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

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Associated NGS Documents:

"State Plane Coordinate System of 2022 Policy", *NGS 2018-xxxx-01*. <https://geodesy.noaa.gov/INFO/Policy/files/DRAFT_SPCS2022_Policy.pdf>

Dennis, M.L., 2018. "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/NOAA_SP_NOS_NGS_0013_v01_2018-03-06.pdf>

Authority/Reference: As original creator of the State Plane Coordinate System, the National Geodetic Survey 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 Superseded policies are listed in the policy document associated with these procedures. The superseded policies include information that can be construed as procedures.

Review Schedule: At least once every two years.

Purpose/Scope

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

1. NGS contact information, criteria for stakeholder input, and deadlines. NGS email and postal addresses for submissions, general submittal requirements, criteria for "consensus" stakeholder input, and deadlines for submitting requests and proposals, and for submitting zone designs.
2. Requirements for stakeholder requests and proposals of SPCS2022 designs. What is required of stakeholders for making requests and proposing designs for SPCS2022.
3. Requirements for submittal of SPCS2022 designs by contributing partners. What is required of contributing partners when submitting SPCS2022 zone designs.
4. NGS role and responsibilities for SPCS2022 reviews and designs. What NGS will do in reviewing requests, design proposals, and submitted designs; the limitations of designs done by NGS; and what will be documented by NGS.
5. Technical specifications for SPCS2022 design and implementation. Detailed technical specifications to augment those given in SPCS2022 policy. This section of the procedures is the longest, but must of it will be moved to a technical design manual shortly after these procedure have been approved.

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

The procedures are based on and derived from the SPCS2022 policy. If any item 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 throughout this document, as in the policy document.

Background

The policy associated with these procedures provides the necessary background information. However, it is worth reiterating that additional information on SPCS is given in *NOAA Special Publication NOS NGS 13*, referenced as part of both the policy and procedures documents. Importantly, that special publication also 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*. Versions of this projection type that are commonly used for large-scale surveying and engineering applications are the Lambert Conformal Conic, Transverse Mercator, Oblique Mercator, and Oblique Stereographic. Existing SPCS uses the first three of these projection types.
- Contributing partners. Organizations or individuals identified by NGS *stakeholders* to design SPCS2022 *zones* on behalf of stakeholders and in cooperation with NGS. A contributing partner can also be a stakeholder.
- 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 system differs from the "true" horizontal distance on or near

the curved surface of the Earth. The "true" distance can be on the *reference ellipsoid* surface but is more commonly the distance at or near the topographic surface. Expressed as a ratio of distorted distance to true distance, for example as parts per million (ppm) or as a unitless ratio (e.g., 100 ppm = 1:10,000). Also known as scale error.

- 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 for the Lambert Conformal Conic projection, the central meridian for the Transverse Mercator projection, and the skew axis (initial or central line) of the Oblique Mercator projection. For the Stereographic projection it is a point at the origin rather than a 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 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 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 area where a projected coordinate system is used.

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

Note: Additional explanatory information is included to provide context through examples, history, rationale, and usage of SPCS. This information is in *blue italicized text* and labeled with "*Remark:*" at the beginning of each entry. The remarks are provided mainly to support informed public input, and they (along with this text box) will be removed in the final approved version of these procedures. The information in the remarks will be captured in NGS technical documents prepared during development of SPCS2022 and upon its official release.

It is important to point out that initial design of SPCS2022 by NGS does *not* require input from states. If no consensus input is received from a state, the default SPCS2022 designs will be used, as described in Section IV of SPCS2022 policy and Section 5.h. of these procedures. The default designs will use the same projection types and have the same zone configuration as SPCS 83 for most zones. All default SPCS2022 zones will exhibit performance very similar to existing SPCS 83, including the few zones where the projection type or zone extents have changed. The default designs are essentially a perpetuation of the SPCS 83 definitions, with overall minor modifications.

