), due to the distribution of distortion, as discussed previously.

Table 6. KRCS linear distortion and ellipsoid height statistics for each zone and entire state.

Zone num	Zone name	Linear distortion (parts per million)						Ellipsoid height (feet)		
		Min	Max	Range	Balance	Mean	Std dev	Min	Max	Range
1	Goodland	-18.5	+19.2	37.8	0.7	-6.6	±6.6	2928	3958	1030
2	Colby	-17.0	+16.1	33.1	-0.9	-5.8	±6.1	2540	3395	855
3	Oberlin	-15.1	+15.5	30.6	0.5	-4.9	±5.3	2197	2947	751
4	Hays	-24.9	+23.8	48.7	-1.1	-6.6	±9.3	1582	2543	962
5	Great Bend	-18.0	+17.6	35.5	-0.4	-0.6	±6.1	1371	2065	694
6	Beloit	-17.1	+15.6	32.7	-1.5	-1.9	±6.1	1200	1875	675
7	Salina	-25.3	+25.0	50.3	-0.3	-4.0	±9.3	1004	1597	594
8	Manhattan	-22.9	+23.0	45.9	0.1	-2.9	±6.9	812	1498	686
9	Emporia	-19.5	+18.6	38.1	-0.9	-1.9	±6.8	947	1550	603
10	Atchison	-25.8	+26.0	51.8	0.2	-4.5	±9.3	669	1430	762
11	Kansas City	-18.6	+16.6	35.2	-2.0	-3.8	±5.5	614	1180	567
12	Ulysses	-22.6	+21.1	43.7	-1.5	-5.9	±8.4	2745	3859	1115
13	Garden City	-23.3	+24.4	47.7	1.1	-7.8	±10.0	2010	3089	1079
14	Dodge City	-20.2	+20.1	40.4	-0.1	-3.7	±8.4	1639	2645	1006
15	Larned	-20.0	+19.9	39.9	-0.1	-5.2	±6.6	1506	2346	839
16	Pratt	-18.1	+17.8	35.9	-0.3	-7.2	±8.3	1154	2027	873
17	Wichita	-23.3	+22.3	45.6	-0.9	-0.4	±8.1	1074	1710	635
18	Arkansas City	-19.9	+19.4	39.3	-0.5	1.6	±5.7	858	1641	783
19	Coffeyville	-26.9	+25.2	52.0	-1.7	-3.3	±8.3	582	1547	965
20	Pittsburg	-21.8	+20.6	42.4	-1.1	-2.8	±7.4	631	1103	473
All 20 KRCS zones		**-26.9**	**+26.0**	**52.9**	**-0.8**	**-4.0**	**±8.2**	**582**	**3958**	**3376**

Three zones have a distortion range of greater than 50 ppm and thus exceed the ±25 ppm limit: zones 7 (Salina, 50.3 ppm), 10 (Atchison, 51.8 ppm), and 19 (Coffeyville, 52.0 ppm). The minimum distortion of -26.9 ppm occurs in Zone 19 (Coffeyville) in northwestern Greenwood County (just outside the southeast corner of Chase County). At this location, Zone 9 (Emporia) has significantly lower distortion (between zero and +10 ppm); compare this location in map B-9 to B-19.

The maximum distortion of +26.0 ppm occurs in Zone 10 (Atchison), and exceeds +25.0 ppm intermittently along the southern border of Jackson County. At this location, both zones 8 (Manhattan) and 11 (Kansas City) have significantly lower distortion (within ±5 ppm for Manhattan Zone and from -5 to -15 ppm for the Kansas City Zone); compare maps B-8 and B-11 to B-10.

Although distortion exceeds the ±25 ppm limit in a few locations, it does so by less than 2 ppm. In addition, only 0.002% of the total Kansas land area is outside this limit, and adjacent zones provide lower distortion in those areas if needed.

Standard deviations in Table 6 indicate the variability of distortion. For the state overall it is ±8.2 ppm, and the maximum is ±10.0 ppm for Zone 13 (Garden City). Although minimizing standard deviation was a consideration in design, minimizing distortion range and achieving distortion balance was more important for keeping distortion within the design limits.

Table 6 shows considerable variability in the range of ellipsoid heights for the zones, from a minimum of 473 feet for Zone 20 (Pittsburgh) to a maximum of 1115 feet for Zone 12 (Ulysses). It is interesting to note that these two zones have nearly the same range in distortion (42.4 ppm for Pittsburg and 43.7 ppm for Ulysses), even though Ulysses has over twice the range in height. The reason such low distortion was achieved in the Ulysses Zone despite its height range is that its TM central meridian was offset east due to fairly uniform increase in topographic height, as discussed previously.

Linear distortion and ellipsoid heights are also given in Appendix D (Table D-1) for 155 cities and towns in Kansas with population of 2500 or greater, based on 2010-2015 Census data (plus Oberlin, the largest town in the Oberlin Zone and the seat of Decatur County, population 1,898). The minimum and maximum KRCS distortion in these cities and towns is -19.7 ppm (Ogallah) and +15.9 ppm (Garland); for SPCS 83 it is -214.3 ppm (Goodland) and +21.4 ppm (Coffeyville), respectively.

For locations not included in Table D-1, distortion can be estimated from the maps in Appendix B. If the distortion rasters are available, distortion can be obtained at any location in the state (the 3 arc-second raster will give the most accurate values). The table includes the coordinate of the point where distortion was computed, so they can also serve as a distortion computation check. Both KRCS and SPCS 83 distortion are given, for the zone where the coordinate is located. This allows direct comparison of distortion between the two coordinate systems, which is the topic of the next section.

Distortion Performance of Other Coordinate Systems Used in Kansas

Other coordinate systems are used in Kansas, most notably the North and South zones of the Kansas State Plane Coordinate System of 1983 (SPCS 83). Figure 7 shows linear distortion for both zones of Kansas SPCS 83 (the distortion is identical for SPCS 27). Because the magnitude of distortion is so much greater than for the KRCS, a different distortion color ramp is used, with an increment of 20 ppm, a minimum category of less than -180 ppm (-1.0 ft/mile) and a maximum of greater than +40 ppm (+0.2 ft/mile). Both zones use the (two-parallel) LCC projection.

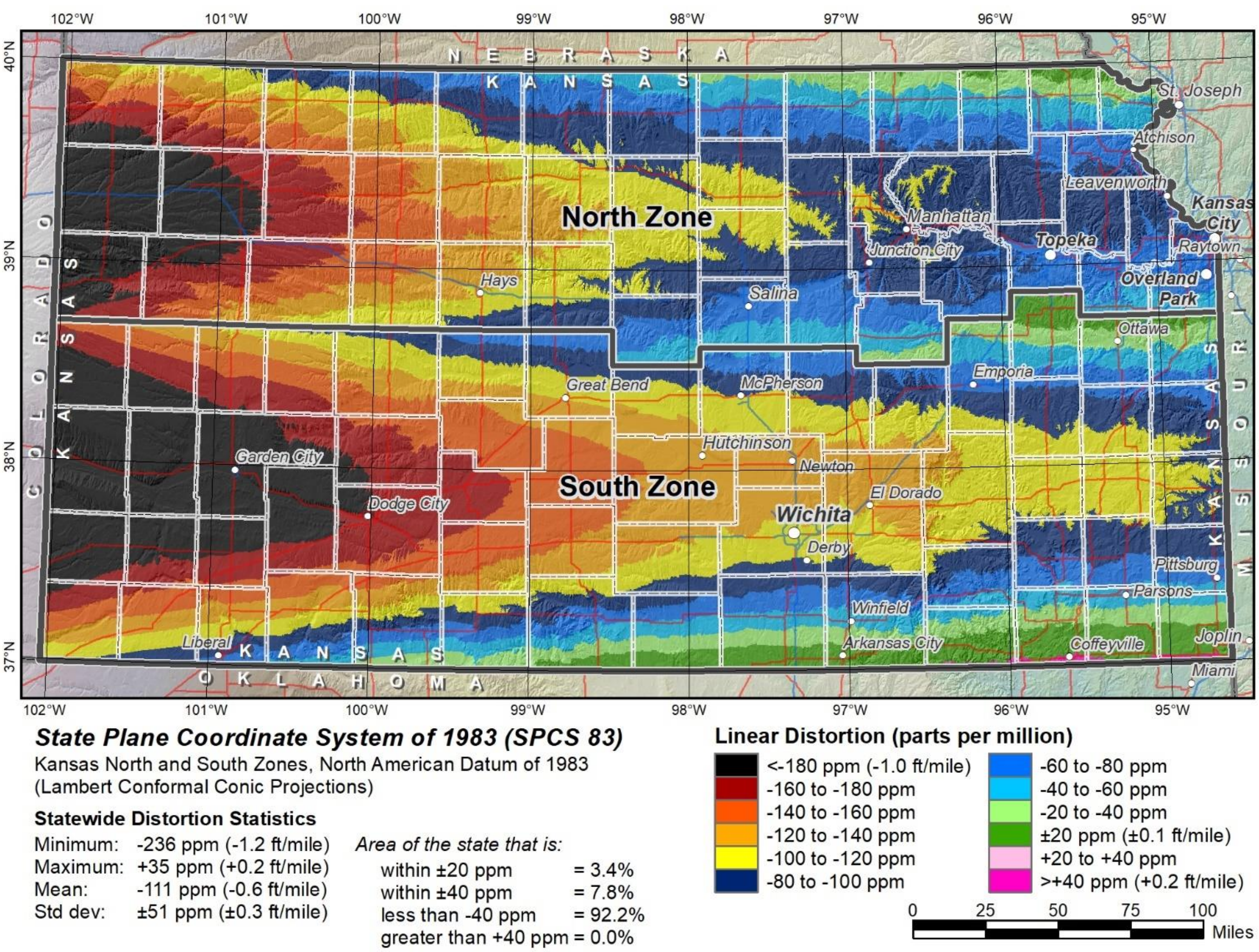

Figure 7. Linear distortion of the North and South zones of Kansas SPCS 83.

Figure 7 includes distortion statistics for SPCS 83, which shows that nearly the entire state has negative distortion, with 92.2% of the state less than -40 ppm and a mean of -111 ppm (-0.6 ft/mile) for the entire state. The maximum distortion is +35 ppm. Only 3.4% of the state is within ±20 ppm, as shown by the narrow green horizontal bands at the north and south edges of the zones (especially the South Zone, since it is wider). The minimum distortion of -236 ppm (-1.2 ft/mile) occurs at the middle of the western end of the South Zone. The increase in negative distortion to the west in both zones is due to increasing topographic height.

Figures 8 and 9 are also distortion maps for LCC projected coordinate systems created by (or for) KDOT, but in these cases for a single zone covering the entire state. Both use the same distortion color ramp as Figure 7, and they show the horizontal banding characteristic of LCC projections. Figure 8 is a recently designed LCC system (called "new" in this report) created to replace the "old" statewide LCC projection in Figure 9. Although they are based on the same projection and cover identical regions, their distortion distributions are strikingly different.

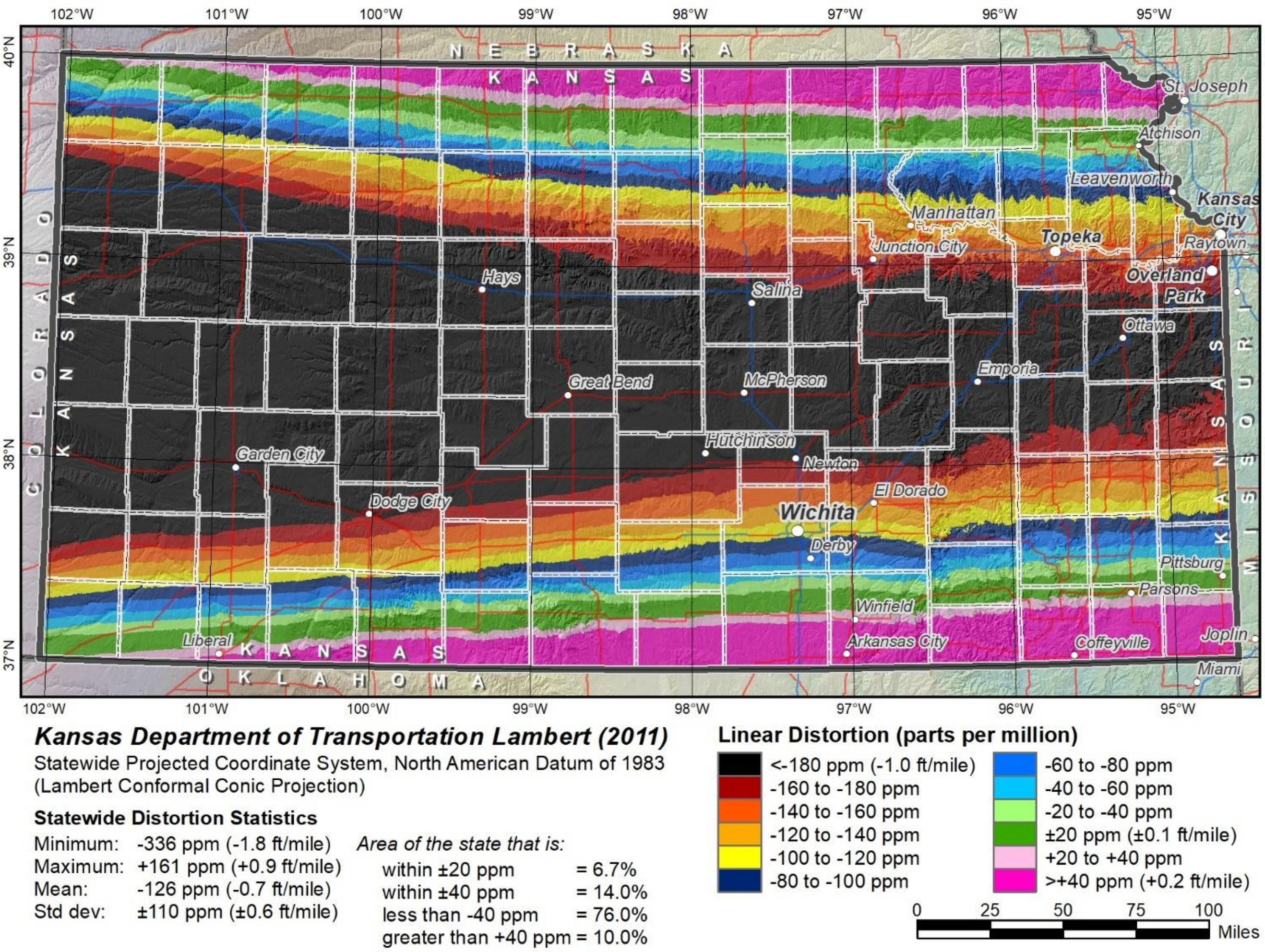

Figure 8. Linear distortion of the new (2011) Kansas DOT Lambert coordinate system.

The new KDOT Lambert is – like the SPCS zones – a "classically" designed LCC. That is, it was designed using two standard parallels spaced such that two-thirds of the state is between the parallels and one-sixth is outside the parallels. This approach more-or-less minimizes distortion with respect to the ellipsoid (rather than the topographic surface). Hence distortion at the topographic surface is strongly negative, as it is for SPCS, only in this case more so because it covers a larger area. The minimum distortion is -336 ppm (-1.8 ft/mile) and the mean is -126 ppm (-0.7 ft/mile). Because of its greater width than SPCS – with respect to its standard parallel spacing – it also has more positive distortion than SPCS, with a maximum of +161 ppm (+0.9 ft/mile).

In contrast, the old KDOT Lambert in Figure 9 was apparently designed to minimize distortion at the topographic surface. The mean distortion of -12 ppm (-0.06 ft/mile) is nearly zero, and the minimum and maximum distortion is fairly well balanced, -222 and +273 ppm, respectively. Whether or not this was the intent of the design is unknown, but it seems unlikely that this was achieved by accident.

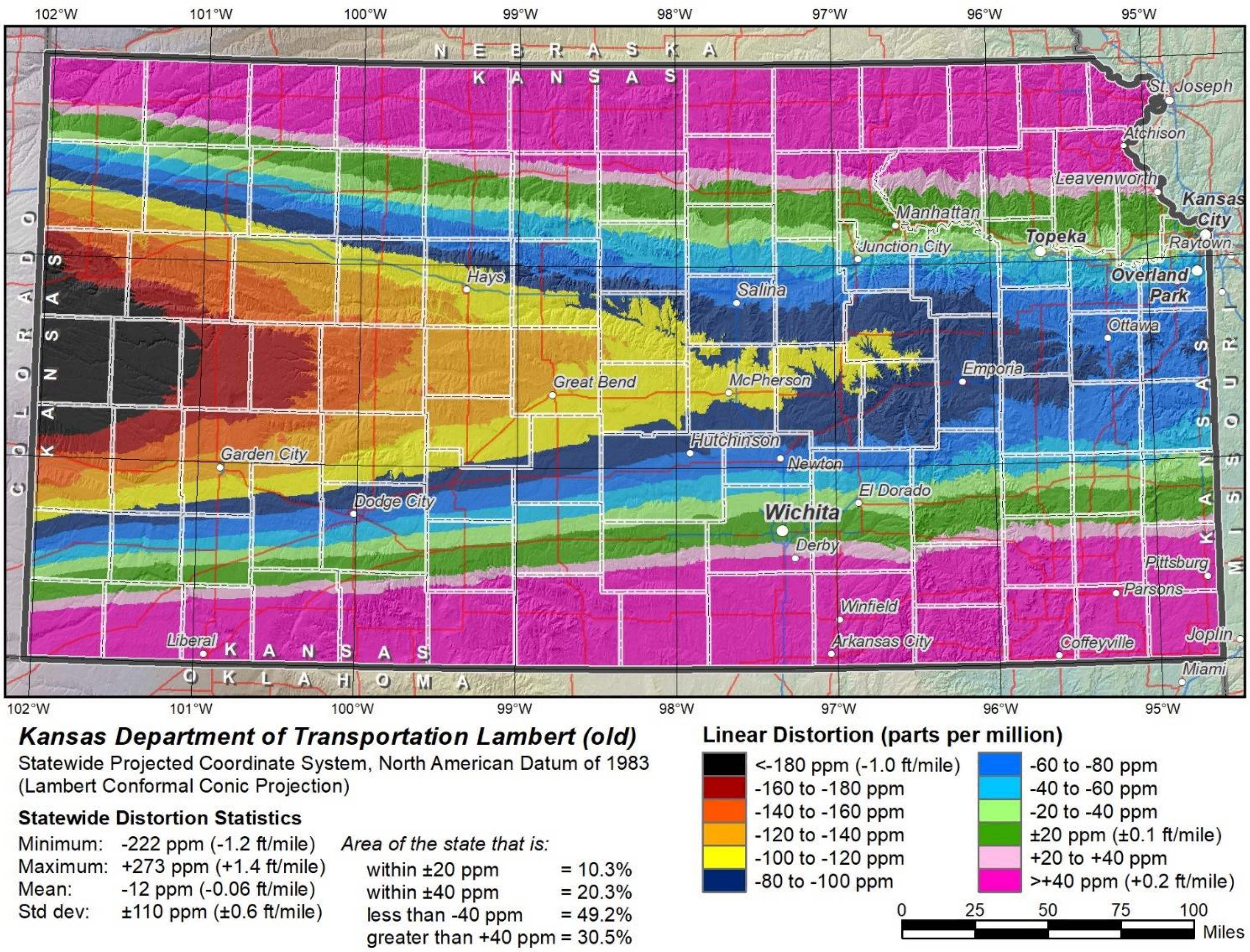

Figure 9. Linear distortion of the old Kansas DOT Lambert coordinate system.

Apparently the main reason for creating the new statewide Lambert was to eliminate negative coordinates in the old Lambert. This occurred because the grid origin was placed in the center of the state, with false northing and easting of zero. Thus negative coordinates were obtained everywhere except in the northeast quarter of the state. That problem could have been fixed by simply replacing the zero false northing and easting with suitably large positive coordinates. Evidently there was also an interest in having a new design to ensure that KDOT was using an appropriate statewide coordinate system.

Ignoring the negative coordinate problem in the old KDOT Lambert (which can be easily fixed), neither design is "better" than the other. The only substantive difference is that the old one minimized distortion at the topographic surface and the new one at the ellipsoid surface (the new one also has a central meridian closer to the middle of the state, but that has no effect on linear distortion). In both cases the magnitude of distortion is large since they cover the entire state, so it seems there is not much gained by minimizing distortion at ground, as done in the old Lambert. Nevertheless, there is no harm in designing a projection for ground, even when it covers an areas as large as Kansas. The fact is that work is done on the topographic surface, not the ellipsoid, so there really is little reason to minimize distortion with respect to the ellipsoid, except when the topographic height is not known. With that in mind, the old Lambert (corrected for negative coordinates) is somewhat preferable, but the preference is very slight. Either one will likely serve KDOT well.

Figure 10 is a distortion map for UTM Zone 14N, again using the same distortion color ramp as in figures 7, 8, and 9. Since it is a TM projection, the distortion banding is north-south. As with SPCS and the new KDOT Lambert, UTM distortion is designed with respect to the ellipsoid. But the distortion for UTM is much greater, especially the positive distortion, with a maximum of +1440 ppm (+7.6 ft/mile) at the east border of the state. Such large positive distortion occurs because Kansas is twice as wide perpendicular to the TM projection axis (central meridian) than it is perpendicular to the LCC projection axis (central parallel). This behavior vividly illustrates why the choice of projection matters when covering large geographic areas.

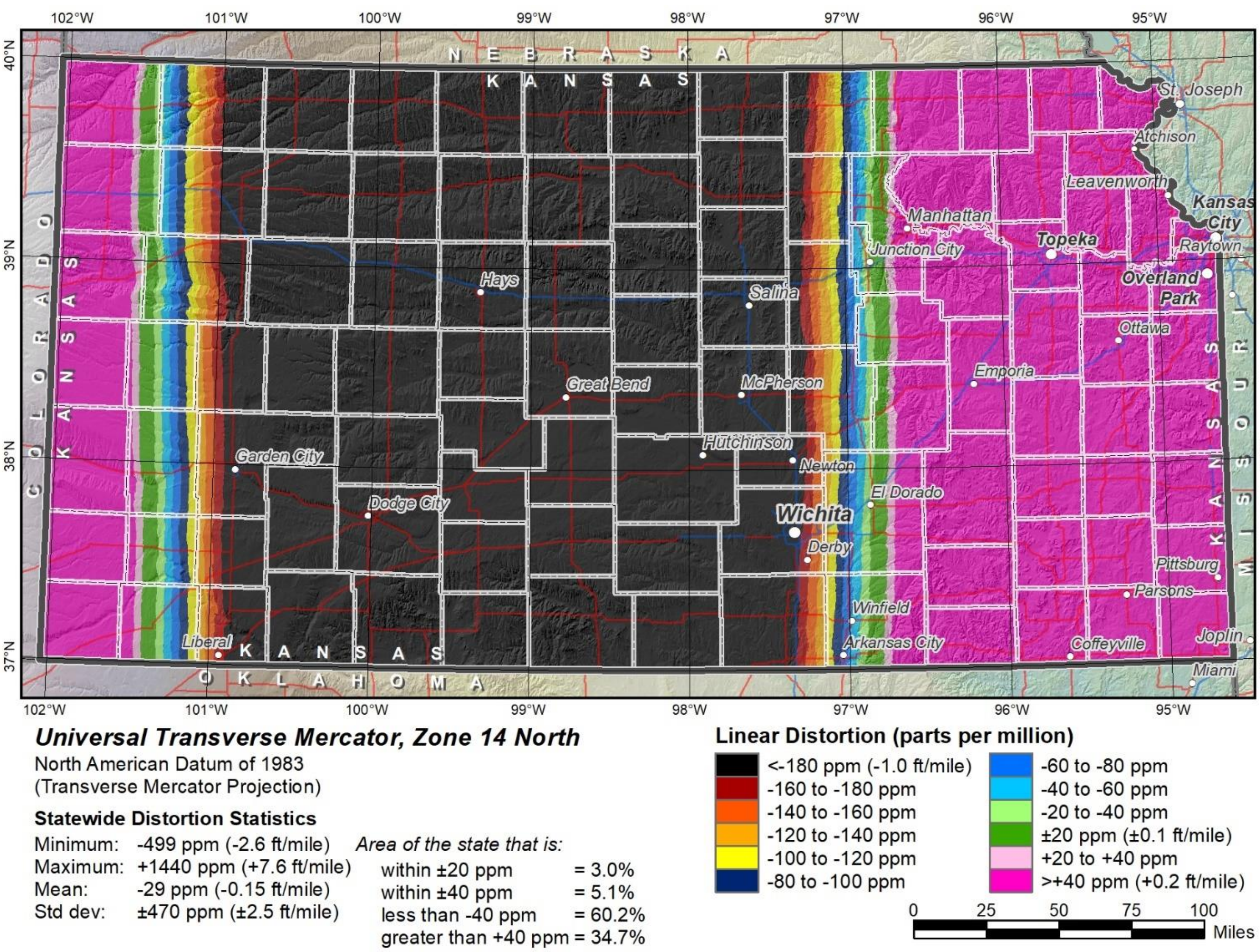

Figure 10. Linear distortion of the UTM 1983 coordinate system, Zone 14 North.

Using and Evaluating the KRCS

Defining the KRCS in Software

The KRCS was designed using the TM and LCC projections, which are well-defined existing conformal map projection types commonly available in GIS, surveying, and engineering software. Definitions were provided in Esri projection (*.prj) format as deliverables for this project (in the "KRCS\GIS\PRJ_files\" folder of the electronic data deliverables, as shown in Appendix A). The *.prj format is a Well-Known Text (WKT) mark-up language representation of a projected coordinate system, as defined by the Open Geospatial Consortium (OGC, 2015). WKT for coordinate reference systems was developed to provide a standardized means of defining coordinate systems in machine-readable format. The Oracle Spatial scripts provided as deliverables in PL (Procedural Language) SQL format are also WKT representations.

Not all geospatial software directly uses WKT representation for defining projected coordinate systems. Definitions for AutoDesk, Bentley, Leica, Safe Feature Manipulation Engine (FME), and Trimble created for this project are available for download from the Kansas Data Access & Support Center (DASC) at http://data.kansasgis.org/ks_ldp/KRCS_Product_Definitions/. For software that is not included in the DASC download and that cannot consume the provided WKT representations, the projection parameters in Table 1 can be used to manually define KRCS zones.

In many coordinate system definition formats (such as WKT), latitude and longitude are represented in decimal degrees. When repeating decimal digits occur (for example, 97°20'W = -97.333333333333…°), it is recommended that full double-precision be used to represent the number. That is, 16 digits should be used, which corresponds to 14 decimal places (for latitude and for longitude less than 100°) and 13 decimal places (for longitude greater than or equal to 100°). The WKT format should automatically use double precision representation when 16 or more significant digits are provided while defining the parameters. Although ten decimal places is likely sufficient for nearly all practical applications (corresponding to about 0.000 04 ft or less), it is nevertheless good practice to define the parameters to full double precision representation. It helps minimize problems with accumulated round-off error, such as for iterated computations (for example by repeatedly projecting and de-projecting coordinates).

An important part of defining the projection parameters is performing computation checks. Doing so provides a means for capturing overlooked errors in the parameters; it also allows checking of projection algorithms, as mentioned previously. The centroid coordinates in Table 3 are provided for that purpose. Geospatial software should match the projected coordinates to the precision shown (to better than ±0.0001 ft). The check also applies in reverse: if the northings and eastings in Table 3 are de-projected, they should yield latitude and longitude values that matches those in the table to six decimal places (±0.000 001"). Table C-1 in the Appendix (NGS control station coordinates) can also be used to check computations. The values are given to ±0.000 01" for latitude and longitude, and to ±0.001 ft for projected coordinates, which should be sufficient for most applications.

In rare instances, the single-parallel LCC projections used for the KRCS may be problematic to implement due to software limitations, for example in surveying field software. For such situations, satisfactory alignment with the KRCS in small areas can usually be achieved using a best-fit planar conformal (similarity) transformation (affine transformations should not be used because the KRCS itself is conformal). Such an approach is sometimes called horizontal "calibration" or "localization" in geospatial software. For areas with a maximum dimension of less than about 3 miles, differential distortion distribution will usually cause less than 0.05 ft mean alignment error. In these cases, the transformation should be based on at least three (but preferably more) common points distributed across the extent of the area. Common points are any physical points correctly referenced to NAD 83 that can be observed in the field and for which KRCS coordinates are available. The KRCS coordinates on NGS control points in Appendix C are suitable for this purpose (if they are used as control for the area of interest), or any point where appropriate NAD 83 coordinates are known (such as SPCS 83) and KRCS coordinates can be determined by other means (such as by using software not available in the field). Although such an approach can produce acceptable results, it should *only* be applied if the rigorous projection definitions cannot be used. It should also only be done by practitioners with sufficient knowledge and skill in using and interpreting such transformations.

NAD 83 Realizations, Relationship to WGS 84, and the Vertical Component

The Esri projection (*.prj) files provided as part of the KRCS design deliverables are referenced to the NAD 83 (2011) epoch 2010.00 realization. However, in reality the KRCS definition is with respect to "generic" NAD 83, not any particular realization (the same is true for SPCS 83). This distinction is a common point of confusion. Only the coordinates themselves are referenced to a specific realization, but that has no effect on the projection or ellipsoid parameters. A realization is included in the *.prj files to serve as a "trigger" to indicate whether a transformation of the data (or data view) should be invoked by the software. For example, if a GIS dataset referenced to NAD 83 (2011) is added to a GIS data frame referenced to NAD 83 "HARN" (High Accuracy Reference Network), the software will attempt to perform a transformation (if one is available), even though the ellipsoid parameters for both are identical. In short, the realization is associated only with the data, not with the formal coordinate system definition.

