CONNECTICUT DEPARTMENT OF TRANSPORTATION

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CONNECTICUT PLANE COORDINATE SYSTEM: GEODETIC DEFINITIONS, PROCEDURES, AND FIELD SPECIFICATIONS

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CONNECTICUT PLANE COORDINATE SYSTEM: GEODETIC DEFINITIONS, PROCEDURES, AND FIELD SPECIFICATIONS

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A. Introduction

Purpose

This manual establishes the standards, technical definitions, and field specifications governing geospatial data within the State of Connecticut with a particular focus on CTDOT Surveys and Engineering. In alignment with state geodetic modernization efforts, Connecticut Public Act No. 25-65 (Substitute Senate Bill No. 1377) formally amended Chapter 241, Section 13a-255 of the General Statutes, establishing the Connecticut Plane Coordinate System (CPCS) as the successor of the state's previous coordinate systems.

The primary objective of this document is to ensure technical consistency across Connecticut Department of Transportation (CTDOT) bureaus, Connecticut State Agencies (State), municipal partners, and external engineering consultants during the transition and continued use of the CPCS. By codifying these geodetic standards, the state transitions from historical static grids to dynamic grids tied to observed and modeled tectonic movement, ensuring all geospatial data remain accurate and integrated with the National Spatial Reference System (NSRS).

The transition to a dynamic reference frame (NATRF2022) and an integrated gravimetric vertical datum (NAPGD2022) inherently alters how horizontal positions, ellipsoid heights, and orthometric elevations interact. Because these components are mathematically interdependent under the modernized system, this document bridges the gap between horizontal and vertical coordinate derivation.

This document establishes the definitions, reference frame parameters, and the vertical-to-horizontal integration rules unique to the modernized system. It dictates how the dynamic components of NATRF2022 and the gravimetric aspects of NAPGD2022 must be applied on State projects, and outlines the explicit, mandatory processing and validation workflows required to tie them together.

This manual does not outline routine field surveying procedures, standard instrumentation setups, or general data collection mechanics.

Accordingly, this document does not supersede or replace other CTDOT survey-related reference manuals. For detailed field execution and GNSS baseline processing workflows, users must continue to refer to the CTDOT GNSS Survey Standards Manual. The CTDOT Location Survey Manual outlines digital leveling techniques, control standards, and general surveying procedures, and the CTDOT LiDAR and Photogrammetry Specifications provides guidelines for remote sensing implementation.

This manual incorporates technical criteria for GNSS and vertical leveling insofar as they are altered by the adoption of the new system. It supersedes the documents entitled “Connecticut Geodetic Survey – CTGS Grid and Elevation Factors” and “The Connecticut Coordinate System”.

Effective Dates

The State of Connecticut's adoption of the modernized coordinate system (CPCS) operates under a protocol in which two conditions must be met. Under the provisions of Section 13a-255(i), the system's updated realizations shall be officially recognized and mandated within State mapping only when the following two conditions are met:

1. **Federal Release:** The official publication and authorization of the Connecticut zone definitions and coordinates by the National Geodetic Survey (NGS) or any formal updates thereof.

2. **State Confirmation:** The review and subsequent approval of its use or update by the Commissioner of the Connecticut Department of Transportation or the Commissioner's designated agent. Approval will be given by a public notice or memorandum to be posted on the Engineering and Construction Directives and Bulletins page.

Until both conditions are met, active surveying and mapping projects shall remain tethered to NAD 83 / Connecticut Coordinate System. Projects that are mid-survey are exempt from transitioning to the new reference frame or realization. The adoption date is estimated to be 2027 within the Location Survey Manual, but actual adoption is through the above condition.

