Procedures for Design and Modification of the State Plane Coordinate System of 2022

Procedures Document
National Geodetic Survey
National Ocean Service
National Oceanic and Atmospheric Administration

AUTHORIZED BY:

CHILDERS.VICKI.ANNETTE.1239483476

Digitally signed by CHILDERS.VICKI.ANNETTE.1239483476
Date: 2023.07.03 14:37:24 -04'00'

Chief, Observation and Analysis Division **Date**

Vicki A. Childers

Tracking Number:
NGS 2023-1214-03-A3

Effective Date:
July 1, 2023

Official Procedure Title: Procedures for Design and Modification of the State Plane Coordinate System of 2022

Tracking Number: NGS 2023-1214-03-A3

Effective Date: July 1, 2023

Internal or External: External

Associated NGS Documents:

"State Plane Coordinate System of 2022 Policy"
<**https://geodesy.noaa.gov/INFO/Policy/files/SPCS2022-Policy.pdf**>

"The State Plane Coordinate System: History, Policy, and Future Directions," *NOAA Special Publication NOS NGS 13*, National Oceanic and Atmospheric Administration, National Geodetic Survey, Silver Spring, Maryland.
<**https://geodesy.noaa.gov/library/pdfs/SP_NOS_NGS_13.pdf**>

Authority/Reference: As original creator of the State Plane Coordinate System, the National Geodetic Survey (NGS) has sole authority to define and establish these procedures.

Supersedes: There are no prior procedures for the State Plane Coordinate System. Superseded policies are listed in the policy document associated with these procedures. However, the superseded policies include information that can be construed as procedures.

Review Schedule: At least once every two years.

Responsible Office/Position: The Observation and Analysis Division (OAD) Chief has the authority to review and approve these procedures. The OAD chief is responsible for ensuring these procedures are consistent with and reflect any changes made to the associated policy.

Purpose/Scope

These procedures define the roles and responsibilities for the National Geodetic Survey (NGS) and stakeholders in defining and modifying the State Plane Coordinate System of 2022 (SPCS2022), as well as its naming conventions and technical specifications. The procedures are divided into the following six sections:

1. NGS contact information and criteria for stakeholder input. NGS email and postal addresses for submissions, general submittal requirements, and criteria for "consensus" stakeholder input for submitting requests and proposals, and for submittal of zone designs by stakeholders.
2. Requirements for stakeholder requests and proposals of SPCS2022 designs. Specifies requirements for stakeholders to make requests for SPCS2022 designs by NGS and for proposing designs by stakeholders.
3. Requirements for submittal of SPCS2022 designs by stakeholders. Specifies requirements for stakeholders when submitting their approved SPCS2022 zone designs.
4. NGS roles and responsibilities for SPCS2022 reviews and documentation. Specifies how NGS reviews requests, design proposals, and submitted designs, as well as what is documented by NGS.

5. Zone numbers, names, and abbreviations. Presents the protocols and requirements for numeric codes, zone names, and name abbreviations for SPCS2022 zones.
6. Technical specifications for SPCS2022 design and implementation. Detailed technical specifications to augment those given in SPCS2022 policy.

This procedures document provides supporting information for implementing SPCS2022 policy. It includes additional details to aid in interpreting and fulfilling the policy objectives.

The procedures are based on and derived from the SPCS2022 policy. If any items in these procedures are construed as being in conflict with policy, the policy shall prevail. Moreover, any information in the policy that is not addressed in these procedures should be considered as complete within the policy itself.

SPCS2022 is established for states, the Federal District, and selected insular areas of the United States. For brevity, the term "state" represents all of these areas throughout this document, as in the policy document.

Background

The policy associated with these procedures provides the necessary background information. Additional information on SPCS is given in *NOAA Special Publication NOS NGS 13*, which includes a comprehensive list of references to other NGS SPCS documents. These documents are a valuable resource for understanding SPCS in the context of its evolution, implementations, and usage since its original creation in the 1930s.

Exceptions

The NGS Director may exercise discretion to approve or deny special requests regarding initial design or subsequent changes of SPCS2022 that depart from these procedures (and associated policy), either in whole or in part.