To illustrate the change in coordinates for different NAD 83 realizations in Kansas, consider the NGS control station SALINA EAST BASE, Permanent Identifier (PID) JF1012, located in Zone 7 (Salina) as shown in Figure 3. This station was monumented in 1895 and was recovered in 2014 by KDOT. Its NAD 83 geodetic coordinates have been updated three times relative to different NAD 83 datum realizations; the coordinates of its latest realization (2011) are given in Table C-1 (the realization year is referred to as a "datum tag" by NGS). Coordinates from its three previous NAD 83 realizations are given in the superseded section of its NGS Datasheet and are shown in Table 7. The coordinates changed not because of a change in the NAD 83 definition but because of changes in the way the position of this station was determined (including different observation types, amount of data, computation methods, and adjustment constraints), as well as unmodeled tectonic motion. The cumulative change in horizontal coordinates for this station is 1.093 ft (the coordinate changes are specific to this station; changes at other locations will in general be somewhat different). It can be seen by this example that including the datum realization as part of the metadata is a crucial part of maintaining accurate coordinates for geospatial data. However, it is important to recognize that the KRCS coordinates in

Table 7 were computed using exactly the same KRCS definition for all four realizations. That is because the realizations have no effect on the KRCS defining parameters, only on the geodetic coordinates.

Table 7. Coordinates and their change for NAD 83 realizations at an NGS control station in Kansas. The station is SALINA EAST BASE (PID JF1012). The "datum tag" is the year associated with each realization (1997 is equivalent to HARN for Kansas).

NAD 83 datum tag	NAD 83 geodetic coordinates associated with datum tag		KRCS Zone 7 (Salina) projected from geodetic coordinates (sft)		Horizontal change in coordinates (ft)	
	Latitude	Longitude	Northing	Easting	Increm.	Cumul.
1986	38°52'25.18203"N	97°31'58.83302"W	500,336.620	7,443,147.178		
					1.110	1.110
1997	38°52'25.17107"N	97°31'58.83228"W	500,335.511	7,443,147.234		
					0.039	1.075
2007	38°52'25.17143"N	97°31'58.83210"W	500,335.547	7,443,147.249		
					0.055	1.093
2011	38°52'25.17130"N	97°31'58.83143"W	500,335.534	7,443,147.302		

Coordinate transformations between the various realizations of NAD 83 have been developed by NGS (such as the NADCON utility). However, these transformations are not appropriate for all applications, and the documentation for each should be reviewed to ensure suitability. Typically these transformations are not of sufficient accuracy for surveying and engineering applications. In such cases, more rigorous methods are necessary and can be done with respect to the desired NAD 83 reference coordinates, such as reprocessing data, recomputing coordinates, or performing custom local transformations.

In some situations, it may be necessary to change the NAD 83 realization of a dataset if it is referenced to the wrong realization. This can occur, for example, if a dataset is referenced to "NAD 83" (without any modifier), which is often interpreted by software as original NAD 83 (1986). Another example is an existing project referenced to an earlier realization, such as NAD 83 (2007), rather than the current 2011 realization. Note that changing the realization has no effect on the coordinates; it merely serves as metadata to identify the correct realization (and possibly avoid inappropriate transformations by software). Although changing the NAD 83 realization can be done, such changes should only be made after it has been verified that the change is necessary, appropriate, and correct.

Note regarding the relationship between NAD 83 and WGS 84. When entering the KRCS projection parameters into vendor software, the datum should be defined as NAD 83 (which uses the GRS-80 reference ellipsoid for all realizations). Some commercial software implementations assume there is no transformation between World Geodetic System of 1984 (WGS 84) and NAD 83 (i.e., all transformation parameters are zero). Other implementations use a non-zero transformation, and in some cases both types are available in a single software package. The type of transformation used will depend on specific circumstances, although often the zero transformation is the appropriate choice (even though it is not technically correct). Check with software support to ensure the appropriate transformation is being used for a given application. It is important to understand that the relationship between NAD 83 and WGS 84 is complex and changes with time, and that there is essentially no direct way to access high-accuracy WGS 84 coordinates. For additional information on WGS 84, refer to National Geospatial-Intelligence Agency (2014a).

Note regarding the vertical component of a coordinate system definition. A complete 3-D coordinate system definition must include a vertical "height" component. Yet the KRCS pertains exclusively to horizontal coordinates. Although the vertical component is essential for most applications, it is not part of the KRCS and must be defined separately. Typically the vertical part consists of ellipsoid heights relative to NAD 83 (when using Global Navigation Satellite System technology) and/or orthometric heights ("elevations") relative to NAVD 88. These two types of heights are related (at least in part) by an NGS hybrid geoid model, such as GEOID12B, and often also some sort of vertical adjustment or transformation to match local vertical control for a project. The approach used for the vertical component usually varies from project to project and requires professional judgment to ensure it is defined correctly. Providing such instructions is beyond the scope of this report.

Distortion and Ground Distance Computations

Linear distortion, δ, at any point in a projected coordinate system can be computed using the following equation,

$$\delta = k\left(\frac{R}{R+h}\right) - 1$$

where k is the projection grid point scale factor
R is the geometric mean radius of curvature of the GRS-80 ellipsoid
h is the NAD 83 ellipsoid height.

Distortion is multiplied by 1,000,000 to obtain parts per million (ppm). Note that if the minus 1 is removed from the equation it becomes the *combined (scale) factor* familiar to surveyors. The quantity in parentheses is the *height (elevation) factor*. These scale factors are given for the points listed in tables 4 and C-2.

For Kansas, an Earth radius of curvature of R = 20,910,000 sft (at latitude 38°30'N) is likely of sufficient accuracy for many applications. It varies from 20,906,133 sft at the south border of Kansas to 20,913,290 sft at the north border. For greater accuracy, R can be computed at any latitude as

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

where a is the semi-major axis of the GRS-80 ellipsoid = 6,378,137 m (exact) ≈ 20,925,604.47417 sft
e^2 is the first eccentricity squared of the GRS-80 ellipsoid = 0.0066943800229
φ is the geodetic latitude.

Some software may not compute the grid point scale factor, k. Equations for computing k are fairly complex and are a function of position (as well as the projection characteristics). For the sake of completeness they are given in Appendix E for the TM and LCC projections.

Linear distortion is defined at a point, but practical applications are concerned with how well the projected (grid) distance matches the true horizontal ground distance between a pair of points. Such evaluations require an accurate method for computing ground distance. Although there is no standard definition for ground distance, it can be argued that a reasonable definition is the (curved) distance parallel to the ellipsoid surface at the mean ellipsoid height of the endpoints. Two relatively simple methods for computing such distance based on this definition are provided below.

One method for computing horizontal ground distance, D, consists of scaling the ellipsoid distance (geodesic) using the average of the ellipsoid heights at the endpoints:

$$D = s\left(1 + \frac{\bar{h}}{R_m}\right)$$

where s is the ellipsoid distance (geodesic)

$\bar{h}$ is the average ellipsoid height of the two points

R_m is the geometric mean radius of curvature at the midpoint latitude of the two points

If software for computing the ellipsoid distance is not available, the NGS Geodetic Tool Kit inversing tools can be used (geodesy.noaa.gov/TOOLS/Inv_Fwd/Inv_Fwd.html).

A second method for computing a horizontal ground distance makes use of a GPS (GNSS) vector directly. Neglecting Earth curvature, this distance can be computed using the vector East-Centered, Earth-Fixed (ECEF) Cartesian coordinate deltas,

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

where $\Delta X, \Delta Y, \Delta Z$ are the GNSS vector components (as ECEF Cartesian coordinate deltas)

Δh is the change in ellipsoid height between vector endpoints

This method can also be used with endpoint coordinates (rather than a GNSS vector), by converting the latitude, longitude, and ellipsoid heights to X, Y, Z ECEF coordinates, and then using the difference in ECEF coordinates. If software is not available for computing ECEF coordinates, the NGS Geodetic Tool Kit *XYZ Conversion* tool can be used for this purpose (geodesy.noaa.gov/TOOLS/XYZ/xyz.shtml).

Curvature increases the horizontal ground distance, but for distances of less than 20 miles, the error due to the increase is less than 1 part per million (ppm), i.e., less than 0.1 ft. The straight-line horizontal distance can be multiplied by the following curvature correction factor, C, to get the approximate curved horizontal ground distance,

$$C = \frac{2R_m \sin^{-1}(D/2R_m)}{D}$$

where all variables are as defined previously. With the curvature correction, for distances of less than 100 miles the error is less than 0.005 ppm, i.e., less than 0.003 ft. A mean Earth radius of curvature of 20,910,000 sft can be used for Kansas, or it can be computed using the equation provided earlier.

Although equations have been provided here for accurately computing long ground distances, it is important to understand that linear distortion varies continuously along the line between two points. When a ground distance is compared to a projected distance, the distortion being evaluated is the "average" (integrated) distortion along the line. For long distances (say greater than a few miles), such comparisons are of questionable value, since the distortion varies both with the distance and height difference between the endpoints.

Concluding Remarks and Recommendations

Summary of the KRCS Design

The Kansas Regional Coordinate System (KRCS) is a 20-zone system of low-distortion projections (LDPs) that optimally minimize map projection linear distortion at the topographic surface ("ground") for the entire state of Kansas. A criterion of ±20 ppm (±0.1 ft/mile) distortion was used for design of the KRCS, and it was achieved for 99% of the state area. A maximum allowable distortion limit was set at ±25 ppm. It was exceeded, but only in 0.002% of the state and by a small amount (less than 2 ppm). These distortion criteria could have been achieved with slightly fewer zones (especially in the western part of the state). But that would have created some zones that were only 30-50 miles wide east-west yet extending the entire 200-mile width of the state north-south. Such long, narrow zones were deemed impractical and it was decided to use a slightly larger number of less elongated zones.

KRCS zones consist of aggregated counties, where the number of counties in each zone ranges from 3 to 10. The zone boundaries correspond to country boundaries at the perimeter of the zone. An initial design objective was to also apply the distortion design and limit criteria to a 6-mile buffer around each zone (corresponding to the width of a PLSS township). However, this objective could not be achieved in all directions from all zones without substantially increasing the number of zones. In addition, in some locations near zone boundaries the distortion is greater within a zone than it is outside of an adjacent zone. These variations are an unavoidable consequence of the size, shape, and distribution of counties. To achieve the best distortion performance for projects located near zone boundaries, it is recommended that the project area be examined prior to selecting the KRCS zone. This can be done using the maps in Appendix B or by overlaying the project area on the distortion rasters in a GIS application. In some cases a project may be too long to assign to a single zone, and it may be better to split the project between two zones rather than use a single zone. Such situations should be uncommon and will require evaluation on a case-by-case basis.

Adoption of the KRCS by the Kansas Department of Transportation (KDOT) replaces the previous method of scaling SPCS 83 coordinates "to ground" (the topographic surface). The scaled SPCS approach required that nearly all projects had their own coordinate system. In addition, since these coordinate systems were based on a modification of SPCS, they were not defined using standard projection parameters, which made them difficult to use consistently across geospatial platforms (e.g., in surveying, engineering, CAD, and GIS software). In contrast, the KRCS is limited to 20 projected coordinate systems which are rigorously defined using two existing projections, the Transverse Mercator (TM) and the (one-parallel) Lambert Conformal Conic (LCC). Both of these projections are supported by a wide range of software platforms. Importantly, they are also available for creating standardized projected coordinate system definitions in the European Petroleum Survey Group (EPSG) *Geodetic Parameter Registry* (2017). The EPSG registry is a freely available database of coordinate system definitions that is widely accessed by the software industry and government organizations. The registry provides machine-readable definitions in either or both Well-Known Text (WKT) and Geography Markup Language (GML) formats. It is recommended that KDOT contact EPSG (though the link provided in the reference list of this report) to have the KRCS added to the registry. Doing so will expedite adoption of the KRCS in commercial software packages.

LDP coordinate systems have been defined and officially adopted by government agencies throughout the US, and it appears that the implementation of LDP systems is accelerating. Documents are listed in the references section of this report for a few of these systems (all documents are available online): *Oregon Coordinate Reference System* (Armstrong, 2017); *Iowa Regional Coordinate System* (Dennis, 2014); *Indiana Geospatial Coordinate System* (Badger, 2016); *Wisconsin Coordinate Reference Systems* (Wisconsin State Cartographer's Office, 2012); *Rocky Mountain Tribal Coordinate Reference System* (Dennis, 2014); and *Pima County Coordinate System* (Dennis, 2017).

Compatibility of the KRCS with the 2022 Terrestrial Reference Frame

As mentioned earlier in this report, NGS will replace NAD 83 with new terrestrial reference frames (TRFs) in 2022 or soon after (see Smith *et al.*, 2017). The TRF referenced to the North American tectonic plate will be called the *North American Terrestrial Reference Frame of 2022* (NATRF2022). NAVD 88 will also be replaced with a new vertical (geopotential) datum at the same time, although that will have no effect on the terrestrial reference frames or projected coordinate systems.

In Kansas, NATRF2022 coordinates will differ horizontally from NAD 83 by about 4.0 to 4.3 ft, and they will be lower than NAD 83 ellipsoid heights by about 3.0 to 3.7 ft (both depending on location). The GRS-80 ellipsoid will still be used for NATRF2022, so the KRCS projected coordinates will change by the same horizontal amount, and the decrease in ellipsoid height will cause an increase of approximately 0.18 ppm in linear distortion. This increase is essentially negligible; it will cause the magnitude of distortion to increase slightly in locations where it is positive and decrease slightly where it is negative. Thus the KRCS will perform equally well when referenced to NATRF2022.

Although the KRCS can be used directly for both NAD 83 and NATRF2022, it is recommended that changes be made to the definitions to reduce the possibility of confusing KRCS coordinates based on NAD 83 with those based on NATRF2022. As part of this project, a redefinition of KRCS for NATRF2022 was proposed. It consisted of redefining the grid origins in "clean" metric units such that the projected coordinates (in feet) will differ substantially from the values as currently defined. The minimum horizontal difference for any location in the KRCS is about 33,000 feet, and the maximum difference is about 159,000 feet. The advantage of this approach is that it has no effect on the distortion, and it preserves the existing projected coordinate numbering scheme. That is, northings will still be less than 1 million feet (but not unique), and eastings will still be more than 1 million feet and will be unique, with the zone number still given by the truncated million feet. The behavior will be the same whether US survey or international feet are used. Details of the proposed redefinition for KRCS referenced to NATRF2022 are given in "KansasLDPs_PrelimDesigns2_def1_2022m.pptx" included in the "KRCS\Presentations\Design\" folder of the electronic deliverables listed in Appendix A. The name can also be changed to further distinguish the systems, for example to "KRCS2022", although that need not be decided at this time.

If meters are instead used as the working unit, the unique characteristics of KRCS coordinates will be lost, but the coordinate values will differ even more (they will be smaller by a factor of about 3.28). In such a case, it may be possible to define the system such that the projected coordinates in meters will possess similar characteristics for uniqueness and self-identification of zones.

Switching to a metric definition for KRCS in the future also gives freedom to use units other than US survey feet for the working units. In fact, the main reason the KRCS is currently defined using US survey feet is to facilitate a possible change to defining units in meters when Kansas migrates to the 2022 terrestrial reference frame. The overall intent in designing the KRCS is that it is compatible with and performs optimally for both the existing and future definitions of the National Spatial Reference System.

Finally, it is important to note that NGS will redefine State Plane as part of the transition to NATRF2022. It is likely the new system will be called the State Plane Coordinate System of 2022 (SPCS2022). At the time of this writing (October, 2017), the SPCS2022 project had just begun, and decisions about how SPCS2022 will be defined had not yet been made. However, one of the initial objectives of the project was to solicit input from stakeholders throughout the US (such as state departments of transportation) to determine their preferences for SPCS2022. One possibility is that some states will choose an LDP system (some already have done so). Whether or not LDPs become part of SPCS2022 depends on what both NGS and the geospatial community of each state decides. The outcome at this time is by no means certain. Yet the possibility exists that the KRCS – slightly redefined for 2022 as described above – could officially become part of SPCS2022, if that is the desire of the state of Kansas.

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Appendices

A. Organization of KRCS electronic data deliverables

The folder structure of the electronic data deliverables to Kansas Department of Transportation for Kansas Regional Coordinate System are listed and described below, and a graphical representation is shown in Figure A-1. The ArcMap documents (*.mxd files) are linked to their data using relative paths based in this folder structure.

KRCS. Main folder

- **GIS.** GIS data
  - **Contours.** Distortion contour shapefiles
    - **Distortion.** Root contains zero contour for map legends
      - **FinalContours**
  - **Export.** Exported distortion maps. Root contains maps for State Plane and Kansas statewide Lambert Conformal Conic projections.
    - **FinalMaps.** Maps for entire state
      - **ByZone.** Maps for each zone (300 dpi resolution) in PDF and PNG format
        - **PDF**
        - **PNG**
  - **Features.** Various shapefiles for distortion maps
    - **Misc.** Boundaries, cities, roads, PLSS township lines
    - **ProjAxes.** Projection axes
    - **Zones.** All zones and individual zones (all with zone parameters); Zone centroids with coordinates and distortion.
      - **Buffer_6mi.** Each zone with 6-mile buffer
  - **MapDocs.** ArcMap document (*.mxd) files for distortion maps (version 10.5.1). Root contains map docs for State Plane and Kansas statewide Lambert Conformal Conic projections.
    - **FinalDesigns.** Root contains distortion map docs for entire state
      - **ByZone.** Distortion map docs for each zone.
    - **v10.4.** Version 10.4 ArcMap document files. Same files and folder structure as v10.5.1 files.
      - **FinalDesigns**
        - **ByZone**
  - **PRJ_Files.** Esri projection (*.prj) files for each KRCS zone
  - **Rasters.** Distortion and digital elevation raster datasets in IMG format
    - **DEM.** Hillshade, topographic ellipsoid height, elevation (NAVD 88) and geoid model (GEOID12B) rasters
    - **Distortion.** Distortion rasters in parts per million
      - **FinalDesign.** Rasters for final designs
        - **3sec.** 3 arc-second (~300-foot) resolution for computation
        - **9sec.** 9 arc-second (~900-foot) resolution for display and contouring in distortion maps

- **KRCS_SQL.** Oracle Spatial scripts for each zone in PL (Procedural Language) SQL format
- **Posters.** Posters for two stakeholder meetings, in Microsoft Publisher and PDF formats
- **Presentations.** PowerPoint files for two stakeholder meeting presentations
  - **Design.** PowerPoint files created for documenting KRCS design process and alternatives. Includes one PDF created as a summary of design options.
- **Spreadsheets.** Spreadsheet of KRCS zone parameters and of KRCS centroid coordinates and distortion for each zone.

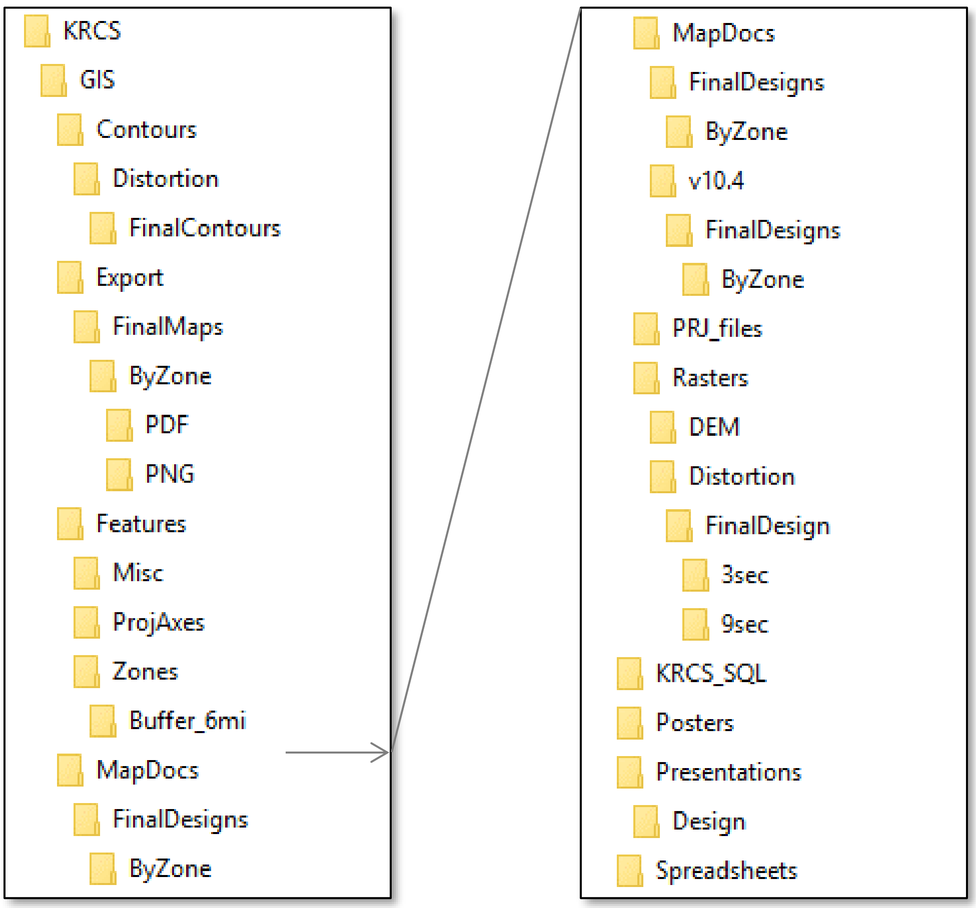

Figure A-1. Folder structure for KRCS data deliverables.

B. Kansas Regional Coordinate System distortion maps by zone

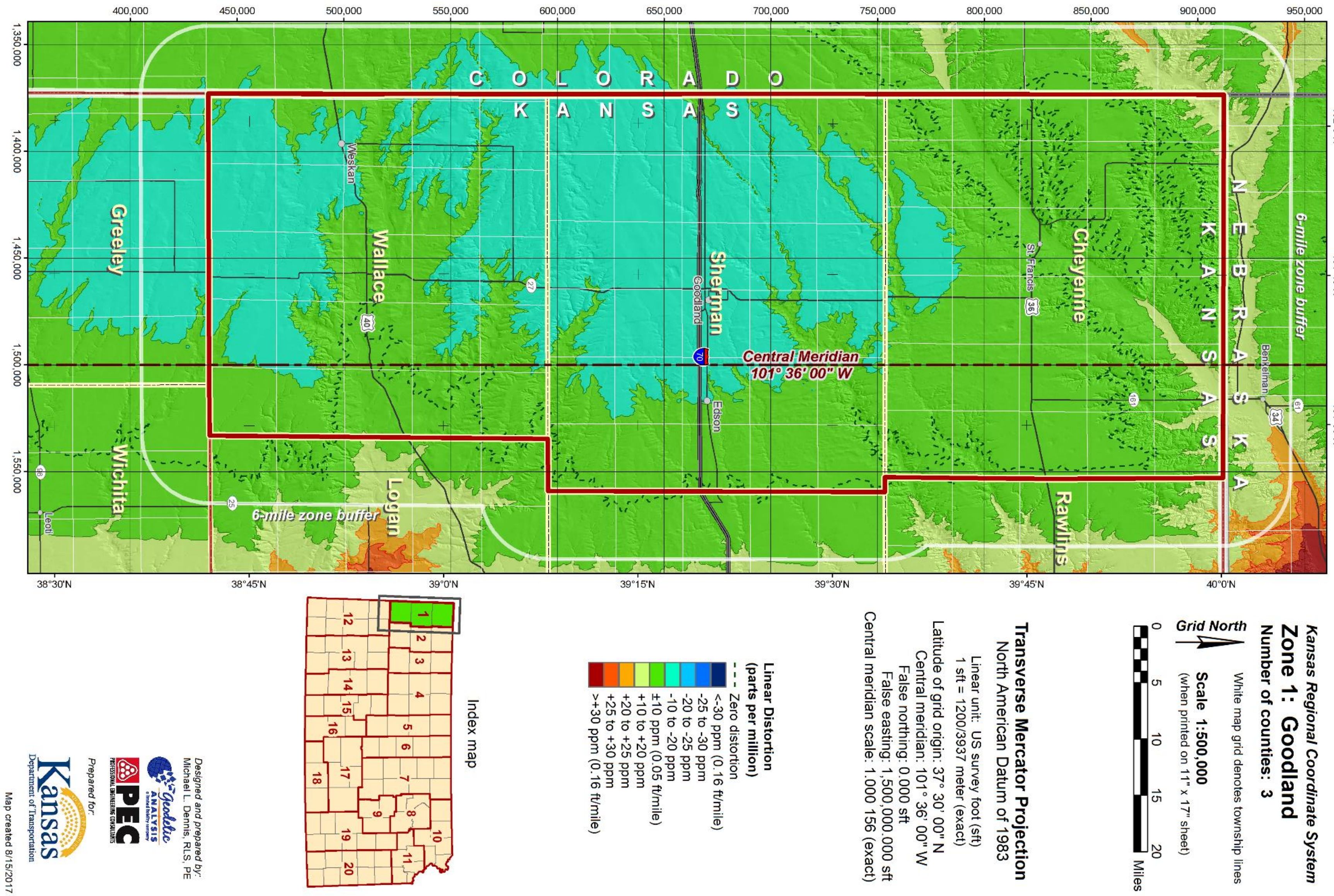

Figure B-1. Distortion map for Kansas Regional Coordinate System Zone 1 (Goodland). Scale when printed on 8-1/2" × 11" sheet is 1:833,333 (60% of original size).

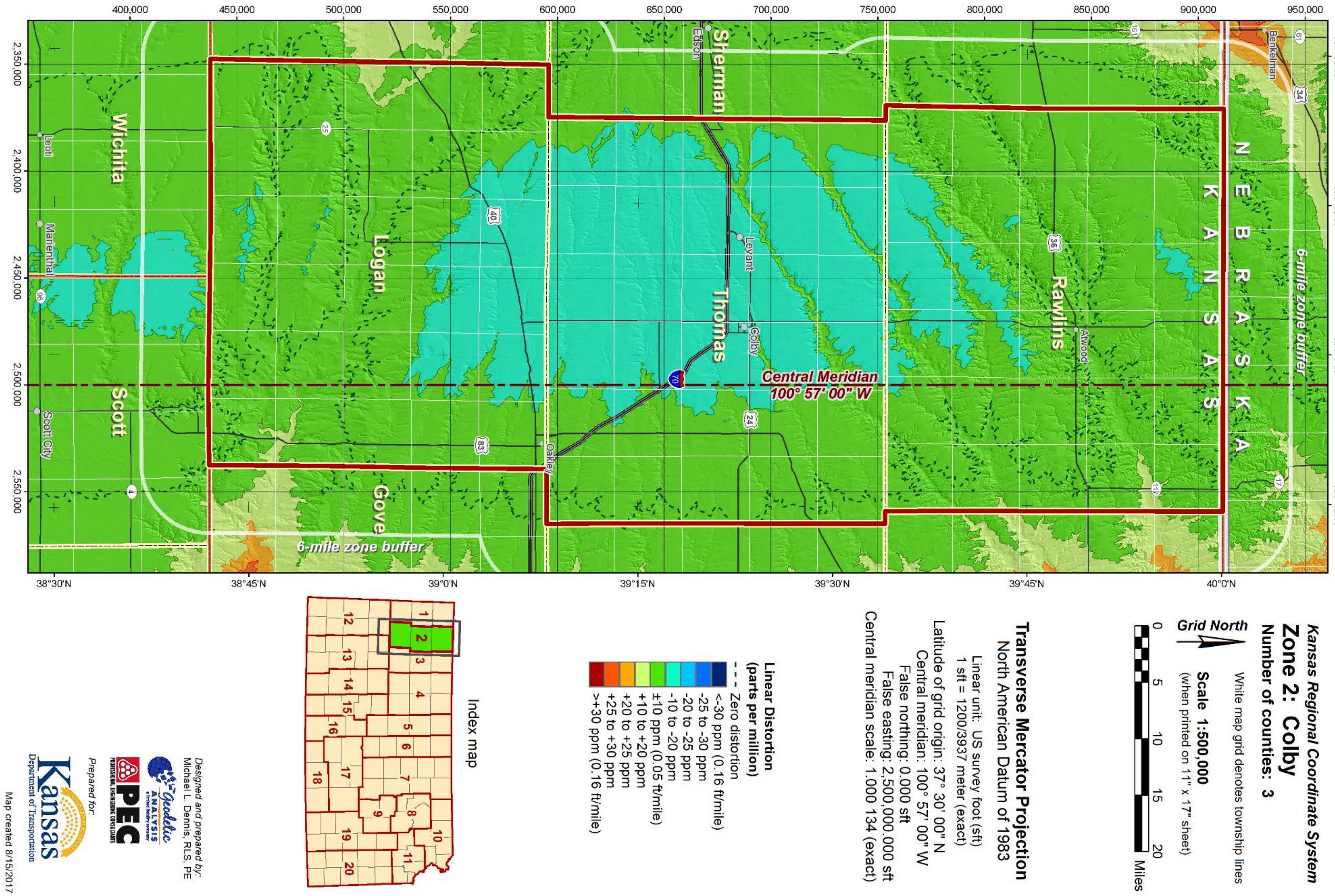

Figure B-2. Distortion map for Kansas Regional Coordinate System Zone 2 (Colby). Scale when printed on 8-1/2" × 11" sheet is 1:833,333 (60% of original size).

