Arizona
Spatial Data Accuracy
and
Georeferencing Standards

Standards for the acquisition
and evaluation of geospatial data

with explanatory remarks and examples

Prepared by the
Geospatial Committee
of the
Arizona Professional Land Surveyors Association
in cooperation with the
Arizona Geographic Information Council

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Arizona Professional Land Surveyors Association

Arizona Geographic Information Council

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Arizona Spatial Data Accuracy and Georeferencing Standards

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The collaboration of a large number of people was essential to make this document possible. Every effort was made to provide a complete list of all of those who contributed, with apologies to any who were inadvertently not included. The expectation is that this list will become more extensive (and more complete) in future versions.

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Introduction

This document gives recommended standards for georeferencing and evaluating the positional accuracy of spatial data. Frequent reference is made to project scope, since it will in most cases be necessary to augment and define aspects of the standards for particular projects. Although prepared specifically for Arizona, with minor modification the standards could be used for other states or regions.

There is a tendency for the terms *standards* and *specifications* to be used interchangeably when defining how a project should be performed. However, as used here, *standards* are concerned with evaluating the deliverables to determine whether project requirements are met, whereas *specifications* dictate the methods and procedures used to develop the deliverables. That is, standards are based on results, while specifications prescribe how those results are obtained.

Because these proposed standards are written in a relatively sparse, technical, and formal manner, information to augment or clarify particular items is included. This information appears as remarks in *italicized Arial font*. Although strictly not part of the standards, these remarks have been left in the document to help readers understand and make effective use of the standards.

The main purpose of these standards is to provide guidance for developing the scope or statement of work for projects involving collection of spatial data. Toward that end, the standards make frequent use of contractual language, such as the terms "project scope", "deliverables", and "client". The term "client" can also be interpreted in a more general sense as the organization or individual for whom the data are being collected, and it does not necessarily indicate or require a contractual relationship between the entity collecting the data and the entity that requires the data.

References to other pertinent spatial data standards and guidelines are provided at the end of these standards, and a glossary is included to aid users in interpreting the technical terminology. In addition, examples are given in the appendices to facilitate implementation of the standards. Appendix A gives project scope / statement of work examples to provide guidance in preparing contractual agreements for receiving or providing geospatial data and services. Appendix B gives example documentation of spatial and accuracy metadata for surveying deliverables.

Arizona Spatial Data Accuracy and Georeferencing Standards

Version 3.1, November 8, 2008

I. Positional Accuracy

A. Accuracy confidence level. In all cases, accuracy shall be determined at the 95% confidence level both horizontally and vertically, including all accuracy values cited within these Standards.

Remark. *The "95% confidence level" can be defined as the region in which there is a 95% probability that the true position lies. For example, if an elevation is 1012.4 ft (±0.2 ft at 95% confidence), then there is a 95% chance that the true elevation is between 1012.2 and 1012.6 ft. Another way of describing this is that if the elevation is independently measured 100 times, then we expect that 95 of the measured elevations will fall between 1012.2 and 1012.6 ft. It is a statistical statement based on data analysis, and the 95% value is widely used in the geospatial community for assessing spatial accuracy.*

B. Point feature positional accuracy.

1. Data collection and accuracy evaluations shall be performed with respect to clearly identified geodetic control in the National Spatial Reference System (NSRS) as published by the National Geodetic Survey (NGS), or approved equal, or by surveys referenced to said control.

   a. Any control station used for georeferencing and/or accuracy determination shall be of equal or higher accuracy than the data being captured and/or evaluated.

   b. Accuracy check points must be one or both of the following:

      i. Occupations of published NGS control stations (or approved equal) during the course of data collection by the firm performing data collection.

      ii. Reoccupations by the Client (or a designated representative) of features surveyed by the firm performing data collection.

         1) The survey technology used for reoccupations shall be capable of achieving accuracies equal to or better than that used by the firm performing the data collection, and shall be used in a manner commensurate with achieving such accuracies. The accuracy of all check points used for data evaluation shall be provided.

         Remark. *It is recommended that if the Client uses a contracted firm for assessing feature accuracy, that the firm selected not be one used for the actual data collection for the project. This will help ensure independent and objective spatial accuracy assessment. In addition, feature attribute accuracy and data completeness can be evaluated as part of the spatial accuracy assessment (although these characteristics are not addressed in these Standards).*

   c. Number of check observations to determine the point feature dataset accuracy:

      i. For datasets larger than or equal to 100 points but less than 1000 points, a minimum of 20 check points shall be used.

      ii. For datasets of 1000 or more points, the number of check points shall be at least 2% of the total number of points in the dataset.

      iii. For datasets of less than 100 points, the number of check points shall be specified in the project scope.

      iv. The datasets being evaluated shall be defined in the project scope and may include all features collected or any subset of features. These check point requirements apply only to datasets in which a point is associated with a specific feature, and it does not include mass points associated with surface modeling, such as acquired from laser scanning or light detection and ranging systems (LiDAR).

      v. To the extent practicable, check points shall be randomly distributed throughout the project area (or well-defined sub areas) such that representative samples of all data collection areas and feature types are obtained.

Remark. *The challenge with this requirement (particularly for non-homogeneous project areas) is achieving a random sample set while ensuring check points occur in all unique areas of the project so as to represent all situations within the dataset. The individuals defining the project scope should be cognizant of this fact and make their best attempt at specifying the location of check points to be as random as possible while representing all unique situations.*

2. The current National Standard for Spatial Data Accuracy (NSSDA) shall be used for computing the horizontal and vertical accuracy of point features. This includes evaluation of the horizontal accuracy of photogrammetric imagery using discrete photo-identifiable features.

Remark. *The NSSDA is documented in the Federal Geographic Data Committee Geospatial Positioning Accuracy Standards (1998) listed in the references at the end of these Standards. Although NSSDA supersedes the 1947 National Map Accuracy Standard (NMAS), NMAS is still often used. Another frequently used measure of accuracy is Root Mean Square Error (RMSE). Although these Standards do not allow the use of NMAS or RMSE for accuracy estimation, the following conversions are supplied for convenience:*

*Horizontal accuracy per NSSDA = 1.1406*CMAS = 2.4477*RMSE (radial)*

*Vertical accuracy per NSSDA = 1.1916*VMAS = 1.9600*RMSE (vertical)*

where CMAS is the Circular Map Accuracy Standard and VMAS is the Vertical Map Accuracy Standard of NMAS. For example, a spatial product with a horizontal accuracy of 1.00 foot per NSSDA has horizontal accuracies of 0.88 ft per CMAS and 0.41 ft radial RMSE, and a product with a vertical accuracy of 1.00 foot per NSSDA has vertical accuracies of 0.84 ft per VMAS and 0.51 ft vertical RMSE. The variation in accuracy determination based on the method used is the reason for specifying NSSDA and 95% confidence for **ALL** *accuracy evaluations in these Standards.*

Note that the NMAS values specified for accuracy depend on the map scale and contour interval of the map product, which is not appropriate for digital products and is the main reason NMAS is not recommended (in addition, NMAS is based on the 90% rather than the 95% confidence level). RMSE is problematic in that it represents a variable confidence level horizontally (~60-70%) and ~68.3% confidence vertically.