1. **NGS contact information, criteria for stakeholder input, and deadlines.** NGS welcomes input from stakeholders on their preferences for SPCS2022. Such input may consist of recommendations and requests for particular SPCS2022 characteristics, as well as submittal of proposed SPCS2022 zone designs by contributing partners. Stakeholders and contributing partners are defined in the "Definitions of Terms" section of this document.

   a. NGS contact information for SPCS2022

      Remark: The following contact information is NOT for comments or questions about the draft SPCS2022 policy and procedures. That correspondence should be sent to ***NGS.Feedback@noaa.gov****.*

      i. Questions, comments, requests, proposals, and design submittals:

         - Email: **NGS.SPCS@noaa.gov**.
         - Postal mail: Michael Dennis
SPCS2022 Project Manager
NOAA/NOS/National Geodetic Survey
1315 East-West Hwy
Rm. 8402 N/NGS4
Silver Spring, MD 20910

      ii. Forms for submitting requests and proposals, and for submitting SPCS2022 zone designs, are available on the NGS State Plane Coordinate System web page (**https://geodesy.noaa.gov/SPCS/**). The requirements for each type of submittal are given in sections 2 and 3, respectively.

         Remark: Forms will become available once these procedures are approved after the end of the SPCS2022 policy and procedures public comment period.

   b. Requirements for submittal of stakeholder input. There are two types of stakeholder input. The first is required for all submittals. The second is only required for submittal of designs by contributing partners.

      i. Stakeholder requests and proposals for SPCS2022 designs. The requirements are given in Section 2 of these procedures. A "request" is for NGS to design or modify SPCS2022 zones. A "proposal" is for SPCS2022 designs created and submitted by contributing partners.

      ii. Contributing partner submittal of SPCS2022 zone designs. The requirements are given in Section 3 of these procedures. Note that the proposed designs must first be approved by NGS.

   c. Qualifying criteria for stakeholder input. NGS requires "consensus" stakeholder input to act on requests, proposals, and contributions to SPCS2022, as described below.

i. Stakeholder input must be provided through the organizations listed in the "Definitions of Terms" section of this document. NGS encourages the various stakeholders within a state to collectively provide their input, rather than each stakeholder group providing input individually.

ii. All requests and proposals for SPCS2022 zones must be submitted in writing to NGS, as specified in the section 1.a. of these procedures. The requests and proposals must be co-signed by the stakeholders as listed under "Definition of Terms." 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. Contributing partners for SPCS2022 designs will only be recognized for states with consensus stakeholder input.

iv. National groups, 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 gives the group that authority, as documented in the required submittals for these procedures.

v. NGS will not act on input from individuals. It is recommended that interested individuals provide input through one or more of the stakeholder organizations for their state. Although NGS cannot act directly on individual input for SPCS2022 designs, such input will be compiled and in certain situations may influence decisions on SPCS2022.

d. Incorporating and confirming input to initial design of SPCS2022. Stakeholder input and contributing partner submittals received and approved by NGS by the dates given below will be part of SPCS2022 at the time of its official release.

Remark: This section will be removed upon official release of SPCS2022.

i. Deadlines for requesting and submitting designs to NGS, and for NGS to provide confirmation of final design characteristics and computational results:

Requests for zones designed by NGS or proposals for zones designed by contributing partners **must be received by NGS no later than December 31, 2019**

For NGS-approved proposed designs by contributing partners, final defining parameters **must be received by NGS no later than December 31, 2020**

Confirmation of final design characteristics and computations will be provided by NGS to stakeholders and contributing partners **no later than December 31, 2021**

ii. Stakeholder requests and contributing partner submittals received after the above deadlines will not be included in the official release of SPCS2022. They will instead be treated as requested modifications to existing SPCS2022. There may be considerable delay in the review and adoption of late submittals, especially those received near the date of official release of SPCS2022.

iii. If no consensus request or final design parameters are received by the above dates, the default designs will be used for initial release of SPCS2022.