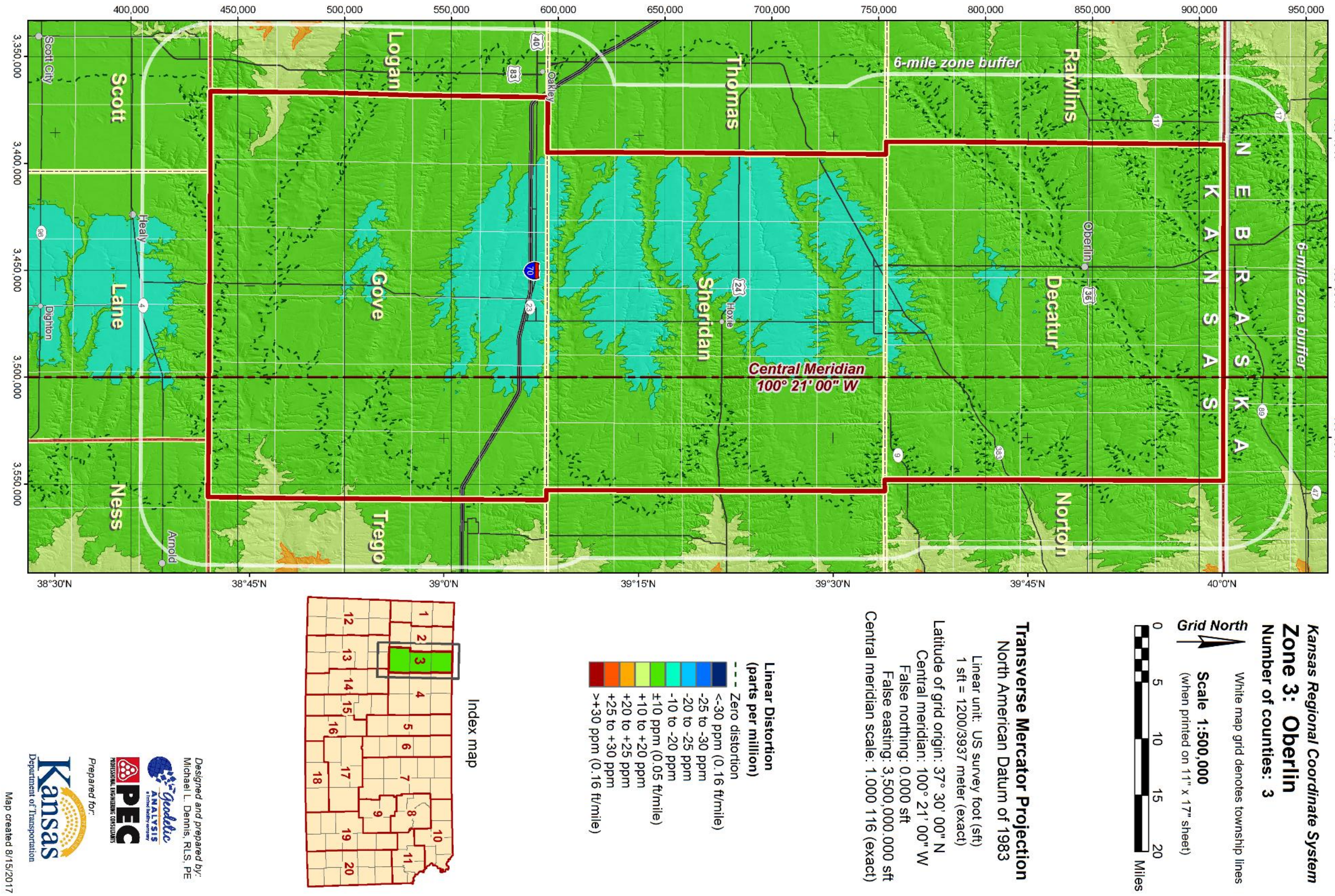

Figure B-3. Distortion map for Kansas Regional Coordinate System Zone 3 (Oberlin). Scale when printed on 8-1/2" × 11" sheet is 1:833,333 (60% of original size).

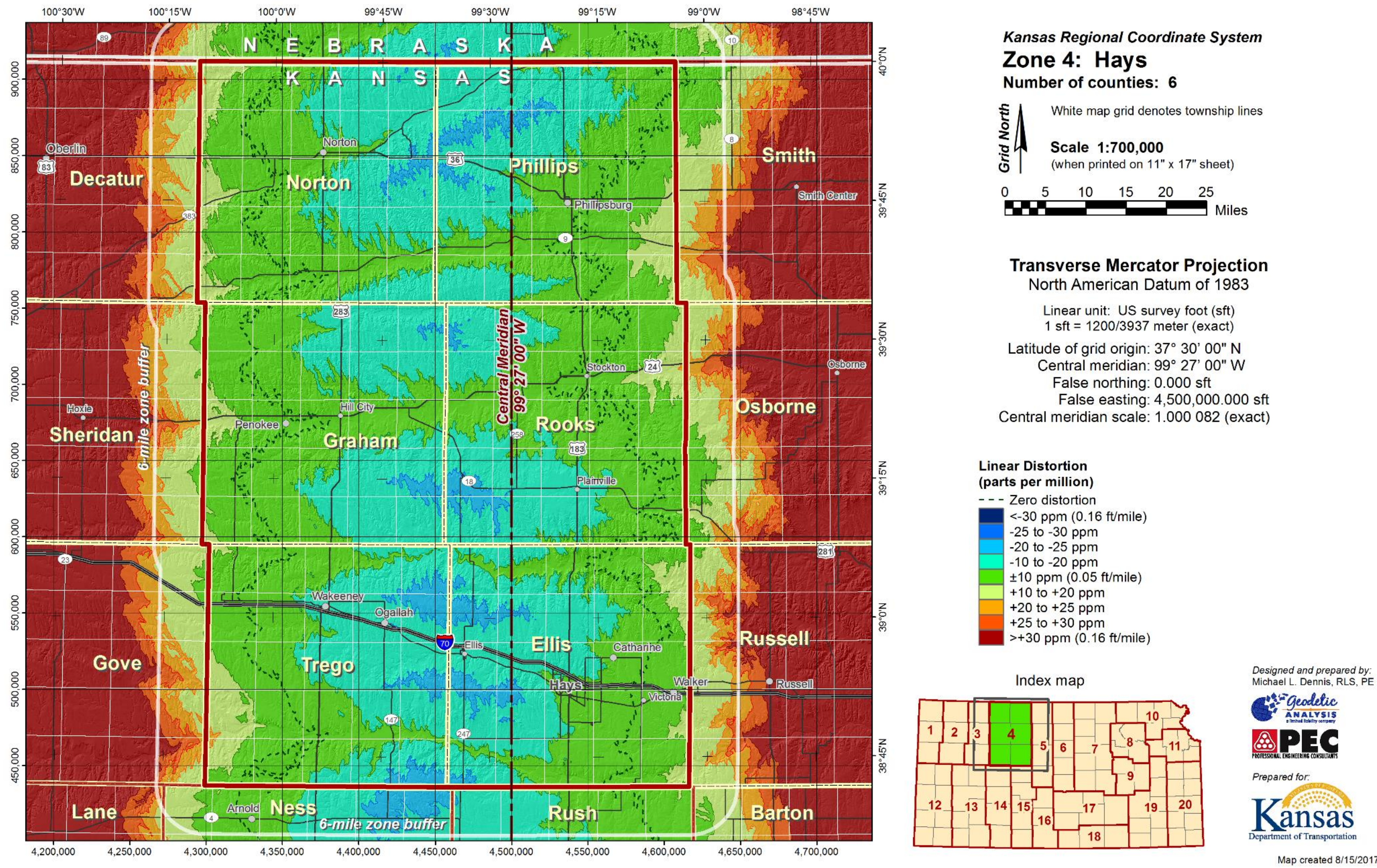

Figure B-4. Distortion map for Kansas Regional Coordinate System Zone 4 (Hays). Scale when printed on 8-1/2" × 11" sheet is 1:1,166,667 (60% of original size).

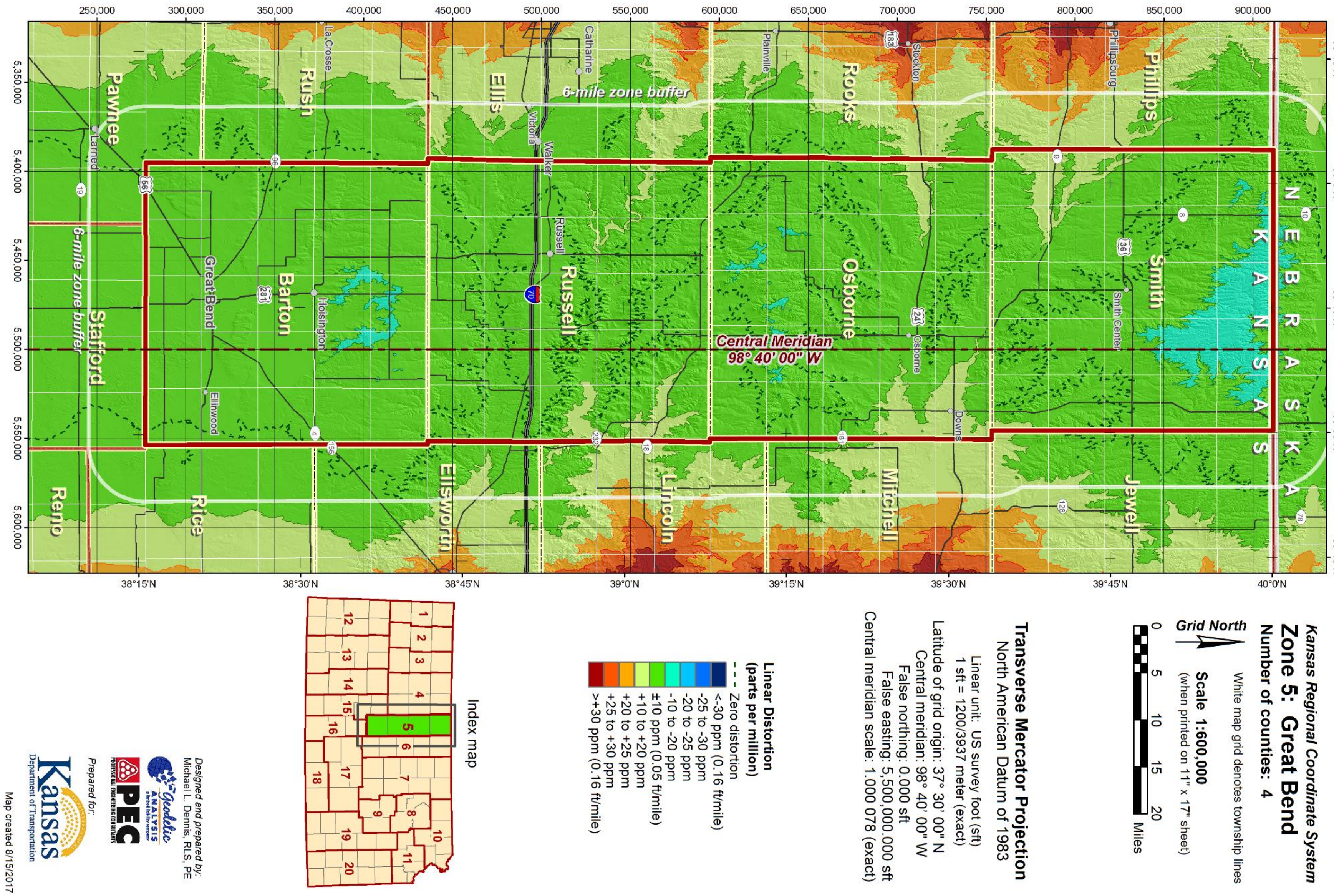

Figure B-5. Distortion map for Kansas Regional Coordinate System Zone 5 (Great Bend). Scale when printed on 8-1/2" × 11" sheet is 1:1,000,000 (60% of original size).

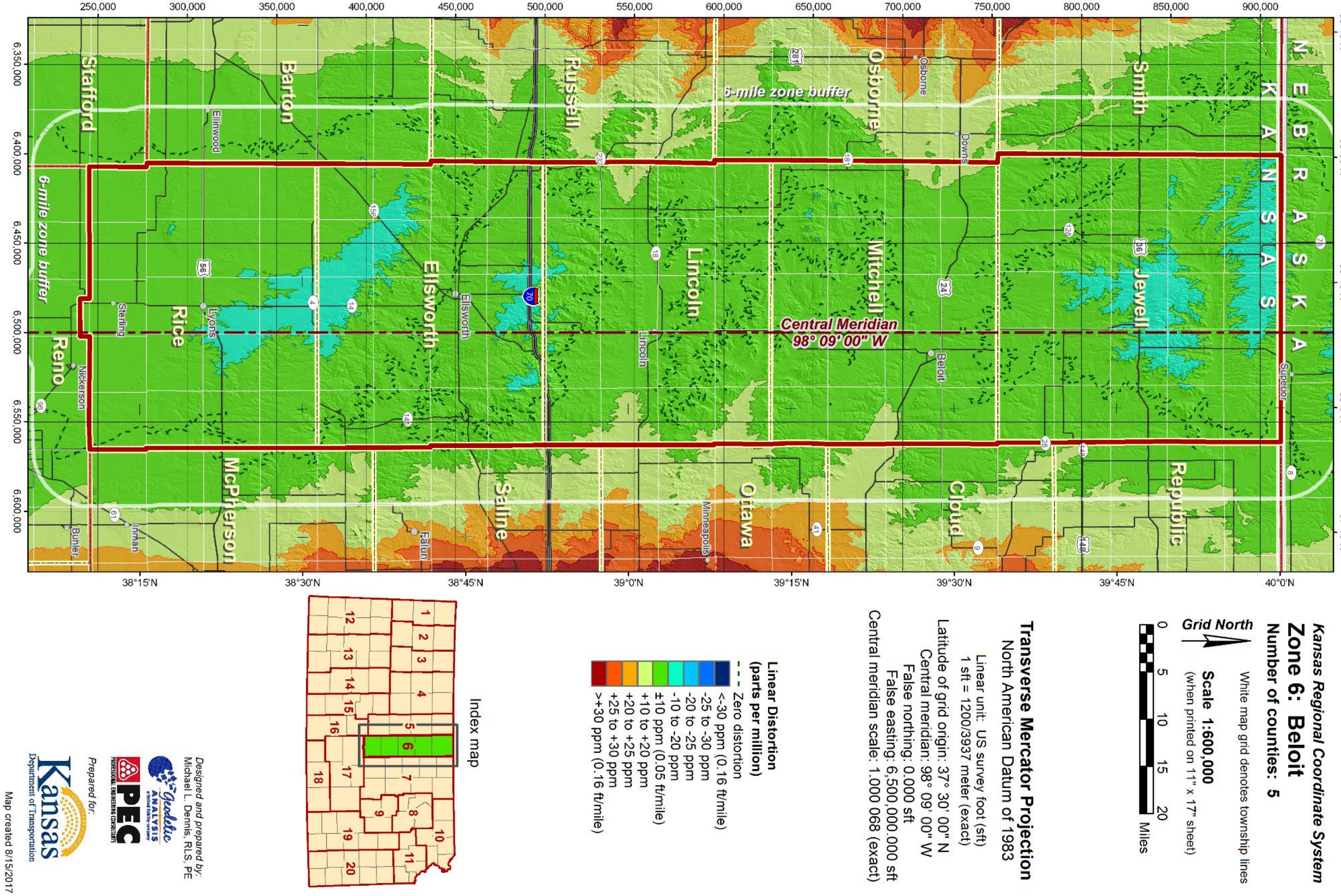

Figure B-6. Distortion map for Kansas Regional Coordinate System Zone 6 (Beloit). Scale when printed on 8-1/2" × 11" sheet is 1:1,000,000 (60% of original size).

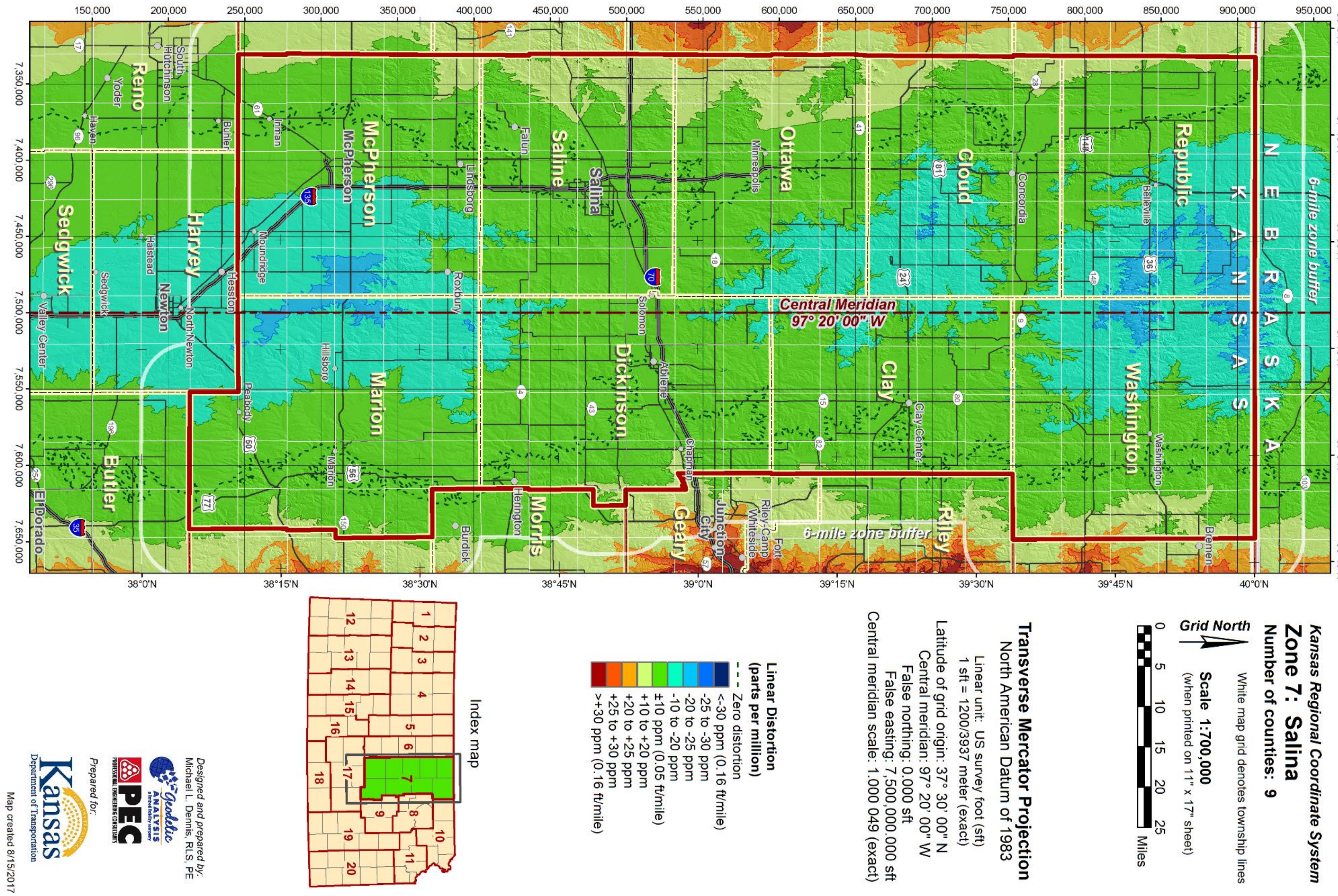

Figure B-7. Distortion map for Kansas Regional Coordinate System Zone 7 (Salina). Scale when printed on 8-1/2" × 11" sheet is 1:1,166,667 (60% of original size).

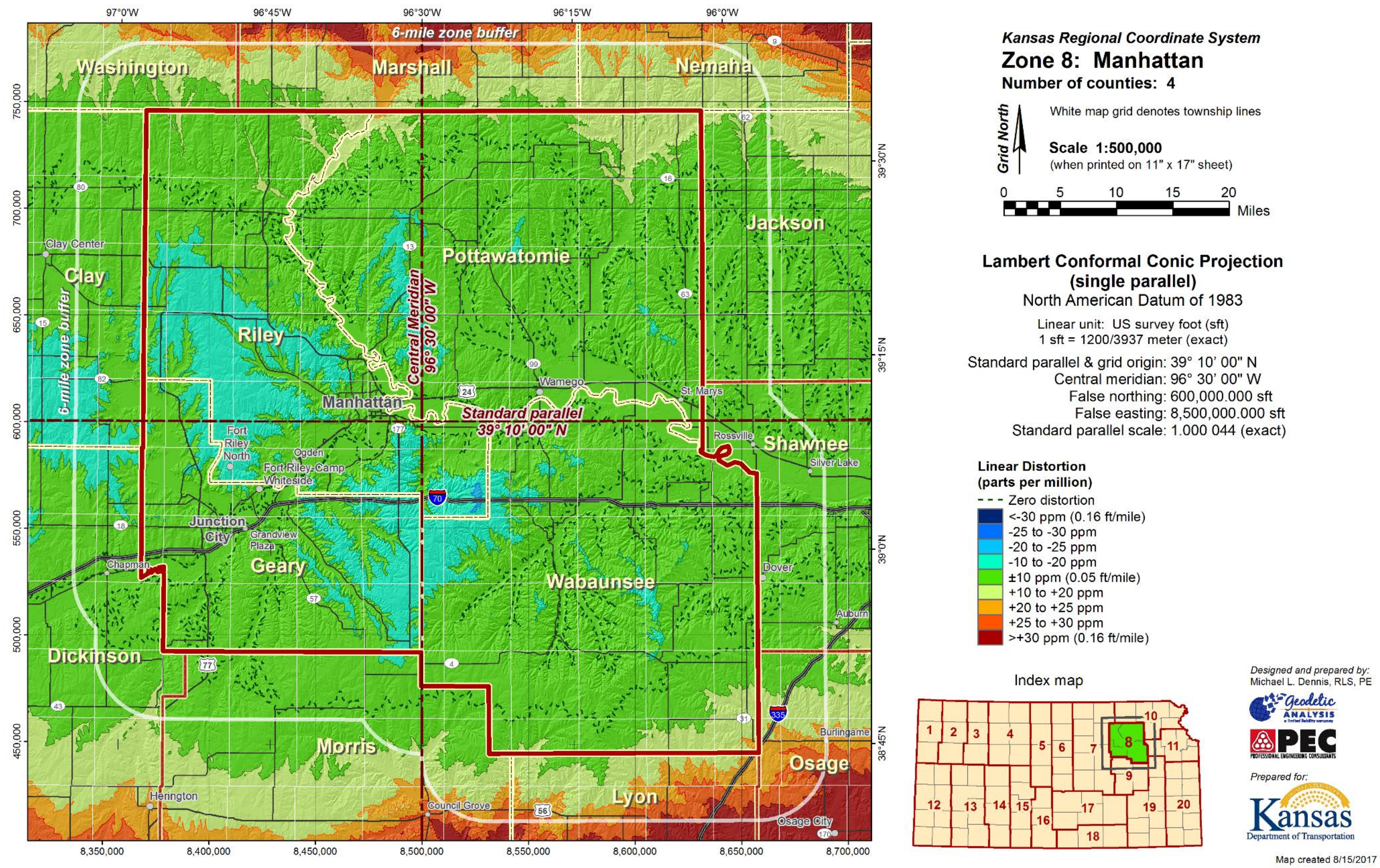

Figure B-8. Distortion map for Kansas Regional Coordinate System Zone 8 (Manhattan). Scale when printed on 8-1/2" × 11" sheet is 1:833,333 (60% of original size).

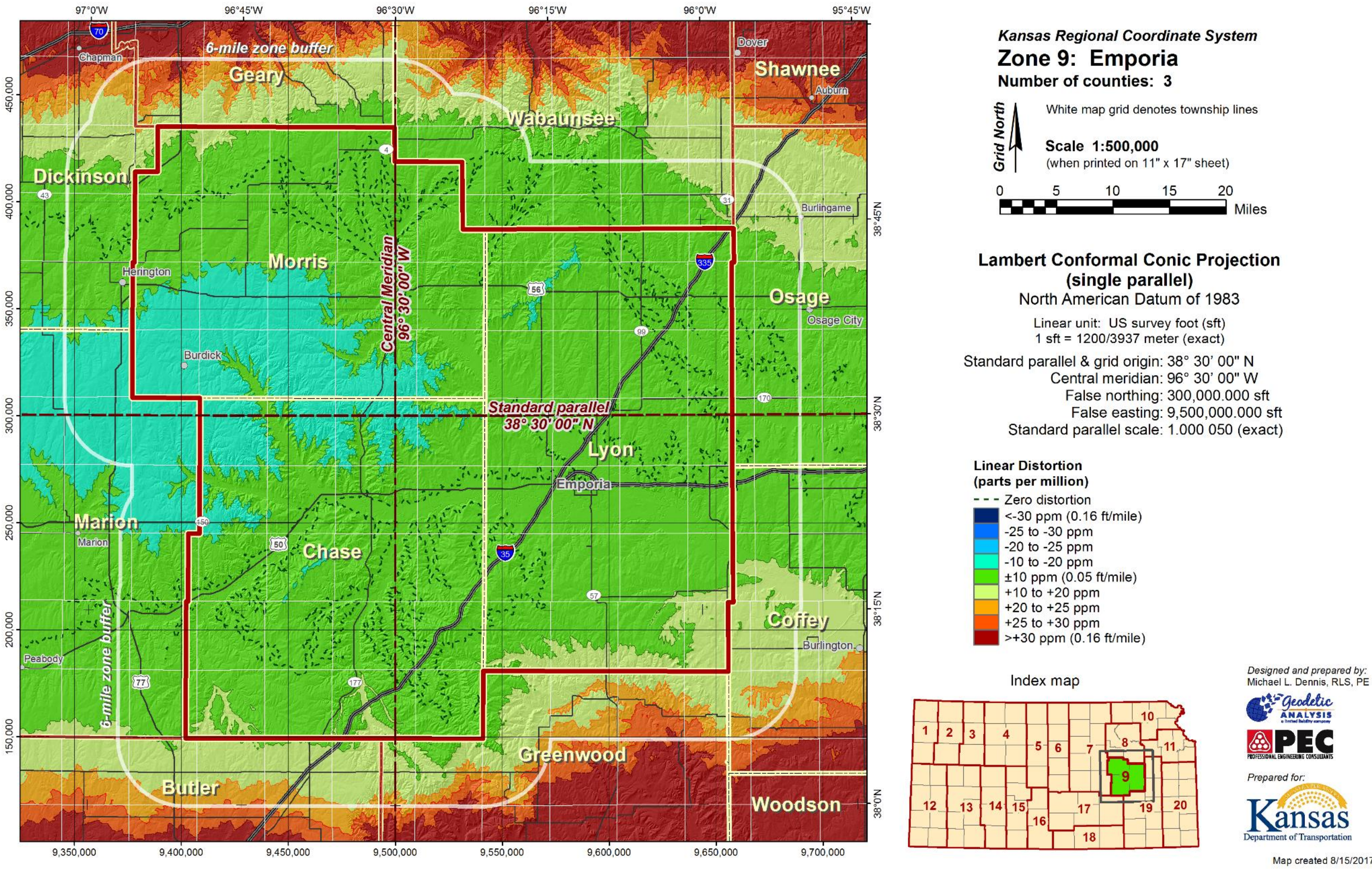

Figure B-9. Distortion map for Kansas Regional Coordinate System Zone 9 (Emporia). Scale when printed on 8-1/2" × 11" sheet is 1:833,333 (60% of original size).

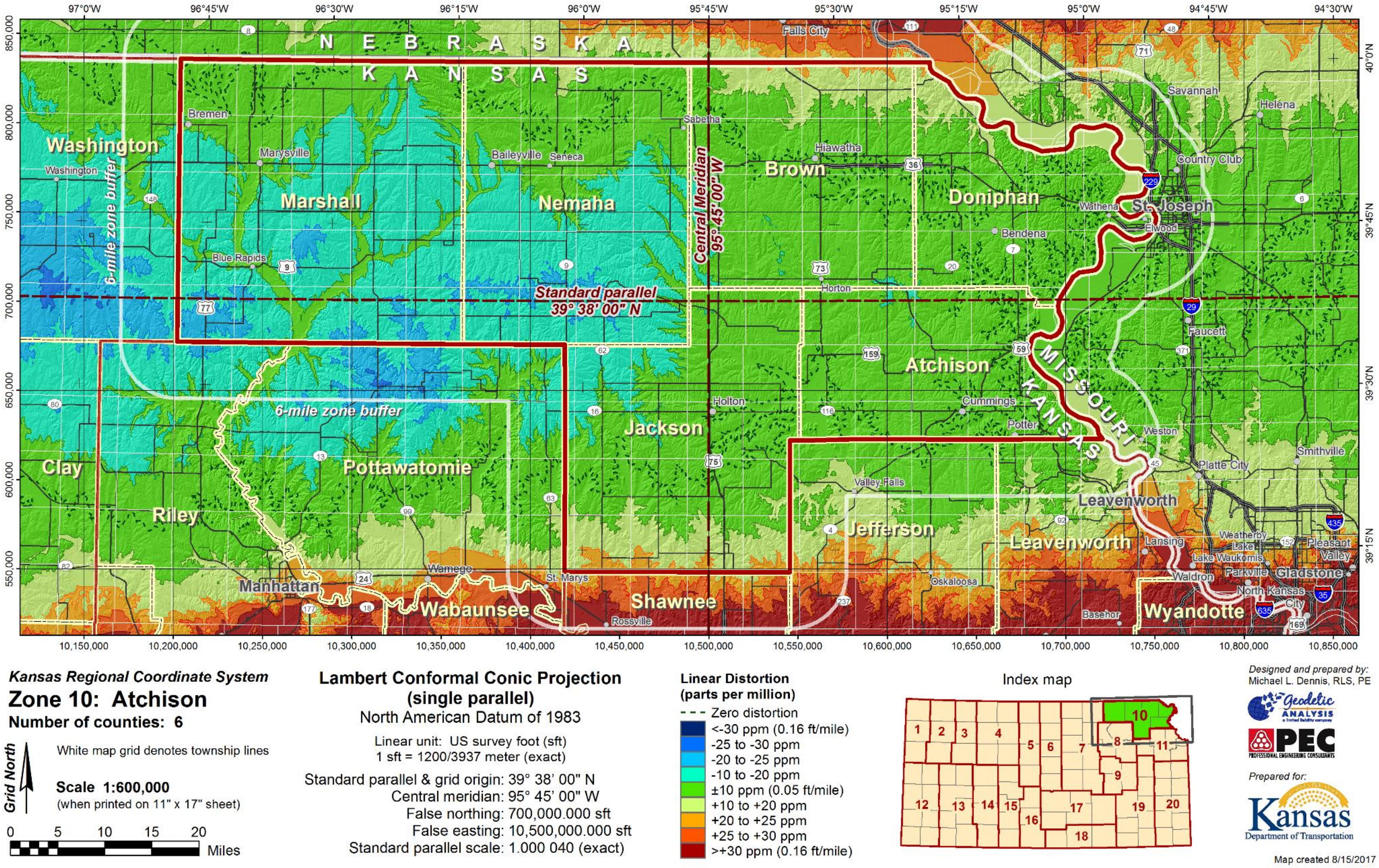

Figure B-10. Distortion map for Kansas Regional Coordinate System Zone 10 (Atchison). Scale when printed on 8-1/2" × 11" sheet is 1:1,000,000 (60% of original size).