Remark. *The NSSDA does not provide a method for computing error ellipses, although it can be done from an NSSDA dataset by computing the horizontal covariance. This provides additional information on accuracy that can be used to better ensure high-quality data. For example, it can be required that the semi-major axis of the error ellipse not be more than twice the length of the semi-minor axis, or that horizontal accuracy be based on the error ellipse semi-major axis rather than the approximate circular error used by the NSSDA. These types of requirements are not included in these Standards because they are not part of the current NSSDA. However, these (or others) could be included in project scope contractual requirements.*

3. Evaluation of the horizontal accuracy of photogrammetric imagery.

   a. Check observations shall be made of discrete features that are visible in the imagery and can be reliably located in the field. The positions of these features shall be determined using methods having a horizontal accuracy at least twice that specified for the imagery in the project scope.

   Remark. *Check points of insufficient accuracy will not provide a valid evaluation. This includes use of check points that are not well-defined in the imagery, and so it is important to only use check points that are clearly visible with positions that can be discerned to an accuracy better than that required for the imagery product.*

b. A minimum of 20 check points randomly distributed throughout the project (or defined project sub-area, if applicable) shall be used such that representative samples are obtained. This minimum number applies at each sub-area as defined in the project scope.

Remark. *For some small aerial imagery projects, 20 check points may seem excessive. The purpose of specifying 20 is to produce a statistically valid sample for evaluation. Although use of a smaller number can be specified in the project scope, it may compromise the evaluation, and under no circumstances should less than 10 points be used. It should be noted that any well-defined object visible in the imagery can be used, and it should not be overly onerous to acquire positions of such objects for evaluation. One approach could be to use permanent objects (such as manholes) that can be positioned once and then used repeatedly for all future imagery (this approach can also be used for evaluating topographic surface models).*

Remark. *Panel points for which coordinates are not provided to the photogrammetric firm ("blind" or "ghost" panel points) can also be used as check points. Subsequent to an initial evaluation, these blind panel point coordinates can be provided to the aerial firm to improve image rectification. However, even if this is done, it is recommended that the minimum number of check points specified in these Standards be retained (i.e., not be provided for use by the firm providing imagery) in order to ensure independent evaluation.*

C. <u>Polyline and polygon feature positional accuracy</u>.

1. The positional accuracy of polyline and polygon features shall be evaluated in the same manner as point features, by observation of discrete points on the perimeter of the feature. If more than one point is evaluated for a single polyline or polygon feature, the mean accuracy of the set of validation measurements shall be used to estimate the overall accuracy of the feature. The minimum number of check observations for each polyline or polygon feature shall be based on the number of vertices using the same criteria as for individual point features.

Remark. *For polylines and polygons with vertices that are well-defined in the field, individual vertices can be evaluated using the same methods as for point features, by reoccupying the vertices and comparing coordinates. For polylines and polygons with ambiguous vertices (i.e., those that cannot be reliably located in the field), the perpendicular distance from a validation point to the polyline or polygon boundary can be used for estimating accuracy. The distance can then be used in the same manner as for evaluating point features.*

Remark. *In some cases the arithmetic mean of accuracy values for a polyline or polygon feature may not provide an adequate representation of overall accuracy, for example when there is high degree of variation in accuracy values. One option for dealing with this is to also require the worst accuracy and/or the standard deviation of the accuracy values. Another option to better account for a wide range in accuracy values is to take the square root of the mean of the squared accuracies rather than using the arithmetic mean (note that for fairly uniform accuracy values, both approaches give similar results).*

D. <u>Surface model vertical accuracy</u>.

1. For the purpose of these standards, a *surface model* represents a <u>continuous</u> surface that is developed such that a value (typically an "elevation") is defined <u>everywhere</u> on that surface and can be extracted from <u>any</u> location on the model. These models are intended to represent a physical surface for some geographic region of the Earth, such as bare earth (with vegetation and structures removed), bottoms of

water bodies, water surfaces, top of vegetation, man-made structures, or any other definable surface that can be measured. A topographic surface (bare earth) model is used for most applications, but the specific type of surface shall be explicitly identified as part of the accuracy evaluation.

Remark. *Digital elevation surfaces usually fall into one of the following general categories: 1) Digital Terrain Model (DTM) or bare earth surface (terrain surface after removal of vegetation and man-made features); 2) Digital Surface Model (DSM) or first reflective surface (the upper-most reflective surface captured by a sensor); 3) Bathymetric surface (submerged surface of underwater terrain); 4) Mixed surfaces (a combination of surface types, such as a surface that has vegetation removed but includes man-made structures); and 5) Point clouds (single points with multiple elevations, such as LiDAR multi-return datasets). For more details on surface types, refer to the National Digital Elevation Program* Guidelines for Digital Elevation Data *listed in the references at the end of these Standards.*

a. Topographic surface model types. Topographic surface models generally fall into one of the following two categories, and in most cases these are bare earth models. These definitions are intended to be consistent with those used in the National Digital Elevation Program *Guidelines for Digital Elevation Data* and in Appendix A of the Federal Emergency Management Agency *Guidelines and Specifications for Flood Hazard Mapping Partners* (both are listed in the references at the end of these Standards).

Remark. *There is no universally agreed upon terminology for describing surface models. Typically such models are developed from point and line datasets, but the behavior of the surface between these points and lines is an explicit and essential characteristic for evaluating the accuracy of the surface model. The important issue here is that the evaluation be performed on a surface that is as close as possible to its original geometry, rather than a generalized or interpolated version of the original surface. For example, consider a surface that is generated as a TIN (Triangulated Irregular Network) from a mass point and breakline dataset. If this surface is generalized to a regular grid of elevations, or is used to generate contours, it would be less desirable to perform an accuracy evaluation using the elevation grid or the contours. This is because some information is inevitably lost in these generalizations and interpolations, which typically would negatively impact the estimated accuracy. However, it is recognized that in some cases the original source dataset is not available for evaluation, and a derived dataset must be used. In such cases, the estimated accuracy is usually worse (a larger value) and therefore such an approach will typically yield conservative accuracy estimates.*

i. Digital Terrain Model (DTM). For the purpose of these standards, a DTM is considered a surface model constructed from the following elements:

1) Mass points. A dataset consisting of non-uniformly spaced points that provide discrete 3-D positions on the surface being modeled.

2) Breaklines. A dataset of 3-D line segments that represent a sudden change in the smoothness or continuity of a surface. These are used to represent features such as ridge lines, cut banks, toes of slopes, drainage flowlines, etc.