Definitions of Terms

Not all technical terms used in this procedures document are defined below. Terms not defined in this list are either defined in the body of this document or by reference to *NOAA Special Publication NOS NGS 13*. Terms in *italics* in the definitions are also defined in this list.

- Conformal map projection. A projection where the *linear distortion* is unique (the same in every direction) at a point and, equivalently, the only angular distortion is the *convergence angle*. The three types of conformal projections used for SPCS are the Lambert Conformal Conic (LCC), Transverse Mercator (TM), and Hotine Oblique Mercator (OM).
- Convergence angle. The difference between geodetic and grid north (with sign convention as geodetic minus grid north); also known as mapping or map angle. Typically computed and used only for *conformal map projections*.
- Linear distortion. For *conformal map projections*, it is the amount by which a distance or length in a projected coordinate reference system differs from the actual horizontal distance

on or near the topographic surface of the Earth. Expressed as a ratio of distorted distance to true distance, for example as parts per million (ppm) or as a ratio (e.g., 100 ppm = 1:10,000). Also known as "scale error" when evaluated with respect to distances on the *reference ellipsoid* surface.

- Projection axis. For *conformal map projections*, it is the line or curve along which *linear distortion* is minimum and constant (or nearly constant) with respect to the *reference ellipsoid*. It is the central parallel of the Lambert Conformal Conic projection, the central meridian of the Transverse Mercator projection, and the skew axis of the Hotine Oblique Mercator projection (also known as the initial or central line).
- Reference ellipsoid. An oblate ellipsoid of revolution that approximates the size and shape of the entire Earth geoid ("mean sea level") or a large portion of it. When oriented with respect to a geometric reference frame or datum, it defines the reference surface for projected coordinate reference systems. Also known as a reference "spheroid."
- Stakeholders. NGS customers and users of SPCS within a state most involved in the use, collection, and distribution of spatial data, and who have a substantial stake in how SPCS2022 is designed. Stakeholders consist of one or more of the following organizations:
  - State departments of transportation.
  - State GIS or cartographer offices.
  - State professional surveying and engineering societies.
  - State GIS or other professional geospatial organizations.
  - Universities, colleges, or other post-secondary educational institutions within a state that perform geospatial education or research.
  - Other departments, offices, and organizations within a state with roles and functions similar to those of the organizations listed above.

  National organizations can also provide input on SPCS2022 as stakeholders, but they cannot represent a specific state except in cases where one or more of the aforementioned state groups have granted them that authority, as documented in the required submittals for these procedures.
- Zone. A region on the surface of the Earth that defines the use area of a projected coordinate reference system, with extents usually based on a specified maximum *linear distortion* magnitude.

Procedures for Design and Modification of the State Plane Coordinate System of 2022

The initial design of SPCS2022 is nearly complete, and NGS is no longer accepting new requests or proposals for design of SPCS2022 zones. NGS will begin accepting requests and proposals for modifications of SPCS2022 after it is officially released in 2025 along with all other components of the Modernized National Spatial Reference System (NSRS). These procedures provide the general process for making requests and proposals, and more details will be provided near the time of the official release of SPCS2022.

1. **NGS contact information and criteria for stakeholder requests and proposals.** Stakeholder may make requests for particular SPCS2022 characteristics or submit proposed SPCS2022 zone designs in accordance with these procedures. Stakeholders are defined in the "Definitions of Terms" section of this document.

   a. NGS contact information for SPCS2022

      i. Questions, comments, requests, proposals, and design submittals can be sent to NGS via email at **NGS.SPCS@noaa.gov**.

      ii. Forms for submitting requests and proposals, and for submitting SPCS2022 zone designs will be made available near the time of the official release of SPCS2022 in 2025.

   b. Requirements for submittal of stakeholder requests and proposals.

      i. Stakeholder requests and proposals for SPCS2022 designs. The requirements are given in §2 of these procedures, and in the associated form (available in 2025). A "request" is for NGS to design or modify SPCS2022 zones. A "proposal" is for SPCS2022 designs created and submitted by stakeholders.