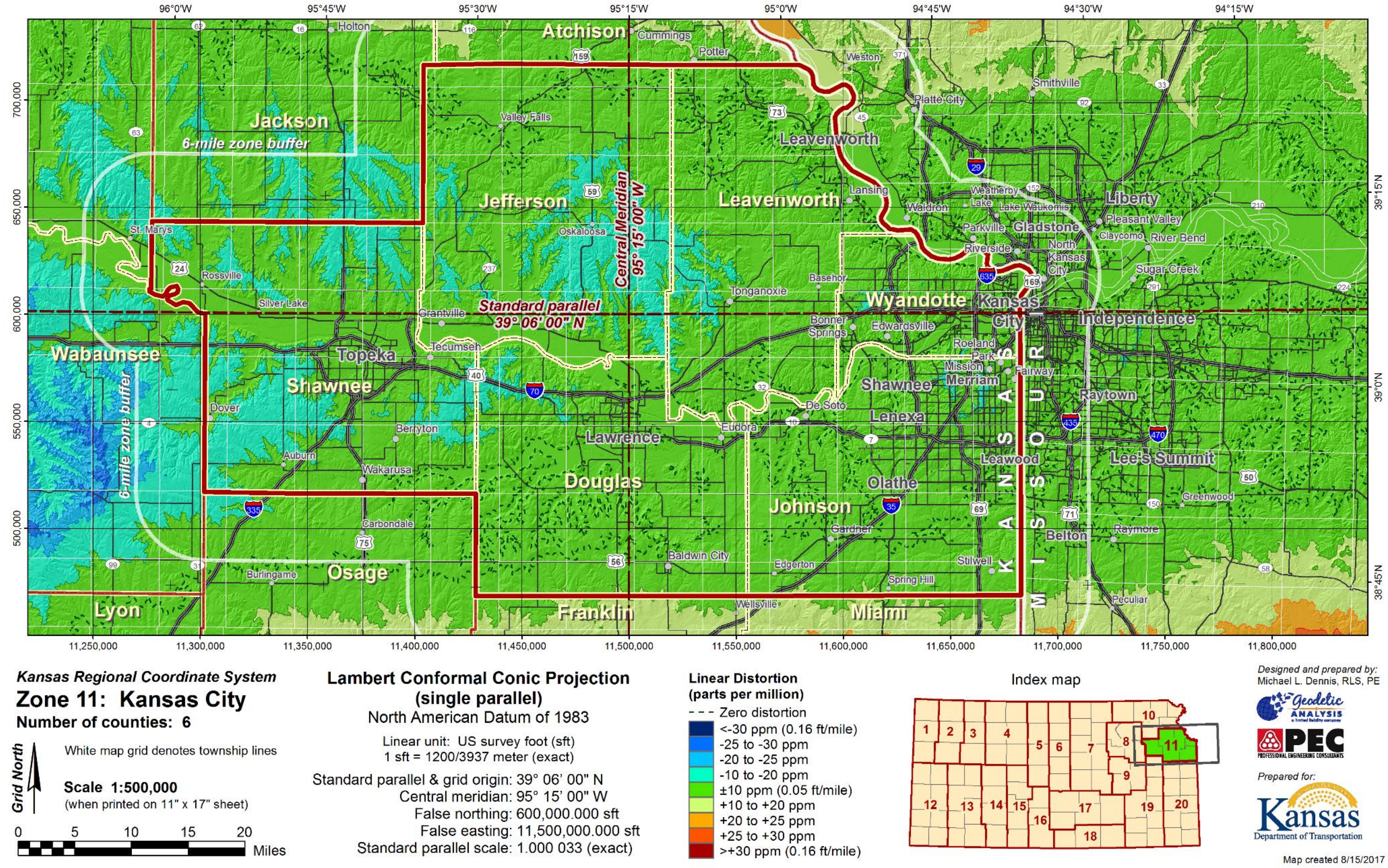

Figure B-11. Distortion map for Kansas Regional Coordinate System Zone 11 (Kansas City). Scale when printed on 8-1/2" × 11" sheet is 1:833,333 (60% of original size).

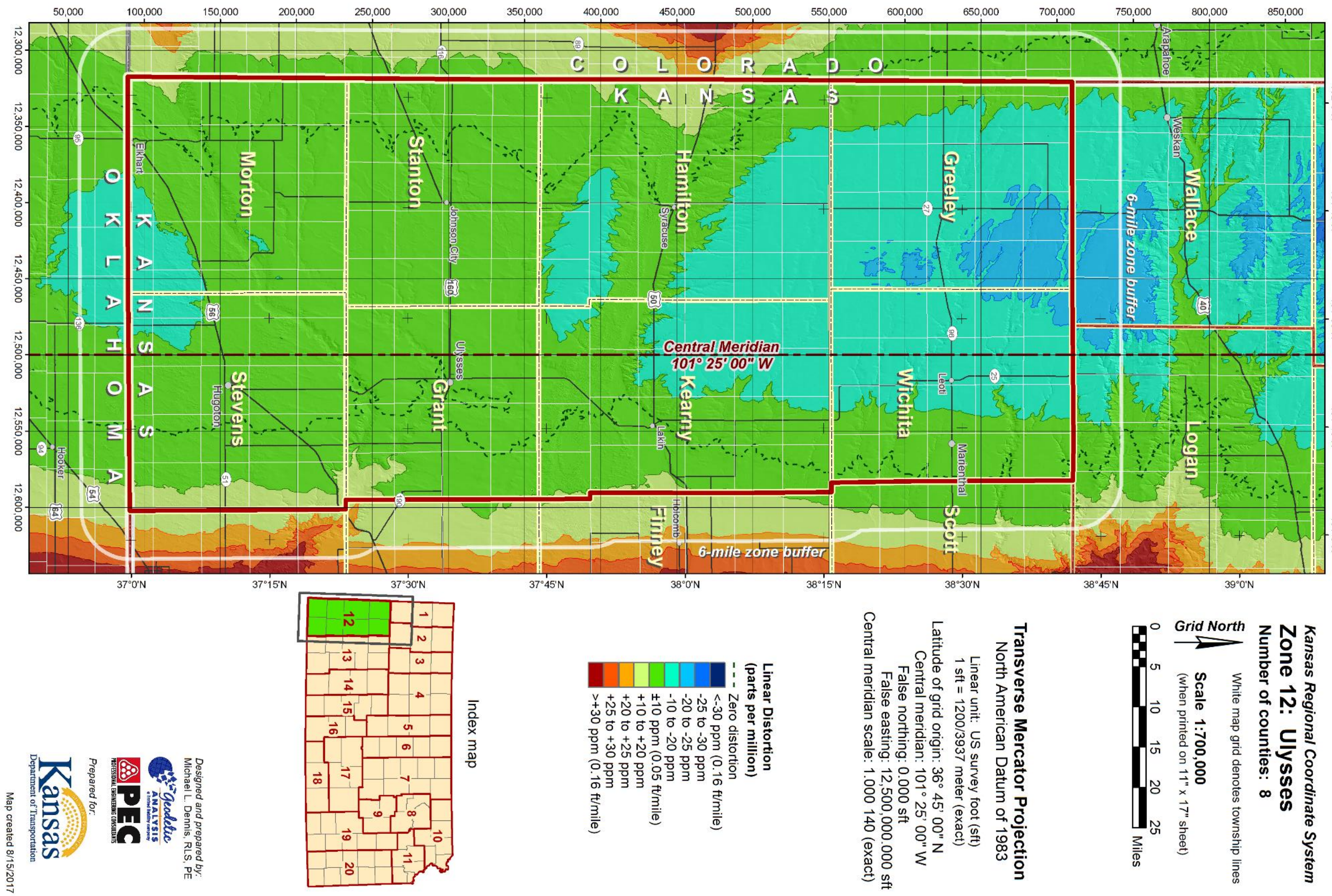

Figure B-12. Distortion map for Kansas Regional Coordinate System Zone 12 (Ulysses). Scale when printed on 8-1/2" × 11" sheet is 1:1,166,667 (60% of original size).

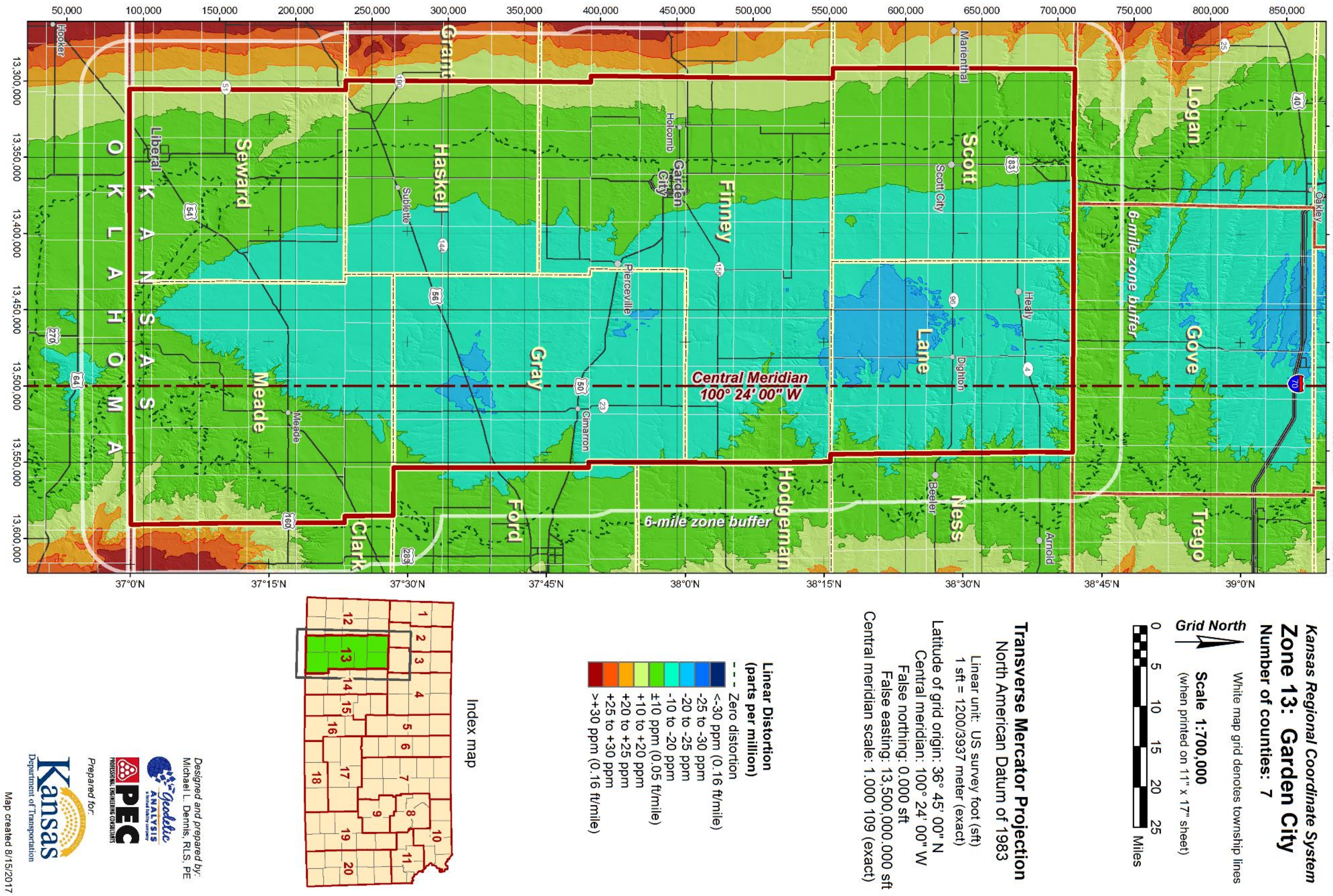

Figure B-13. Distortion map for Kansas Regional Coordinate System Zone 13 (Garden City). Scale when printed on 8-1/2" × 11" sheet is 1:1,166,667 (60% of original size).

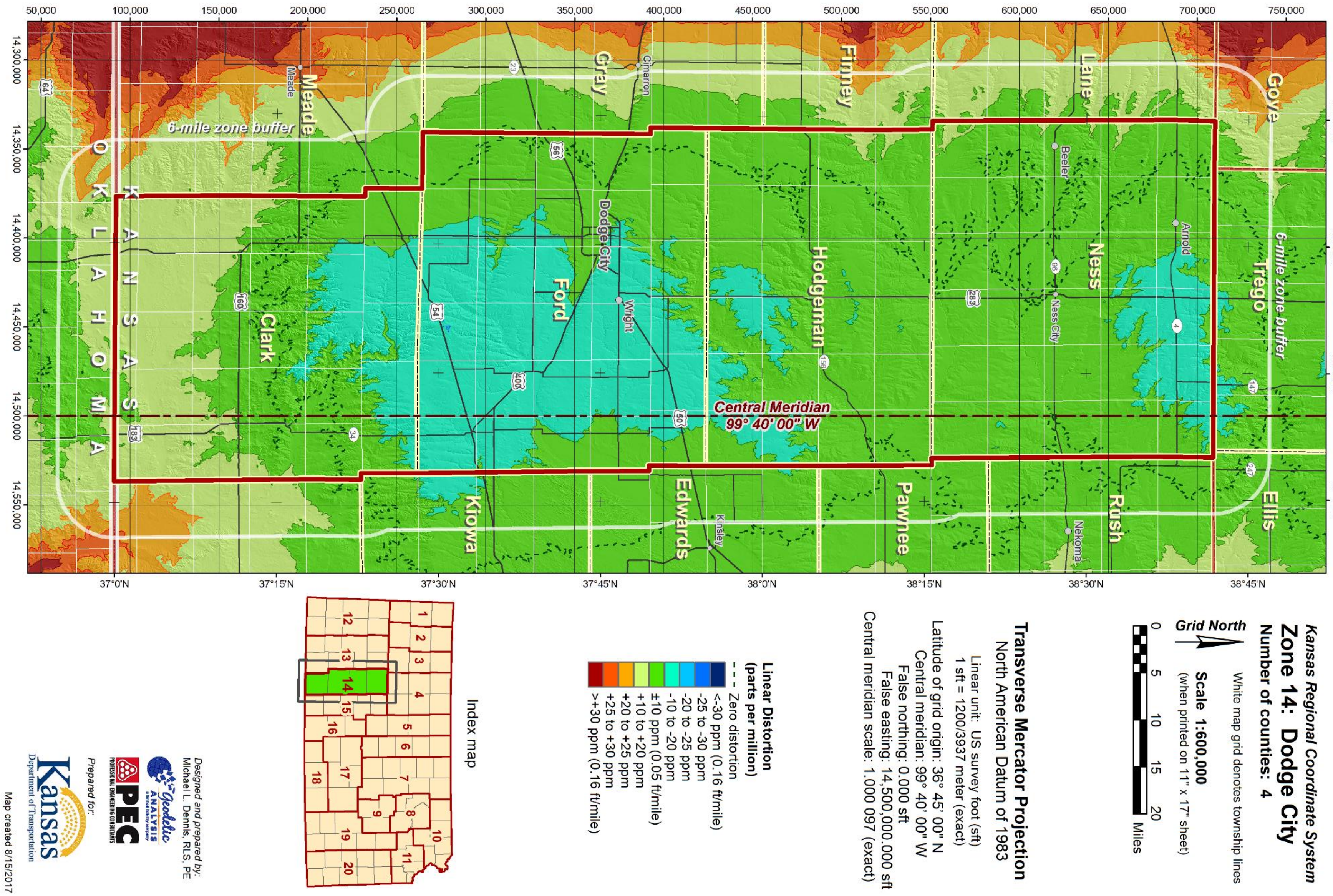

Figure B-14. Distortion map for Kansas Regional Coordinate System Zone 14 (Dodge City). Scale when printed on 8-1/2" × 11" sheet is 1:1,000,000 (60% of original size).

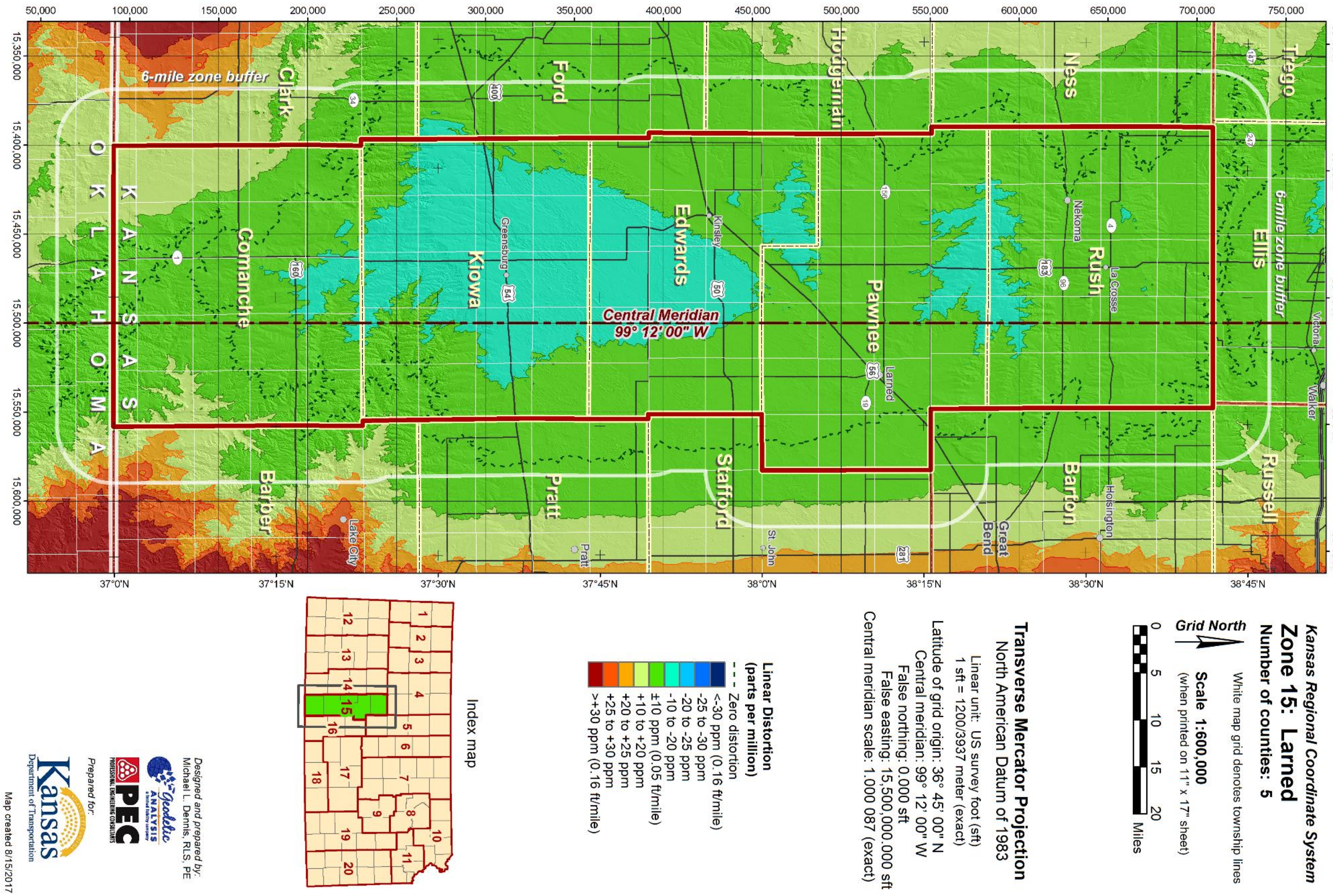

Figure B-15. Distortion map for Kansas Regional Coordinate System Zone 15 (Larned). Scale when printed on 8-1/2" × 11" sheet is 1:1,000,000 (60% of original size).

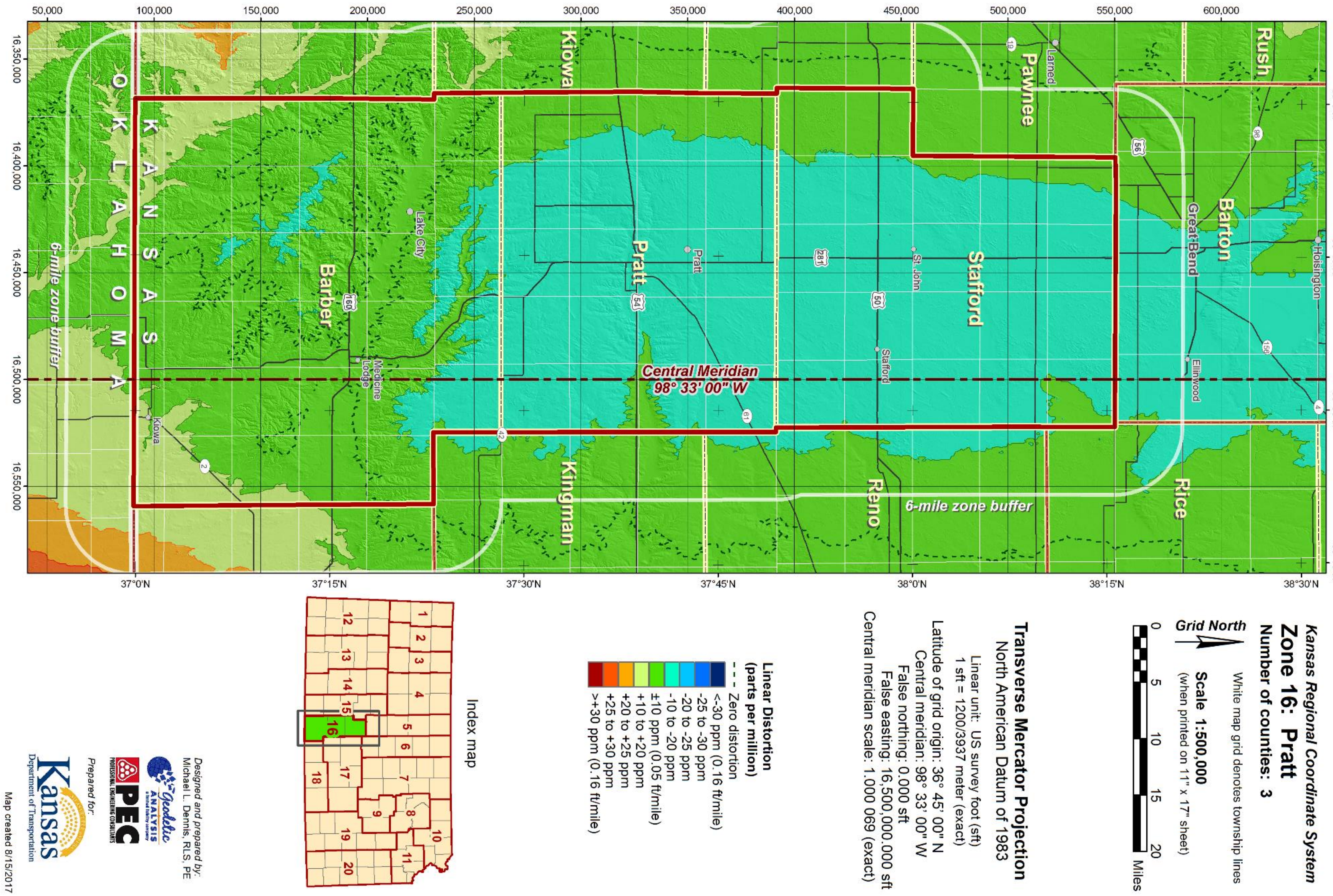

Figure B-16. Distortion map for Kansas Regional Coordinate System Zone 16 (Pratt). Scale when printed on 8-1/2" × 11" sheet is 1:833,333 (60% of original size).

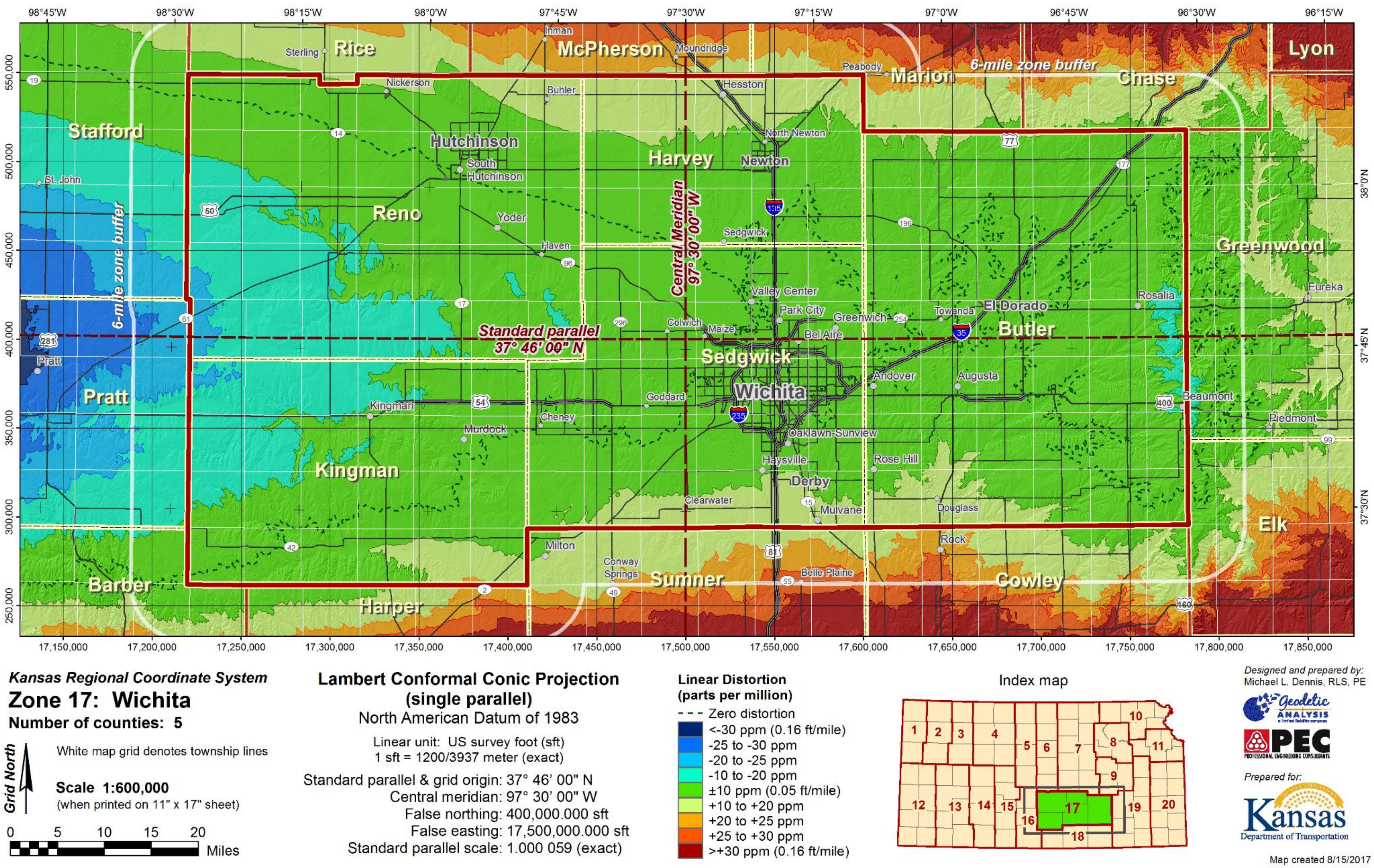

Figure B-17. Distortion map for Kansas Regional Coordinate System Zone 17 (Wichita). Scale when printed on 8-1/2" × 11" sheet is 1:1,000,000 (60% of original size).

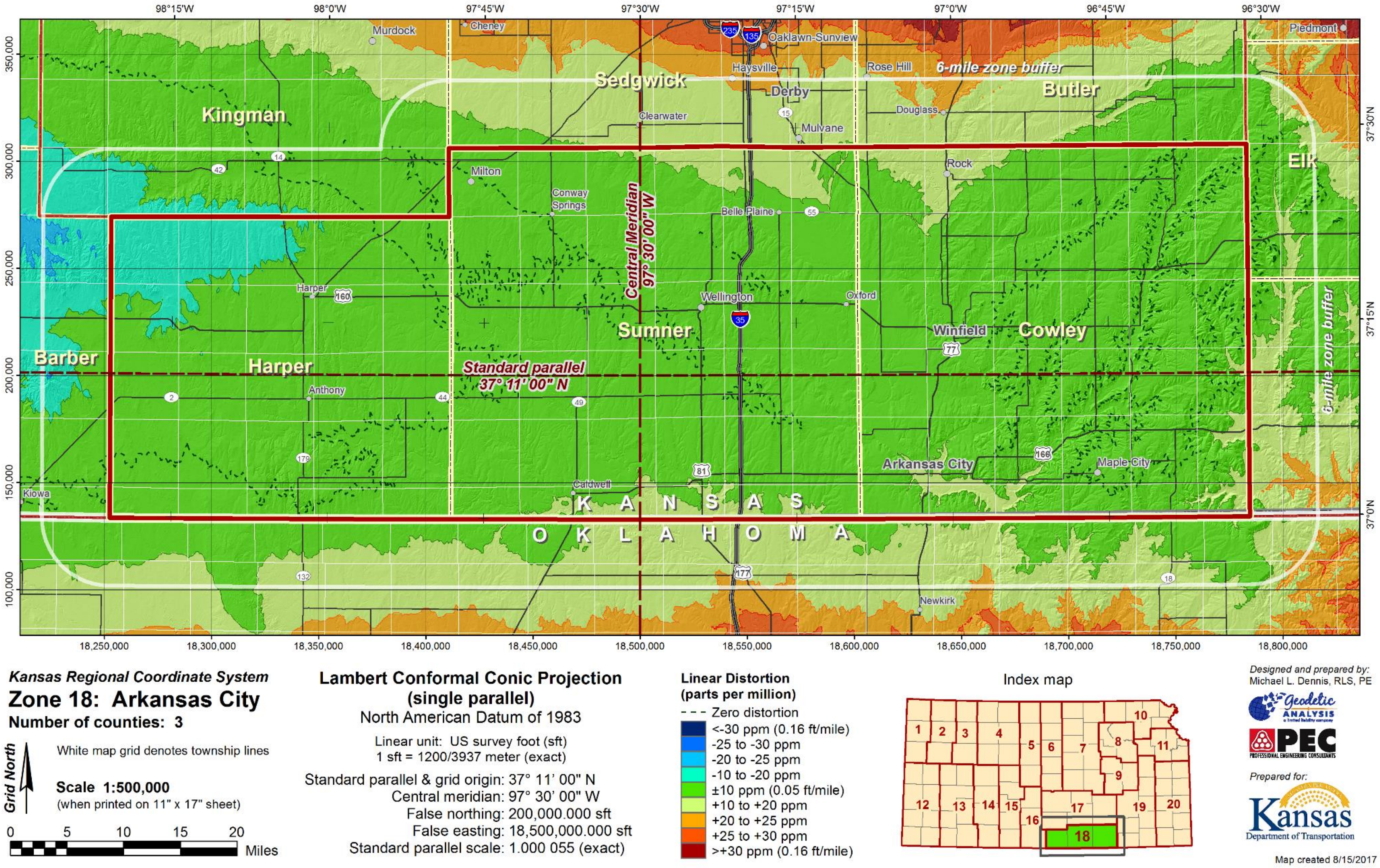

Figure B-18. Distortion map for Kansas Regional Coordinate System Zone 18 (Arkansas City). Scale when printed on 8-1/2" × 11" sheet is 1:833,333 (60% of original size).