Remark. *A DTM may or may not include breaklines. Generally, breaklines are preferred in order to better model sudden grade changes,* *especially in products used for hydraulic modeling. However, some datasets (such as LiDAR) consist solely of mass points.*

3) Triangulated Irregular Network (TIN). A type of surface model created from datasets containing mass points and/or breaklines. The most common method for developing a surface from such data is to construct a network of 3-D triangles by connecting lines between adjacent points and breakline vertices (such that each breakline segment forms the edge of a triangle). None of the triangles in the network overlaps and each one forms an inclined planar surface, and are typically constructed in a manner than creates triangles with side lengths as uniform as possible (e.g., by using the Delaunay criterion).

ii. Digital Elevation Models (DEM). For the purpose of these standards, a DEM is a grid (raster) of uniformly spaced elevation nodes (points) with implicitly defined horizontal coordinates. The "post spacing" of the grid is the horizontal (x, y) distance between the elevation nodes. A DEM grid can be defined in either a Cartesian or geographic coordinate system. A Cartesian (orthogonal) grid has post spacing in linear units (such as feet or meters), and is usually based on a defined projected coordinate system. A geographic DEM grid has post spacing defined by latitude (y) and longitude (x) given in angular units such as decimal degrees.

Remark. *Note that a TIN can be generated from a grid, particularly when the grid is combined with breaklines (which is fairly common practice), and that a DEM can be interpolated from a DTM TIN. The opposite can also occur, by interpolating a DEM grid from a DTM TIN (this is often done with TINs based on LiDAR mass points).*

Remark. *A surface can also be defined by directly deriving elevation contours, for example from photogrammetric stereocompilation. In such cases the surface accuracy is tested by evaluating the contours, which usually requires interpolation between contours. However, creation of surface representations utilizing this approach is becoming very uncommon. In modern practice, contours are typically generated from a DTM TIN or DEM grid.*

b. Surface model construction. In some cases, the dataset used to evaluate a particular surface model is not the surface itself, but rather consists of data used to develop the surface (such as mass points and breaklines). In such cases, the surface constructed for evaluation from the dataset shall be identical to the original surface that was used to generate other deliverables (such as contours), insofar as possible. Construction of a surface model for evaluation from data that have been generalized and interpolated from the original surface (such as an elevation grid or contours) should be avoided unless no other option is available. Particular care should be exercised when attempting to construct a surface directly from contours using automated methods (such as TIN construction).

Remark. *Because there is not yet a standardized digital format for surfaces, the product evaluated may actually be the data used to develop a surface model. For example, a DTM may be provided as mass points and breaklines, which must then be used to construct a test surface in order to perform an accuracy assessment. For* *such cases, it is important that all the data used to construct the original surface also be used to construct the test surface, and that the same construction method be used.*

Remark. *A DEM is constructed from a grid of points such that the points (nodes) correspond to a particular location within the grid of elevation "cells", and a node can represent the center or any of the four corners of a cell. Because the location of the node for a particular DEM will effect the interpolated elevation, the definition is important and should be verified prior to performing an accuracy assessment. For example, the USGS National Elevation Dataset (NED) is defined such that the elevation nodes correspond to the lower left (southwest) corner of a cell.*

c. Interpolation. Whenever possible, the interpolation method used to evaluate the accuracy of the surface model shall be the same as that used to define the surface model as a deliverable or as used to generate other deliverables (such as contours).

i. Surfaces based on mass points and/or breaklines (DTMs). These are typically constructed using the Delaunay criterion to construct a TIN that consists of planar triangular faces. Linear (planar) interpolation should be used to evaluate such a surface unless it is known that an alternative interpolation method was used to construct the surface.

ii. Surfaces based on an elevation grid (DEMs). These surfaces can be defined and interpolated in a variety of ways. Because these form regular grids, ordinary TIN construction is ambiguous, since the diagonal TIN line will yield different results depending on whether it connects from the upper-left (northwest) or upper-right (northeast) corner of a cell. As such, unless the specific interpolation method is known, an interpolation method that generates a unique surface is recommended.

Remark. *There are many interpolation techniques that will yield unique surfaces, such as bilinear, bicubic, certain planar methods, and many others. Bilinear and planar interpolations are among the simplest for producing a continuous surface.*

2. The current National Standard for Spatial Data Accuracy (NSSDA) shall be used for computing vertical accuracies based on discrete check points with vertical accuracies at least twice that specified for the surface model in the project scope.

a. A minimum of 20 check points randomly distributed throughout each project sub-area shall be used such that representative samples of all data collection sub-areas are obtained. Project sub-areas shall be defined in the project scope. Check points shall be located in areas with a uniform slope of not more than 20%. The horizontal distance of check points from sudden grade changes and structures shall be at least five times the vertical accuracy specified in the project scope.

Remark. *Project sub-areas may consist of areas with different ground cover types, for example paved areas, agricultural fields, grassland, desert scrub, forests, etc.*

Remark. *The reason for specifying a maximum slope and minimum distance to a sudden grade change is that the effect of horizontal error on vertical accuracy assessment increases as the slope of the surface increases. An example of minimum distance from sudden grade changes is at least 5 ft for a surface model with vertical accuracy specified as 1 ft in the project scope.*

Remark. *LiDAR-specific ground targets in place during data acquisition can be used for evaluating LiDAR-derived surface models. These can also be used as ground control specifically for LiDAR-derived data.*

b. To allow for non-normal vertical error distributions, a supplemental vertical accuracy estimation utilizing the 95th percentile method is permitted if this method better matches the observed error distribution. Guidelines for using the 95th percentile method are provided under "Supplemental and Consolidated Vertical Accuracies" in the NDEP *Guidelines for Digital Elevation Data* (listed in the references at the end of these Standards). If the 95th percentile method is used, results shall be provided in addition to the fundamental accuracy estimates computed per the NSSDA.

c. For surface models used to generate elevation contours, the vertical accuracy of the elevation model shall be at least twice that of the contour interval.

Remark. *For example, a DEM or DTM used to generate contours at a 2-ft interval should have a vertical accuracy equal to or better than 1 ft at 95% confidence.*

d. For projects where the surface model will be used for analyzing unconfined water flow, such as flood hazard mapping, it is recommended that cross-section surveys of channels also be performed to evaluate the accuracy of the surface model. It is also recommended that the surface model be based on a DTM that includes three-dimensional breaklines (sudden topographic grade changes) as TIN boundaries. These and other guidelines for flood hazard mapping accuracy evaluations can be found in Appendix A of the Federal Emergency Management Agency *Guidelines and Specifications for Flood Hazard Mapping Partners* listed in the references at the end of these Standards.

E. <u>Control survey requirements</u>.

1. Surveys performed for the purpose of establishing geodetic control shall be based on an appropriately constrained and weighted least-squares adjustment of over-determined and statistically independent observations. If statistically dependent observations are included, their affect on the estimated accuracy must be accounted for and documented.