      ii. Stakeholder submittal of SPCS2022 zone designs. The requirements are given in §3 of these procedures, and in the associated form (available in 2025). Note that the proposed designs must first be approved by NGS per §2.

   c. Qualifying criteria for stakeholder input. To act on requests, proposals, and contributions to SPCS2022, NGS requires consensus input from one or more stakeholder groups, as described below.

      i. Stakeholder input must be provided through at least one of the organizations listed in the "Definitions of Terms" section of this document. If more than one stakeholder provides input for a state, they are encouraged to do so collectively, rather than each stakeholder group providing input individually.

      ii. All requests and proposals for SPCS2022 zones must be submitted using forms provided by NGS, as specified in the §2 of these procedures. NGS will only act on unanimous agreement of stakeholder groups. In the absence of unanimity, NGS has sole authority to design SPCS2022 zones for a state.

      iii. National groups, federal agencies, or regional groups consisting of multiple states, can provide input as stakeholders. But the input will only be considered as representing that of a state if at least one of the state stakeholder organizations is also listed on the request/proposal or design submittal forms.

      iv. Requests or proposals for changes to zones that were designed based on previous requests or proposals should include the same stakeholder groups (or their successors or equivalents) as in the previous request or proposal. In the event that the previous stakeholder groups are not included, NGS will determine whether there is sufficient stakeholder representation in the new request or proposal.

      v. NGS will not act on input from individuals. Interested individuals should provide input through stakeholder organizations for their state.

d. Special use zones. Per SPCS2022 policy §III.A.2.b, these zones are in more than one state, or not in any state, and require approval of the NGS Director on a case-by-case basis. Use the SPCS2022 contact information above to make inquiries for a specific case.

2. Requirements for stakeholder requests and proposals of SPCS2022 designs

a. The required information will be provided to NGS using an updated version of the NGS *SPCS2022 Request and Proposal Form*. This form will be available in 2025.

b. Must comply with all SPCS2022 policies and procedures, including all technical specifications.

c. Providing all required information is the responsibility of the submitter.

d. NGS will review requests/proposals and respond to inquiries as quickly as possible.

e. Proposed designs by stakeholders must be approved by NGS before any submitted designs are reviewed by NGS.

3. Requirements for submittal of SPCS2022 designs by stakeholders

a. The required information will be provided to NGS using the NGS *SPCS2022 Zone Design Submittal Form*. This form will be available in 2025.

b. Must comply with all SPCS2022 policies and procedures, including all technical specifications.

c. The design proposal must be approved by NGS before a submitted design will be reviewed (per §2) for inclusion in SPCS2022.

d. Providing all required information is the responsibility of the submitter.

e. NGS will review submitted designs and respond to inquiries as quickly as possible.

f. Customer technical support requests received by NGS for zones designed by stakeholders will be redirected to the state point of contact designated by the stakeholders.

4. NGS role and responsibilities for SPCS2022 reviews and documentation

a. For requests, design proposals, and submitted designs, NGS will:

i. Confirm receipt of stakeholder requests and of stakeholder designs. If submittals are incomplete, NGS will notify the submitter.

ii. Review requests and proposals for designs submitted by stakeholders. Only submittals with all required information will be reviewed.

iii. Review SPCS2022 zone designs submitted by stakeholders. Only submittals based on an approved proposal and containing all required information will be reviewed.

iv. Notify submitters when a request, proposal, or submitted design is approved or denied. If denied, the reason(s) will be provided.

v. Provide guidance on SPCS2022 zone design via workshops, presentations, webinars, website content, correspondence, and/or technical manuals.

vi. Maintain a record of finalized SPCS2022 zones on the NGS web site.

b. NGS will document all approved designs and associated parameters. The documentation will include the following:

i. Update of this policy and associated procedures, as necessary.

ii. Load SPCS2022 defining parameters for all zones into an NGS database.

iii. Publish an official NGS report completely defining SPCS2022, revised as needed to address any changes.

iv. Create and maintain a set of SPCS2022 web pages, with links to documents, defining parameters, and to applications and tools that use SPCS2022.