Restrictions on Legacy Datums: For new projects initiated after the CPCS Effective Dates, tying into or holding existing legacy NAD 83 control points is prohibited. Exceptions will only be considered when the surveyor or mapper formally demonstrates that linking to a legacy project control is critical to the project's data continuity or practical execution (e.g., matching a major ongoing multi-phase project), and that the older project control remains geodetically sound. All such instances must localize accurately to those control values with a least squares adjustment software. In instances where a transformation is needed, the NGS Coordinate Conversion and Transformation Tool (NCAT) is required to document and log transformation parameters.

Possibility of Expansion of Low-Distortion Grids

While the initial release of CPCS provides a single, low-distortion zone designed to define the grid projection across the state, areas of significant topographic relief and micro-scale engineering requirements may necessitate the need for the addition of regionalized low-distortion grids tied to the NSRS in the future. Section 13a-255(c) of the amended statute grants CTDOT the authority to publish alternative or additional systems, which allows a proactive framework for future scalability. If determined necessary by regional survey or mapping requirements, CTDOT may integrate additional Low-Distortion Projections (LDPs) in particular localities. Any future grids must still remain strictly anchored to the NSRS network to preserve a single global reference frame across the state.

Integration of the Vertical Component (NAPGD2022)

Although the statute prioritizes horizontal coordinates, the updated text of Section 13a-255(b) formally establishes that the state's official geodetic reference frame includes – but is not limited to – latitude, longitude, *ellipsoidal height, orthometric height,* and *dynamic height* as defined within the NSRS.

To expand upon the statute's designations, this document serves to explicitly clarify and codify the department's transition to the North American-Pacific Geodetic Datum of 2022 (NAPGD2022), which is formally the vertical component of the NSRS. Therefore, height measurements and derivations, when required for mapping, must be treated not as separate, detached elevation values, but as fully-integrated vertical elements of the modernized NSRS. This manual details the explicit guidelines for utilizing digital gravimetric geoid models to process both ellipsoid and orthometric heights, replacing legacy vertical datums (NGVD 29 / NAVD 88) with the modernized geopotential reference frame.

State Mapping Mandates and Exemptions

Upon formal approval by the Commissioner, the use of the current CPCS realization is a requirement for all new state mapping projects:

- **Production Standard:** All state-funded surveys, engineering designs, and Geographic Information System (GIS) layers initiated after the Effective Date must be based on the current CPCS grid realization. Every deliverable must feature explicit metadata detailing its specific reference frame parameters and derivation.

- **Alternative Projection:** The statute does not strictly prohibit alternative reference frames if they are determined to be technically necessary. However, any mapping utilizing a non-CPCS projection must contain comprehensive projection parameters and an explicit statement of purpose within the metadata explaining the decision to bypass the state standard.

- **The Hardship Exemption:** To prevent fragmentation of public spatial data, projects executed in alternative datums must also be processed and delivered as an identical parallel dataset projected in CPCS where feasible. A project is exempt from this parallel delivery mandate if it can be demonstrated and documented that providing a CPCS equivalent would generate an "undue hardship or burden" on the creator of the project.

B. Definitions & Horizontal Reference Frames

The State of Connecticut legally recognizes the system of plane coordinates established by the National Geodetic Survey (NGS) anchored to the National Spatial Reference System (NSRS) as the Connecticut Plane Coordinate System (CPCS). Three versions of this system have been formally recognized within Chapter 241, Section 13a-255, the first two of which were known as the “Connecticut Coordinate System”:

The Connecticut Coordinate System of 1927 (CCS 27): Based on the Lambert conformal conic projection of the Clarke Spheroid of 1866, with standard parallels established at North Latitudes 41°51' and 41°12'. Its status is now deprecated. The use of this grid system is permissible exclusively for the historical reconciliation of legacy R.O.W. maps and early baseline reestablishment.

The Connecticut Coordinate System of 1983 (CCS 83): Based on the Lambert conformal conic projection of the Geodetic Reference System of 1980 (GRS 80) and referenced to the North American Datum of 1983 (NAD 83). It became the production standard in Connecticut beginning at the end of 1996 and is the system of the NSRS until the formal release and adoption of SPCS2022.