Remark. *These are characteristics that apply to a correctly performed survey network adjustment, and they should be part of standard survey practice. They are listed here to make it explicit that correct procedures must be followed, in particular to prevent misrepresentation of a survey as a control survey when it is not. A survey is "over-determined" if it has redundancy (more observations than the minimum necessary to determine positions), which is essential for a meaningful adjustment to be performed. "Statistically independent observations" is meant to prevent introduction of false redundancy in a network through representation of the same (or nearly the same) data more than once, which can lead to exaggerated accuracy claims. However, including statistically dependent ("trivial") vectors is common practice in survey networks established using GNSS (Global Navigation Satellite System, which includes GPS). If trivial vectors are included, the final error estimates should account for the false redundancy created by including these vectors. It should be noted that considerable professional judgment often comes into play when performing network adjustments, and some allowance should be given for such judgment. One purpose of the project report required in section III.C. of* *these Standards is to provide a mechanism for documenting and justifying a particular approach for establishing control.*

Remark. *It is highly recommended that control surveys be planned so as to allow inclusion into the NSRS. Although this may somewhat increase the cost, the benefit will be that all geospatial data acquired in the future, based on this control, will be supported by the NGS in future adjustments (datum realizations). Additionally, NGS, through the Arizona Geodetic Advisor, will assist in the planning and execution of surveys intended for inclusion into the NSRS, which could decrease overall project cost.*

2. A minimally constrained adjustment must be performed and results documented. The statistical characteristics of the network must be substantially the same for both the minimally and fully constrained adjustments as determined using standard statistical analyses.

   Remark. *For example, minimally and fully constrained control networks can be evaluated using the Chi-Squared, Tau, and F-tests. The Chi-Squared Test is a commonly used statistical method for evaluating "goodness of fit", that is, how well a network fits together geometrically when compared to the accuracy of the measurements used to define it. The Tau Test is a statistical method for identifying outliers, which are measurement residuals that differ markedly from other residuals in the network based on comparison to the adjusted values. The F-test is used to compare sample variances, for example to determine whether the network variance ("error") is statistically the same in both the minimally and fully constrained adjustments.*

3. The stations selected for constraining the network shall have coordinates explicitly defined in the datum and realization required for the project, and these coordinates must be documented values obtained from the NGS (or approved equal). Full or weighted constraints may be used, but if weighted constraints are used the values and basis for weighting shall be documented.

   Remark. *The realization of a datum is the reference date that indicates when the adjusted coordinates were determined on a specific datum. In Arizona, for example, NAD 83 has had realizations in 1986 (original), 1992 (High Accuracy Reference Network), and 2002 (for the nationwide Continuously Operating Reference Station network). The current NAD 83 realization in Arizona (and nationwide) was referenced to time 2007.0 and is denoted as NSRS2007.*

   Remark. *Fully constrained control is used when the control coordinates are held absolutely fixed in a network adjustment, making the control in essence "errorless". However, this can cause estimated errors at other points to become too large. One method to reduce this effect is to assign the control standard errors based on estimated accuracy of the control, which are used to determine finite weights so that the control is not absolutely fixed. In such cases, the stations used as constraints, their coordinates, their assigned standard error, and the datum and realization of the constrained (control) stations should be explicitly listed in the project report.*

4. Local point accuracy estimates determined from the control network shall be based on the fully constrained post-adjustment variance-covariance matrix for each point. Results shall include at the minimum the horizontal error ellipse axis dimensions scaled to 95% confidence using the bivariate scalar, and the linear vertical error scaled to 95% using the univariate scalar.

   Remark. *The post-adjustment point variance-covariance matrix is a set of numbers that completely defines the estimated accuracy of a point based on the results of a network adjustment. It can be used to compute other quantities, such as the horizontal error ellipse, which provides accuracy information in a graphical format. The "scalars" are* *numbers used to scale the standard error to a desired confidence level. At the 95% confidence level, the bivariate scalar equals 2.4477 and the univariate scalar equals 1.9600.*

5. The required final accuracy of an appropriately constrained control survey shall be determined on a project-by-project basis and specified in the project scope.

6. Procedures may be less rigorous than the foregoing control survey requirements for establishing control check points within a project area, or for establishing points for the purpose of georeferencing terrestrial (optical) equipment. However, in all cases the method used for establishing such points shall be of an accuracy equal to or better than that used for the data collection, and the procedures for establishing such points shall be specified in the project scope.

   Remark. *The purpose here is to allow more freedom for evaluating and supporting certain types of data collection, such as using radial Real Time Kinematic (RTK) GNSS to evaluate mapping-grade GNSS data, or using RTK GNSS to establish setup and backsight points for an optical total station to collect data in areas where GNSS cannot be used.*

II. Coordinate System Definition

Remark. *A consistent coordinate system must be completely defined for a data collection effort to be successful. This may seem an obvious point, but it is stressed here because there are some subtleties. Note in particular that in February 2007 the NGS completed a readjustment of the entire National Spatial Reference System (NSRS), which is designated as NSRS2007. Although this readjustment may have minimal impact on "mapping grade" inventory-type feature positions, it will have a noticeable impact on survey control coordinates. To reliably utilize spatial data, it is important to rigorously define the coordinate system with respect to the NSRS. Thus the recommended coordinate system parameters in these Standards are intended to be consistent with existing spatial data and the latest realization of the NSRS.*

A. Linear unit. Specified in the project scope.

1. The same units shall be used for all linear measures for all data delivered (horizontal coordinates, elevations, heights, accuracies, dimensions, coordinate system parameters, metadata, etc.). Any quantities derived from linear units (such as area and volume) shall be computed using the linear unit defined in the project metadata.

   Remark. *If State Plane coordinates will be provided in feet, it is recommended that the international foot be used rather than the US survey foot since the international foot has been specified by the Arizona Legislature as the linear unit of the Arizona Coordinate System. Note that the meter is used by the NGS for the NSRS, and it is also commonly used for certain coordinate systems, such as Universal Transverse Mercator (UTM).*

   Remark. *Some derived quantities are associated with specific linear units. For example, according to National Institute of Standards and Technology (Thompson and Taylor, 2008), the acre is based only on the US survey foot. Nonetheless it is deemed more pragmatic and logically consistent to have derived measures such as the acre be consistent with the linear unit used for all other measurements for a particular project or deliverable. Therefore, if the international foot is the specified linear unit, acreage shall be computed using the international foot.*

B. Geometric reference system. North American Datum of 1983 (NSRS2007).

Remark. *The term "geometric reference system" replaces the former term "horizontal datum". This change is consistent with terminology adopted by the NGS in 2008, and it reflects the reality that modern "horizontal" datums are not purely horizontal — they are actually three-*

dimensional reference frames because they explicitly include ellipsoid heights and are referenced to the Earth's center of mass. The term "geometric" emphasizes the fact that such systems are purely spatial constructs. This distinguishes such systems from other systems that are referenced to the Earth's local or regional gravity field, such as vertical datums that yield orthometric or other "physical" heights.

1. NAD 83 (1992), also known as the High Accuracy Reference Network (HARN) realization, and NAD 83 (2002.0) may be used as reference frames for data collection, but if these are used they must be documented.