2. Requirements for stakeholder requests and proposals of SPCS2022 designs

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

b. Applies to requests and proposals for initial designs of SPCS2022 and modifications of existing SPCS2022 zones.

c. The required information can be supplied using the NGS *SPCS2022 Request and Proposal Form*, available at **https://geodesy.noaa.gov/SPCS/**.

Remark: When these procedures are approved, the following listed requirements will be removed from the procedures and placed in a form available from the NGS website.

   i. State whether it is a *request* for designs by NGS or a *proposal* for designs by a contributing partner.

   ii. Name and contact information for at least one main point of contact for the overall submittal.

   iii. List of the state stakeholder organizations supporting the submittal. For submittals from national or regional multi-state organizations, such organizations can be listed as stakeholders, but at least one state stakeholder organization for the affected state(s) must be included.

   iv. Name and contact information for at least one point of contact for each listed stakeholder group. The main point of contact can fulfill this role for one or more stakeholder groups (for example, a representative of a state DOT who is also an officer in a state professional surveying or engineering association).

   v. Distortion design criterion (for example ±50 ppm for all zones within a state).

   vi. Provide expected number of zones (can be estimated if not known exactly) and a description of how the zone boundaries will be defined. Zones may be defined using irregular polygons, such as counties, groups of counties, aggregated townships, DOT districts, etc., or by using rectangular latitude and longitude bounds. The actual zone extents are provided as part of the design submittal (see Section 3).

   vii. Projection types (if known). It is sufficient to state that projection types will be determined in the design process.

   viii. If output of SPCS2022 coordinates in feet are desired, specify the type of foot (international or U.S. survey). Note that the type of foot used cannot conflict with relevant state statute. If there is supporting statute (or similar authoritative record), provide a reference to the relevant source.

   ix. Preferences (if any) for grid origin false northing and easting values within the zone(s).

   x. Specify a single 2022 Terrestrial Reference Frame to which the zones are referenced (North American, Caribbean, Pacific, or Marianas).

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

e. Proposed designs by contributing partners must be approved by NGS before any submitted designs will be reviewed by NGS.

3. Requirements for submittal of SPCS2022 designs by contributing partners

a. Must adhere to all SPCS2022 policies and procedures, including all technical specifications.

b. The design proposal must be approved by NGS before a submitted design will be reviewed (per Section 2 above).

c. The required information can be supplied using the NGS *SPCS2022 Zone Design Submission Form*, available at **https://geodesy.noaa.gov/SPCS/**.

Remark: When the procedures are approved, the following requirements will be removed from the procedures and placed in a form available from the NGS website.

i. Confirmation that NGS has approved the proposed designs.

ii. Point of contact for design.

iii. Point of contact for customer technical support requests received by NGS.

iv. List of stakeholders endorsing the design.

v. Complete set of defining projection parameters for every zone

vi. Unique names and/or numbers for all zones. Names cannot be longer than 30 characters (including spaces). The word "zone" is not part of the name.

vii. Well-defined geographic extent for each zone, including a digital graphical representation of the polygon in a non-proprietary format, such as shapefile or keyhole markup language. The digital geometry must be in geographic coordinates in decimal degrees and the datum to which it refers must be specified. Preference is for any realization of the North American Datum of 1983 (NAD 83), but any realization of the World Geodetic System of 1984 (WGS 84), the International Terrestrial Reference Frame (ITRF), or the International GNSS Service (IGS) will suffice. Where applicable, limiting topographic heights can also be specified to better define areas of usage. Note however that topographic height limits are usually not appropriate for zones wider than about 80 km perpendicular to the projection axis.

viii. Bounding latitude and longitude values for each zone to nearest arc-second or 0.0001 decimal degree (with respect to same datum used for the submitted polygons, per the previous item).

ix. No report is required, but one may be helpful to NGS in the review process, especially for complex or unusual designs.

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

e. Submitted designs must be reviewed and approved by NGS before being incorporated in SPCS2022.