The State Plane Coordinate System of 2022 (SPCS2022 / SPCS 22), known as the Connecticut Plane Coordinate System (CPCS) within Connecticut: The coordinate system defined by the NGS, integrating the North American Terrestrial Reference Frame of 2022 (NATRF2022). Coordinates consist of derived northing (y-coordinate) and easting (x-coordinate) expressed in meters or the international foot. Its use is pending Federal and State approval as of publication.

National Geodetic Survey CPCS Definitions

To resolve linear distortion between a flat mapping grid and the Earth's true surface, the NGS SPCS2022 design for Connecticut (CPCS) includes the following:

Statewide Zone (Zone Code: 090001-CT). Provides one unified projection optimized for survey and engineering-grade mapping and statewide enterprise GIS. Zone 090001 has the following definitions, also maintained by the NGS:

I. Projection Type: Lambert Conformal Conic, one parallel
II. Origin latitude and longitude (west): 41°30'N, 72°45'W
III. Projection origin scale: 0.999990
IV. False northing and easting (meters): 457,200 N 762,000 E
V. False northing and easting (international feet): 1,500,000 N 2,500,000 E
VI. Reference frame: NATRF2022

Note that the false northings and easting in international feet (ft.) ensure no coordinate value overlaps with previous versions of the Connecticut Coordinate System (NAD 83 and NAD 27) for positions within Connecticut

.

Low-Distortion Zones (LDPs). Localized, surface-optimized grids configured specifically for local topography. These zones minimize systemic linear scale factor distortion to ratios below 1:10,000, eliminating the need for significant ground-to-grid adjustment calculations for precise applications. At the time of development, it was determined there was no practical need to divide Connecticut into multiple zones or provide additional LDPs. However, CTDOT reserves the ability to define LDPs if needed.

Time-Dependent Coordinates and Tectonic Plate Motion (NATRF2022)

Upon formal adoption of CPCS by CTDOT, surveyors and mappers must account for the North American Terrestrial Reference Frame of 2022 (NATRF2022) being a dynamic reference frame that incorporates continuous tectonic plate motion. Prior to the official CPCS Effective Date, all ongoing projects remain tethered to a NAD 83 realization. Following adoption, the following mandates take effect:

1. Reference Epoch Standard

The authoritative Reference Epoch for all CTDOT surveys and State mapping is fixed to Reference Epoch 2020.00, unless formally updated by CTDOT to align with subsequent federal datums or realizations.

2. Coordinate Observation Epoch

Field measurements captured via GNSS represent the coordinate locations at the actual calendar date of the survey (the Observation Epoch, e.g., 2026.45).

- Prior to importing field-observed coordinates into any active survey file, GIS layer, or final deliverable, the user must propagate the coordinates from the Observation Epoch back to the Reference Epoch of 2020.00.
- This time-dependent transformation must be executed using the National Geodetic Survey's (NGS) authorized tectonic velocity models and intra-plate deformation algorithms (built natively into the NGS Coordinate Conversion and Transformation Tool – NCAT and many data collection/processing software packages).
- For projects where field data collection spans multiple observation epochs across several seasons or years, each baseline session must be independently adjusted to Reference Epoch 2020.00.

3. Title Block Notes

To ensure repeatability, all final survey deliverables must explicitly feature the following statements within the primary title block. The 400-foot grid requirement should be interpreted to imply a 400-foot grid tick interval. This title block language supplements existing Location Manual Section 5.9 requirements:

*400 FOOT GRID BASED ON CONNECTICUT PLANE COORDINATE SYSTEM (CPCS), NATRF2022, REFERENCE EPOCH 2020.00. COORDINATES WERE OBTAINED FROM A [INSERT METHOD, E.G., STATIC, RTK A] GNSS SURVEY ON *DATE* AND ADJUSTED TO THE REFERENCE EPOCH.*

VERTICAL DATUM BASED ON N.A.P.G.D. 2022 REFERENCE EPOCH 2020.00, UTILIZING THE GRAVIMETRIC GEOID MODEL ([INSERT MODEL VERSION, e.g., GEOID22]).