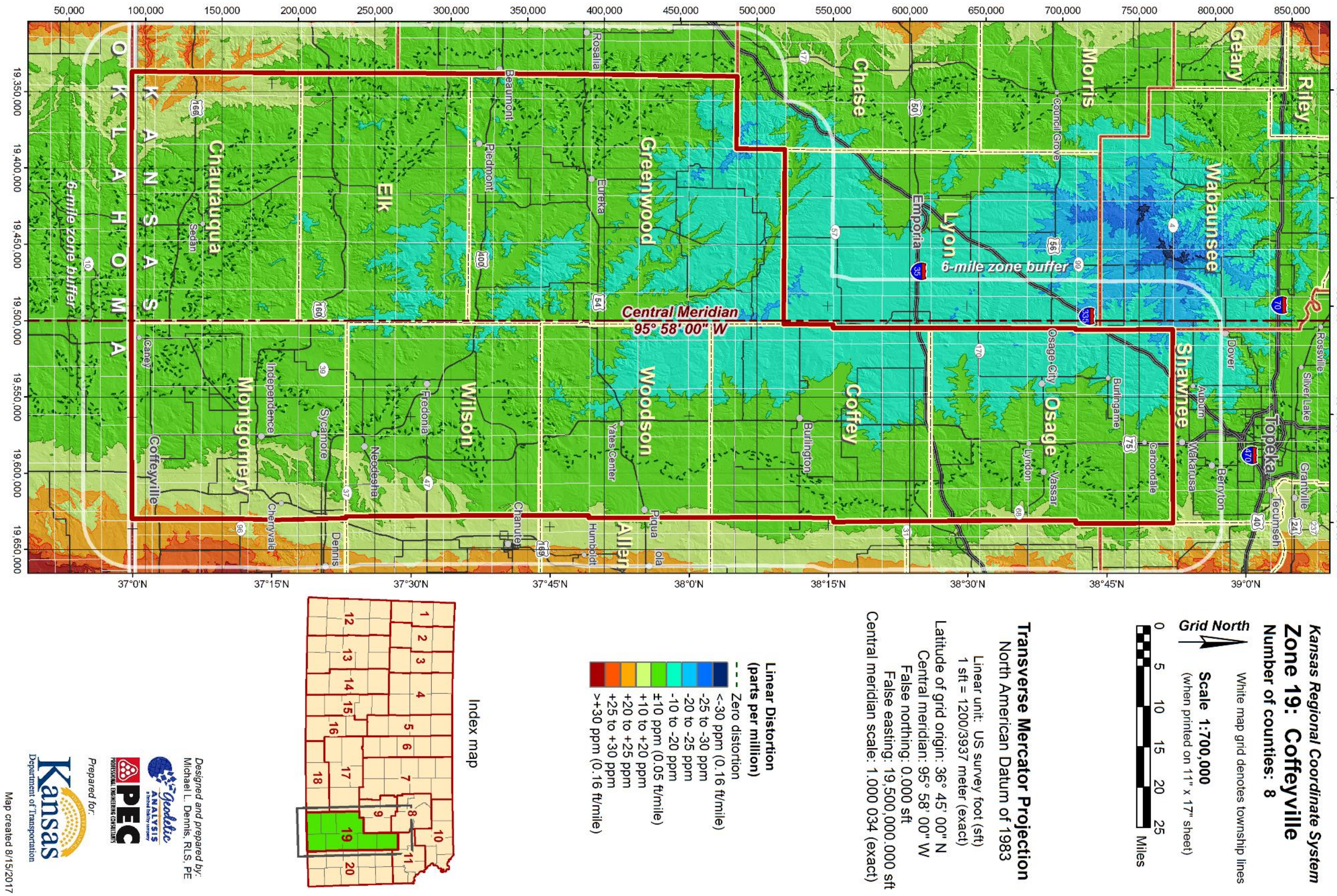

Figure B-19. Distortion map for Kansas Regional Coordinate System Zone 19 (Coffeyville). Scale when printed on 8-1/2" × 11" sheet is 1:1,166,667 (60% of original size).

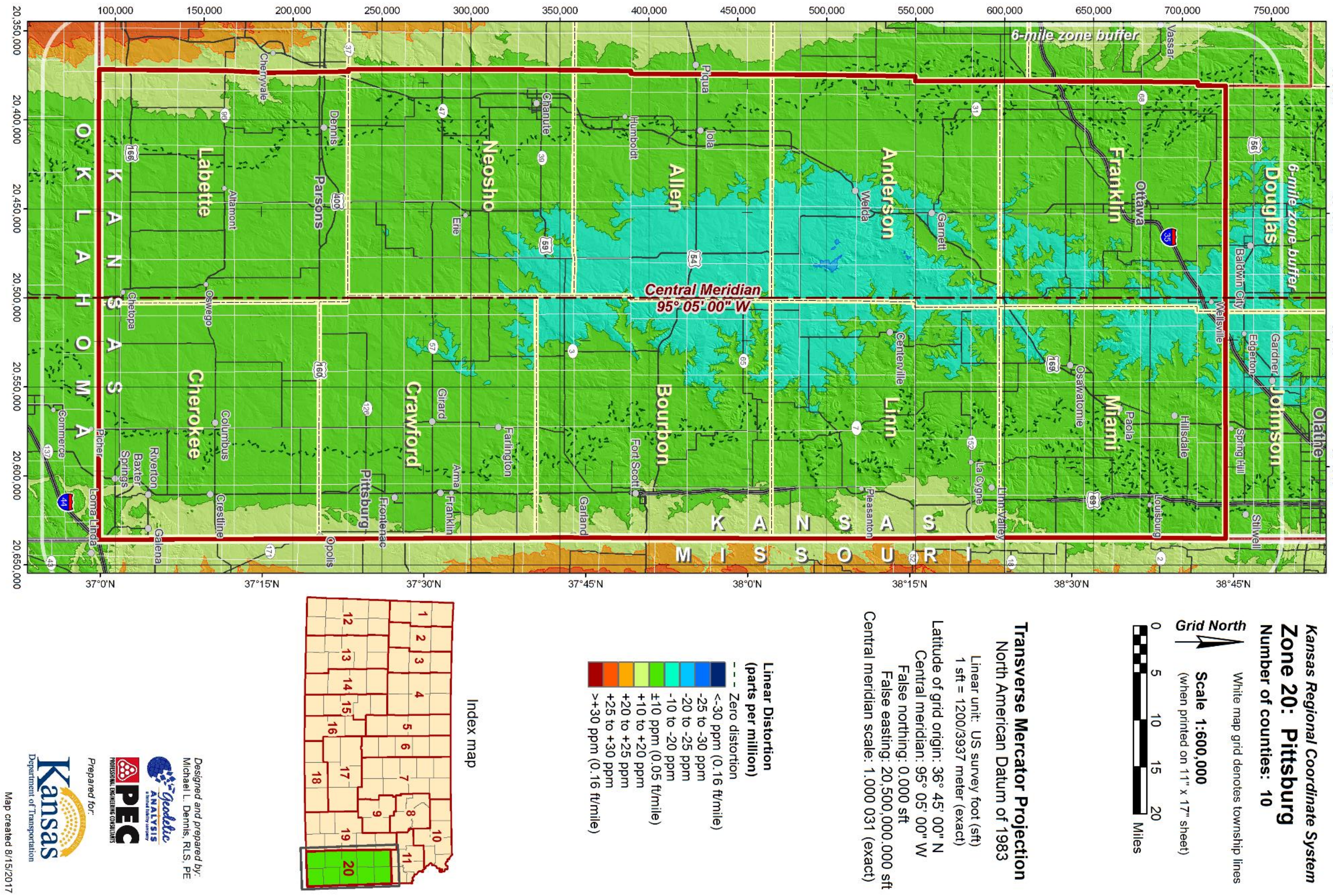

Figure B-20. Distortion map for Kansas Regional Coordinate System Zone 20 (Pittsburg). Scale when printed on 8-1/2" × 11" sheet is 1:1,000,000 (60% of original size).

C. KRCS coordinates and distortion for NGS NAD 83 (2011) epoch 2010.00 control

Tables C-1 and C-2 give Kansas Regional Coordinate System (KRCS) coordinates and distortion values, respectively, for 282 NGS-published NAD 83 (2011) epoch 2010.00 control stations in Kansas (including six currently operating CORS). The stations were not occupied or recovered to create these tables, and so some stations may presently be obstructed, removed, damaged, destroyed, or otherwise unavailable or unsuitable for use. The stations given here were obtained from the NGS Integrated Data Base (NGSIDB) on August 28, 2017, and represent the status of NGS control at that time. KRCS coordinates were computed directly from the NGS published latitude and longitude values using Geodetic Analysis software, and the ellipsoid heights (published in meters) were converted to US survey feet.

The NGS control station distortion values in Table C-2 are linear distortion, grid point scale factor, height scale factor, combined scale factor, and convergence (mapping) angle. Linear distortion is given in parts per million (ppm), feet per mile, and as a dimensionless ratio.

Table C-1. KRCS projected coordinates computed for NGS NAD 83 (2011) epoch 2010.00 control. The six currently operational (as of October 2017) Kansas CORS Antenna Reference Points (ARPs) are listed first. Stations are listed alphabetically by designation within each KRCS zone.

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	Latitude	Longitude	Ellipsoid ht (sft)	Northing (sft)	Easting (sft)
8. Manhattan	DI3428	KSU1_KSUN_KS2006 CORS ARP (KSU1)	39°06'02.67733"N	96°36'34.09360"W	1071.602	576,006.453	8,468,930.544
11. Kansas City	DF9221	KANSAS CTY WAAS 1 CORS ARP (ZKC1)	38°52'48.55022"N	94°47'26.96359"W	1005.700	520,254.208	11,630,725.741
17. Wichita	DK6487	WICHITA ICT1 CORS ARP (ICT1)	37°35'15.77366"N	97°18'31.95899"W	1195.575	334,888.964	17,555,384.960
17. Wichita	DK6491	WICHITA ICT3 CORS ARP (ICT3)	37°45'09.31280"N	97°12'58.38121"W	1319.984	394,997.055	17,582,054.640
17. Wichita	DK6493	WICHITA ICT4 CORS ARP (ICT4)	37°37'08.55552"N	97°37'56.95827"W	1290.152	346,268.055	17,461,622.625
17. Wichita	DK6495	WICHITA ICT5 CORS ARP (ICT5)	37°47'12.01949"N	97°37'32.69149"W	1352.307	407,309.768	17,463,657.248
1. Goodland	AC9422	GLD C	39°22'10.38286"N	101°41'57.87438"W	3568.530	680,989.763	1,471,890.299
1. Goodland	KH0542	R 100	39°31'30.94159"N	101°42'25.25216"W	3547.145	737,718.941	1,469,807.194
2. Colby	KH0159	A 302 RESET	39°07'09.24920"N	100°49'01.96649"W	2955.667	589,800.295	2,537,680.625
2. Colby	KH0214	D 154	39°25'06.67069"N	100°58'49.90487"W	2999.157	698,799.967	2,491,373.605
2. Colby	KH0839	K60 A AZ MK	39°50'05.27752"N	101°02'33.61768"W	2847.022	850,467.435	2,473,970.904
2. Colby	KH0562	OAKPORT 1986	39°07'01.42714"N	100°48'48.62332"W	2956.592	589,010.349	2,538,733.580
2. Colby	KH0842	OAKPORT 1989	39°06'59.52221"N	100°49'05.82017"W	2962.884	588,815.590	2,537,378.289
2. Colby	AH7032	OEL A	39°06'11.32970"N	100°48'54.64120"W	2935.821	583,940.348	2,538,266.736
3. Oberlin	KH0159	A 302 RESET	39°07'09.24920"N	100°49'01.96649"W	2955.667	590,103.185	3,367,422.387

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	Latitude	Longitude	Ellipsoid ht (sft)	Northing (sft)	Easting (sft)
3. Oberlin	KH0562	OAKPORT 1986	39°07'01.42714"N	100°48'48.62332"W	2956.592	589,306.300	3,368,470.101
3. Oberlin	KH0842	OAKPORT 1989	39°06'59.52221"N	100°49'05.82017"W	2962.884	589,120.499	3,367,113.552
3. Oberlin	AH7032	OEL A	39°06'11.32970"N	100°48'54.64120"W	2935.821	584,239.492	3,367,969.774
4. Hays	KG0480	A 365	39°18'22.84138"N	99°50'49.22147"W	2170.514	658,146.178	4,387,646.980
4. Hays	KG0481	B 365	39°19'42.59355"N	99°50'46.79348"W	2097.837	666,215.259	4,387,873.218
4. Hays	JG0343	D 164	38°51'02.49405"N	99°14'12.71714"W	1911.876	491,995.491	4,560,706.275
4. Hays	DI3132	HLC A	39°22'45.42023"N	99°49'58.81093"W	2127.095	684,698.880	4,391,722.431
4. Hays	DI3133	HLC B	39°23'11.54968"N	99°49'47.13498"W	2157.952	687,339.008	4,392,650.462
4. Hays	DI3134	HLC C	39°22'26.08419"N	99°49'59.82490"W	2105.294	682,742.634	4,391,634.500
4. Hays	JG0346	HYS AP STA A	38°51'11.88708"N	99°16'36.76726"W	1910.452	492,921.770	4,549,307.434
4. Hays	JG0347	HYS AP STA B	38°50'16.97747"N	99°16'21.05110"W	1899.324	487,368.465	4,550,561.623
4. Hays	JG0381	Q 267	38°51'24.63352"N	99°16'56.50566"W	1902.913	494,208.529	4,547,743.451
4. Hays	JG0582	X 301	38°59'30.30921"N	99°45'36.69778"W	2312.351	543,455.620	4,411,823.253
5. Great Bend	JG0176	B 30	38°21'48.26668"N	98°37'37.93869"W	1718.320	314,442.553	5,511,315.902
5. Great Bend	KG0215	DOWNS	39°30'09.81287"N	98°32'39.45004"W	1397.989	729,457.511	5,534,535.044
5. Great Bend	AE5424	GBD ARP	38°20'50.08807"N	98°51'49.16285"W	1797.575	308,614.475	5,443,499.010
5. Great Bend	KG0640	MEADES RANCH RESET	39°13'26.71220"N	98°32'31.74540"W	1883.070	627,957.186	5,535,278.919
5. Great Bend	KG0537	SMITH CENTER	39°45'37.83281"N	98°47'28.22238"W	1714.111	823,366.607	5,464,993.673
6. Beloit	KF0604	D 287	39°46'41.94796"N	97°57'05.42550"W	1389.850	829,883.915	6,555,793.599
6. Beloit	JG0958	LYONS RESET	38°20'51.50142"N	98°13'25.33532"W	1602.671	308,702.551	6,478,860.326
7. Salina	JF1039	A 214	38°38'53.71305"N	97°32'16.94700"W	1313.321	418,240.163	7,441,530.889
7. Salina	JF1057	C 292	38°47'01.05095"N	97°36'13.62173"W	1154.046	467,594.428	7,422,898.741
7. Salina	KF0790	CNK A	39°32'44.16959"N	97°39'08.55561"W	1387.438	745,191.329	7,410,021.742
7. Salina	JF1065	D 292	38°46'10.46995"N	97°36'13.11828"W	1156.989	462,476.805	7,422,923.489
7. Salina	JF0975	F 291	38°48'45.57883"N	97°43'34.02037"W	1165.749	478,296.484	7,388,068.831
7. Salina	JF1069	G 292	38°43'31.10243"N	97°36'14.04152"W	1180.273	446,353.179	7,422,802.707
7. Salina	JF1634	GARRISON	38°55'35.77645"N	97°47'42.05844"W	1384.695	519,890.623	7,368,644.393
7. Salina	KF0548	H 286	39°33'59.60721"N	97°37'31.81944"W	1281.799	752,798.977	7,417,624.890
7. Salina	AE5425	HBRK A	38°18'15.74309"N	97°17'53.48920"W	1374.456	292,932.657	7,510,085.112
7. Salina	AE5426	HBRK B	38°18'30.07438"N	97°17'53.17301"W	1371.086	294,382.507	7,510,109.765
7. Salina	JF1625	LODER RESET	38°38'23.64647"N	97°52'15.15583"W	1535.095	415,582.822	7,346,447.180
7. Salina	JF1586	NORTH POLE MOUND RESET	38°57'09.92371"N	97°36'32.32628"W	1376.083	529,202.193	7,421,603.505

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	Latitude	Longitude	Ellipsoid ht (sft)	Northing (sft)	Easting (sft)
7. Salina	JF0595	PARK	38°55'42.31449"N	97°23'25.86929"W	1140.575	520,224.694	7,483,730.214
7. Salina	JF1063	PUMP	38°47'28.85848"N	97°38'27.59409"W	1163.124	470,441.373	7,412,298.892
7. Salina	KF0306	Q 112	39°42'56.21677"N	96°55'08.88203"W	1276.021	807,233.464	7,616,529.218
7. Salina	AE1678	SALINA BASE STATION	38°48'01.61307"N	97°38'16.10819"W	1177.612	473,752.271	7,413,219.400
7. Salina	DF7126	SALINA BASE STATION ARP	38°48'01.61335"N	97°38'16.10854"W	1177.340	473,752.299	7,413,219.373
7. Salina	JF1012	SALINA EAST BASE	38°52'25.17130"N	97°31'58.83143"W	1108.994	500,335.534	7,443,147.302
7. Salina	DL6188	SLN A	38°47'13.55129"N	97°39'03.19058"W	1191.070	468,902.306	7,409,474.921
7. Salina	DL6187	SLN B	38°46'47.38423"N	97°39'07.82861"W	1187.317	466,256.140	7,409,098.423
7. Salina	DL6189	SLN C	38°47'42.48490"N	97°39'17.02601"W	1162.832	471,833.486	7,408,389.628
7. Salina	JF0638	SMOKY	38°58'09.56232"N	97°04'54.65633"W	1128.141	535,216.412	7,571,507.967
7. Salina	JF1604	TOTUM	38°48'45.06139"N	97°39'41.06384"W	1244.811	478,171.424	7,406,509.088
8. Manhattan	KF0798	3JC B	39°02'55.65248"N	96°50'37.13352"W	986.465	557,249.582	8,402,395.694
8. Manhattan	KF0142	DEEP	39°04'10.13620"N	96°29'08.18489"W	1177.747	564,601.213	8,504,086.795
8. Manhattan	KE0876	DRY	39°03'29.56100"N	95°59'14.02503"W	971.852	560,907.082	8,645,619.356
8. Manhattan	KF0138	EAST	39°03'51.61464"N	96°30'35.98265"W	1267.557	562,727.054	8,497,161.747
8. Manhattan	KF0291	GROVE	39°03'44.15701"N	96°32'00.63403"W	1348.885	561,974.101	8,490,484.304
8. Manhattan	KF0150	GUIDE	39°03'52.10046"N	96°25'57.33944"W	1362.806	562,783.163	8,519,140.634
8. Manhattan	KF0153	KAW	39°03'53.69390"N	96°24'25.52293"W	1407.002	562,950.785	8,526,382.790
8. Manhattan	DH7065	KST1 A	39°02'41.46659"N	96°02'21.75460"W	990.339	555,961.566	8,630,835.189
8. Manhattan	DH7064	KST1 B	39°03'07.28308"N	96°02'21.48680"W	982.357	558,573.718	8,630,843.054
8. Manhattan	KF0765	M 370	39°07'52.98806"N	96°40'21.91477"W	943.312	587,195.572	8,450,990.905
8. Manhattan	KF0197	MAPLE	39°03'30.39685"N	96°00'57.19014"W	932.236	560,946.937	8,637,480.825
8. Manhattan	AJ8083	MHK A	39°08'05.84281"N	96°40'41.63731"W	947.436	588,499.219	8,449,439.256
8. Manhattan	AJ8084	MHK B	39°08'18.40548"N	96°39'55.17946"W	944.237	589,763.375	8,453,102.427
8. Manhattan	AJ8085	MHK C	39°08'38.81823"N	96°40'07.17799"W	945.989	591,830.475	8,452,160.836
8. Manhattan	KF0179	MILL	39°03'39.15369"N	96°10'34.00520"W	1012.550	561,630.302	8,591,976.089
8. Manhattan	KF0766	N 370	39°09'27.93372"N	96°37'34.12935"W	929.755	596,780.393	8,464,226.341
8. Manhattan	KF0680	OGDEN	39°04'00.43403"N	96°47'34.83179"W	1167.750	563,753.597	8,416,799.602
8. Manhattan	KF0249	PLAZA	39°01'38.37276"N	96°47'39.69553"W	1138.879	549,381.350	8,416,369.335
8. Manhattan	KF0047	POTT	39°03'56.74736"N	96°17'19.59604"W	1117.416	563,316.045	8,559,978.171
8. Manhattan	KF0162	POWER	39°03'54.85551"N	96°18'59.19929"W	1245.936	563,107.536	8,552,122.192
8. Manhattan	KF0191	VERA	39°03'33.48884"N	96°04'35.54175"W	1069.217	561,173.617	8,620,254.924

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	Latitude	Longitude	Ellipsoid ht (sft)	Northing (sft)	Easting (sft)
9. Emporia	AH5750	EMP A	38°19'57.43501"N	96°11'23.41844"W	1105.975	239,189.499	9,588,976.745
9. Emporia	AH5751	EMP B	38°19'31.84364"N	96°11'31.41438"W	1100.434	236,598.371	9,588,348.239
9. Emporia	AH5752	EMP C	38°20'15.96405"N	96°11'18.10558"W	1085.693	241,065.447	9,589,393.761
9. Emporia	JF1376	LYON	38°19'52.73816"N	96°11'17.46294"W	1107.281	238,715.939	9,589,452.927
9. Emporia	JF0232	MORRIS RM 3	38°24'45.59784"N	96°04'47.25871"W	1066.822	268,467.183	9,620,412.135
9. Emporia	JF0142	Q 13	38°24'04.92508"N	96°10'17.02088"W	1044.325	264,245.649	9,594,178.336
10. Atchison	KE1727	ATCHPORT	39°34'08.59881"N	95°10'47.40323"W	962.068	677,095.225	10,660,744.440
10. Atchison	AE5422	BUTT RESET	39°14'44.42264"N	95°48'02.85580"W	1065.250	558,791.724	10,485,613.357
10. Atchison	LG0754	ELK RESET	40°00'02.59351"N	96°34'55.11698"W	1189.847	834,915.576	10,266,902.512
10. Atchison	KF0339	G 106	39°53'08.48710"N	96°38'58.08461"W	1077.721	793,194.370	10,247,574.336
10. Atchison	KE0998	SKIRT RM 2	39°30'45.14730"N	95°44'54.09800"W	1044.821	655,998.458	10,500,462.581
10. Atchison	KE0493	W 281	39°34'20.78222"N	95°08'44.71888"W	894.388	678,390.811	10,670,343.752
11. Kansas City	KE0765	AP STA B	39°03'54.88967"N	95°36'50.03971"W	770.140	587,548.548	11,396,669.072
11. Kansas City	KE1084	B 276 RESET	39°00'01.55678"N	95°13'59.28264"W	711.901	563,734.092	11,504,793.549
11. Kansas City	KE1062	C 367	39°04'50.60855"N	95°42'44.35346"W	784.483	593,313.068	11,368,751.061
11. Kansas City	JE1585	C 371	38°58'19.32670"N	95°16'44.80418"W	890.225	553,391.698	11,491,722.545
11. Kansas City	KE1204	ECKMAN RESET	39°02'32.58026"N	95°00'07.21342"W	898.906	579,109.888	11,570,442.429
11. Kansas City	AA2874	EPA BASE STATION KANSAS CITY	39°08'33.94259"N	94°36'44.18524"W	679.664	616,210.579	11,680,885.903
11. Kansas City	AC9461	FOE ARP	38°57'01.39179"N	95°39'53.27496"W	951.438	545,774.550	11,382,025.252
11. Kansas City	AJ8115	FOE B	38°57'45.59893"N	95°40'21.88586"W	962.875	550,257.624	11,379,785.704
11. Kansas City	AJ8075	FOE C	38°56'43.53647"N	95°39'07.32179"W	932.852	543,951.718	11,385,647.719
11. Kansas City	AJ8074	FOE D	38°57'24.61969"N	95°39'56.60920"W	955.218	548,125.835	11,381,772.589
11. Kansas City	DF7132	GABLEMANN=LV51	39°03'04.66046"N	95°08'59.97056"W	789.103	582,275.164	11,528,403.412
11. Kansas City	KE0864	GOLDEN	39°02'03.95398"N	95°38'38.49843"W	882.331	576,360.156	11,388,065.632
11. Kansas City	DF7125	JCBASE	38°51'52.30770"N	94°50'46.15899"W	953.102	514,489.102	11,614,998.338
11. Kansas City	DF7124	JCPW 1023	38°44'19.28927"N	95°03'22.86693"W	956.917	468,458.503	11,555,240.830
11. Kansas City	AE5428	KAN1 A	39°07'23.24300"N	95°24'50.14375"W	822.472	608,464.357	11,453,489.655
11. Kansas City	AE5429	KAN1 B	39°07'33.75345"N	95°24'27.93610"W	835.510	609,524.690	11,455,241.726
11. Kansas City	JE1579	KANWAKA	38°59'34.43813"N	95°23'46.79421"W	1026.113	561,023.373	11,458,405.946
11. Kansas City	AE5430	KNOX KNOB TOP 2 RESET	39°00'34.83012"N	95°44'11.65117"W	1039.634	567,470.416	11,361,728.328
11. Kansas City	KE1660	LAKE 2	39°10'23.39712"N	94°46'26.56268"W	766.130	627,003.711	11,634,943.197
11. Kansas City	JE1763	LAST	38°52'34.21575"N	95°36'47.04291"W	990.438	518,680.105	11,396,630.222

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11. Kansas City	KE1085	LLOYD	39°00'21.90768"N	95°12'49.72823"W	724.205	565,794.732	11,510,283.950
11. Kansas City	KE1086	LLOYD AZ MK	39°00'49.72676"N	95°12'59.04378"W	725.054	568,609.094	11,509,547.519
11. Kansas City	DF7122	LOPATA=LV50	39°18'51.24871"N	95°09'40.21047"W	976.888	678,047.476	11,525,135.161
11. Kansas City	AJ8082	LWC A	39°00'31.76742"N	95°13'00.37732"W	725.671	566,791.987	11,509,442.922
11. Kansas City	JE1988	MARTY 2	38°59'22.91862"N	94°40'15.89424"W	981.566	560,348.694	11,664,560.977
11. Kansas City	KE1661	MT HOPE 3	39°07'42.87009"N	94°40'38.12724"W	902.226	610,920.429	11,662,486.585
11. Kansas City	KE0867	N 346	39°01'46.60192"N	95°37'28.20337"W	899.959	574,581.077	11,393,605.379
11. Kansas City	KE1068	N 367	39°02'37.26726"N	95°35'41.74833"W	814.523	579,673.952	11,402,025.790
11. Kansas City	JE2044	NAVY	38°50'23.52284"N	94°54'21.36014"W	947.744	505,436.303	11,598,010.108
11. Kansas City	AJ8091	OJC D	38°50'53.57604"N	94°44'11.70473"W	969.125	508,704.541	11,646,232.823
11. Kansas City	AJ8092	OJC E	38°51'07.35491"N	94°44'10.80901"W	986.232	510,098.994	11,646,295.807
11. Kansas City	AJ8093	OJC F	38°50'37.66650"N	94°44'18.87017"W	951.242	507,091.724	11,645,674.978
11. Kansas City	KE1177	OVERLOOK	39°09'06.65369"N	94°39'04.44786"W	778.876	619,444.980	11,669,813.045
11. Kansas City	KE1145	PARKER	39°06'48.92179"N	94°37'06.56997"W	733.447	605,572.646	11,679,196.114
11. Kansas City	KE1662	PIPER 2	39°08'35.18008"N	94°51'28.54066"W	899.919	615,940.873	11,611,208.084
11. Kansas City	DF7130	SIMMONS RESET	38°47'04.77727"N	95°26'05.04393"W	1089.591	485,196.271	11,447,335.956
11. Kansas City	JE2097	STANLEY 2	38°51'16.42806"N	94°44'31.14943"W	995.690	511,007.905	11,644,681.491
11. Kansas City	DG6508	TOP A 2004	39°04'12.46859"N	95°37'20.80627"W	776.330	589,336.962	11,394,249.628
11. Kansas City	DG6500	TOP B	39°04'25.95047"N	95°37'39.51041"W	776.498	590,707.106	11,392,780.097
11. Kansas City	DF7123	TT 20 L	38°50'28.96824"N	95°16'10.56000"W	996.320	505,802.246	11,494,416.890
11. Kansas City	KE0893	VALENCIA	39°03'29.85967"N	95°53'24.68303"W	964.394	585,449.685	11,318,198.579
11. Kansas City	DF7121	VALENCIA 2	39°03'31.03350"N	95°53'26.14193"W	966.002	585,569.258	11,318,084.335
11. Kansas City	KE1664	WY 01	39°11'19.16782"N	94°48'03.11401"W	650.150	632,607.791	11,627,311.382
11. Kansas City	KE1665	WY 02	39°11'15.97286"N	94°47'17.01574"W	666.649	632,302.730	11,630,942.710
11. Kansas City	KE1666	WY 03	39°11'12.64826"N	94°54'01.36030"W	883.299	631,824.143	11,599,106.259
11. Kansas City	KE1667	WY 04	39°11'12.05439"N	94°51'50.40475"W	754.815	631,805.803	11,609,417.996
11. Kansas City	KE1668	WY 05	39°11'04.45086"N	94°49'35.70882"W	787.006	631,083.735	11,620,027.588
11. Kansas City	KE1669	WY 06	39°09'57.99650"N	94°49'36.54363"W	844.549	624,359.675	11,619,993.174
11. Kansas City	KE1670	WY 07	39°09'42.44683"N	94°44'01.44657"W	906.465	622,922.860	11,646,395.365
11. Kansas City	KE1671	WY 08	39°09'53.18257"N	94°41'24.55924"W	656.390	624,082.265	11,658,746.292
11. Kansas City	KE1672	WY 09	39°09'27.87848"N	94°54'02.45822"W	862.853	621,223.329	11,599,060.568
11. Kansas City	KE1673	WY 10	39°09'27.56325"N	94°51'50.45467"W	849.421	621,233.515	11,609,458.984
11. Kansas City	KE1674	WY 11	39°09'07.91012"N	94°37'19.04174"W	644.854	619,628.168	11,678,115.865