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

4. NGS role and responsibilities for SPCS2022 reviews and designs

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

i. Confirm receipt of stakeholder requests and of contributing partner designs. If submittals are incomplete, NGS will notify 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 contributing partners. 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 reasons will be provided.

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

vi. Maintain a record of finalized SPCS2022 zones on the NGS SPCS web page (**https://geodesy.noaa.gov/SPCS/**).

b. Limitations for zones designed by NGS

i. NGS will design SPCS2022 zones only for cases where the linear distortion design criterion is **±50 ppm** (1:20,000) or greater. This corresponds to a zone width of about 180 km (112 miles) for regions of overall modest topographic relief.

Remark: Currently 30 of the SPCS 83 zones already meet or exceed a ±50 ppm distortion design criterion (but with respect to the ellipsoid, not necessarily the topographic surface). The 180-km zone width also corresponds to a TM zone roughly 2° wide perpendicular to the central meridian (at 35° latitude; for comparison, UTM zones are 6° wide). On a historical note, an alternative considered for SPCS 83 was a UTM-like system with zones 2° wide. Compare this to the nominal SPCS distortion design criterion of ±100 ppm (1:10,000) and its corresponding nominal zone width of 225 km (158 miles).

ii. Design of "low-distortion" zones by contributing partners. NGS typically will not design zones with a linear distortion criterion of less than ±50 ppm, except for small states where lower distortion is achieved by default (e.g., states less than 180 km wide perpendicular to the projection axis). Stakeholders who want such "low-distortion" SPCS2022 zones must design them as contributing partners. Any such designs must conform to all requirements herein and must be approved by NGS for incorporation in SPCS2022.

c. 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 to SPCS2022.

iv. Create and maintain an SPCS2022 web page, with links to documents, defining parameters, and to applications and tools that use SPCS2022.

5. **Technical specifications for SPCS2022 design and implementation.** This section applies both to NGS and contributing partners. It provides details to augment general characteristics in Section II of SPCS2022 policy.

   Note: Most of this section of the procedures will be moved to a technical design manual created soon after final approval of the SPCS2022 policy and procedures.

   a. Specific conformal projection types used for SPCS2022

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

         Remark: The one- and two-parallel forms of the LCC projection are mathematically identical. The only difference is that the one-parallel form requires that the projection axis (standard parallel) scale be specified explicitly, whereas for the two-parallel form the scale is defined implicitly, by the separation between the north and south standard parallels. The reasons for requiring the one-parallel form are 1) the defining scale is much more readily apparent since it is stated rather than inferred; 2) it is easier to design zones with respect to distortion at the topographic surface with one parallel than it is with two parallels; 3) it is consistent with the TM and OM projections, which both use explicit projection axis scales; 4) LCCs used for most low-distortion projections will be one-parallel, and so using one-parallel LCCs for all zones also improves system consistency 5) the number of defining parameters can be reduced to 5, which is the same as for a TM; and 6) there is more flexibility in assigning a single parallel that is evenly divisible by 3 (and thus has an exact decimal representation), than there is in doing the same for two parallels, since the separation between them is controlled by the desired projection scale. Note the secant LCC projections can be defined as single parallel (in which case the intersecting "standard" parallels are computed rather than explicitly defined).

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

      iii. **Oblique Mercator** (OM). Specifically the (rectified) Hotine form (also known as "rectified skew orthomorphic").

         Remark: NGS will consider allowing use of the Oblique Stereographic projection if a compelling case can be made by stakeholders.

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

      i. SPCS2022 computations are performed using the following *exact* parameters:

         - Semi-major axis of ***a* = 6,378,137 meters**
         - Inverse geometric flattening of **1/*f* = 298.257222101** (dimensionless). This is actually a derived value, but it is specified as exact here to enforce computational consistency.

      ii. All other ellipsoid parameters are derived from the above two quantities.

      iii. "Scaled" or otherwise modified versions of the reference ellipsoid cannot be used.