   Remark. *Prior to the NSRS2007 realization in February 2007, the "official" NAD 83 realization in Arizona was NAD 83 (1992), also called the HARN realization. Currently, NAD 83 (2002.0) is the most recent publicly available realization of the NGS Continuously Operating Reference Station network. For data with accuracy requirements coarser than approximately ±0.2 ft (±6 cm) horizontally and vertically (i.e., ellipsoid height), NAD 83 (NSRS2007), (2002.0), and (1992) may be considered essentially equivalent in most of Arizona. Only in a few isolated areas does the NSRS2007 realization differ from the 2002.0 and 1992 realizations by more than ±0.3 ft (±10 cm), either horizontally or vertically. Nonetheless it is recommended that NSRS2007 be used when possible and that the realization be explicitly identified regardless which one is used.*

   a. Spatial data shall <u>not</u> be referenced to the following reference systems: NAD 27; the original realization of NAD 83 (1986); any realization of the World Geodetic System of 1984 (WGS 84); or any International Terrestrial Reference Frame (ITRF) realization of the International Terrestrial Reference System (ITRS), unless specifically required in the project scope.

      Remark. *NAD 83 has been the official and legal geodetic datum of the United States since 1986. The NAD 27 datum is obsolete and is especially poorly suited for GNSS projects since it is not geocentric and is of low accuracy relative to modern positioning methods. ITRF 2000 and WGS 84 (G1150) are global datums that can be considered equivalent at the 0.1-ft (3-cm) level, but they differ horizontally from NAD 83 by about 4 feet (1.2 m) in Arizona. Although ITRF 2000 and WGS 84 are nearly identical, they are not quite the same, and since WGS 84 control coordinates are not available to the public, this datum cannot be explicitly referenced and therefore it should never be cited as the datum for any dataset with accuracies better than 10 feet (3 m). In addition, both ITRF and WGS 84 are moving with respect to NAD 83 at a rate of approximately 0.6 ft (0.2 m) per decade in Arizona, and hence the current coordinates of these stations are continuously changing with time, which complicates their use in mapping and surveying applications.*

2. Valid geodetic control for determining NAD 83 coordinates for a project shall consist solely of appropriate stations published by the NGS (or approved equal). The stated accuracy of the control used shall have a positional accuracy equal to or better than that required for the project.

3. Any and all geodetic datum transformations (change of geodetic coordinates by mathematical means from those based on field observations) must be documented.

   a. If a geodetic datum transformation is performed, its accuracy shall be equal to or better than the most accurate data required for the project, and this accuracy must be demonstrated using objective statistical methods such as those provided by the NSSDA or by reference to such testing performed by others.

      Remark. *Care should be exercised when using datum transformations, because there are many different methods available, even for the "same" transformation, and these* *vary greatly in accuracy. For example, the NAD 83 to ITRF 00 / WGS 84 transformation is available in virtually all GNSS devices as Molodensky (three-parameter) transformations published by the US Department of Defense (DoD). A more accurate version of this transformation has been developed by the NGS (called NADCON), and in Arizona it differs from the DoD version by as much as 15 ft (5 m). However, NADCON has been incorporated into far fewer GNSS devices than the DoD transformations.*

C. Map projection. Specified in the project scope.

1. The map projection parameters shall be explicitly provided in the project documentation, regardless of the coordinate system used. This shall consist of the map projection type, all parameters necessary to define the projection, and the linear unit. The projection must directly reference the datum defined in these Standards or the project scope.

   Remark. *Providing map projection parameters is essential for projects utilizing a custom projection, but it is also important for published coordinates systems (such as State Plane or Universal Transverse Mercator) to ensure the correct parameters were used. Parameters used to define a projection vary, but typically consist of latitude of grid origin, longitude of grid origin, false northing, false easting, and projection axis scale factor (explicit or implied).*

2. For GNSS (Global Navigation Satellite Systems) data collection, the grid (map) coordinates shall be determined from the GNSS-derived geodetic coordinates entirely by the map projection without any post-projection modification (e.g., translation, rotation, or scaling).

   Remark. *Transforming grid coordinates after projecting disrupts the relationship to the original coordinates and decreases data transferability.*

3. For non-GNSS (terrestrial) data collection, the grid (map) coordinates shall be determined in a manner that fully preserves the geometric characteristics of the coordinate system, in terms of coordinate values, scale, and angular orientation.

D. Vertical datum. North American Vertical Datum of 1988.

1. The height (elevation) of spatial data shall not be referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29), or any vertical datum other than NAVD 88, unless specifically required in the project scope. Except when referencing historical data, "Mean Sea Level" be shall not be used as a vertical datum.

   Remark. *"Mean Sea Level" (MSL) should not be used as a vertical reference because it is ambiguous. There is no MSL datum for the United States, and so to specify MSL as a vertical datum creates confusion. When this is done it is not clear whether "MSL" is intended to represent NGVD 29, NAVD 88, some other vertical datum, or one of the many local tidal datums used in coastal areas throughout the US.*

   MSL is not used as a vertical datum because it is not known to sufficient accuracy on a national scale. The reason for this is that tide gauges are subject to local sea surface topography effects (due to persistent currents, salinity variation, etc.) which cause the measured water levels to depart from the "true" mean sea level that would be caused by gravity alone. This makes MSL unsuitable as a national vertical datum, and it is the reason the NGS changed the name of the US vertical datum from "Mean Sea Level Datum" to NGVD 29 in 1976. For similar reasons NAVD 88 also cannot be considered a mean sea level datum.

The geoid is related to MSL in that it is intended to represent the gravitational equipotential surface that most closely approximates MSL over the entire globe (as determined from satellite altimetry over the open oceans). However, that does not mean that a geoid model can therefore be considered an MSL datum. One problem is that global MSL is only known to an accuracy of 1-2 meters. Another problem is that not all "geoid" models are purely gravimetric (for example, the NGS model GEOID03 is a "hybrid" geoid model that has been modified to best match NAVD 88). And finally, the geoid cannot be directly observed, but rather is computed from gravity data via complex computations based on various models and assumptions – there is no direct connection between a geoid model and measured "mean sea level" based on water levels.

2. Valid control for determining orthometric heights (elevations) for a project shall consist solely of appropriate stations published by the NGS (or approved equal).

   a. For projects requiring vertical accuracy of ±0.3 ft (±9 cm) or better, only NGS NAVD 88 elevations published to at least the nearest centimeter shall be used for control (or approved equal), except for published values determined using the NGS vertical transformation program VERTCON. Under certain circumstances, NGS control stations with VERTCON-derived NAVD 88 elevations published to the nearest centimeter may be used, but in all cases this must be specified in the project scope.

   b. For projects with a vertical accuracy requirement coarser than ±0.3 ft (±9 cm), the vertical control used shall be of an accuracy commensurate with that set forth in the project scope.