5. Zone codes, names, and abbreviations. NGS assigns codes and adopts names for SPCS2022 zones as described below. Examples are given in Table 1, including ones based on hypothetical future changes to SPCS2022 zones.

a. Zone numeric code. Assigned by NGS and consists of six digits, where the first two digits correspond to the American National Standard Institute (ANSI) numeric code for the state (including leading zero placeholder), formerly known as Federal Information Processing Standards (FIPS) codes. State ANSI and U.S. Postal Service codes used for SPCS2022 are available at **https://www.census.gov/library/reference/code-lists/ansi/ansi-codes-for-states.html**.

i. There is a one-to-one relationship between the zone code and its defining parameters. If any parameters (other than the zone name or abbreviation) or the zone extents change, the zone code will also change. This is not necessarily true for the zone name and abbreviation. Although zone names and abbreviations are unique in SPCS2022, a change in defining parameters might not include a change in the name or abbreviation. However, the zone code will change.

ii. For a statewide zone, the third through fifth digits are zero (i.e., "000"), and the last (sixth) digit is 1 for the initially adopted design. This digit will increment from 2 through 9 sequentially if later replaced by a new statewide zone.

iii. Multiple-zone (multizone) layers are indicated by a third digit that is not zero, and a maximum of two multizone layers can exist simultaneously. It increments sequentially from 1 through 9 to allow for zone replacement over time. For multizone layers that provide discontinuous (partial) coverage of a state, zones can be added without incrementing to a new layer number. In such cases, incrementing the layer number only occurs when parameters or extents of existing zones are changed, or when existing zones are removed or replaced by new zones.

iv. For multizone layers (third digit not equal to zero), the last three digits are the sequential number for the zones in that layer (1 through 999).

v. For zones consisting of the entirety of more than one state, the ANSI numeric code of the state with the lowest ANSI code is used.

vi. For special use zones, the first two digits are zero because these zones are in more than one state (or in no state at all) and thus are not associated with any single state.

The third digit is set to 1 for the initial version of a special use zone, which will increment sequentially from 2 through 9 for an existing zone if any of its defining parameters change. The last digit is 1 for the first special use zone and increases sequentially by one digit as zones are added. For example, the first special use zone is "001001" (Gulf of Mexico Zone), the second is "001002" (Navajo Nation Zone), etc.

b. Zone name. Begins with the state or territory name, followed by the zone name.
   i. For statewide zones, the name is the state or territory name followed by the word "Zone" (e.g., "Arizona Zone"). For combined states or territories, the name is hyphenated. There are two such zones currently in SPCS2022, the "Puerto Rico-Virgin Islands Zone" and the "Guam-Northern Mariana Islands Zone."
   ii. Multizone layers begin with the state or territory name followed by an alphanumeric descriptive name, and ending with word "Zone." The descriptive zone name cannot exceed 50 characters, including spaces. Special characters are limited to the hyphen or dash (-) and the underscore (_).
   iii. For zone layouts that are similar to previous versions of SPCS, a similar naming convention is used, as appropriate (e.g., "Central" for the middle zone of a 3-zone state).
   iv. For special use zones, the complete name consists only of the zone name, without any preceding state name.
   v. Abbreviations cannot be used in zone names.

c. Zone abbreviation. The official 2-character U.S. Postal Service code is used for the first two characters of a zone abbreviation corresponding to the state or territory.
   i. The abbreviation for a statewide zone is the same as the state abbreviation (total of two letters).
   ii. A subsequent string of 1 to 4 alphanumeric characters is used to abbreviate the name of multiple zones within a state. The characters used for a zone cannot include a space or underscore, because it is separated from the state code by a space or underscore (e.g., "AZ C" or "AZ_C" for Arizona Central Zone).
   iii. For zone layouts that are similar to previous versions of SPCS, a similar abbreviation convention is recommended (e.g., "C" for Central Zone).
   iv. For zones consisting of more than one state, the first and last 2-character state abbreviations are concatenated in alphabetical order. There are currently two such zones, both consisting of two territories: "PRVI" for Puerto Rico and the U.S. Virgin Islands, and "GUMP" for Guam and the Northern Mariana Islands.
   v. For special use zones, the 2-character state abbreviation is blank and the zones are assigned a unique 1- to 4-character abbreviation consistent with the zone name, for example "GULF" for the Gulf of Mexico Zone. This abbreviation is the entire abbreviation for special use zones.