International Foot Mandate

In compliance with federal geodetic modernization directives, the U.S. Survey Foot is formally deprecated upon the official administrative adoption and activation of the CPCS*. For all future CPCS (SPCS2022) calculations, any linear measurements, distances, or coordinate pairs expressed in feet must use the exact definition of the International Foot:

1 International Foot = 0.3048 Meters (Exactly)

* For legacy NAD 83 and NAD 27 historical systems, the U.S. Survey Foot remains the mandatory unit:

$$1 \text{ U.S. Survey Foot} = \frac{1200}{3937} \text{ Meters} = \text{approximately } 0.30480061 \text{ Meters}$$

If the wrong foot definition is selected in the operating software of data collectors, total stations, or CAD systems, a systematic mathematical error of approximately 2.03 parts per million (ppm) is introduced.

While a 2 ppm error is negligible over a short distance, it scales linearly over state plane grid magnitudes. For a typical Connecticut Easting coordinate value (e.g., 2,500,000 feet), choosing the incorrect foot definition introduces an immediate 5-foot systematic horizontal displacement of the coordinate.

Mitigation:

To eliminate the risk of an undetected foot-definition mismatch, field crews should adhere to the following QA/QC rules:

1. **File Isolation:** Field data collection files (.job, .rw5, etc.) must never contain multiple units. If a crew is recovering legacy NAD 83 control (U.S. Survey Foot) and establishing a new CPCS project (International Foot), they must manage them in entirely separate jobs within the data collector.

2. **Physical Check Shot Validation:** Before recording any new survey points under the CPCS framework, the field crew should execute a physical check shot on a known, primary control point within the correct reference frame. If the data collector's readout shows a discrepancy of approximately 2 feet or more, work should be stopped until the unit and datum issue is corrected.

C. Vertical Reference Frames, GNSS, and Leveling Procedures

Modernized Vertical Reference Frame (NAPGD2022)

Upon adoption of CPCS, all active CTDOT location surveys and State mapping projects must transition away from legacy vertical datums (NGVD 29 and NAVD 88). At that point, the department formally adopts the North American-Pacific Geopotential Datum of 2022 (NAPGD2022) as the primary vertical project reference frame for State of Connecticut mapping, as supported by the statutory update of Chapter 241, Section 13a-255.

Orthometric heights (H) must be derived relative to the active gravimetric geoid model published by the National Geodetic Survey (NGS) as part of the modernized NSRS/CPCS framework, utilizing this primary mathematical relationship:

$$H = h - N$$

Where:

H = Orthometric height (elevation)
h = Ellipsoid height derived from GNSS observations
N = Geoid height interpolated from the current NGS gravimetric geoid model

Prior to CPCS adoption, orthometric heights not transferred from appropriate physical benchmarks shall be derived using the current NGS-designated national geoid model (GEOID18 at time of publication); upon adoption, the NAPGD2022 gravimetric geoid model supersedes it.

Vertical Accuracy Classifications

In reference to the Regulations of Connecticut State Agencies (RCSA Section 20-300b-11), vertical control values established for CTDOT survey projects are categorized into two levels depending on project scope:

Class V-1 Vertical Accuracy (State Geodetic Standard)

This standard is strictly reserved for primary state geodetic control networks and high-precision structural deformation monitoring, such as bridge movement monitoring. For loops exceeding one mile, the maximum allowable vertical misclosure shall not exceed an error limit defined by $\pm 0.02\sqrt{M}$ where M is length of level loop in miles. The limit is $\pm 0.006\sqrt{N}$ where N is the number of instruments setups in a level loop if the loop is less than a mile.