3. Orthometric height (elevation) determination using GNSS:

   Remark. *There are a number of complications with determining NAVD 88 orthometric heights ("elevations") with GNSS. These include the accuracy of the NAD 83 ellipsoid height, the geoid model used, and any "corrections" applied to the heights (whether a constant shift, planar correction surface, or any other modifications).*

   a. The variation in separation between the reference ellipsoid and geoid shall be taken into account. The recommended approach is to reference elevations to appropriate NAVD 88 control, and to use the most current high-resolution NGS geoid model to account for the change in geoid height in the project area. Other methods may be used to model variation in geoid height, but in all cases such methods shall be documented and the final orthometric heights must meet the accuracy requirements set forth in the project scope.

      Remark. *Whenever possible, existent NAVD 88 benchmarks should be incorporated into a project to validate the accuracy of the geoid model used for GNSS-derived orthometric heights. These can also serve as a starting point for conventional leveling, as well as a means to assess/predict the accuracy of the resultant heights.*

      Remark. *An analysis of the "fit" of the geoid model to the existent NAVD 88 benchmarks in the area should be made to look for a systematic offset (bias) of the model with respect to the actual differences of ellipsoid and orthometric heights at the benchmarks. Any observed bias in the geoid model should be removed from the GNSS-derived orthometric heights to insure a best fit with the existent leveling data. Note: it is imperative that benchmark subsidence be considered in many areas of Arizona before assuming the geoid model is the source of a bias. Field elevation data for leveling lines in the NSRS may be obtained from NGS to assess the likelihood of subsidence in the project area.*

Remark. *As of the publication date of these Standards, the current NGS "hybrid" geoid model is GEOID03. A new NGS hybrid geoid model (GEOID09) is presently in the final stages of development and will be officially released for public use no later than February 2009.*

Remark. *If inclined planar corrections are used to model variation in geoid separation, they should be used with caution, particularly if data will be collected outside the area used to determine planar correction parameters. In addition, an inclined plane may not adequately represent geoid surface undulation in mountainous regions or over areas of large extent. In general, the use of inclined planar corrections is not recommended, in part because it is not a universally used approach and may therefore limit data transferability.*

b. If ties to control with accurate NAVD 88 elevations are not practicable, NGS control with ellipsoid heights published to at least the nearest centimeter (or approved equal) may be used in combination with the most current high-resolution NGS geoid model. Use of said ellipsoid height control must be explicitly stated in the project scope. This approach shall only be used if the ellipsoid height accuracy is equal to or better than that required for orthometric heights as stated in the project scope.

4. For projects requiring ellipsoid heights rather than orthometric heights (elevations), the ellipsoid heights shall be based on NAD 83 control as specified in section II.B.2. of these Standards, and a geoid model shall <u>not</u> be used.

5. For projects requiring GNSS-derived ellipsoid and/or orthometric heights accurate to ±0.2 ft (±6 cm) or better, it is recommended that the survey plan be compliant with guidelines in *NOAA Technical Memorandum NOS NGS-58* (Zilkoski *et al.*, 1997) and the draft version of *NOAA Technical Memorandum NOS NGS-59* (Zilkoski *et al.*, 2005) currently entitled "DRAFT Guidelines for Establishing GPS-derived Orthometric Heights (Standards: 2 cm and 5 cm)". These documents are listed in the references at the end of these Standards.

6. For orthometric height determination using optical (and other terrestrial) methods, such as differential spirit leveling or trigonometric leveling, the accuracy requirements and specifications for performing the work shall be defined in the project scope.

   Remark. *The accuracy that can be achieved using optical methods is highly variable, and it depends on equipment type and its condition, field procedures, corrections applied, environmental factors, size of area surveyed, data redundancy, and handling (adjustment) of redundant data. With the proper equipment, procedures, corrections, and adjustments, differential spirit leveling can achieve relative accuracies (at 95% confidence) on the order of 0.004 foot times the square root of miles leveled (1.4 mm × square root km), however it is labor intensive and expense. Although not as accurate as differential leveling, in rugged terrain trigonometric leveling can economically achieve reliable results that will satisfy the requirements for many types of projects. Because of the variability, there are no good general "rules of thumb" that can be applied to these methods. As a guideline for specifying accuracy for differential leveling, refer to Bossler (1984) in the reference list of these Standards. If vertical accuracy is of paramount concern, it is highly recommended that the survey include sufficient independent redundant observations to allow reliable accuracy estimates based on a least-squares network adjustment.*

7. Any and all vertical datum transformations (change of derived orthometric heights by mathematical means) must be documented.

a. If a vertical datum transformation is performed, its accuracy shall be equal to or better than the most accurate vertical data required for a project, and this accuracy must be demonstrated using objective statistical methods such as those provided by the NSSDA.

Remark. *Examples of vertical datum transformations include the NGS program VERTCON, vertical offsets, and best-fit planar correction surfaces. Note that in general VERTCON is not appropriate for transformations requiring geodetic accuracy.*

III. Documentation

A. Metadata. Information relevant to documenting spatial characteristics of the captured data shall be provided with the content and in the format specified in the project scope. This shall include the person or persons in responsible charge of data collection, the Client or dataset owner, and a statement as to the intended uses and purpose of the data.

Remark. *The Client may wish to specify existing metadata formats, such as those developed by the Federal Geographic Data Committee (FGDC) or the International Organization for Standardization (ISO). In addition, development of a metadata format specifically for Arizona survey data has been proposed by the Geospatial Committee of APLS. Regardless of the metadata format used, it is strongly recommended that all geospatial data prepared wholly or in part by public funds include proper metadata to proactively describe its usefulness. Blanket disclaimers are not acceptable — these merely indicate that the data are of low quality and imply that public funds were not well spent.*

B. Feature-level metadata. The required information shall be specified in the project scope, but the following feature-level metadata is recommended for every feature collected: Positional accuracy (horizontal for all features, and vertical if applicable), linear unit, coordinate system (including datums), equipment, date(s) of data collection, person in responsible charge, name of the prime contractor, name of the project, and a unique identifier for all features collected.

Remark. *A unique feature identifier should be used that can be generated automatically and that ensures uniqueness regardless of the quantity of data collected, the number of crews collecting data, or the time span over which data collection occurs. For example, a timestamp can be used which includes the year, month, day, and time to the millisecond as a unique 17-character ID.*

C. Project report. A project report shall be required to document methods, procedures, and results of the data collection effort. The content and format of the report shall be specified in the project scope.

IV. Performance Requirements

A. Responsible charge for data collection.

1. The person or persons in responsible charge of data collection shall be explicitly identified. This will consist of individuals with data content expertise with regard to the intended uses and purpose of the data, and this information shall be provided as part of the metadata as specified in section III.A. of these Standards.

Remark. *Although the following requirements distinguish between authoritative and non-authoritative data records, it is recognized that the term "authoritative" has yet to be fully defined. Because of this, determination as to whether the data are "authoritative" is reserved to the Client in this version of the Standards. Both APLS and AGIC are currently reviewing the processes and policies for the collection of geospatial data, which includes* *consideration as to what constitutes "authoritative" data. In addition, it is important to note that the Arizona State Board of Technical Registration (SBTR) may influence the data collection performance requirements in these Standards through policy statements, disciplinary actions, or other future measures, and the Standards will be updated to reflect such changes.*

For additional information on use of the term "authoritative", please refer to the National Council of Examiners for Engineering and Surveying (NCEES) Model Rules listed in the References section of these Standards.