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11. Kansas City	KE1675	WY 12	39°09'01.45623"N	94°47'22.20197"W	726.885	618,690.507	11,630,603.340
11. Kansas City	KE1676	WY 13	39°08'33.57236"N	94°49'12.13227"W	885.868	615,826.831	11,621,956.317
11. Kansas City	KE1677	WY 14	39°08'35.09671"N	94°44'02.22583"W	921.763	616,108.192	11,646,372.692
11. Kansas City	KE1678	WY 15	39°08'34.66908"N	94°41'41.39979"W	862.636	616,130.341	11,657,468.406
11. Kansas City	KE1679	WY 16	39°08'34.55519"N	94°39'33.06243"W	828.640	616,182.593	11,667,579.960
11. Kansas City	KE1680	WY 17	39°08'15.54374"N	94°37'10.46515"W	721.091	614,334.596	11,678,828.275
11. Kansas City	DI2811	WY 17 OLD	39°08'15.54193"N	94°37'10.46518"W	722.269	614,334.413	11,678,828.274
11. Kansas City	KE1681	WY 18	39°07'43.56747"N	94°54'04.30871"W	840.464	610,668.763	11,598,955.321
11. Kansas City	KE1682	WY 19	39°07'42.79326"N	94°52'11.80002"W	918.548	610,625.997	11,607,821.898
11. Kansas City	KE1683	WY 20	39°07'42.72771"N	94°50'23.11272"W	923.610	610,656.619	11,616,387.045
11. Kansas City	KE1684	WY 21	39°07'42.53579"N	94°48'16.11182"W	891.665	610,684.340	11,626,395.451
11. Kansas City	KE1685	WY 22	39°07'43.49085"N	94°46'24.57560"W	903.131	610,825.574	11,635,184.550
11. Kansas City	KE1686	WY 23	39°07'42.29238"N	94°44'40.66749"W	889.939	610,748.566	11,643,373.653
11. Kansas City	KE1687	WY 24	39°07'42.64824"N	94°42'32.27006"W	842.741	610,842.844	11,653,491.764
11. Kansas City	KE1688	WY 25	39°07'42.88992"N	94°38'26.64827"W	692.830	610,989.839	11,672,847.666
11. Kansas City	KE1689	WY 26	39°06'57.78241"N	94°54'08.43979"W	872.567	606,035.080	11,598,647.498
11. Kansas City	KE1690	WY 27	39°06'57.57270"N	94°52'02.66931"W	914.831	606,053.704	11,608,560.713
11. Kansas City	KE1691	WY 28	39°06'59.82036"N	94°48'43.24317"W	893.200	606,352.105	11,624,278.200
11. Kansas City	KE1692	WY 29	39°06'58.88044"N	94°46'05.73291"W	858.299	606,319.849	11,636,693.375
11. Kansas City	KE1693	WY 30	39°07'00.28299"N	94°44'25.39820"W	807.065	606,504.903	11,644,600.790
11. Kansas City	KE1694	WY 31	39°07'00.15040"N	94°41'36.38029"W	858.588	606,569.659	11,657,922.471
11. Kansas City	KE1695	WY 32	39°07'00.98264"N	94°39'37.64341"W	831.173	606,712.894	11,667,280.470
11. Kansas City	KE1696	WY 33	39°06'05.93641"N	94°50'06.21343"W	897.334	600,869.573	11,617,763.525
11. Kansas City	KE1697	WY 34	39°06'08.05666"N	94°38'20.36994"W	791.294	601,398.293	11,673,406.956
11. Kansas City	KE1698	WY 35	39°05'49.71323"N	94°52'54.80665"W	921.284	599,170.874	11,604,479.110
11. Kansas City	KE1699	WY 36	39°05'44.04817"N	94°45'38.19648"W	798.243	598,760.156	11,638,904.537
11. Kansas City	KE1700	WY 37	39°05'41.83521"N	94°41'11.73563"W	654.369	598,657.985	11,659,914.044
11. Kansas City	KE1701	WY 38	39°06'01.85665"N	94°40'00.39398"W	796.980	600,719.172	11,665,525.739
11. Kansas City	KE1702	WY 39	39°05'12.93054"N	94°54'31.48831"W	829.637	595,419.539	11,596,870.681
11. Kansas City	KE1703	WY 40	39°05'13.99061"N	94°48'02.29620"W	866.055	595,660.329	11,627,558.531
11. Kansas City	KE1704	WY 41	39°05'15.61622"N	94°43'26.22271"W	654.966	595,941.665	11,649,326.189
11. Kansas City	KE1705	WY 42	39°04'21.00599"N	94°52'54.75758"W	861.596	590,195.746	11,604,519.346
11. Kansas City	KE1706	WY 43	39°04'23.39154"N	94°41'16.16691"W	788.319	590,719.203	11,659,613.787

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11. Kansas City	KE1707	WY 44	39°04'20.02729"N	94°38'25.78633"W	680.028	590,465.476	11,673,053.294
11. Kansas City	KE1708	WY 45	39°04'41.88325"N	94°36'43.19548"W	801.449	592,732.312	11,681,128.772
11. Kansas City	KE1709	WY 46	39°03'53.74153"N	94°51'39.10417"W	673.942	587,462.084	11,610,497.767
11. Kansas City	KE1710	WY 47	39°03'56.56138"N	94°45'07.57717"W	656.557	587,898.151	11,641,378.209
11. Kansas City	KE1711	WY 48	39°03'28.79224"N	94°54'31.35003"W	767.098	584,883.176	11,596,921.167
11. Kansas City	KE1712	WY 49	39°03'28.91528"N	94°48'57.42247"W	665.615	585,008.030	11,623,262.564
11. Kansas City	KE1713	WY 50	39°02'38.56359"N	94°41'11.37398"W	861.799	580,115.517	11,660,057.574
11. Kansas City	KE1714	WY 51	39°00'51.63858"N	94°54'31.55376"W	680.947	568,982.865	11,596,964.819
11. Kansas City	KE1715	WY 52	39°10'47.42325"N	94°47'55.04344"W	741.078	629,399.071	11,627,962.801
11. Kansas City	KE1716	WY 53	39°09'27.48289"N	94°49'15.03326"W	748.086	621,280.310	11,621,701.983
11. Kansas City	KE1717	WY 55	39°06'04.57505"N	94°48'43.90265"W	875.569	600,762.289	11,624,253.158
11. Kansas City	KE1718	WY 56	39°04'22.96985"N	94°47'44.82082"W	781.376	590,505.074	11,628,962.291
11. Kansas City	KE1719	WY 57	39°03'04.95991"N	94°47'24.34495"W	683.850	582,620.443	11,630,617.111
11. Kansas City	KE1720	WY 60=JO 1008	39°02'34.52458"N	94°36'43.37334"W	858.939	579,846.692	11,681,205.232
11. Kansas City	KE1721	WY 61=JO 1009	39°02'39.74472"N	94°39'22.38148"W	752.830	580,289.791	11,668,656.127
11. Kansas City	KE1722	WY 62=JO 1010	39°02'37.62444"N	94°43'03.29745"W	951.117	579,967.235	11,651,227.529
11. Kansas City	KE1723	WY 63=JO 1011	39°02'17.09837"N	94°47'19.68044"W	769.428	577,779.869	11,631,009.682
11. Kansas City	KE1059	Y 368	39°05'59.82412"N	95°48'59.76161"W	801.891	600,483.672	11,339,190.845
11. Kansas City	AA5898	ZKC A	38°52'46.22383"N	94°47'28.40835"W	958.771	520,018.261	11,630,612.676
11. Kansas City	AA5899	ZKC B	38°52'27.83899"N	94°47'09.66288"W	908.315	518,165.726	11,632,104.609
12. Ulysses	HH0691	2K3 A	37°34'59.00955"N	101°44'03.32012"W	3239.669	303,522.394	12,407,953.694
12. Ulysses	HH0694	2K3 B	37°34'45.96365"N	101°43'49.33032"W	3239.236	302,198.845	12,409,075.579
12. Ulysses	DL5948	2K3 C	37°35'40.54171"N	101°43'56.49218"W	3239.636	307,722.071	12,408,517.520
12. Ulysses	JH0332	E 272	38°27'18.19662"N	101°40'45.37704"W	3470.065	621,066.531	12,424,786.263
12. Ulysses	HH0498	HELLWIG	37°39'52.32958"N	101°45'41.16178"W	3244.055	333,223.583	12,400,185.647
12. Ulysses	AE5434	P 91 DISTURBED	37°44'10.51858"N	101°21'49.27297"W	2993.636	359,164.062	12,515,323.494
12. Ulysses	HH0574	Q 32	37°55'59.51585"N	101°32'46.91747"W	3055.332	430,912.977	12,462,586.253
12. Ulysses	JH0231	Q 99	38°09'44.34700"N	101°16'03.52055"W	3089.420	514,370.210	12,542,853.931
12. Ulysses	HH0698	ULS B	37°35'56.43724"N	101°22'28.48359"W	2974.968	309,179.088	12,512,195.649
12. Ulysses	AH8198	ULS C	37°36'50.48205"N	101°22'24.20430"W	2977.186	314,646.592	12,512,537.572
12. Ulysses	AH8199	ULS D	37°35'38.94156"N	101°21'53.02078"W	2977.714	307,410.601	12,515,051.052
12. Ulysses	JH0324	Y 271	38°28'06.59085"N	101°34'28.46073"W	3391.424	625,894.529	12,454,781.958

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13. Garden City	JH0456	AERO	38°28'46.35969"N	100°53'18.99654"W	2876.812	630,231.148	13,360,106.474
13. Garden City	HH0101	AP STA B	37°02'15.22499"N	100°57'21.50046"W	2784.702	105,185.113	13,337,699.535
13. Garden City	AE5423	ELLE	37°57'45.02043"N	100°50'18.29209"W	2736.140	441,844.575	13,373,586.503
13. Garden City	HH0194	J 191	37°30'37.91064"N	100°44'51.88386"W	2782.521	277,131.295	13,399,118.859
13. Garden City	AE5427	JEAN	37°59'46.41985"N	100°52'59.32366"W	2793.154	454,190.043	13,360,752.321
13. Garden City	JH0441	M 358	38°15'53.99128"N	100°53'35.15550"W	2826.973	552,094.287	13,358,403.851
13. Garden City	AE5431	MARY	37°59'32.39392"N	100°50'17.45651"W	2777.262	452,706.933	13,373,704.550
13. Garden City	JH0433	TENNIS	38°08'45.13450"N	100°52'59.88876"W	2801.474	508,691.468	13,360,990.573
13. Garden City	AH7035	TQK A	38°28'45.05966"N	100°53'04.56445"W	2878.295	630,093.550	13,361,253.577
13. Garden City	AH7036	TQK B	38°28'09.74707"N	100°53'06.88152"W	2874.062	626,521.739	13,361,050.472
13. Garden City	HH0676	X 363	37°58'08.98901"N	100°54'04.80320"W	2765.349	444,360.935	13,355,457.015
13. Garden City	HH0008	Z 191	37°38'56.42112"N	100°14'59.63079"W	2646.809	327,408.784	13,543,464.196
14. Dodge City	HH0639	F 353	37°45'19.85426"N	100°04'05.56244"W	2438.191	366,407.482	14,383,894.694
14. Dodge City	JG0976	FAA 48K A	38°28'00.36545"N	99°54'29.88395"W	2195.448	625,289.774	14,430,806.632
14. Dodge City	HG0571	Y 34	37°38'04.89002"N	99°45'13.06458"W	2319.979	322,168.893	14,474,814.358
14. Dodge City	HG0500	Z 181	37°10'39.81854"N	99°45'52.55556"W	1865.948	155,764.067	14,471,464.578
15. Larned	AE5113	HVLK A	37°38'40.36382"N	99°06'24.31341"W	2043.352	325,755.893	15,527,001.717
15. Larned	AE5114	HVLK B	37°38'50.77477"N	99°06'23.91113"W	2036.800	326,809.082	15,527,033.027
16. Pratt	HG0277	D 184	37°05'40.16718"N	98°31'51.59824"W	1278.580	125,436.401	16,505,542.268
17. Wichita	AJ8079	AAO A	37°44'55.78784"N	97°13'11.62617"W	1314.351	393,625.704	17,580,994.928
17. Wichita	AJ8080	AAO B	37°45'15.59473"N	97°13'09.21931"W	1303.888	395,629.891	17,581,182.239
17. Wichita	AJ8081	AAO C	37°44'34.19602"N	97°13'15.42352"W	1318.167	391,440.630	17,580,696.432
17. Wichita	HF1435	AFTON	37°37'11.57379"N	97°38'17.94205"W	1308.367	346,575.813	17,459,934.665
17. Wichita	DF7129	BOEING AIRCRAFT BASE STA ARP	37°37'18.65937"N	97°17'24.63626"W	1276.792	347,331.097	17,560,776.322
17. Wichita	AE5419	BOEING AIRCRAFT BASE STATION	37°37'18.65936"N	97°17'24.63614"W	1277.025	347,331.096	17,560,776.332
17. Wichita	HF0552	BROADWAY	37°45'27.35821"N	97°20'06.79466"W	1256.097	396,739.989	17,547,642.052
17. Wichita	HG0745	C 307 RESET	37°39'39.75376"N	98°07'23.13997"W	1499.698	362,136.187	17,319,613.926
17. Wichita	HF1487	CESSNAPORT AZ MK	37°38'37.01072"N	97°15'01.27569"W	1278.081	355,285.083	17,572,289.892
17. Wichita	HF0551	E 349	37°37'21.93333"N	97°20'11.12548"W	1181.923	347,635.542	17,547,380.090
17. Wichita	AC9439	EWK A	38°03'40.14891"N	97°16'42.88560"W	1436.421	507,320.904	17,563,756.912
17. Wichita	AJ8116	EWK B 2001	38°03'09.97092"N	97°16'41.60297"W	1430.837	504,268.228	17,563,866.740
17. Wichita	AJ8117	EWK C 2001	38°02'47.90072"N	97°16'44.29642"W	1429.344	502,035.017	17,563,656.556

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	Latitude	Longitude	Ellipsoid ht (sft)	Northing (sft)	Easting (sft)
17. Wichita	AJ8070	HUT A	38°04'00.27280"N	97°51'36.99688"W	1427.858	509,481.012	17,396,268.165
17. Wichita	AJ8071	HUT B	38°04'20.31741"N	97°52'19.94134"W	1430.840	511,522.243	17,392,841.618
17. Wichita	AJ8072	HUT C	38°03'32.93806"N	97°51'25.91115"W	1422.087	506,712.335	17,397,144.222
17. Wichita	AJ8087	ICT G	37°39'22.64041"N	97°26'16.60942"W	1234.456	359,810.303	17,517,965.629
17. Wichita	AJ8088	ICT H	37°38'36.27746"N	97°26'24.36760"W	1217.763	355,120.008	17,517,344.699
17. Wichita	DE8254	ICT J	37°38'31.66697"N	97°25'48.48953"W	1224.007	354,655.632	17,520,230.951
17. Wichita	HF0573	KELLOGG RM 1	37°40'19.14310"N	97°24'04.59590"W	1245.188	365,535.018	17,528,576.451
17. Wichita	HF0567	NEVADA RM 2	37°42'51.13405"N	97°23'57.58348"W	1262.419	380,910.495	17,529,123.744
17. Wichita	HF0299	POLE	37°40'00.74697"N	96°39'38.76793"W	1399.748	364,748.726	17,742,937.216
17. Wichita	JF0765	R 347	38°07'17.49233"N	97°23'41.47266"W	1394.702	529,249.998	17,530,251.684
17. Wichita	HF1436	RAUSCH	37°40'44.58356"N	97°41'52.98174"W	1379.758	368,154.079	17,442,677.813
17. Wichita	HF0543	S 348	37°43'22.91651"N	97°19'00.68342"W	1215.857	384,161.697	17,552,976.276
17. Wichita	HF0394	SMILEY	37°30'19.09776"N	96°53'57.71393"W	1215.424	305,381.585	17,674,248.270
17. Wichita	JF0771	U 347	38°05'26.49081"N	97°21'33.54244"W	1372.005	518,033.932	17,540,492.673
17. Wichita	HF1492	WICHITA CBL 0	37°34'03.82206"N	97°18'55.14217"W	1171.133	327,606.961	17,553,533.164
17. Wichita	JF0833	Y 295	38°04'23.66796"N	97°53'18.58125"W	1437.153	511,880.263	17,388,153.475
17. Wichita	JF0841	Z 295	38°03'33.74627"N	97°53'49.99385"W	1434.748	506,840.564	17,385,619.937
18. Arkansas City	HF0661	RUTH	37°11'16.18525"N	97°24'06.94668"W	1142.540	201,651.873	18,528,570.696
18. Arkansas City	AC9471	WLD A	37°10'28.39364"N	97°02'13.13691"W	1058.879	197,132.562	18,634,913.312
18. Arkansas City	AC9469	WLD ARP	37°10'04.53888"N	97°02'13.06505"W	1055.014	194,719.778	18,634,930.913
18. Arkansas City	AJ8098	WLD B	37°10'12.43841"N	97°02'32.57221"W	1062.898	195,511.116	18,633,348.051
18. Arkansas City	HF0712	X 45	37°08'36.44885"N	97°02'58.76944"W	1070.057	185,792.025	18,631,273.700
18. Arkansas City	HF0711	Z 42	37°10'20.40621"N	97°02'58.05415"W	1066.064	196,307.148	18,631,281.647
19. Coffeyville	JE1764	CARBON	38°51'15.65482"N	95°41'13.98327"W	996.343	766,443.763	19,579,586.676
19. Coffeyville	JE1809	DRAG	38°43'27.59925"N	95°45'08.67729"W	1012.898	719,038.961	19,561,130.784
19. Coffeyville	JE1833	GOOD	38°45'24.95451"N	95°52'19.43766"W	1051.710	730,854.476	19,526,978.814
19. Coffeyville	AJ8076	IDP A	37°09'24.68091"N	95°46'45.59832"W	722.013	148,193.637	19,554,596.851
19. Coffeyville	AJ8077	IDP B	37°10'01.97712"N	95°46'30.83268"W	725.737	151,968.349	19,555,784.605
19. Coffeyville	AJ8078	IDP C	37°08'47.74410"N	95°46'31.48758"W	727.525	144,459.948	19,555,746.732
19. Coffeyville	HE0843	INDEPENDENCE	37°14'28.97233"N	95°42'22.05081"W	731.478	179,021.797	19,575,848.017
19. Coffeyville	JE1835	MABON	38°47'49.60154"N	95°47'10.40208"W	1138.843	745,525.608	19,551,431.276
19. Coffeyville	DF7127	NDS1 A	37°18'42.15866"N	95°36'13.39065"W	838.227	204,729.092	19,605,561.856

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	Latitude	Longitude	Ellipsoid ht (sft)	Northing (sft)	Easting (sft)
19. Coffeyville	DF7128	NDS1 B	37°17'49.19428"N	95°35'56.11035"W	795.212	199,377.255	19,606,978.787
19. Coffeyville	AE5432	NDSK A	37°23'04.16023"N	95°38'32.17487"W	775.648	231,189.385	19,594,258.325
19. Coffeyville	AE5433	NDSK B	37°22'09.34398"N	95°38'18.70263"W	707.269	225,648.537	19,595,364.986
19. Coffeyville	HF0052	U 216	37°51'40.44690"N	96°14'18.38120"W	990.474	404,748.729	19,421,534.944
19. Coffeyville	HE0647	X 42	37°32'30.20431"N	95°52'13.00502"W	762.088	288,297.067	19,527,948.281
20. Pittsburg	JE0710	EE 252	38°29'33.52689"N	94°52'00.91773"W	731.111	634,655.452	20,561,944.461
20. Pittsburg	HE0224	G 253	37°23'49.36748"N	94°49'21.84228"W	877.607	235,703.891	20,575,708.352
20. Pittsburg	JE1044	K 56	38°12'36.22494"N	95°08'41.49157"W	927.485	531,673.136	20,482,320.748
20. Pittsburg	HE0353	M 55	37°38'49.12242"N	95°10'45.06310"W	870.330	326,624.370	20,472,246.521
20. Pittsburg	DF7131	PAOLA MAGNETIC RESET	38°33'02.56138"N	94°55'04.57980"W	922.223	655,772.784	20,547,303.546
20. Pittsburg	HE1184	PITTPORT	37°26'37.88633"N	94°43'45.20697"W	825.399	252,837.995	20,602,810.535
20. Pittsburg	HE1185	PITTPORT AZ MK	37°26'42.40031"N	94°44'01.76416"W	842.577	253,289.598	20,601,473.519
20. Pittsburg	AH5860	PTS A	37°26'53.37611"N	94°43'53.15979"W	830.064	254,402.382	20,602,163.296

Table C-2. KRCS projection distortion computed for NGS NAD 83 (2011) epoch 2010.00 control. The six currently operational (as of October 2017) Kansas CORS Antenna Reference Points (ARPs) are listed first. Stations are listed alphabetically by designation within each KRCS zone.

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	KRCS linear distortion (ft/mile)	KRCS linear distortion (ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
8. Manhattan	DI3428	KSU1_KSUN_KS2006 CORS ARP (KSU1)	-6.586	-0.0348	1 : 151,834	1.000044659	0.999948757	0.999993414	–0°04'08.90"
11. Kansas City	DF9221	KANSAS CTY WAAS 1 CORS ARP (ZKC1)	-7.771	-0.0410	1 : 128,691	1.000040324	0.999951907	0.999992229	+0°17'22.53"
17. Wichita	DK6487	WICHITA ICT1 CORS ARP (ICT1)	6.669	0.0352	1 : 149,947	1.000063853	0.999942819	1.000006669	+0°07'01.39"
17. Wichita	DK6491	WICHITA ICT3 CORS ARP (ICT3)	-4.103	-0.0217	1 : 243,729	1.000059030	0.999936871	0.999995897	+0°10'25.69"
17. Wichita	DK6493	WICHITA ICT4 CORS ARP (ICT4)	0.596	0.0031	1 : 1,678,100	1.000062303	0.999938296	1.000000596	–0°04'52.11"
17. Wichita	DK6495	WICHITA ICT5 CORS ARP (ICT5)	-5.618	-0.0297	1 : 178,003	1.000059061	0.999935325	0.999994382	–0°04'37.25"
1. Goodland	AC9422	GLD C	-13.741	-0.0726	1 : 72,773	1.000156903	0.999829382	0.999986259	–0°03'47.01"
1. Goodland	KH0542	R 100	-12.577	-0.0664	1 : 79,510	1.000157042	0.999830407	0.999987423	–0°04'05.18"
2. Colby	KH0159	A 302 RESET	-5.720	-0.0302	1 : 174,830	1.000135623	0.999858676	0.999994280	+0°05'01.61"
2. Colby	KH0214	D 154	-9.332	-0.0493	1 : 107,154	1.000134085	0.999856602	0.999990668	–0°01'09.79"
2. Colby	KH0839	K60 A AZ MK	-1.363	-0.0072	1 : 733,935	1.000134774	0.999863881	0.999998637	–0°03'33.71"

Appendix C

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	(ft/mile)	(ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
2. Colby	KH0562	OAKPORT 1986	-5.672	-0.0299	1 : 176,301	1.000135715	0.999858632	0.999994328	+0°05'10.01"
2. Colby	KH0842	OAKPORT 1989	-6.091	-0.0322	1 : 164,179	1.000135597	0.999858331	0.999993909	+0°04'59.16"
2. Colby	AH7032	OEL A	-4.720	-0.0249	1 : 211,852	1.000135674	0.999859625	0.999995280	+0°05'06.13"
3. Oberlin	KH0159	A 302 RESET	-5.247	-0.0277	1 : 190,571	1.000136096	0.999858676	0.999994753	–0°17'41.23"
3. Oberlin	KH0562	OAKPORT 1986	-5.608	-0.0296	1 : 178,317	1.000135779	0.999858632	0.999994392	–0°17'32.76"
3. Oberlin	KH0842	OAKPORT 1989	-5.499	-0.0290	1 : 181,857	1.000136190	0.999858331	0.999994501	–0°17'43.60"
3. Oberlin	AH7032	OEL A	-4.464	-0.0236	1 : 224,002	1.000135930	0.999859625	0.999995536	–0°17'36.24"
4. Hays	KG0480	A 365	-7.362	-0.0389	1 : 135,837	1.000096432	0.999896216	0.999992638	–0°15'05.37"
4. Hays	KG0481	B 365	-3.945	-0.0208	1 : 253,512	1.000096374	0.999899691	0.999996055	–0°15'04.26"
4. Hays	JG0343	D 164	-5.217	-0.0275	1 : 191,681	1.000086214	0.999908577	0.999994783	+0°08'01.31"
4. Hays	DI3132	HLC A	-6.313	-0.0333	1 : 158,403	1.000095404	0.999898293	0.999993687	–0°14'34.80"
4. Hays	DI3133	HLC B	-8.017	-0.0423	1 : 124,734	1.000095175	0.999896818	0.999991983	–0°14'27.52"
4. Hays	DI3134	HLC C	-5.249	-0.0277	1 : 190,518	1.000095426	0.999899335	0.999994751	–0°14'35.34"
4. Hays	JG0346	HYS AP STA A	-6.583	-0.0348	1 : 151,915	1.000084780	0.999908645	0.999993417	+0°06'30.97"
4. Hays	JG0347	HYS AP STA B	-5.907	-0.0312	1 : 169,278	1.000084923	0.999909177	0.999994093	+0°06'40.70"
4. Hays	JG0381	Q 267	-6.396	-0.0338	1 : 156,357	1.000084606	0.999909006	0.999993604	+0°06'18.62"
4. Hays	JG0582	X 301	-19.689	-0.1040	1 : 50,789	1.000090890	0.999889431	0.999980311	–0°11'42.64"
5. Great Bend	JG0176	B 30	-4.033	-0.0213	1 : 247,973	1.000078146	0.999917827	0.999995967	+0°01'28.17"
5. Great Bend	KG0215	DOWNS	12.512	0.0661	1 : 79,924	1.000079364	0.999933154	1.000012512	+0°04'40.24"
5. Great Bend	AE5424	GBD ARP	-4.319	-0.0228	1 : 231,534	1.000081651	0.999914037	0.999995681	–0°07'19.98"
5. Great Bend	KG0640	MEADES RANCH RESET	-10.626	-0.0561	1 : 94,110	1.000079423	0.999909958	0.999989374	+0°04'43.46"
5. Great Bend	KG0537	SMITH CENTER	-2.564	-0.0135	1 : 390,031	1.000079401	0.999918042	0.999997436	–0°04'46.67"
6. Beloit	KF0604	D 287	5.099	0.0269	1 : 196,121	1.000071559	0.999933545	1.000005099	+0°07'37.20"
6. Beloit	JG0958	LYONS RESET	-8.137	-0.0430	1 : 122,896	1.000068511	0.999923357	0.999991863	–0°02'44.62"
7. Salina	JF1039	A 214	-9.898	-0.0523	1 : 101,028	1.000052909	0.999937196	0.999990102	–0°07'40.25"
7. Salina	JF1057	C 292	0.607	0.0032	1 : 1,646,598	1.000055797	0.999944813	1.000000607	–0°10'09.86"
7. Salina	KF0790	CNK A	-8.089	-0.0427	1 : 123,620	1.000058256	0.999933659	0.999991911	–0°12'11.28"
7. Salina	JF1065	D 292	0.462	0.0024	1 : 2,163,792	1.000055793	0.999944672	1.000000462	–0°10'09.36"
7. Salina	JF0975	F 291	7.576	0.0400	1 : 131,996	1.000063326	0.999944253	1.000007576	–0°14'46.28"
7. Salina	JF1069	G 292	-0.630	-0.0033	1 : 1,586,755	1.000055815	0.999943558	0.999999370	–0°10'09.35"
7. Salina	JF1634	GARRISON	2.510	0.0133	1 : 398,468	1.000068729	0.999933785	1.000002510	–0°17'24.33"
7. Salina	KF0548	H 286	-4.536	-0.0240	1 : 220,456	1.000056758	0.999938710	0.999995464	–0°11'09.99"