Table 1. Example SPCS2022 zone codes, names, and abbreviations, including hypothetical future changes (spaces in names and/or abbreviations can be replaced with underscores).

Description of zone layers	Examples for each layer type		
	Code	**Name**	**Abbreviation**
Arizona (three zone layers): statewide, multizone complete, and multizone partial coverage layers			
Initial statewide zone	040001	Arizona	AZ
Initial multizone layer with complete state coverage (44 zones, 041001-041044)	041014	Arizona Camp Verde-Cottonwood-Sedona	AZ CVCS
Initial multizone layer with partial state coverage (18 zones, 042001-042018)	042007	Arizona Central Arizona Project	AZ CAP
Hypothetical change in name and abbreviation of previously existing zone 041014 but no change in parameters or extents (no change to zone code)	041014	Arizona Verde Valley	AZ VVAL
Hypothetical change in name and abbreviation of previously existing zone 041014 *and* change in parameters; third digit of code increments by one for all zones in layer with zones (optionally) renumbered	043042	Arizona Verde Valley	AZ VVAL
Iowa (two zone layers): statewide zone and multizone layer with complete state coverage			
Initial statewide zone	190001	Iowa	IA
Initial multizone layer with complete state coverage (14 zones, 191001-191014)	191008	Iowa Ames-Des Moines	IA AMES
Hypothetical new statewide zone definition to replace previous (only the code changes)	190002	Iowa	IA
Montana (two zone layers): statewide zone and multizone layer with partial state coverage			
Initial statewide zone	300001	Montana	MT
Initial multizone layer with partial state coverage (19 zones, 301001-301019)	301004	Montana Bobcat	MT BC
Hypothetical addition of new zones to get complete state coverage but no change to previous zone parameters or extents (no change to previous codes)	301004	Montana Bobcat	MT BC
Washington (two zone layers): statewide zone and multizone layer with complete state coverage			
Initial statewide zone	530001	Washington	WA
Initial multizone layer with complete state coverage (2 zones, 531001 and 531002)	531001	Washington North	WA N
Hypothetical replacement of previous 2-zone layer with new complete-coverage multizone layer (with Seattle zone as the 34th zone in the new layer)	532034	Washington Seattle	WA SEAT
Gulf of Mexico and Navajo Nation special use zones			
Initial Gulf of Mexico (GULF) zone design	001001	Gulf of Mexico	GULF
Initial Navajo Nation (NAVA) zone design	001002	Navajo Nation	NAVA
Hypothetical new GULF zone definition to replace previous (only the code changes)	002001	Gulf of Mexico	GULF

vi. The entire zone abbreviation is unique for all SPCS2022 zones. For multizone layers, the length of the abbreviation ranges from a minimum of 4 to a maximum of 9 characters including the space or underscore separating the state from the zone abbreviation.

6. Technical specifications for SPCS2022 design and implementation. This section applies both to NGS and stakeholders. It provides details to augment general characteristics in §II of SPCS2022 policy.

a. Specific conformal projection types used for SPCS2022

i. **Lambert Conformal Conic** (LCC). Limited to the one-parallel form.

ii. **Transverse Mercator** (TM). Specifically, the Gauss-Krüger form.

iii. **Hotine Oblique Mercator** (OM). Specifically, the centered (local) rectified form (also known as "rectified skew orthomorphic") with specified skew azimuth.

b. Geodetic Reference System of 1980 (GRS 80) ellipsoid

i. SPCS2022 computations are performed using the following parameters:

- Semi-major axis of $\boldsymbol{a}$ **= 6,378,137 meters** (*exact by definition*)
- Inverse geometric flattening of exactly $\mathbf{1/}\boldsymbol{f}$ **= 298.257 222 101** (dimensionless). This exact value of 12 digits is used for SPCS2022 calculations, even though additional digits can be computed from the fundamental defining parameters of the GRS 80 ellipsoid.

ii. All other ellipsoid parameters are derived from a and f using at least double-precision computations. For reference, two commonly used derived parameters are given below at double precision (15 significant digits) based on the exact a and $1/f$ values give above (note that these values will differ slightly if $1/f$ is computed to more than 12 significant digits):

- Semi-minor axis, b = 6,356,752.314 140 36 m
- First eccentricity squared, e^2 = 0.006 694 380 022 900 79

iii. "Scaled" or otherwise modified versions of the reference ellipsoid cannot be used. Linear distortion can only be reduced be modifying projection axis scale, location, and/or orientation.

c. 2022 Terrestrial Reference Frames. SPCS2022 zones are assigned as follows:

i. *North American Terrestrial Reference Frame of 2022 (NATRF2022).* All zones in the conterminous U.S. and Alaska.

ii. *Caribbean Terrestrial Reference Frame of 2022 (CATRF2022).* All zones in Puerto Rico, the U.S. Virgin Islands, and other areas on the Caribbean plate.

iii. *Pacific Terrestrial Reference Frame of 2022 (PATRF2022).* All zones in Hawaii, American Samoa, and other islands on the Pacific plate other than those within the jurisdictions of conterminous U.S. states and Alaska.

iv. *Mariana Terrestrial Reference Frame of 2022 (MATRF2022).* All zones in Guam and the Commonwealth of the Northern Mariana Islands.

d. Linear distortion design criteria. Linear distortion is evaluated at the **topographic surface** for design, *not* the ellipsoid surface. NGS designs are based on both coverage area and population distribution (using data from the U.S. Census Bureau). Table 1 gives zone width and height ranges corresponding to various linear distortion ranges.

i. The **linear distortion design criterion** is the smallest specific distortion range of ±5, ±10, ±20, ±30, ±40, ±50, ±75, ±100, ±150, ±200, ±300, or ±400 ppm that satisfies *all three* of the following *minimum* percentages:

- 90% of zone population.
- 75% of cities and towns (based on location only, irrespective of population).
- 50% of total zone area.

ii. For a known zone width (in km) perpendicular to the projection axis, an initial value of the linear distortion design criterion (in ±ppm) can be estimated as $\mathbf{\pm 0.00154 \times (km)^2}$. This equation gives the approximate total range in distortion for the ideal case of a zone with no variation in topographic height and with the projection axis passing through the zone midpoint.

iii. Zones designed by NGS will generally have a linear distortion design criterion between **±50 ppm** (1:20,000) and **±400 ppm** (1:2500). These criteria correspond to zone widths of approximately 180 and 510 km, respectively, for zones with no variation in topographic height. Zone layers designed by NGS for a state will provide complete coverage of that state.

- Zones with linear distortion design criteria of less than ±50 ppm will not be designed by NGS. Such zones must instead be designed by stakeholders, per §3. Zones designed by stakeholders do not require use of the aforementioned 90%, 75%, and 50% minimum percentages used by NGS, since it is assumed that the designs are optimized for maximum stakeholder benefit based on local knowledge.
- Exceptions where zones designed by NGS have a design criterion of less than ±50 ppm are for statewide zones or previously existing SPCS 83 zones where lower distortion is achieved due to the small size of the state or previously existing zone.
- Exceptions where zones designed by NGS have a design criterion greater than ±400 ppm occur only for the statewide zones of New Mexico, Texas, and Alaska.
- For a given distortion design criterion (in ±ppm), the zone width (in km) perpendicular to the projection axis can be estimated as $\mathbf{25.5 \times \sqrt{ppm}}$. For the ideal case of no variation in topographic height and the projection axis passing through the zone midpoint, the distortion will be within the design criterion for the entire zone width.

- Linear distortion changes at a rate of 15.7 ppm per 100 m change in topographic height (or 4.8 ppm per 100 ft). It decreases (becomes more negative) with increasing height, and vice versa. For a given design criterion, the area of zone coverage typically decreases as the range in topographic height increases.