2. Determination as to whether the collected data will be used to populate authoritative records shall be made by the Client or dataset owner. For the purpose of these Standards, the term "authoritative" refers exclusively to data used to define real property, or to data for which the feature locations (positions) are certified as authoritative.

   a. Data collection for authoritative records shall be performed under the supervision of qualified professionals who are licensed specifically to provide surveying and mapping services by the Arizona State Board of Technical Registration. In such cases all deliverables provided for the project shall be sealed by the registrant in responsible charge.

   b. Data collection for non-authoritative records shall be performed under the supervision of the project manager in responsible charge, as approved by the Client. Deliverables in such cases need not be sealed by a licensed registrant. However, the deliverables will nonetheless be subject to the Client's requirements for positional accuracy, content, and completeness.

   Remark. *Regarding the role of registrants in supervising data collection, the key issue is the potential for misuse and harm to the public caused by geospatial data that are distributed beyond their original intent and limitations. Prudent business practice should govern what type of technical professionals should be involved in geospatial data collection, use, and distribution.*

B. Independent accuracy determination. Determination of data spatial accuracy shall be made independently by the Client (or designated representative) using the same criteria as set forth in these Standards and the project scope.

C. Accuracy evaluation criteria. Deliverables shall be evaluated as set forth in these Standards and the project scope to ensure the requirements for spatial accuracy and documentation have been satisfied. The criterion for evaluating spatial accuracy shall be at the 95% confidence level as specified in these Standards. Establishment of criteria for evaluating data content accuracy and completeness is beyond the scope of these Standards and shall be specified in the project scope.

Remark. *In some cases it may be advantageous to evaluate the entire dataset generated, prior to "clipping" or removal of data outside the project area.*

Remark. *Data content accuracy and completeness includes feature attribute accuracy, data completeness (both in terms of attributes and the features collected), and data format. These characteristics are not addressed in these Standards because they vary greatly by feature type and project.*

D. Primacy of project scope. Data submitted as final deliverables shall meet the requirements set forth in these Standards and in the project scope. If there is a conflict between these Standards and the project scope, the project scope shall prevail.

Remark. *For large projects, partial datasets may be submitted over time, rather than as a single complete submittal. This can affect the time available for data evaluation, especially once the last dataset is submitted. In such cases it is recommended that the requirements for partial data submittals be clearly defined in the project scope, including provision of sufficient time for data evaluation. This is good practice for any project, whether the data submittals are partial or complete, and it is particularly important if final payment is contingent upon the results of the accuracy evaluation.*

V. Currency of Standards and Specifications

A. Updating of Standards. It is recognized that positioning technologies are continuously evolving, that control available for georeferencing may be revised or augmented, and that legal requirements for data collection may change with time. Therefore these Standards will be periodically updated and the version in force during data collection shall be specifically referenced in the project scope.

Glossary

Autonomous position. A *GPS* position obtained with a single receiver using only the ranging capability of the *GPS* code (i.e., with no corrections applied).

Breakline. Three-dimensional lines that represent discontinuities in the slope of a topographic surface, such as stream flowlines, road cuts, and ridge lines. Used in a *DTM* to capture abrupt changes in a surface by incorporating the breaklines as *TIN* triangle edges.

Cartesian coordinates. Coordinates based on a system of two or three mutually perpendicular axes. *Map projection* and *ECEF* coordinates are examples two- and three-dimensional Cartesian coordinates, respectively.

Confidence interval or level. A computed probability that the "true" value will fall within a specified region (e.g., 95% confidence level). Applies only to randomly distributed errors.

CORS (Continuously Operating Reference Stations). A nation-wide system of permanently mounted *GPS* antennas and receivers that collect *GPS* data continuously. The CORS network is extremely accurate and constitutes the primary survey control for the US. CORS data can be used to correct *GPS* survey and mapping results, and the data are freely available over the Internet.

Datum transformation. Mathematical method for converting one *geodetic* or *vertical datum* to another (there are several types, and they vary widely in accuracy).

DEM (Digital Elevation Model). The representation of continuous elevation values over a topographic surface by a regular array of height values, referenced to a common *vertical datum*.

DTM (Digital Terrain Model). The representation of continuous elevation values over a topographic surface by a combination of non-uniformly spaced mass points and (optionally) *breaklines*, typically modeled as a Triangulated Irregular Network (*TIN*).

ECEF (Earth-Centered, Earth-Fixed). Refers to a global three-dimensional (X, Y, Z) *Cartesian coordinate* system with its origin at the Earth's center of mass, and "fixed" so that it rotates with the solid Earth. The Z-axis corresponds to the Earth's conventional spin axis, and the X- and Y-axes lie in the equatorial plane. Widely used for geodetic and *GPS* computations.

Ellipsoid height. Straight-line height above and perpendicular to the *ellipsoid*. This is the type of height determined by *GPS*, and it does not equal elevation. Can be converted to orthometric heights ("elevations") using a *geoid* model.

Ellipsoid. A simple mathematical model of the Earth corresponding to mean sea level (the *geoid*) and used as part of a *geodetic datum* definition. Constructed by rotating an ellipse about its semi-minor axis. Also referred to as a "spheroid".

Delaunay criterion. A principle used in triangulation that creates a mesh of contiguous, non-overlapping triangles from a dataset of points. The criterion is satisfied if no data points are contained within a circle circumscribed around each triangle. Named for the Russian mathematician Boris Nikolaevich Delaunay.

FGDC (Federal Geographic Data Committee). Develops and promulgates information on spatial data formats, accuracy, specifications, and standards. Widely referenced by other organizations. Includes the Federal Geodetic Control Subcommittee (FGCS) and the *NSSDA*.

Foot, International. Linear unit adopted by the US in 1959, and defined such that one foot equals exactly 0.3048 meter. Shorter than the *US survey foot* by 2 *parts per million* (ppm).

Foot, US Survey. Linear unit of the US prior to 1959, and defined such that one foot equals exactly 1200 / 3937 meter. Longer than the *international foot* by 2 *parts per million* (ppm).

Geodetic datum. Reference frame for computing geodetic coordinates (latitude, longitude, and ellipsoid height) of a point. A datum always refers to a particular *ellipsoid* and a specific adjustment (e.g. the 1992 adjustment of *NAD 83* for the Arizona *HARN*).

Geographic "projection". This is not a true *map projection* in the sense that it does not transform geodetic coordinates (latitude and longitude) into linear units. However, it is a projection in the sense that it represents geodetic coordinates on a regular flat grid, such that the difference in angular units (e.g., decimal degrees) is equal in all directions. Because of meridian convergence, this results in an extremely distorted coordinate system, especially at high latitudes, and the distortion varies greatly with direction.

Geoid. Surface of constant gravitational equipotential (a level surface) that best corresponds to global mean sea level. Often used as a reference surface for *vertical datums*.