         Remark: In 1964, a modified Clarke 1866 ellipsoid was used to define three new Michigan SPCS 27 LCC zones to replace the previous three TM zones. The ellipsoid was scaled such that its surface was near the topographic surface, to reduce linear distortion of projected coordinates at the ground surface. Such an *approach will not be permitted for SPCS2022 because it is more complex and prone to errors than other methods for reducing linear distortion, with no corresponding improvement in performance.*

c. Linear distortion design and zone extent criteria. Linear distortion is evaluated at the **topographic surface** for design, *not* the ellipsoid surface. Because of variation in topographic relief, this criterion will often be a nominal value associated with areas of interest within a zone that excludes topographic extremes (such as mountains).

i. Maximum and minimum distortion design criteria. The linear distortion design criterion cannot be greater than **±400 ppm** (1:2500) or less than **±20 ppm** (1:50,000). Exceptions at the upper end are statewide zones for Texas and Alaska. Exceptions at the lower end are design areas where distortion of less than ±20 ppm is readily achieved due to the small size of some states with subdued topographic relief. For the ±20 ppm minimum, NGS strongly encourages contributing partners to design zones that are as large as possible, to prevent creation of an excessive number of small zones.

Remark: The ±400 ppm upper limit is intended to prevent design of zones with excessive distortion. It is the distortion design limit used for UTM (with respect to the ellipsoid), which corresponds to a zone width of about 508 km (316 miles). Note that Montana has a maximum distortion magnitude (also with respect to the ellipsoid) of 625 ppm (1:1600). That corresponds to a zone width of 629 km (391 miles), which is actually greater than the maximum 516-km (320-mile) north-south width of Montana. The statewide Montana zone could be redesigned to meet the maximum ±400 ppm criterion. Only Texas and Alaska are too large to meet this criterion.

Remark: The ±20 ppm lower limit corresponds to a zone width of about 114 km (71 miles). Note that ten SPCS 83 zones have a projection axis scale corresponding to less than 20 ppm (1:50,000) linear distortion (with respect to the ellipsoid), including two tangent projections (i.e., zero scale error on the projection axis).

ii. Limitations on minimum zone size. The objective should be to create the largest zone possible that meets the distortion design criterion, to avoid creating an excessive number of small SPCS2022 zones within a state. For design areas where the range in topographic height is less than 250 m (820 ft), zones should not be created if they are bounded by a rectangle with a minimum dimension of less than 50 km (31 miles). The bounding region is the rectangle with the smallest width that encloses the design area. Rectangle corners can be represented using geodetic or projected coordinates (whichever is more convenient), but the minimum dimension should reasonably represent the actual horizontal distance on the surface of the Earth. Well-defined geographic regions (such as counties, townships, urbanized areas, etc.) that do not meet this requirement should be aggregated with other areas to create zones that are larger than the minimum size.

Because there is some ambiguity in defining a zone design area and its bounding rectangle, NGS has sole authority to make the final determination as to whether it meets the minimum dimension criterion. 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.

Linear distortion is a function of both Earth curvature (zone width perpendicular to the projection axis) and variation in topographic height. Zone width and height ranges corresponding to various distortion ranges are given in the table below.

Linear distortion (ppm = parts per million)	**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)
±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)
±50 ppm (1:20,000)	180 km (112 miles)	637 m (2,090 ft)
±100 ppm (1:10,000)	255 km (158 miles)	1,274 m (4,180 ft)
±400 ppm (1:2,500)	508 km (316 miles)	5,097 m (16,722 ft)

Distortion at the ground surface 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. This behavior typically reduces the area of zone coverage, but in some cases it can be used to increase the area of coverage.