Class V-2 Vertical Accuracy (CTDOT Location Survey Standard)

This standard serves for all routine highway design, corridor mapping, survey control, and construction benchmarks as mandated by the CTDOT Location Survey Manual. Physical digital level loop misclosures remain the definitive measure of vertical accuracy. For loops exceeding one mile, the maximum allowable vertical misclosure shall not exceed an error limit defined by $\pm 0.035\sqrt{M}$ where M is length of level loop in miles. The limit is $\pm 0.010\sqrt{N}$ where N is the number of instruments setups in a level loop if the loop is less than a mile.

Specific baseline error allowances under these standards include:

- At **1.0 mile**, Class V-1 allows a maximum error budget of ±0.020 feet, while Class V-2 allows ± 0.035 feet.
- At **2.0 miles**, the Class V-1 budget is ±0.028 feet, while Class V-2 scales to ±0.049 feet.
- At **5.0 miles**, Class V-1 allows ±0.045 feet, while Class V-2 allows ±0.078 feet.
- At **10.0 miles**, the Class V-1 error budget is restricted to ±0.063 feet, whereas the Class V-2 location survey budget allows up to ±0.111 feet.

Digital Leveling Procedures

When execution of a physical level run is mandated by project specifications, digital leveling equipment and adjustment must be in accordance with the CTDOT Location Survey Manual.

Closed digital levelling loops (or trigonometric leveling as allowed by the Location Survey Manual) are required to establish final elevations on all intermediate project control points and benchmarks except as described in the Bench-Closing Workflow below.

Integration of GNSS-Derived Vertical Control

To balance field efficiency with strict vertical integrity within the new reference frame, CTDOT has a two-part workflow: GNSS establishes the basis for primary control elevation, while digital leveling generally controls local accuracy between those points. This workflow supplements the Location Manual Section 3.3's suggestion that level runs may begin and end on Second Order, Class II or higher benchmarks. That allowance applies only to situations in which GNSS derivation is impossible. Validated Level I GNSS benchmarks per Section D of this document are considered equivalent for this purpose.

1. Primary Project Control (Point Spacing at ± 2.0 Miles)

Standalone GNSS-derived elevations are fully permissible to establish primary project benchmarks, provided the physical spacing between the monuments is equal to or greater than 2.0 miles. These primary marks must meet established Level I spatial accuracy thresholds (providing a maximum 0.06-foot vertical uncertainty at a 95% confidence interval). Every primary point must be verified using independent, redundant occupations. This GNSS rule governs primary project benchmark establishment specifically. The GNSS Manual's Vertical Note regarding the need for digital leveling still applies to local relative accuracy between those primary points and intermediate points.

2. Intermediate Control and Benchmarks (Point Spacing ≤ 2.0 Miles)

Standalone GNSS is strictly prohibited for establishing survey control or benchmark elevations for points spaced less than 2.0 miles apart. This minimum spacing applies exclusively to Level I GNSS benchmarks meeting the ±0.06-foot vertical uncertainty threshold at 95% confidence. Level II and Level III GNSS-derived elevations are not permitted as primary corridor control anchors regardless of spacing; their appropriate uses are described in Section D. Because intermediate points require tighter tolerances than standalone GNSS can reliably deliver at closer spacings, all intermediate points must be established using digital leveling in accordance with the CTDOT Location Survey Manual.

3. Small Projects (Single GNSS Anchor Point)

For small projects (such as intersection or local bridge surveys) where a linear control network is not required, project elevation may originate from a single, validated Level II or Level III GNSS benchmark. All project benchmarks and control points must still be extended from this single anchor via closed digital leveling loops to ensure local relative accuracy.

Bench-Closing Workflow and Error Adjustment

In cases where V-2 accuracy is required and distances between Primary Project Control are spaced at approximately 2.0 miles, field crews may utilize a bench-closing workflow to link Level I GNSS benchmarks and digital level runs into a single network, eliminating the need for return loops on standard corridor projects:

1. **Level Run:** The level line must start at a validated Level I primary GNSS benchmark, run sequentially through all intermediate survey benchmarks, and terminate on a separate validated Level I primary GNSS benchmark at the opposite end of the control line.