Table 2. Range in map projection linear distortion for various zone widths and ranges in topographic height.

Linear distortion range Expressed in parts per million (ppm) and as a ratio	**Corresponding zone dimension and height limits**	
	Zone width perpendicular to projection axis (for no variation in topographic height)	Topographic height range (independent of zone width)
±1 ppm (1:1,000,000)	25 km (16 miles)	13 m (42 ft)
±5 ppm (1:200,000)	57 km (35 miles)	64 m (209 ft)
±10 ppm (1:100,000)	81 km (50 miles)	127 m (418 ft)
±20 ppm (1:50,000)	114 km (71 miles)	255 m (836 ft)
±30 ppm (1:33,333)	140 km (87 miles)	382 m (1,254 ft)
±40 ppm (1:25,000)	161 km (100 miles)	510 m (1,672 ft)
±50 ppm (1:20,000)	180 km (112 miles)	637 m (2,090 ft)
±75 ppm (1:13,333)	221 km (137 miles)	956 m (3,135 ft)
±100 ppm (1:10,000)	255 km (158 miles)	1,274 m (4,180 ft)
±150 ppm (1:6,667)	312 km (194 miles)	1,911 m (6,271 ft)
±200 ppm (1:5,000)	360 km (224 miles)	2,548 m (8,361 ft)
±300 ppm (1:3,333)	441 km (274 miles)	3,823 m (12,541 ft)
±400 ppm (1:2,500)	510 km (317 miles)	5,097 m (16,722 ft)

e. Minimum zone size. Applies to zones designed by stakeholders. The objective is to create the largest zones possible that meet the distortion design criterion and thus avoid creating an excessive number of small SPCS2022 zones within a state.

i. The minimum zone width is based on the range in topographic height within the proposed zone:

- **50 km** (31 miles) for a zone with a topographic height range of 250 m (820 ft) or less.
- **10 km** (6 miles) for a zone with a topographic height range of more than 250 m (820 ft).
- Minimum zone size is evaluated as the short side of a rectangle with the smallest width that completely encloses the zone extents (minimum bounding rectangle by width). The rectangle must be in the same SPCS2022 projected coordinate reference system as the zone being evaluated and can be at any orientation.

ii. Well-defined geographic regions (such as counties, townships, urbanized areas, etc.) that do not meet the minimum size requirement should be aggregated with other areas to create zones that are larger than the minimum size.

iii. The presence of multiple zones within a state that are near the minimum size will make it more likely that the zone configurations will not be accepted by NGS for SPCS2022. NGS has sole authority to make the final determination as to whether zones meet the minimum dimension criterion.

f. Specifications for projection defining parameters

i. All projections are defined using the following five parameters (plus one additional parameter for the OM projection):

- Latitude of grid origin.
- Longitude of grid origin (central meridian for LCC and TM projections).
- Scale on projection axis (central parallel for LCC, central meridian for TM, and skew axis at the center origin for OM projection).
- False northing.
- False easting.
- *OM projection only:* Skew axis azimuth at center (local) origin.

ii. The combined set of three geodetic parameters (origin latitude, origin longitude, and projection axis scale) must be unique for all SPCS2022 zones.

iii. The 2022 TRF geodetic origin latitude and longitude for all projections are defined in sexagesimal units (degrees-minutes) to a numerical precision of **not less than one arc-minute** (or the equivalent in decimal degrees).

- To avoid infinitely repeating decimal places in decimal degree representations, arc-minutes evenly divisible by 3 are recommended, if doing so does not compromise distortion performance.
- The latitude of grid origin for TM projections must have arc-minutes evenly divisible by 3.
- If decimal degree representations result in infinitely repeating digits, the parameter must be given to at least 12 decimal places.
- Definitions in decimal degrees must not result in fractional arc-minutes.

iv. Projection axis scale factors are defined to a numerical precision of **6 decimal places** or less, or, equivalently, 1 part per million (ppm) or greater. Numerical precision of 5 decimal places or less is recommended for zones more than 100 km wide perpendicular to the projection axis.

v. Projection grid origins (false northings and eastings) are defined in meters, selected such that SPCS2022 coordinates (northings and eastings) are positive at all locations within a zone.