Note that a height change of 250 m corresponds to about ±20 ppm change in distortion, which is the minimum allowed design criterion. The 50-km minimum dimension requirement is substantially less than the 114 km width corresponding to ±20 ppm distortion for flat terrain. This was done to accommodate irregularly-shaped zones and situations where aggregated areas (such as counties) cause distortion to exceed the design criterion.

iii. <u>Limitations on maximum zone size</u>. The following limitations are specified both to control distortion and to ensure projection calculations are sufficiently accurate within a zone, regardless of the application:

- Zones cannot be more than 20° wide perpendicular to the projection axis (10° each side).
- Oblique Mercator (OM) zones cannot be longer than 2000 km parallel to the skew axis.

d. <u>Specifications for projection defining parameters</u>

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

- Longitude of grid origin (central meridian for LCC and TM projections).

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

ii. The 2022 TRF geodetic origin latitude and longitude for all projections are defined in sexagesimal units (degrees-minutes-seconds) 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 that does not compromise distortion performance.
- The latitude of grid origin for the TM projection must have arc-minutes evenly divisible by 3.
- If decimal degree representations result in repeating decimal places, they must be given to at least 12 decimal places.
- Definitions in decimal degrees must not result in fractional arc-minutes.

Remark: Enforcing the requirement that arc-minute values must be evenly divisible by 3 can compromise the ability to minimize linear and angular distortion, because it limits options for design. Nonetheless this approach is recommended when possible. Note that for the TM, the origin latitude has no effect on linear or angular distortion, and for the LCC the central meridian affects only angular distortion.

iii. 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.

Remark: A change of one unit at the 6^{th} decimal place corresponds to the linear distortion caused by a 6-meter change in height. Since most (if not all) SPCS2022 zones will have variations in height much greater than 6 m, there should be no need to use more than 6 decimal places.

Remark: Historically, SPCS projection axis scale factors were defined using ratios for the TM and OM projections. Most SPCS 83 zones have a projection scale of less than 1:10,000 (scale = 0.9999). For example, 1:30,000 is used for several zones (scale = 0.9999666666666…). It is recommended that future projection axis scale factors use a finite decimal definition exact to not more than 6 decimal places. Decimal representations are more compatible with computer implementations.

iv. Projection grid origins (false northings and eastings) are defined in meters using whole numbers evenly divisible by 1000 meters selected such that SPCS2022 coordinates (northings and eastings) are positive at all locations within a zone.

v. Parameters specific to each projection type:

- LCC: Defined using one standard parallel that is also the latitude of grid origin (thus false northing is not zero).

  Remark: Making the standard parallel the same as the latitude of grid origin reduces the number of defining parameters to five, which is the same as for the TM projection. This makes the definitions more consistent. In addition, all TM projections will have a false northing of zero, which will distinguish them from LCC projections (with false northings not equal to zero).
- TM: The false northing is exactly zero (where the latitude of grid origin intersects the central meridian).
- OM: The false northing and easting is defined at the local (center) origin, not at the natural origin. The skew axis (initial line) azimuth is defined to the nearest whole degree, from 0° to ±90°, at the local (center) origin and must differ from geodetic north-south and east-west by at least ±5°.

  Remark: The local origin is the point on the skew axis where the convergence angle is zero (analogous to the central meridian of the TM and LCC projections) and the skew axis scale is exactly equal to its defined value. The reason for defining the OM grid origin as local is that it specifies coordinates at the center of the projection, which is usually within the zone. This is more intuitively obvious and meaningful than using the natural (mathematical) origin, which is on the equator of the "aposphere", an intermediate surface used in the computations. It is not the same as the ellipsoid equator and is typically at a longitude far outside the zone. For example, the OM projection used for Alaska SPCS 83 Zone 1 has a false northing and easting of -5 million and +5 million, respectively, which bears no relationship to the SPCS coordinates within the zone, and it corresponds to a longitude passing through western Kansas, far from the Alaska panhandle. In addition, for Alaska Zone 1 a local skew axis azimuth of -36°52'11.6315250385" was selected because its tangent is exactly equal to -¾. That was done to simplify calculations, at a time when computing OM coordinates was difficult (ca. 1960). That is no longer the case, and so there is no benefit to using such a seemingly unusual azimuth today.