2. **Validation:** The total misclosure between the two primary GNSS endpoints must fall within the Combined Allowable Misclosure, calculated as $\sqrt{(\text{Budget}^2 + \text{Endpoint Allowance}^2)}$, where Budget = $\pm 0.035\sqrt{M}$ (the Class V-2 closure limit for the run length M in miles) and Endpoint Allowance = $\sqrt{(\sigma_1^2 + \sigma_2^2)}$, the RSS of the two endpoint vertical uncertainties at 95% confidence as reported in their individual network adjustments. Neither endpoint may carry a vertical uncertainty exceeding ±0.06 feet (Level I); any endpoint exceeding this threshold must be reobserved before this workflow may proceed. The maximum combined endpoint allowance is ±0.085 feet, corresponding to two endpoints each at the Level I limit. If the observed misclosure

exceeds the Combined Allowable Misclosure, field crew must execute a return loop; if the return loop closes within the Budget alone, the leveling is proven sound and one or both GNSS endpoints must be reobserved.

This workflow is valid only where both endpoints meet Level I vertical uncertainty thresholds (±0.06 feet at 95% confidence). Level II or Level III GNSS benchmarks may not serve as bench-closing endpoints regardless of point spacing; projects anchored to Level II or Level III control must close level runs via return loop to the originating benchmark.

Example: a 2.0-mile run between two Level I endpoints each with σ = ±0.06' yields a Budget of ±0.049', an Endpoint Allowance of ±0.085', and a Combined Allowable Misclosure of ±0.098'.

The Combined Allowable Misclosure derives from standard error propagation: the leveling budget and the GNSS endpoint uncertainty are independent error sources, and their combined effect on the observed misclosure is their root sum of squares. The Budget term is the existing Class V-2 standard ($\pm 0.035\sqrt{M}$). The Endpoint Allowance term reflects that two independently observed Level I GNSS benchmarks each contribute up to ±0.06 feet of vertical uncertainty at 95% confidence, and their combined effect on the height difference between them is $\sqrt{(0.06^2 + 0.06^2)} = \pm 0.085$ feet. The ±0.06-foot Level I threshold is itself a conservative ceiling because a well-executed static or RTK GNSS observations processed through ACORN or OPUS typically achieve vertical uncertainties of ±0.03 to ±0.04 feet under good conditions, meaning the Combined Allowable Misclosure for a given run will generally be tighter than the worst-case example above when actual reported adjustment uncertainties are substituted for σ_1 and σ_2. Requiring the observed misclosure to fall within bare V-2 limits alone would impose a closure standard tighter than the GNSS inputs can support, causing sound level runs to fail for reasons unrelated to leveling quality. The endpoint allowance term accounts for this mathematically rather than through an arbitrary allowance.

3. **Error Distribution:** Once the level run passes the required field screening check, the closing difference between the level run and the GNSS endpoints must be distributed proportionally across every instrument setup in the line. This correction may be applied via standard traditional balancing methods or through simultaneous network adjustment software. Holding both GNSS endpoints as fixed constraints without distributing this error is prohibited. For longer runs with intermediate Level I control points, each segment must independently satisfy its Combined Allowable Misclosure before network adjustment proceeds. For runs exceeding 4 miles, traditional proportional balancing is not permitted; simultaneous network adjustment software is required.