- Recommend origin values that have exact (whole number) equivalents in international feet (ift) by defining them in increments of 38,100 m (125,000 ift exactly). This approach is used for zones designed by NGS.
- Allow using increments of 3810 m (12,500 ift exactly) only in situations where smaller increments are needed to achieve specific requirements, such as small zones where finer coordinate resolution is needed.
- If metric grid origins do not have exact ift equivalents, they must be defined in meters using whole numbers evenly divisible by 1000 m.
- Recommend that origins be defined such that northing and easting coordinate values are not equal anywhere within a zone polygon. This approach is generally used for zones designed by NGS.

vi. Parameters specific to each projection type:

- **LCC.** Defined using one central parallel that is also the latitude of grid origin.
- **TM.** False northing is exactly zero. In cases where this requirement causes the latitude of origin to fall south of the equator, the latitude of origin is set at the equator and the false northing is greater than zero.
- **OM.** The false northing and easting are defined at the center (local) origin, not at the natural (true) origin. The skew axis (initial line) azimuth is defined as positive clockwise to the nearest whole degree, from ±(5° to 85°), at the center origin. A two-point definition of the skew axis cannot be used.

g. Specifications for SPCS2022 distortion output

i. **Point scale factor, *k*.** The ratio of the projected distance to the ellipsoidal distance at a point. The value $k - 1$ is the scale error with respect to the ellipsoid and can be considered as linear distortion due to curvature, and it is a function of horizontal position only.

ii. **Height factor.** The ratio of Earth radius to Earth radius plus the height of a point above (or below) the reference ellipsoid surface. Computed as $R / (R + h)$, where h is the **ellipsoidal height** and R is the GRS 80 **Geometric mean (Gaussian) radius of curvature** at the geodetic latitude of the point, φ, and where R is computed as $a\sqrt{1 - e^2}/(1 - e^2 \sin^2 \varphi)$. The height factor minus 1 can be considered the component of linear distortion due to height. Historically referred to as the "elevation factor."

iii. **Combined factor.** The product of the point scale factor and the height factor, computed as $k\,[R / (R + h)]$. The combined factor minus 1 can be considered the total combined effect of linear distortion, due to both curvature and height.

iv. **Linear distortion.** The combined factor minus 1, normally given in ppm.

v. **Convergence angle.** Geodetic minus grid north, normally given in sexagesimal units (degrees, minutes, and decimal seconds).

h. Computational accuracy and methods.

i. The following accuracies are achieved by NGS for map projection computations within a zone:

- **Coordinates** to **±0.01 mm**, or better, for both the direct (geodetic to projected) and inverse (projected to geodetic) calculations.
- **Point scale factor**, **height factor**, and **combined factor** to at least **10 decimal places**, and thus **linear distortion** to ±0.0001 ppm, or better.
- **Convergence angle** and **arc-to-chord correction** to **±0.001 arc-second**, or better.

ii. To the extent possible, and within the above accuracy requirements, NGS algorithms will conform to accepted and common practice within the geodetic community (both private and government) for performing map projection calculations.

RECORD OF REVIEW AND CHANGES

This is a living document that is reviewed at least once every two years. It will be updated, when appropriate, to reflect changes in controlling federal policies, organizational strategic goals/objectives, technology, or other matters that may have an impact on these procedures. Modifications made to this document are recorded in the below table. This record will be maintained throughout the life of the document.

Version Number	Date	Section/Page Affected	Summary of Change or Annual Review	Author / Reviewer
1	4/23/2019	All	Previous SPCS policy document replaced with a new policy and this new procedures document.	Michael Dennis
2	10/9/2019	Varies	Minor changes of technical details, file names, URLs, and wording.	Michael Dennis
3	7/1/2023	Most sections	Significant edits mainly to account for changes from initial to finalized design, along with various technical refinements and clarifications.	Michael Dennis / Vicki Childers