e. Specifications for SPCS2022 distortion output

i. **Grid point scale factor.** Linear distortion at a point with respect to the reference ellipsoid surface. Can be considered as linear distortion due to curvature, and is a function of horizontal position only.

ii. **Height factor.** Linear distortion at a point due to its height above (or below) the reference ellipsoid surface. Computed using use the **ellipsoid height** and **Geometric mean (Gaussian) radius of curvature** at the geodetic latitude of the point. Historically referred to as the *elevation factor*.

Remark: Also previously called the elevation factor, *it has always been a function of ellipsoid height. Elevation was used in the past as an estimate since the ellipsoid height was not generally known prior to Global Navigation Satellite System (GNSS) positioning.*

iii. **Combined factor.** Total linear distortion at a point due to the combined effect of distortion due to curvature and height. Computed as the product of the grid point scale and height factors.

Remark: To obtain a combined factor accurate to 8 decimal places (±0.01 ppm) requires an ellipsoid height accurate to ±3 cm. The ellipsoid height must be with respect to the same geometric reference frame used for the SPCS2022 or UTM calculations.

Remark: For some NGS products and services, only the grid point scale and combined factors are given, since the height factor can be computed from the other two.

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

f. Computational accuracy and methods.

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

- **Coordinates** to **±0.01 mm**, or better, for both the forward (geodetic to projected) and inverse (projected to geodetic) calculations.
- **Grid point scale factor** to at least **10 decimal places** (±0.0001 ppm).
- **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.

Remark: For example, algorithms are specified by National Geospatial-intelligence Agency (NGA) for the TM projection used in UTM, and by European Petroleum Survey Group (EPSG) for the LCC, TM, OM, and many other projections. EPSG algorithms have been widely adopted (or used as a basis of comparison) for map projection algorithms in commercial software.

g. Default SPCS2022 designs. Projection type and zone extents will not change for most zones. Some adjacent SPCS 83 zones may be combined into a single zone or reconfigured, but in no case will these changes cause the linear distortion to exceed the nominal SPCS criterion of 100 ppm (1:10,000). The net result would be a slight decrease in the total number of zones, if the default approach was used for all of SPCS2022.

Remark: This section will be removed upon official release of SPCS2022.

i. The default design approach used will differ from that of SPCS 83 in the following ways and will comply with all other SPCS2022 policy and procedure requirements:

- The projection axis scale will be modified, if necessary, to minimize linear distortion at the topographic surface, rather than at the reference ellipsoid surface. The scale will be defined to six decimal places or less.

- Lambert Conformal Conic projections will be converted to the one-parallel definition and scaled in the same manner as the Transverse and Oblique Mercator projections.
- Oblique Mercator projections will be defined using the local (center) origin for parameters with the skew axis azimuth specified to the nearest whole degree.
- Geodetic latitude and longitude origins will be specified that have defining arc-minutes evenly divisible by 3 in situations where doing so does not compromise distortion performance.

ii. Changes under consideration to existing SPCS 83 zones are given below.

- Single OM zone for Hawaii (to replace existing five TM zones)
- Combine two TM zones of the Florida peninsula into single OM zone.
- Group the one zone of Rhode Island, the one zone of Connecticut, and the two zones of Massachusetts into a single LCC zone.
- Include Guam and Commonwealth of Northern Mariana Islands (CNMI) in a single TM zone (CNMI currently has no SPCS zone). The existing Guam zone could be used for this purpose with no modification, although somewhat better overall distortion performance could be achieved by designing a zone for the entire region.
- Define an LCC zone for American Samoa (currently has no SPCS zone).
- For Alaska, redefine zones so that they better correspond to land use and distribution of surveying, engineering, and mapping activity (e.g., one LCC zone for the North Slope, rather than having it divided across six narrow TM zones).
- Add a zone for Washington, D.C.