Secondary Use of Elevations from Adjacent Projects

Existing vertical control data and benchmarks established by prior or concurrent CTDOT projects may be incorporated into a new survey project. If integrating an existing vertical benchmark elevation via GNSS, the point spacing criteria detailed in the previous section must be maintained (minimum 2.0 miles), and the elevation must be re-verified using redundant static or RTK observations to confirm it matches current Level I absolute thresholds. If integrating existing benchmarks via digital leveling, a continuous digital level run must connect the legacy point elevation to the new project network via a closed loop that either returns to the beginning point or ties to a separate, validated primary benchmark. Single, unclosed spur runs to existing benchmarks are prohibited unless the leveling is part of an extended run (≥ 2.0 miles) establishing intermediate project benchmarks, in which case the line may utilize the formal bench-closing validation workflow by anchoring to primary GNSS control at both endpoints. In all scenarios, the leveling data must satisfy the applicable closure standard relative to active project control to verify that no local settlement, disturbance, or geoid slope deformation has compromised the integrity of the benchmark over time. Where the level run closes via return loop to its originating benchmark, Class V-2 budget ($\pm 0.035\sqrt{M}$) applies. Where the run terminates on a separate validated Level I GNSS benchmark, the Combined Allowable Misclosure defined in the Bench-Closing Workflow applies.

D. Equivalence of Positional Uncertainties and Class V-1 and V-2

To preserve procedural consistency across Department manuals without modifying pre-established control accuracy standards, CTDOT formally recognizes the mathematical relationship between Weighted Least Squares Positional Uncertainty at the 95% Confidence Level. The uncertainty threshold levels can be found at the end of this document (and also Exhibit 25 of the Location Manual and within the GNSS Standards Manual). Although this technique is mandated for horizontal control adjustment (See Section 3.2 and 3.4 of the Location Survey Manual), its use is encouraged but optional for vertical adjustment. For this purpose, traditional Class V-2 Linear Vertical Misclosure is seen as equivalent to CTDOT vertical control levels, subject to the following parameters:

- **Level I Control Equivalence:** Level I vertical thresholds (±0.06' at 95% confidence) serve as a conservative estimate of standard static GNSS capabilities. Standalone GNSS observations are prohibited from satisfying Class V-1 geodetic standards unless the final network adjustment explicitly demonstrates that the achieved vertical positional uncertainty satisfies the V-1 error budget for that baseline. On all other setups, digital leveling remains mandatory. Standalone Level I GNSS-derived elevations are permissible to anchor standalone points or when primary point spacing is equal to or greater than 2.0 miles.

- **Level II and Level III Control Equivalence:** Recognized as technically equivalent to V-2 regulatory accuracy for standalone project anchors, secondary control densification, topographic and LiDAR control where appropriate. Level II or Level III GNSS-derived elevations may not serve as endpoints in the bench-closing workflow defined in Section C, where Level I is required at both endpoints.

E. Standard Operating Procedures

To ensure data processing uniformity and collection repeatability, the following requirements must be considered:

Metadata Requirement

Every spatial data deliverable, engineering drawing, map, submitted to CTDOT or to/by the State must display or include metadata with the following information: (1) The explicit reference system utilized (e.g., NAD 83, CPCS); (2) The reference epoch; (3) A statistically verified statement of relative accuracy; and (4) The exact calendar date of raw observations. A full required deliverable report for GNSS-derived data can be found in Section I of the GNSS Manual.

Redundant Network Corrections: CORS, ACORN, and Baseline Processing

Any spatial reference control framework establishing horizontal or vertical values within the CPCS must implement field-observed, statistically independent vectors processed from active GNSS networks tied to the NSRS:

NOAA CORS Network(NCN): The National Oceanic and Atmospheric Administration's Continuously Operating Reference Stations network.

ACORN Network: The Advanced Connecticut Real-Time Network, operated and maintained by the Connecticut Department of Transportation and University of Connecticut. ACORN provides continuous, real-time network corrections via a statewide system of GNSS reference stations, which are also part of the NCN.

Baseline Processing and Network Adjustment details, whether with Trimble Business Center, OPUS, or another software, can be found in the Location Survey Manual and GNSS Survey Standards Manual.

Standardized Transformations

For all horizontal and vertical datum transformations between historical reference frames (CCS 27 / CCS 83) and the modernized CPCS, the NGS Coordinate Conversion and Transformation Tool (NCAT) shall be used (and noted) when field localizations or transformations cannot be performed.