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	(ft/mile)	(ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
7. Salina	AE5425	HBRK A	-16.617	-0.0877	1 : 60,179	1.000049116	0.999934270	0.999983383	+0°01'18.42"
7. Salina	AE5426	HBRK B	-16.455	-0.0869	1 : 60,771	1.000049117	0.999934431	0.999983545	+0°01'18.62"
7. Salina	JF1625	LODER RESET	2.548	0.0135	1 : 392,496	1.000075962	0.999926591	1.000002548	–0°20'08.38"
7. Salina	JF1586	NORTH POLE MOUND RESET	-9.779	-0.0516	1 : 102,258	1.000056028	0.999934197	0.999990221	–0°10'23.86"
7. Salina	JF0595	PARK	-5.242	-0.0277	1 : 190,765	1.000049303	0.999945458	0.999994758	–0°02'09.36"
7. Salina	JF1063	PUMP	2.171	0.0115	1 : 460,696	1.000057795	0.999944379	1.000002171	–0°11'33.90"
7. Salina	KF0306	Q 112	3.507	0.0185	1 : 285,150	1.000064524	0.999938987	1.000003507	+0°15'52.80"
7. Salina	AE1678	SALINA BASE STATION	1.294	0.0068	1 : 772,681	1.000057611	0.999943686	1.000001294	–0°11'26.84"
7. Salina	DF7126	SALINA BASE STATION ARP	1.307	0.0069	1 : 764,981	1.000057611	0.999943699	1.000001307	–0°11'26.84"
7. Salina	JF1012	SALINA EAST BASE	-0.339	-0.0018	1 : 2,948,586	1.000052696	0.999946968	0.999999661	–0°07'31.14"
7. Salina	DL6188	SLN A	1.410	0.0074	1 : 709,372	1.000058371	0.999943043	1.000001410	–0°11'56.13"
7. Salina	DL6187	SLN B	1.667	0.0088	1 : 599,790	1.000058449	0.999943222	1.000001667	–0°11'58.92"
7. Salina	DL6189	SLN C	2.986	0.0158	1 : 334,884	1.000058597	0.999944393	1.000002986	–0°12'04.93"
7. Salina	JF0638	SMOKY	0.897	0.0047	1 : 1,115,318	1.000054847	0.999946053	1.000000897	+0°09'29.38"
7. Salina	JF1604	TOTUM	-0.536	-0.0028	1 : 1,865,564	1.000058995	0.999940473	0.999999464	–0°12'20.27"
8. Manhattan	KF0798	3JC B	-1.068	-0.0056	1 : 936,519	1.000046107	0.999952828	0.999998932	–0°13'01.35"
8. Manhattan	KF0142	DEEP	-10.889	-0.0575	1 : 91,836	1.000045432	0.999943681	0.999989111	+0°00'32.73"
8. Manhattan	KE0876	DRY	-0.692	-0.0037	1 : 1,444,931	1.000045783	0.999953527	0.999999308	+0°19'25.88"
8. Manhattan	KF0138	EAST	-15.028	-0.0793	1 : 66,543	1.000045588	0.999939387	0.999984972	–0°00'22.73"
8. Manhattan	KF0291	GROVE	-18.852	-0.0995	1 : 53,045	1.000045653	0.999935498	0.999981148	–0°01'16.19"
8. Manhattan	KF0150	GUIDE	-19.587	-0.1034	1 : 51,055	1.000045584	0.999934833	0.999980413	+0°02'33.26"
8. Manhattan	KF0153	KAW	-21.714	-0.1146	1 : 46,054	1.000045570	0.999932719	0.999978286	+0°03'31.25"
8. Manhattan	DH7065	KST1 A	-1.110	-0.0059	1 : 900,952	1.000046250	0.999952643	0.999998890	+0°17'27.31"
8. Manhattan	DH7064	KST1 B	-0.985	-0.0052	1 : 1,015,022	1.000045993	0.999953024	0.999999015	+0°17'27.48"
8. Manhattan	KF0765	M 370	-0.922	-0.0049	1 : 1,085,164	1.000044189	0.999954892	0.999999078	–0°06'32.79"
8. Manhattan	KF0197	MAPLE	1.195	0.0063	1 : 837,015	1.000045776	0.999955421	1.000001195	+0°18'20.72"
8. Manhattan	AJ8083	MHK A	-1.155	-0.0061	1 : 865,812	1.000044153	0.999954694	0.999998845	–0°06'45.24"
8. Manhattan	AJ8084	MHK B	-1.034	-0.0055	1 : 967,379	1.000044121	0.999954847	0.999998966	–0°06'15.90"
8. Manhattan	AJ8085	MHK C	-1.161	-0.0061	1 : 861,229	1.000044077	0.999954764	0.999998839	–0°06'23.48"
8. Manhattan	KF0179	MILL	-2.725	-0.0144	1 : 367,002	1.000045697	0.999951581	0.999997275	+0°12'16.42"
8. Manhattan	KF0766	N 370	-0.450	-0.0024	1 : 2,222,789	1.000044012	0.999955540	0.999999550	–0°04'46.82"
8. Manhattan	KF0680	OGDEN	-10.331	-0.0545	1 : 96,801	1.000045513	0.999944159	0.999989669	–0°11'06.21"

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	(ft/mile)	(ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
8. Manhattan	KF0249	PLAZA	-7.519	-0.0397	1 : 132,989	1.000046943	0.999945540	0.999992481	–0°11'09.28"
8. Manhattan	KF0047	POTT	-7.892	-0.0417	1 : 126,704	1.000045544	0.999946566	0.999992108	+0°08'00.25"
8. Manhattan	KF0162	POWER	-14.022	-0.0740	1 : 71,317	1.000045560	0.999940421	0.999985978	+0°06'57.35"
8. Manhattan	KF0191	VERA	-5.384	-0.0284	1 : 185,746	1.000045748	0.999948871	0.999994616	+0°16'02.81"
9. Emporia	AH5750	EMP A	1.352	0.0071	1 : 739,455	1.000054246	0.999947109	1.000001352	+0°11'35.09"
9. Emporia	AH5751	EMP B	1.985	0.0105	1 : 503,654	1.000054615	0.999947374	1.000001985	+0°11'30.11"
9. Emporia	AH5752	EMP C	2.065	0.0109	1 : 484,191	1.000053989	0.999948079	1.000002065	+0°11'38.40"
9. Emporia	JF1376	LYON	1.356	0.0072	1 : 737,288	1.000054313	0.999947046	1.000001356	+0°11'38.80"
9. Emporia	JF0232	MORRIS RM 3	0.136	0.0007	1 : 7,378,816	1.000051157	0.999948982	1.000000136	+0°15'41.70"
9. Emporia	JF0142	Q 13	1.530	0.0081	1 : 653,682	1.000051475	0.999950057	1.000001530	+0°12'16.42"
10. Atchison	KE1727	ATCHPORT	-5.378	-0.0284	1 : 185,938	1.000040627	0.999953997	0.999994622	+0°21'49.29"
10. Atchison	AE5422	BUTT RESET	11.815	0.0624	1 : 84,641	1.000062756	0.999949062	1.000011815	–0°01'56.64"
10. Atchison	LG0754	ELK RESET	3.619	0.0191	1 : 276,288	1.000060514	0.999943109	1.000003619	–0°31'50.50"
10. Atchison	KF0339	G 106	-1.860	-0.0098	1 : 537,658	1.000049673	0.999948469	0.999998140	–0°34'25.48"
10. Atchison	KE0998	SKIRT RM 2	-7.750	-0.0409	1 : 129,035	1.000042212	0.999950040	0.999992250	+0°00'03.76"
10. Atchison	KE0493	W 281	-2.206	-0.0116	1 : 453,284	1.000040562	0.999957233	0.999997794	+0°23'07.55"
11. Kansas City	KE0765	AP STA B	-3.646	-0.0193	1 : 274,273	1.000033183	0.999963172	0.999996354	–0°13'46.21"
11. Kansas City	KE1084	B 276 RESET	0.459	0.0024	1 : 2,180,463	1.000034503	0.999965957	1.000000459	+0°00'38.29"
11. Kansas City	KE1062	C 367	-4.459	-0.0235	1 : 224,282	1.000033056	0.999962486	0.999995541	–0°17'29.67"
11. Kansas City	JE1585	C 371	-7.090	-0.0374	1 : 141,052	1.000035483	0.999957429	0.999992910	–0°01'06.10"
11. Kansas City	KE1204	ECKMAN RESET	-9.483	-0.0501	1 : 105,448	1.000033503	0.999957015	0.999990517	+0°09'23.06"
11. Kansas City	AA2874	EPA BASE STATION KANSAS CITY	0.775	0.0041	1 : 1,290,198	1.000033277	0.999967499	1.000000775	+0°24'07.91"
11. Kansas City	AC9461	FOE ARP	-9.106	-0.0481	1 : 109,814	1.000036393	0.999954502	0.999990894	–0°15'41.77"
11. Kansas City	AJ8115	FOE B	-10.187	-0.0538	1 : 98,163	1.000035859	0.999953955	0.999989813	–0°15'59.82"
11. Kansas City	AJ8075	FOE C	-7.989	-0.0422	1 : 125,173	1.000036622	0.999955391	0.999992011	–0°15'12.79"
11. Kansas City	AJ8074	FOE D	-9.573	-0.0505	1 : 104,458	1.000036107	0.999954321	0.999990427	–0°15'43.88"
11. Kansas City	DF7132	GABLEMANN=LV51	-4.376	-0.0231	1 : 228,504	1.000033360	0.999962265	0.999995624	+0°03'47.06"
11. Kansas City	KE0864	GOLDEN	-8.542	-0.0451	1 : 117,064	1.000033652	0.999957807	0.999991458	–0°14'54.61"
11. Kansas City	DF7125	JCBASE	-4.178	-0.0221	1 : 239,344	1.000041402	0.999954422	0.999995822	+0°15'16.90"
11. Kansas City	DF7124	JCPW 1023	7.006	0.0370	1 : 142,736	1.000052769	0.999954239	1.000007006	+0°07'19.66"
11. Kansas City	AE5428	KAN1 A	-6.250	-0.0330	1 : 159,992	1.000033081	0.999960670	0.999993750	–0°06'12.19"
11. Kansas City	AE5429	KAN1 B	-6.852	-0.0362	1 : 145,943	1.000033103	0.999960046	0.999993148	–0°05'58.18"

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	(ft/mile)	(ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
11. Kansas City	JE1579	KANWAKA	-14.331	-0.0757	1 : 69,779	1.000034739	0.999950932	0.999985669	–0°05'32.24"
11. Kansas City	AE5430	KNOX KNOB TOP 2 RESET	-15.479	-0.0817	1 : 64,602	1.000034237	0.999950285	0.999984521	–0°18'24.72"
11. Kansas City	KE1660	LAKE 2	-2.825	-0.0149	1 : 354,023	1.000033812	0.999963364	0.999997175	+0°18'00.62"
11. Kansas City	JE1763	LAST	-6.773	-0.0358	1 : 147,641	1.000040592	0.999952637	0.999993227	–0°13'44.32"
11. Kansas City	KE1085	LLOYD	-0.295	-0.0016	1 : 3,384,102	1.000034337	0.999965368	0.999999705	+0°01'22.16"
11. Kansas City	KE1086	LLOYD AZ MK	-0.547	-0.0029	1 : 1,827,875	1.000034126	0.999965328	0.999999453	+0°01'16.28"
11. Kansas City	DF7122	LOPATA=LV50	-6.745	-0.0356	1 : 148,258	1.000039970	0.999953287	0.999993255	+0°03'21.68"
11. Kansas City	AJ8082	LWC A	-0.442	-0.0023	1 : 2,260,067	1.000034261	0.999965298	0.999999558	+0°01'15.44"
11. Kansas City	JE1988	MARTY 2	-12.095	-0.0639	1 : 82,677	1.000034845	0.999953062	0.999987905	+0°21'54.40"
11. Kansas City	KE1661	MT HOPE 3	-10.021	-0.0529	1 : 99,788	1.000033124	0.999956856	0.999989979	+0°21'40.37"
11. Kansas City	KE0867	N 346	-9.286	-0.0490	1 : 107,690	1.000033751	0.999956964	0.999990714	–0°14'10.28"
11. Kansas City	KE1068	N 367	-5.471	-0.0289	1 : 182,791	1.000033481	0.999961050	0.999994529	–0°13'03.14"
11. Kansas City	JE2044	NAVY	-2.071	-0.0109	1 : 482,811	1.000043253	0.999954678	0.999997929	+0°13'01.18"
11. Kansas City	AJ8091	OJC D	-3.741	-0.0198	1 : 267,330	1.000042605	0.999953656	0.999996259	+0°19'25.68"
11. Kansas City	AJ8092	OJC E	-4.848	-0.0256	1 : 206,256	1.000042316	0.999952838	0.999995152	+0°19'26.24"
11. Kansas City	AJ8093	OJC F	-2.546	-0.0134	1 : 392,837	1.000042945	0.999954511	0.999997454	+0°19'21.16"
11. Kansas City	KE1177	OVERLOOK	-3.839	-0.0203	1 : 260,504	1.000033408	0.999962755	0.999996161	+0°22'39.45"
11. Kansas City	KE1145	PARKER	-2.046	-0.0108	1 : 488,680	1.000033028	0.999964927	0.999997954	+0°23'53.80"
11. Kansas City	KE1662	PIPER 2	-9.753	-0.0515	1 : 102,534	1.000033282	0.999956967	0.999990247	+0°14'50.17"
11. Kansas City	DF7130	SIMMONS RESET	-4.045	-0.0214	1 : 247,197	1.000048062	0.999947895	0.999995955	–0°06'59.43"
11. Kansas City	JE2097	STANLEY 2	-5.489	-0.0290	1 : 182,185	1.000042127	0.999952386	0.999994511	+0°19'13.41"
11. Kansas City	DG6508	TOP A 2004	-3.990	-0.0211	1 : 250,634	1.000033135	0.999962876	0.999996010	–0°14'05.61"
11. Kansas City	DG6500	TOP B	-4.030	-0.0213	1 : 248,159	1.000033104	0.999962868	0.999995970	–0°14'17.41"
11. Kansas City	DF7123	TT 20 L	-4.513	-0.0238	1 : 221,585	1.000043134	0.999952355	0.999995487	–0°00'44.50"
11. Kansas City	KE0893	VALENCIA	-12.855	-0.0679	1 : 77,793	1.000033264	0.999953883	0.999987145	–0°24'13.51"
11. Kansas City	DF7121	VALENCIA 2	-12.936	-0.0683	1 : 77,306	1.000033260	0.999953806	0.999987064	–0°24'14.43"
11. Kansas City	KE1664	WY 01	3.102	0.0164	1 : 322,371	1.000034193	0.999968910	1.000003102	+0°16'59.73"
11. Kansas City	KE1665	WY 02	2.289	0.0121	1 : 436,823	1.000034169	0.999968121	1.000002289	+0°17'28.80"
11. Kansas City	KE1666	WY 03	-8.095	-0.0427	1 : 123,530	1.000034145	0.999957762	0.999991905	+0°13'13.79"
11. Kansas City	KE1667	WY 04	-1.956	-0.0103	1 : 511,352	1.000034140	0.999963905	0.999998044	+0°14'36.38"
11. Kansas City	KE1668	WY 05	-3.550	-0.0187	1 : 281,700	1.000034085	0.999962366	0.999996450	+0°16'01.33"
11. Kansas City	KE1669	WY 06	-6.724	-0.0355	1 : 148,727	1.000033663	0.999959614	0.999993276	+0°16'00.81"

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11. Kansas City	KE1670	WY 07	-9.768	-0.0516	1 : 102,372	1.000033579	0.999956654	0.999990232	+0°19'32.14"
11. Kansas City	KE1671	WY 08	2.247	0.0119	1 : 444,975	1.000033637	0.999968612	1.000002247	+0°21'11.09"
11. Kansas City	KE1672	WY 09	-7.756	-0.0410	1 : 128,927	1.000033506	0.999958739	0.999992244	+0°13'13.10"
11. Kansas City	KE1673	WY 10	-7.116	-0.0376	1 : 140,537	1.000033504	0.999959381	0.999992884	+0°14'36.35"
11. Kansas City	KE1674	WY 11	2.576	0.0136	1 : 388,250	1.000033413	0.999969163	1.000002576	+0°23'45.93"
11. Kansas City	KE1675	WY 12	-1.375	-0.0073	1 : 727,306	1.000033385	0.999965241	0.999998625	+0°17'25.53"
11. Kansas City	KE1676	WY 13	-9.087	-0.0480	1 : 110,050	1.000033276	0.999957639	0.999990913	+0°16'16.20"
11. Kansas City	KE1677	WY 14	-10.798	-0.0570	1 : 92,612	1.000033282	0.999955922	0.999989202	+0°19'31.65"
11. Kansas City	KE1678	WY 15	-7.972	-0.0421	1 : 125,441	1.000033280	0.999958749	0.999992028	+0°21'00.47"
11. Kansas City	KE1679	WY 16	-6.347	-0.0335	1 : 157,563	1.000033280	0.999960375	0.999993653	+0°22'21.41"
11. Kansas City	KE1680	WY 17	-1.268	-0.0067	1 : 788,438	1.000033215	0.999965518	0.999998732	+0°23'51.34"
11. Kansas City	DI2811	WY 17 OLD	-1.325	-0.0070	1 : 754,911	1.000033215	0.999965461	0.999998675	+0°23'51.34"
11. Kansas City	KE1681	WY 18	-7.066	-0.0373	1 : 141,518	1.000033126	0.999959810	0.999992934	+0°13'11.93"
11. Kansas City	KE1682	WY 19	-10.802	-0.0570	1 : 92,576	1.000033124	0.999956076	0.999989198	+0°14'22.89"
11. Kansas City	KE1683	WY 20	-11.044	-0.0583	1 : 90,545	1.000033124	0.999955834	0.999988956	+0°15'31.44"
11. Kansas City	KE1684	WY 21	-9.517	-0.0503	1 : 105,074	1.000033123	0.999957361	0.999990483	+0°16'51.53"
11. Kansas City	KE1685	WY 22	-10.063	-0.0531	1 : 99,373	1.000033125	0.999956813	0.999989937	+0°18'01.88"
11. Kansas City	KE1686	WY 23	-9.435	-0.0498	1 : 105,987	1.000033122	0.999957444	0.999990565	+0°19'07.41"
11. Kansas City	KE1687	WY 24	-7.177	-0.0379	1 : 139,328	1.000033123	0.999959701	0.999992823	+0°20'28.39"
11. Kansas City	KE1688	WY 25	-0.008	-0.0000	1 : 123,705,708	1.000033124	0.999966869	0.999999992	+0°23'03.29"
11. Kansas City	KE1689	WY 26	-8.688	-0.0459	1 : 115,103	1.000033039	0.999958274	0.999991312	+0°13'09.33"
11. Kansas City	KE1690	WY 27	-10.709	-0.0565	1 : 93,378	1.000033039	0.999956253	0.999989291	+0°14'28.65"
11. Kansas City	KE1691	WY 28	-9.672	-0.0511	1 : 103,394	1.000033042	0.999957288	0.999990328	+0°16'34.42"
11. Kansas City	KE1692	WY 29	-8.004	-0.0423	1 : 124,936	1.000033041	0.999958957	0.999991996	+0°18'13.76"
11. Kansas City	KE1693	WY 30	-5.552	-0.0293	1 : 180,109	1.000033043	0.999961407	0.999994448	+0°19'17.04"
11. Kansas City	KE1694	WY 31	-8.016	-0.0423	1 : 124,749	1.000033042	0.999958943	0.999991984	+0°21'03.63"
11. Kansas City	KE1695	WY 32	-6.704	-0.0354	1 : 149,165	1.000033044	0.999960254	0.999993296	+0°22'18.52"
11. Kansas City	KE1696	WY 33	-9.911	-0.0523	1 : 100,898	1.000033000	0.999957090	0.999990089	+0°15'42.10"
11. Kansas City	KE1697	WY 34	-4.840	-0.0256	1 : 206,617	1.000033001	0.999962161	0.999995160	+0°23'07.25"
11. Kansas City	KE1698	WY 35	-11.055	-0.0584	1 : 90,453	1.000033001	0.999955945	0.999988945	+0°13'55.77"
11. Kansas City	KE1699	WY 36	-5.170	-0.0273	1 : 193,424	1.000033003	0.999961828	0.999994830	+0°18'31.13"
11. Kansas City	KE1700	WY 37	1.711	0.0090	1 : 584,475	1.000033004	0.999968708	1.000001711	+0°21'19.18"

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	(ft/mile)	(ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
11. Kansas City	KE1701	WY 38	-5.112	-0.0270	1 : 195,599	1.000033000	0.999961889	0.999994888	+0°22'04.17"
11. Kansas City	KE1702	WY 39	-6.648	-0.0351	1 : 150,414	1.000033026	0.999960327	0.999993352	+0°12'54.79"
11. Kansas City	KE1703	WY 40	-8.391	-0.0443	1 : 119,177	1.000033025	0.999958586	0.999991609	+0°17'00.25"
11. Kansas City	KE1704	WY 41	1.702	0.0090	1 : 587,699	1.000033023	0.999968680	1.000001702	+0°19'54.36"
11. Kansas City	KE1705	WY 42	-8.088	-0.0427	1 : 123,642	1.000033115	0.999958799	0.999991912	+0°13'55.80"
11. Kansas City	KE1706	WY 43	-4.589	-0.0242	1 : 217,901	1.000033109	0.999962303	0.999995411	+0°21'16.38"
11. Kansas City	KE1707	WY 44	0.597	0.0032	1 : 1,675,250	1.000033117	0.999967481	1.000000597	+0°23'03.84"
11. Kansas City	KE1708	WY 45	-5.255	-0.0277	1 : 190,299	1.000033071	0.999961675	0.999994745	+0°24'08.54"
11. Kansas City	KE1709	WY 46	0.958	0.0051	1 : 1,044,367	1.000033187	0.999967772	1.000000958	+0°14'43.51"
11. Kansas City	KE1710	WY 47	1.781	0.0094	1 : 561,595	1.000033178	0.999968603	1.000001781	+0°18'50.44"
11. Kansas City	KE1711	WY 48	-3.416	-0.0180	1 : 292,721	1.000033268	0.999963317	0.999996584	+0°12'54.88"
11. Kansas City	KE1712	WY 49	1.436	0.0076	1 : 696,259	1.000033267	0.999968170	1.000001436	+0°16'25.48"
11. Kansas City	KE1713	WY 50	-7.738	-0.0409	1 : 129,239	1.000033475	0.999958789	0.999992262	+0°21'19.41"
11. Kansas City	KE1714	WY 51	1.548	0.0082	1 : 645,861	1.000034113	0.999967437	1.000001548	+0°12'54.75"
11. Kansas City	KE1715	WY 52	-1.472	-0.0078	1 : 679,497	1.000033967	0.999964562	0.999998528	+0°17'04.82"
11. Kansas City	KE1716	WY 53	-2.270	-0.0120	1 : 440,493	1.000033504	0.999964227	0.999997730	+0°16'14.37"
11. Kansas City	KE1717	WY 55	-8.870	-0.0468	1 : 112,735	1.000033000	0.999958131	0.999991130	+0°16'34.01"
11. Kansas City	KE1718	WY 56	-4.256	-0.0225	1 : 234,945	1.000033110	0.999962635	0.999995744	+0°17'11.27"
11. Kansas City	KE1719	WY 57	0.656	0.0035	1 : 1,525,225	1.000033359	0.999967298	1.000000656	+0°17'24.18"
11. Kansas City	KE1720	WY 60=JO 1008	-7.582	-0.0400	1 : 131,899	1.000033494	0.999958926	0.999992418	+0°24'08.43"
11. Kansas City	KE1721	WY 61=JO 1009	-2.532	-0.0134	1 : 394,903	1.000033469	0.999964000	0.999997468	+0°22'28.14"
11. Kansas City	KE1722	WY 62=JO 1010	-12.004	-0.0634	1 : 83,304	1.000033479	0.999954518	0.999987996	+0°20'08.82"
11. Kansas City	KE1723	WY 63=JO 1011	-3.214	-0.0170	1 : 311,151	1.000033581	0.999963206	0.999996786	+0°17'27.12"
11. Kansas City	KE1059	Y 368	-5.347	-0.0282	1 : 187,007	1.000033000	0.999961654	0.999994653	–0°21'26.43"
11. Kansas City	AA5898	ZKC A	-5.483	-0.0290	1 : 182,372	1.000040367	0.999954151	0.999994517	+0°17'21.62"
11. Kansas City	AA5899	ZKC B	-2.725	-0.0144	1 : 366,906	1.000040712	0.999956564	0.999997275	+0°17'33.44"
12. Ulysses	HH0691	2K3 A	-5.262	-0.0278	1 : 190,052	1.000149690	0.999845072	0.999994738	–0°11'37.33"
12. Ulysses	HH0694	2K3 B	-5.476	-0.0289	1 : 182,622	1.000149455	0.999845092	0.999994524	–0°11'28.74"
12. Ulysses	DL5948	2K3 C	-5.378	-0.0284	1 : 185,933	1.000149571	0.999845073	0.999994622	–0°11'33.34"
12. Ulysses	JH0332	E 272	-19.484	-0.1029	1 : 51,325	1.000146469	0.999834072	0.999980516	–0°09'47.93"
12. Ulysses	HH0498	HELLWIG	-3.766	-0.0199	1 : 265,534	1.000151394	0.999844863	0.999996234	–0°12'38.40"
12. Ulysses	AE5434	P 91 DISTURBED	-2.913	-0.0154	1 : 343,257	1.000140269	0.999856838	0.999997087	+0°01'56.73"

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	(ft/mile)	(ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
12. Ulysses	HH0574	Q 32	-4.528	-0.0239	1 : 220,830	1.000141601	0.999853892	0.999995472	–0°04'47.03"
12. Ulysses	JH0231	Q 99	-5.655	-0.0299	1 : 176,821	1.000142100	0.999852266	0.999994345	+0°05'31.49"
12. Ulysses	HH0698	ULS B	-2.121	-0.0112	1 : 471,439	1.000140170	0.999857729	0.999997879	+0°01'32.44"
12. Ulysses	AH8198	ULS C	-2.217	-0.0117	1 : 450,995	1.000140180	0.999857623	0.999997783	+0°01'35.09"
12. Ulysses	AH8199	ULS D	-2.164	-0.0114	1 : 462,192	1.000140259	0.999857597	0.999997836	+0°01'54.07"
12. Ulysses	JH0324	Y 271	-19.853	-0.1048	1 : 50,370	1.000142338	0.999837832	0.999980147	–0°05'53.63"
13. Garden City	JH0456	AERO	-6.204	-0.0328	1 : 161,188	1.000131378	0.999862436	0.999993796	–0°18'14.53"
13. Garden City	HH0101	AP STA B	5.930	0.0313	1 : 168,620	1.000139131	0.999866818	1.000005930	–0°20'05.61"
13. Garden City	AE5423	ELLE	-3.587	-0.0189	1 : 278,772	1.000127275	0.999869154	0.999996413	–0°16'10.89"
13. Garden City	HH0194	J 191	-12.447	-0.0657	1 : 80,342	1.000120640	0.999866929	0.999987553	–0°12'42.29"
13. Garden City	AE5427	JEAN	-2.415	-0.0127	1 : 414,149	1.000131175	0.999866428	0.999997585	–0°17'50.76"
13. Garden City	JH0441	M 358	-3.275	-0.0173	1 : 305,350	1.000131927	0.999864815	0.999996725	–0°18'19.37"
13. Garden City	AE5431	MARY	-5.587	-0.0295	1 : 178,973	1.000127241	0.999867188	0.999994413	–0°16'11.02"
13. Garden City	JH0433	TENNIS	-2.887	-0.0152	1 : 346,411	1.000131098	0.999866033	0.999997113	–0°17'54.69"
13. Garden City	AH7035	TQK A	-6.640	-0.0351	1 : 150,596	1.000131013	0.999862365	0.999993360	–0°18'05.54"
13. Garden City	AH7036	TQK B	-6.374	-0.0337	1 : 156,899	1.000131077	0.999862567	0.999993626	–0°18'06.74"
13. Garden City	HH0676	X 363	0.633	0.0033	1 : 1,579,352	1.000132893	0.999867757	1.000000633	–0°18'30.40"
13. Garden City	HH0008	Z 191	-15.433	-0.0815	1 : 64,798	1.000111161	0.999873421	0.999984567	+0°05'30.07"
14. Dodge City	HH0639	F 353	-4.198	-0.0222	1 : 238,223	1.000112417	0.999883398	0.999995802	–0°14'45.12"
14. Dodge City	JG0976	FAA 48K A	-2.522	-0.0133	1 : 396,500	1.000102475	0.999895014	0.999997478	–0°09'01.12"
14. Dodge City	HG0571	Y 34	-13.236	-0.0699	1 : 75,550	1.000097725	0.999889049	0.999986764	–0°03'11.17"
14. Dodge City	HG0500	Z 181	8.679	0.0458	1 : 115,223	1.000097931	0.999910756	1.000008679	–0°03'33.05"
15. Larned	AE5113	HVLK A	-9.897	-0.0523	1 : 101,037	1.000087834	0.999902277	0.999990103	+0°03'25.02"
15. Larned	AE5114	HVLK B	-9.582	-0.0506	1 : 104,361	1.000087836	0.999902591	0.999990418	+0°03'25.28"
16. Pratt	HG0277	D 184	7.877	0.0416	1 : 126,949	1.000069035	0.999938846	1.000007877	+0°00'41.26"
17. Wichita	AJ8079	AAO A	-3.815	-0.0201	1 : 262,099	1.000059048	0.999937140	0.999996185	+0°10'17.58"
17. Wichita	AJ8080	AAO B	-3.340	-0.0176	1 : 299,392	1.000059023	0.999937641	0.999996660	+0°10'19.05"
17. Wichita	AJ8081	AAO C	-3.960	-0.0209	1 : 252,527	1.000059086	0.999936958	0.999996040	+0°10'15.25"
17. Wichita	HF1435	AFTON	-0.313	-0.0017	1 : 3,198,452	1.000062266	0.999937425	0.999999687	–0°05'04.96"
17. Wichita	DF7129	BOEING AIRCRAFT BASE STA ARP	1.111	0.0059	1 : 900,486	1.000062179	0.999938935	1.000001111	+0°07'42.62"
17. Wichita	AE5419	BOEING AIRCRAFT BASE STATION	1.099	0.0058	1 : 909,611	1.000062179	0.999938924	1.000001099	+0°07'42.62"
17. Wichita	HF0552	BROADWAY	-1.065	-0.0056	1 : 938,963	1.000059012	0.999939926	0.999998935	+0°06'03.31"