CAD Definitions

Upon adoption of CPCS, CAD drawing working units must be updated from U.S. Survey Feet to Feet (International Feet), and the defined coordinate system shall be CPCS (Epoch: 2020) Zone 090001-CT with NAPGD2022 (Epoch: 2020) for vertical.

F. Combined Scale Factor and Sample Computations

All grid scaling adjustments previously handled via manual lookups must now be computed digitally utilizing current ellipsoid height interpolation models. Approved computation suites include the National Geodetic Survey (NGS) Geodetic Toolkit (NCAT/SPCS2022 engine) or proprietary data collector/office software, provided the underlying algorithm matches the NGS single-parallel Lambert Conformal Conic definitions for Zone 090001-CT.

To convert a measured ground distance to a coordinate grid distance, users must compute the project **Combined Scale Factor (CSF)**, which is derived from the **Grid Scale Factor (k)** and the **Elevation Factor (EF):**

$$\text{Elevation Factor (EF)} = \frac{R}{(R + h)}$$

Combined Scale Factor (CSF) = k x EF

Grid Distance = Ground Distance x CSF

Where:

R = The mean radius of the Earth ellipsoidal model, held to a constant 20,906,000 feet (6,371,000 meters)
h = The ellipsoidal height of the baseline derived from GNSS observations or geoid model interpolation
k = The grid scale factor derived from the CPCS model (NCAT)
Example:

Field Parameters & Given Variables:

- **Measured Ground Distance:** 4,512.850 International Feet (ift or ft)

- **Field-Observed Ellipsoid Height (h):** -95.150 ift (Derived via ACORN GNSS)
- **Derived Local Grid Scale Factor (k):** 0.9999912 (Interpolated for Zone 090001-CT at the project centroid)

Step 1: Calculate the Elevation Factor (EF)

Reduce the measured ground profile to the ellipsoid surface using the mean earth radius (R = 20,906,000 ft.):

$$EF = \frac{R}{(R+h)} = \frac{20{,}906{,}000}{(20{,}906{,}000 + (-95.150))}$$

EF = 1.000004551

Step 2: Calculate the Combined Scale Factor (CSF)

Multiply the local grid scale factor (k) by the calculated elevation factor (EF):

CSF = k x EF = 0.9999912 x 1.000004551

CSF = 0.999995751

Step 3: Compute the Final CPCS Grid Distance

Apply the Combined Factor to the measured ground distance:

Grid Distance = Ground Distance x CF
Grid Distance = 4,512.850 x 0.999995751
Grid Distance = 4,512.831 International Feet

Verification Check: Due to the single-parallel Lambert design compression (k_0 = 0.999990) and local elevation reduction, the grid distance is exactly 0.019 feet shorter than the measured ground distance. Field data collector readouts should closely match this value.

State Positional Accuracy Classes*

SPATIAL ACCURACY	**Level** I	**Level** I I	**Level** I I I	**Level** IV
Application	Geodetic Control Primary Project Control Densification	Primary Project Control Aerial and LiDAR Control	Secondary Project Control Aerial and LiDAR Control ROW Bounds Property Corners	Topography Non-critical stakeout
Maximum allowable horizontal error at 95% confidence interval	0.03’	0.05’	0.07’	0.10’
Maximum allowable vertical error at 95% confidence interval (when applicable)	0.06’	0.10’	0.10’	0.15’
Legacy and Regulatory Guidance Equivalence (approximate, situation-dependent)	1:10,000 or better (A-1)	1:7,500 or better (A-2)	1:5,000 or better (A-2)	90% within ½ contour interval (T-1) (vertical, exceeds considerably)

*Positional uncertainty thresholds (Level I-IV) are intended for standard project distances. For baselines exceeding 2 miles, a distance-dependent error allowance of 2 ppm may be applied to the 95% confidence interval to account for GNSS scale and atmospheric effects, provided level-specific thresholds are not substantially exceeded. All accuracy standards refer to the positional uncertainty of individual points.