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	(ft/mile)	(ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
17. Wichita	HG0745	C 307 RESET	-11.037	-0.0583	1 : 90,602	1.000060691	0.999928276	0.999988963	–0°22'53.80"
17. Wichita	HF1487	CESSNAPORT AZ MK	0.166	0.0009	1 : 6,039,527	1.000061295	0.999938874	1.000000166	+0°09'10.42"
17. Wichita	HF0551	E 349	5.608	0.0296	1 : 178,317	1.000062139	0.999943472	1.000005608	+0°06'00.65"
17. Wichita	AC9439	EWK A	3.472	0.0183	1 : 288,041	1.000072172	0.999931305	1.000003472	+0°08'08.19"
17. Wichita	AJ8116	EWK B 2001	2.999	0.0158	1 : 333,438	1.000071432	0.999931572	1.000002999	+0°08'08.98"
17. Wichita	AJ8117	EWK C 2001	2.543	0.0134	1 : 393,235	1.000070905	0.999931643	1.000002543	+0°08'07.33"
17. Wichita	AJ8070	HUT A	4.386	0.0232	1 : 227,977	1.000072677	0.999931714	1.000004386	–0°13'14.34"
17. Wichita	AJ8071	HUT B	4.756	0.0251	1 : 210,241	1.000073190	0.999931572	1.000004756	–0°13'40.64"
17. Wichita	AJ8072	HUT C	3.979	0.0210	1 : 251,349	1.000071993	0.999931990	1.000003979	–0°13'07.55"
17. Wichita	AJ8087	ICT G	1.804	0.0095	1 : 554,411	1.000060847	0.999940960	1.000001804	+0°02'16.81"
17. Wichita	AJ8088	ICT H	3.058	0.0161	1 : 327,012	1.000061303	0.999941759	1.000003058	+0°02'12.06"
17. Wichita	DE8254	ICT J	2.807	0.0148	1 : 356,193	1.000061351	0.999941460	1.000002807	+0°02'34.04"
17. Wichita	HF0573	KELLOGG RM 1	0.803	0.0042	1 : 1,245,691	1.000060359	0.999940447	1.000000803	+0°03'37.67"
17. Wichita	HF0567	NEVADA RM 2	-0.963	-0.0051	1 : 1,038,652	1.000059417	0.999939623	0.999999037	+0°03'41.96"
17. Wichita	HF0299	POLE	-6.439	-0.0340	1 : 155,312	1.000060510	0.999933056	0.999993561	+0°30'50.35"
17. Wichita	JF0765	R 347	11.427	0.0603	1 : 87,514	1.000078132	0.999933300	1.000011427	+0°03'51.83"
17. Wichita	HF1436	RAUSCH	-5.828	-0.0308	1 : 171,574	1.000060164	0.999934012	0.999994172	–0°07'16.66"
17. Wichita	HF0543	S 348	1.136	0.0060	1 : 880,669	1.000059289	0.999941850	1.000001136	+0°06'43.80"
17. Wichita	HF0394	SMILEY	11.214	0.0592	1 : 89,171	1.000069349	0.999941869	1.000011214	+0°22'04.29"
17. Wichita	JF0771	U 347	9.330	0.0493	1 : 107,185	1.000074949	0.999934385	1.000009330	+0°05'10.18"
17. Wichita	HF1492	WICHITA CBL 0	8.982	0.0474	1 : 111,334	1.000064997	0.999943988	1.000008982	+0°06'47.19"
17. Wichita	JF0833	Y 295	4.541	0.0240	1 : 220,208	1.000073276	0.999931270	1.000004541	–0°14'16.56"
17. Wichita	JF0841	Z 295	3.393	0.0179	1 : 294,723	1.000072013	0.999931385	1.000003393	–0°14'35.80"
18. Arkansas City	HF0661	RUTH	0.353	0.0019	1 : 2,830,950	1.000055003	0.999945353	1.000000353	+0°03'33.37"
18. Arkansas City	AC9471	WLD A	4.363	0.0230	1 : 229,187	1.000055012	0.999949354	1.000004363	+0°16'47.40"
18. Arkansas City	AC9469	WLD ARP	4.572	0.0241	1 : 218,705	1.000055036	0.999949539	1.000004572	+0°16'47.44"
18. Arkansas City	AJ8098	WLD B	4.186	0.0221	1 : 238,904	1.000055026	0.999949162	1.000004186	+0°16'35.65"
18. Arkansas City	HF0712	X 45	4.058	0.0214	1 : 246,435	1.000055241	0.999948820	1.000004058	+0°16'19.82"
18. Arkansas City	HF0711	Z 42	4.026	0.0213	1 : 248,371	1.000055018	0.999949011	1.000004026	+0°16'20.25"
19. Coffeyville	JE1764	CARBON	-6.405	-0.0338	1 : 156,133	1.000041243	0.999952354	0.999993595	+0°10'31.12"
19. Coffeyville	JE1809	DRAG	-10.167	-0.0537	1 : 98,361	1.000038273	0.999951562	0.999989833	+0°08'02.52"
19. Coffeyville	JE1833	GOOD	-15.463	-0.0816	1 : 64,670	1.000034832	0.999949706	0.999984537	+0°03'33.20"

KRCS zone	NGS PID	Station designation (and CORS ID if applicable)	KRCS linear distortion (ppm)	(ft/mile)	(ratio)	Grid point scale factor	Height scale factor	Combined scale factor	Convergence angle
19. Coffeyville	AJ8076	IDP A	2.874	0.0152	1 : 347,903	1.000037410	0.999965466	1.000002874	+0°06'47.34"
19. Coffeyville	AJ8077	IDP B	2.846	0.0150	1 : 351,339	1.000037560	0.999965288	1.000002846	+0°06'56.36"
19. Coffeyville	AJ8078	IDP C	2.756	0.0146	1 : 362,866	1.000037555	0.999965202	1.000002756	+0°06'55.76"
19. Coffeyville	HE0843	INDEPENDENCE	5.593	0.0295	1 : 178,802	1.000040581	0.999965013	1.000005593	+0°09'27.63"
19. Coffeyville	JE1835	MABON	-17.437	-0.0921	1 : 57,348	1.000037025	0.999945540	0.999982563	+0°06'47.02"
19. Coffeyville	DF7127	NDS1 A	6.653	0.0351	1 : 150,310	1.000046747	0.999959908	1.000006653	+0°13'12.01"
19. Coffeyville	DF7128	NDS1 B	9.055	0.0478	1 : 110,439	1.000047091	0.999961965	1.000009055	+0°13'22.21"
19. Coffeyville	AE5432	NDSK A	7.063	0.0373	1 : 141,591	1.000044163	0.999962902	1.000007063	+0°11'49.06"
19. Coffeyville	AE5433	NDSK B	10.573	0.0558	1 : 94,579	1.000044403	0.999966172	1.000010573	+0°11'56.99"
19. Coffeyville	HF0052	U 216	-6.331	-0.0334	1 : 157,963	1.000041042	0.999952630	0.999993669	–0°10'00.49"
19. Coffeyville	HE0647	X 42	-1.557	-0.0082	1 : 642,205	1.000034893	0.999963551	0.999998443	+0°03'31.44"
20. Pittsburg	JE0710	EE 252	0.423	0.0022	1 : 2,365,193	1.000035388	0.999965036	1.000000423	+0°08'04.91"
20. Pittsburg	HE0224	G 253	-4.420	-0.0233	1 : 226,241	1.000037556	0.999958025	0.999995580	+0°09'29.78"
20. Pittsburg	JE1044	K 56	-13.000	-0.0686	1 : 76,922	1.000031357	0.999955644	0.999987000	–0°02'17.00"
20. Pittsburg	HE0353	M 55	-9.746	-0.0515	1 : 102,607	1.000031881	0.999958374	0.999990254	–0°03'30.76"
20. Pittsburg	DF7131	PAOLA MAGNETIC RESET	-10.545	-0.0557	1 : 94,827	1.000033559	0.999955897	0.999989455	+0°06'11.07"
20. Pittsburg	HE1184	PITTPORT	3.611	0.0191	1 : 276,924	1.000043090	0.999960522	1.000003611	+0°12'55.06"
20. Pittsburg	HE1185	PITTPORT AZ MK	2.477	0.0131	1 : 403,703	1.000042778	0.999959701	1.000002477	+0°12'45.01"
20. Pittsburg	AH5860	PTS A	3.236	0.0171	1 : 309,003	1.000042939	0.999960299	1.000003236	+0°12'50.30"

D. KRCS and SPCS linear distortion for Kansas cities and towns

Table D-1. Kansas city and town NAD 83 coordinates and both KRCS and SPCS 83 linear distortion. Consists of 155 cities and towns with population of 2500 or greater (plus Oberlin with population 1,898). The minimum and maximum distortion for KRCS is -19.7 ppm (Ogallah) and +15.9 ppm (Garland), and for SPCS 83 it is -214.3 ppm (Goodland) and +21.4 ppm (Coffeyville), respectively.

City or town name	Latitude	Longitude	Ellipsoid height (ft)	KRCS zone	Linear distortion (ppm)	
					KRCS	SPCS 83 (zone)
Abilene	38.9217	-97.2216	1061	7. Salina	-0.6	-77.5 (N)
Andover	37.6940	-97.1352	1256	17. Wichita	-0.3	-116.6 (S)
Arkansas City	37.0694	-97.0390	991	18. Arkansas City	9.6	-2.8 (S)
Arnold	38.6381	-100.0457	2477	14. Dodge City	-8.1	-103.5 (S)
Atchison	39.5609	-95.1274	723	10. Atchison	6.2	-63.1 (N)
Augusta	37.6931	-96.9714	1183	17. Wichita	3.2	-113.0 (S)
Baileyville	39.8415	-96.1829	1186	10. Atchison	-10.1	-46.8 (N)
Baldwin City	38.7770	-95.1861	951	11. Kansas City	3.3	-54.7 (N)
Baxter Springs	37.0237	-94.7354	743	20. Pittsburg	7.3	21.1 (S)
Beaumont	37.6587	-96.5350	1495	17. Wichita	-10.7	-125.4 (S)
Beeler	38.4508	-100.1961	2451	14. Dodge City	6.1	-138.1 (S)
Bel Aire	37.7640	-97.2807	1304	17. Wichita	-3.4	-122.9 (S)
Beloit	39.4652	-98.1090	1354	6. Beloit	3.4	-100.9 (N)
Bendena	39.7401	-95.1798	993	10. Atchison	-5.8	-54.2 (N)
Berryton	38.9393	-95.6325	875	11. Kansas City	-4.9	-70.3 (N)
Bonner Springs	39.0830	-94.8818	850	11. Kansas City	-7.6	-79.5 (N)
Bremen	39.9008	-96.7891	1244	10. Atchison	-8.6	-38.3 (N)
Burdick	38.5638	-96.8454	1356	9. Emporia	-14.2	-36.7 (N)
Burlington	38.1993	-95.7447	921	19. Coffeyville	-5.4	-96.1 (S)
Catharine	38.9293	-99.2156	1935	4. Hays	-5.5	-120.0 (N)
Centerville	38.2209	-95.0160	819	20. Pittsburg	-7.7	-89.3 (S)
Chanute	37.6746	-95.4610	870	20. Pittsburg	3.1	-96.7 (S)
Clay Center	39.3804	-97.1246	1121	7. Salina	-0.6	-94.2 (N)
Coffeyville	37.0403	-95.6309	644	19. Coffeyville	14.2	21.4 (S)
Colby	39.3871	-101.0457	3070	2. Colby	-12.0	-187.1 (N)
Columbus	37.1787	-94.8426	791	20. Pittsburg	-1.2	-19.4 (S)
Concordia	39.5655	-97.6575	1305	7. Salina	-3.9	-90.5 (N)
Crestline	37.1708	-94.7044	769	20. Pittsburg	8.2	-16.6 (S)
Cummings	39.4627	-95.2468	886	10. Atchison	2.0	-78.7 (N)
De Soto	38.9693	-94.9600	691	11. Kansas City	2.5	-64.2 (N)
Dennis	37.3466	-95.4125	819	20. Pittsburg	2.3	-53.9 (S)
Derby	37.5479	-97.2579	1190	17. Wichita	9.3	-100.3 (S)
Dodge City	37.7573	-100.0166	2476	14. Dodge City	-9.7	-178.6 (S)
Dover	38.9644	-95.9376	904	11. Kansas City	-7.4	-74.0 (N)
Edson	39.3395	-101.5404	3488	1. Goodland	-10.5	-208.7 (N)
Edwardsville	39.0707	-94.8259	725	11. Kansas City	-1.5	-72.9 (N)
El Dorado	37.8174	-96.8582	1223	17. Wichita	0.9	-121.0 (S)

City or town name	Latitude	Longitude	Ellipsoid height (ft)	KRCS zone	Linear distortion (ppm) KRCS	SPCS 83 (zone)
Ellsworth	38.7349	-98.2260	1459	6. Beloit	-1.2	-72.7 (N)
Emporia	38.4123	-96.1929	1059	9. Emporia	0.5	-77.5 (S)
Eudora	38.9419	-95.0989	744	11. Kansas City	1.2	-64.3 (N)
Eureka	37.8253	-96.2883	982	19. Coffeyville	-3.1	-109.8 (S)
Fairway	39.0251	-94.6275	821	11. Kansas City	-5.4	-74.7 (N)
Falun	38.6711	-97.7599	1252	7. Salina	6.1	-52.2 (N)
Farlington	37.6159	-94.8324	895	20. Pittsburg	-5.8	-93.1 (S)
Fort Riley North	39.1085	-96.8173	1238	8. Manhattan	-14.7	-99.3 (N)
Fort Riley-Camp Whiteside	39.0793	-96.7688	1003	8. Manhattan	-2.8	-86.7 (N)
Fort Scott	37.8275	-94.7028	729	20. Pittsburg	10.0	-97.7 (S)
Franklin	37.5261	-94.7049	887	20. Pittsburg	2.4	-83.3 (S)
Fredonia	37.5300	-95.8235	789	19. Coffeyville	-1.8	-79.1 (S)
Frontenac	37.4552	-94.6966	847	20. Pittsburg	4.9	-72.2 (S)
Galena	37.0749	-94.6392	801	20. Pittsburg	11.9	4.9 (S)
Garden City	37.9750	-100.8609	2745	13. Garden City	-2.1	-194.8 (S)
Gardner	38.8110	-94.9199	942	11. Kansas City	0.6	-58.9 (N)
Garland	37.7312	-94.6210	743	20. Pittsburg	15.9	-94.3 (S)
Garnett	38.2850	-95.2493	947	20. Pittsburg	-11.7	-88.9 (S)
Girard	37.5138	-94.8434	893	20. Pittsburg	-6.2	-82.1 (S)
Goodland	39.3416	-101.7076	3606	1. Goodland	-15.4	-214.3 (N)
Grantville	39.0875	-95.5578	765	11. Kansas City	-3.6	-75.7 (N)
Great Bend	38.3618	-98.7783	1765	5. Great Bend	-5.2	-118.5 (S)
Greenwich	37.7840	-97.2083	1304	17. Wichita	-3.3	-123.7 (S)
Hays	38.8809	-99.3250	1926	4. Hays	-8.7	-114.5 (N)
Haysville	37.5644	-97.3514	1168	17. Wichita	9.3	-101.0 (S)
Healy	38.6006	-100.6164	2768	13. Garden City	-19.0	-125.5 (S)
Herington	38.6706	-96.9469	1226	7. Salina	4.3	-50.9 (N)
Hesston	38.1447	-97.4270	1389	17. Wichita	14.3	-122.7 (S)
Hiawatha	39.8529	-95.5374	1027	10. Atchison	-1.8	-37.1 (N)
Hillsdale	38.6597	-94.8512	789	20. Pittsburg	-1.7	-18.0 (S)
Hoisington	38.5216	-98.7781	1762	5. Great Bend	-5.1	-92.9 (S)
Holton	39.4634	-95.7419	983	10. Atchison	-2.6	-83.3 (N)
Hugoton	37.1757	-101.3481	3024	12. Ulysses	-4.2	-125.5 (S)
Hutchinson	38.0721	-97.9131	1437	17. Wichita	4.4	-129.2 (S)
Independence	37.2324	-95.7066	671	19. Coffeyville	8.5	-25.2 (S)
Iola	37.9277	-95.4091	862	20. Pittsburg	-0.1	-105.3 (S)
Junction City	39.0283	-96.8372	1009	8. Manhattan	-1.3	-83.9 (N)
Kansas City	39.1027	-94.6262	695	11. Kansas City	-0.2	-73.1 (N)
Kingman	37.6464	-98.1132	1436	17. Wichita	-7.5	-121.6 (S)
Lake City	37.3536	-98.8204	1520	16. Pratt	3.4	-88.7 (S)
Lansing	39.2451	-94.8869	668	11. Kansas City	4.3	-75.1 (N)
Larned	38.1826	-99.0983	1917	15. Larned	-3.7	-145.1 (S)

City or town name	Latitude	Longitude	Ellipsoid height (ft)	KRCS zone	Linear distortion (ppm) KRCS	Linear distortion (ppm) SPCS 83 (zone)
Lawrence	38.9426	-95.2606	788	11. Kansas City	-0.9	-66.5 (N)
Leavenworth	39.3246	-94.9199	737	11. Kansas City	5.4	-77.6 (N)
Leawood	38.9129	-94.6255	802	11. Kansas City	0.0	-64.2 (N)
Lenexa	38.9683	-94.8103	811	11. Kansas City	-3.2	-69.9 (N)
Levant	39.3809	-101.1946	3226	2. Colby	-14.8	-194.8 (N)
Liberal	37.0469	-100.9315	2760	13. Garden City	4.5	-81.5 (S)
Lincoln	39.0402	-98.1513	1295	6. Beloit	6.1	-98.4 (N)
Lindsborg	38.5735	-97.6745	1237	7. Salina	0.7	-57.8 (S)
Linn Valley	38.3770	-94.7117	821	20. Pittsburg	4.7	-71.3 (S)
Lyons	38.3477	-98.2018	1607	6. Beloit	-8.6	-112.8 (S)
Manhattan	39.1921	-96.5984	1030	8. Manhattan	-5.2	-91.9 (N)
Maple City	37.0565	-96.7687	1252	18. Arkansas City	-2.4	-11.9 (S)
Marienthal	38.4818	-101.2133	3135	12. Ulysses	-6.1	-165.6 (S)
Marysville	39.8422	-96.6456	1098	10. Atchison	-5.9	-42.4 (N)
McPherson	38.3729	-97.6671	1407	7. Salina	-7.8	-99.9 (S)
Merriam	39.0149	-94.6864	912	11. Kansas City	-9.5	-78.3 (N)
Milton	37.4317	-97.7716	1379	18. Arkansas City	-1.6	-94.3 (S)
Mission	39.0277	-94.6584	928	11. Kansas City	-10.6	-80.0 (N)
Mission Hills	39.0151	-94.6169	840	11. Kansas City	-6.1	-74.9 (N)
Mulvane	37.4874	-97.2446	1175	17. Wichita	14.6	-92.3 (S)
Murdock	37.6113	-97.9307	1391	17. Wichita	-3.9	-116.4 (S)
Nekoma	38.4723	-99.4411	1949	15. Larned	-0.8	-110.5 (S)
Neodesha	37.4175	-95.6824	707	19. Coffeyville	8.0	-60.0 (S)
Newton	38.0428	-97.3451	1352	17. Wichita	5.9	-126.4 (S)
Norton	39.8385	-99.8888	2237	4. Hays	-7.6	-97.5 (N)
Oaklawn-Sunview	37.6058	-97.3011	1170	17. Wichita	7.0	-105.3 (S)
Oberlin	39.8239	-100.5342	2548	3. Oberlin	-2.8	-115.0 (N)
Ogallah	38.9921	-99.7421	2292	4. Hays	-19.7	-142.6 (N)
Olathe	38.8835	-94.8182	917	11. Kansas City	-3.8	-66.6 (N)
Opolis	37.3399	-94.6222	813	20. Pittsburg	12.7	-52.5 (S)
Osage City	38.6347	-95.8219	979	19. Coffeyville	-10.9	-32.7 (S)
Osawatomie	38.4989	-94.9509	762	20. Pittsburg	-3.8	-49.1 (S)
Ottawa	38.6085	-95.2686	801	20. Pittsburg	-4.1	-29.8 (S)
Overland Park	38.9276	-94.6861	913	11. Kansas City	-6.2	-71.0 (N)
Paola	38.5753	-94.8652	803	20. Pittsburg	-3.0	-36.7 (S)
Park City	37.7959	-97.3174	1283	17. Wichita	-2.2	-123.2 (S)
Parsons	37.3405	-95.2674	798	20. Pittsburg	-3.9	-51.9 (S)
Penokee	39.3504	-99.9726	2143	4. Hays	4.5	-144.1 (N)
Phillipsburg	39.7486	-99.3188	1839	4. Hays	-4.4	-93.4 (N)
Piedmont	37.6234	-96.3670	1101	19. Coffeyville	-3.3	-103.6 (S)
Pierceville	37.8789	-100.6777	2665	13. Garden City	-11.1	-191.3 (S)
Piqua	37.9200	-95.5370	928	19. Coffeyville	7.2	-108.5 (S)

City or town name	Latitude	Longitude	Ellipsoid height (ft)	KRCS zone	Linear distortion (ppm) KRCS	SPCS 83 (zone)
Pittsburg	37.4111	-94.6938	823	20. Pittsburg	6.3	-64.6 (S)
Potter	39.4256	-95.1423	856	10. Atchison	5.6	-79.4 (N)
Prairie Village	38.9884	-94.6387	895	11. Kansas City	-7.9	-75.5 (N)
Pratt	37.7105	-98.7602	1866	16. Pratt	-16.0	-146.8 (S)
Riverton	37.0749	-94.7046	734	20. Pittsburg	9.9	8.1 (S)
Rock	37.4408	-97.0066	1076	18. Arkansas City	13.6	-81.1 (S)
Roeland Park	39.0365	-94.6398	875	11. Kansas City	-8.2	-78.0 (N)
Rosalia	37.8151	-96.6200	1419	17. Wichita	-8.5	-130.3 (S)
Rose Hill	37.5652	-97.1351	1230	17. Wichita	6.3	-104.1 (S)
Roxbury	38.5512	-97.4273	1251	7. Salina	-10.0	-62.8 (S)
Russell	38.8855	-98.8562	1748	5. Great Bend	-2.3	-106.5 (N)
Salina	38.8180	-97.6130	1142	7. Salina	1.6	-69.4 (N)
Scott City	38.4785	-100.9069	2888	13. Garden City	-5.0	-154.3 (S)
Shawnee	39.0092	-94.8113	689	11. Kansas City	1.3	-67.3 (N)
South Hutchinson	38.0279	-97.9403	1434	17. Wichita	0.8	-130.8 (S)
Stilwell	38.7692	-94.6565	965	11. Kansas City	3.4	-54.2 (N)
Sycamore	37.3270	-95.7109	731	19. Coffeyville	5.4	-46.3 (S)
Tecumseh	39.0443	-95.5762	768	11. Kansas City	-3.3	-73.4 (N)
Tonganoxie	39.1163	-95.0841	758	11. Kansas City	-3.2	-76.7 (N)
Topeka	39.0474	-95.6815	838	11. Kansas City	-6.7	-77.0 (N)
Ulysses	37.5765	-101.3544	2964	12. Ulysses	-1.4	-188.2 (S)
Valley Center	37.8250	-97.3720	1247	17. Wichita	-0.1	-122.4 (S)
Vassar	38.6374	-95.6197	979	19. Coffeyville	-1.6	-32.1 (S)
Wakarusa	38.8865	-95.6873	847	11. Kansas City	-0.6	-63.6 (N)
Wakeeney	39.0213	-99.8792	2355	4. Hays	-13.6	-147.8 (N)
Walker	38.8671	-99.0770	1857	4. Hays	6.1	-109.7 (N)
Wamego	39.2047	-96.3051	912	8. Manhattan	0.6	-86.4 (N)
Welda	38.1668	-95.2924	1012	20. Pittsburg	-13.3	-103.1 (S)
Wellington	37.2707	-97.4021	1106	18. Arkansas City	3.3	-53.7 (S)
Weskan	38.8689	-101.9639	3761	1. Goodland	-11.6	-200.9 (N)
Wichita	37.6860	-97.3356	1201	17. Wichita	2.5	-113.4 (S)
Winfield	37.2405	-96.9872	1034	18. Arkansas City	6.0	-44.2 (S)
Wright	37.7788	-99.8921	2444	14. Dodge City	-15.0	-178.0 (S)
Yoder	37.9382	-97.8669	1443	17. Wichita	-5.5	-133.0 (S)

E. Equations for computing projection grid point scale factors

The projection grid point scale factor, k, is required to compute map projection distortion for a point on the ground. Because some surveying, engineering, and GIS software does not provide k, formulas for computing it are given below for the Transverse Mercator and Lambert Conformal Conic projections. These equations were derived from those provided in *NOAA Manual NOS NGS 5* "State Plane Coordinate System of 1983" by James Stem (1990). Equations for computing the convergence angle of these projections are also provided.

For the Transverse Mercator projection, the grid scale factor at a point can be computed as follows (modified from Stem, 1990, pp. 32-35):

$$k = k_0 \left\{ 1 + \frac{(\Delta\lambda \cos\varphi)^2}{2} \left(1 + \frac{e^2 \cos^2\varphi}{1-e^2} \right) \left[1 + \frac{(\Delta\lambda \cos\varphi)^2}{12} \left(5 - 4\tan^2\varphi + \frac{e^2 \cos^2\varphi}{1-e^2} (9 - 24\tan^2\varphi) \right) \right] \right\}$$

where $\Delta\lambda = \lambda_0 - \lambda$ (in radians, for negative west longitude)

λ_0 = central meridian longitude

λ = geodetic longitude of point

φ = geodetic latitude of point

e^2 = reference ellipsoid first eccentricity squared

The following shorter equation can be used to approximate k for the Transverse Mercator projection. It is accurate to better than 0.02 part per million (at least 7 decimal places) if the computation point is within about ±1° of the central meridian (about 50 to 60 miles between latitudes of 30° and 45°):

$$k \approx k_0 \left\{ 1 + \frac{(\Delta\lambda \cos\varphi)^2}{2} \left(1 + \frac{e^2 \cos^2\varphi}{1-e^2} \right) \right\}$$

Note that this equation may not be sufficiently accurate for computing k throughout a UTM system zone (at the zone width of ±3° from the central meridian the error can exceed 1 ppm).

An even simpler equation can be used to approximate the grid scale factor, which utilizes the grid coordinate easting value and is about twice as accurate as the previous equation (i.e., better than 0.01 part per million if the computation point is within about ±1° of the central meridian):

$$k \approx k_0 + \frac{(E_0 - E)^2}{2(k_0 R)^2}$$

where E = Easting of the point where k is computed (in same units as R_G)

E_0 = False easting (on central meridian) of projection definition (in same units as R_G)

R = Earth geometric mean radius of curvature

For the Lambert Conformal Conic projection, the grid scale factor at a point can be computed as follows (modified from Stem, 1990, pp. 26-29):

$$k = k_0 \frac{\cos\varphi_C}{\cos\varphi}\sqrt{\frac{1-e^2\sin^2\varphi}{1-e^2\sin^2\varphi_C}}\exp\left\{\frac{\sin\varphi_C}{2}\left[\ln\frac{1+\sin\varphi_C}{1-\sin\varphi_C}-\ln\frac{1+\sin\varphi}{1-\sin\varphi}+e\left(\ln\frac{1+e\sin\varphi}{1-e\sin\varphi}-\ln\frac{1+e\sin\varphi_C}{1-e\sin\varphi_C}\right)\right]\right\}$$

where k_0 = projection grid scale factor applied to central parallel (tangent to ellipsoid if k_0 = 1)

φ_C = geodetic latitude of central parallel = standard parallel for one-parallel LCC

$e = \sqrt{e^2} = \sqrt{2f - f^2}$ = first eccentricity of the reference ellipsoid

and all other variables are as defined previously. To use this equation for a two-parallel LCC, the two-parallel LCC must first be converted to an equivalent one-parallel LCC by computing φ_C and k_0. The equations to do this are long, but are provided here for the sake of completeness. For a two-parallel LCC, the central parallel is

$$\varphi_C = \sin^{-1}\left[\frac{2\ln\left(\frac{\cos\varphi_S}{\cos\varphi_N}\sqrt{\frac{1-e^2\sin^2\varphi_N}{1-e^2\sin^2\varphi_S}}\right)}{\ln\left(\frac{1+\sin\varphi_N}{1-\sin\varphi_N}\right)-\ln\left(\frac{1+\sin\varphi_S}{1-\sin\varphi_S}\right)+e\left[\ln\left(\frac{1+e\sin\varphi_S}{1-e\sin\varphi_S}\right)-\ln\left(\frac{1+e\sin\varphi_N}{1-e\sin\varphi_N}\right)\right]}\right],$$

and the central parallel scale factor is

$$k_0 = \frac{\cos\varphi_N}{\cos\varphi_C}\sqrt{\frac{1-e^2\sin^2\varphi_0}{1-e^2\sin^2\varphi_N}}$$

$$\times\ \exp\left\{\frac{\sin\varphi_C}{2}\left[\ln\left(\frac{1+\sin\varphi_N}{1-\sin\varphi_N}\right)-\ln\left(\frac{1+\sin\varphi_C}{1-\sin\varphi_C}\right)+e\left(\ln\left[\frac{1+e\sin\varphi_C}{1-e\sin\varphi_C}\right]-\ln\left[\frac{1+e\sin\varphi_N}{1-e\sin\varphi_N}\right]\right)\right]\right\},$$

where φ_N and φ_S = geodetic latitude of northern and southern standard parallels, respectively, and all other variables are as defined previously.

Convergence angles. For the TM, the convergence angle can be approximated as $\gamma = -\Delta\lambda\sin\varphi$ (where all variables are as defined previously; the units of γ are the same as the units of $\Delta\lambda$). This equation is accurate to better than ±00.2” if the computation point is within ~1° of the central meridian. For any LCC, the convergence angle is exactly $\gamma = -\Delta\lambda\sin\varphi_C$.