GNSS (Global Navigation Satellite System). A generic term for all satellite navigation systems (including *GPS*) that transmit data used to provide geospatial positioning with global coverage.

GPS (Global Positioning System). A constellation of satellites used for navigation, mapping, surveying, and timing. Microwave signals transmitted by the satellites are observed by GPS receivers to determine a three-dimensional position. Accuracy varies greatly depending on the type of receiver and methods used.

Grid distance. The horizontal distance between two points on a flat plane. This is the type of distance obtained from *map projections*.

Ground distance. The horizontal distance between two points as measured on the curved Earth surface.

GRS-80 (Geodetic Reference System of 1980). The reference *ellipsoid* currently used for many *geodetic datums* throughout the world, including *NAD 83* and *ITRF*.

HARN (High Accuracy Reference Network). Network of *GPS* stations adjusted by the *NGS* on a state-by-state basis. The Arizona HARN was adjusted in 1992. In some states it is referred to as a High Precision *GPS* (or Geodetic) Network (HPGN).

ITRF (International Terrestrial Reference Frame). Global geodetic reference system that takes into account plate tectonics (continental drift) and is used mainly in scientific studies. A new ITRF "epoch" is computed periodically and is referenced to a specific time (e.g., ITRF 2000 1997.0). Each epoch is a realization of the International Terrestrial Reference System (ITRS). See Soler (2007), and Soler and Snay (2004) for information on its relationship to *NAD 83* and *WGS 84*.

Map projection. A functional (one-to-one) mathematical relationship between geodetic coordinates (latitude, longitude) on the curved *ellipsoid* surface, and grid coordinates (northings, eastings) on a planar (flat) map surface. All projections are distorted, in that the relationship between projected coordinates differs from that between their respective geodetic coordinates. See Snyder (1987) for details.

NAD 27 (North American Datum of 1927). *Geodetic datum* of the US prior to *NAD 83*, and superseded by *NAD 83* in 1986. This is the datum of *SPCS* 27 and *UTM* 27.

NAD 83 (North American Datum of 1983). Current official *geodetic datum* of the US. Replaced *NAD 27* in 1986, which is the year of the initial NAD 83 adjustment. This is the datum of *SPCS* 83 and *UTM* 83. See Schwarz (1986) for details.

NADCON. *Datum transformation* computer program developed by the NGS for transforming coordinates between *NAD 27* and *NAD 83*, and also between the *NAD 83* 1986 adjustment and the various *HARN* adjustments. See Dewhurst (1990) for details.

NAVD 88 (North American Vertical Datum of 1988). Current official vertical datum of the US. Replaced *NGVD 29* in 1991. See Zilkoski et al. (1992) for details.

NGS (National Geodetic Survey). Federal agency within the Department of Commerce responsible for defining, maintaining, and promulgating the *NSRS* within the US and its territories.

NGVD 29 (National Geodetic Vertical Datum of 1929). Previous *vertical datum* of the US, superseded by *NAVD 88* in 1991. Not referenced to the *geoid* or mean sea level, and not as compatible with *GPS*-derived elevations as *NAVD 88*. Called "Mean Sea Level" (MSL) datum prior to 1976.

NSRS (National Spatial Reference System). The framework for latitude, longitude, height, scale, gravity, orientation and shoreline throughout the US. Consists of geodetic control point coordinates and sets of models describing relevant geophysical characteristics of the Earth, such as the *geoid* and surface gravity. Defined, maintained, and promulgated by the *NGS* (see Doyle, 1994, for details).

NSSDA (National Standard for Spatial Data Accuracy). *FGDC* methodology for determining the positional accuracy of spatial data (see Federal Geographic Data Committee, 1998).

OPUS (Online Positioning User Service). A free *NGS* service that computes *NSRS* and *ITRF* coordinates with respect to the *CORS* using raw *GPS* data submitted via the Internet.

Parts per million (ppm). A method for conveniently expressing small numbers, accomplished by multiplying the number by 1 million (e.g., 0.00001 = 10 ppm). Exactly analogous to percent, which is "parts per hundred".

RMSE (Root Mean Square Error). A measure of error based on the difference between a set of test values and their corresponding "true" (control) values, such as the difference between aerially mapped features and their surveyed coordinates. Computed by summing the squared differences between test and control values, dividing that number by the number of test points, and then taking the square root.

SPCS (State Plane Coordinate System). A system of standardized *map projections* covering each state with one or more zones such that a specific distortion criterion is met (usually 1:10,000). Projection parameters (including units of length) are independently established by the legislature of each state. Can be referenced to either the *NAD 83* or *NAD 27* datums (SPCS 83 and SPCS 27, respectively). See Stem (1989) for details.

TIN (Triangulated Irregular Network). A network constructed by connecting three-dimensional points with line segments using a method (such as the *Delaunay criterion*) to create a contiguous, non-overlapping mesh of triangles. Each triangle represents an inclined planar surface, and these triangular "faces" can be used collectively to construct a *DTM***.** A TIN may include *breakline* segments as triangle edges.

Triangulation. A method for determining positions from angles measured between points (requires at least one distance to provide scale).

Trilateration. A method for determining positions from measured distances only.

Trivial vector. A *GPS* vector (computed line connecting two *GPS* stations) that is not statistically independent from other *GPS* vectors observed at the same time.

UTM (Universal Transverse Mercator). A grid coordinate system based on the Transverse Mercator *map projection* which divides the Earth (minus the polar regions) into 120 zones in order to keep map scale error within 1:2500. Can be referenced to either the *NAD 83* or *NAD 27* datums (UTM 83 and UTM 27, respectively). See Hager et al. (1989) for details.

Vertical datum. Reference system for determining "elevations", usually through optical differential leveling. Modern vertical datums typically use the *geoid* as a reference surface and allow elevation determination using *GPS* when combined with a *geoid* model.

WGS 84 (World Geodetic System of 1984). Reference *ellipsoid* and *geodetic datum* of *GPS*, defined and maintained by the US Department of Defense. Current realizations of WGS 84 are considered identical to *ITRF* 2000 at the 2 cm level. See National Imagery and Mapping Agency (1997) for details, and Merrigan et al. (2002) for information on the most recent realization.

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Appendix A:

Project Scope / Statement of Work Examples

consistent with *Arizona Spatial Data Accuracy and Georeferencing Standards*

This appendix contains three project scope / statement of work examples to provide guidance in using these Standards for preparing contracts for receiving or providing geospatial data and services. Although the examples are written in the context of contractual agreements, they can also be used internally within organizations to develop protocols for their own data collection. The examples are: 1) Inventory of a water and sewer system with accurate manhole elevations; 2) Establishment of horizontal and vertical geodetic control using GNSS; and 3) Aerial imagery and topographic surface models.

Example A1: Water & Sewer System Inventory with Accurate Manhole Elevations

The inventoried water and sewer system point features shall conform to the *Arizona Spatial Data Accuracy and Georeferencing Standards,* version 3.1 (November 8, 2008), and these shall apply unless specifically stated otherwise herein. The following items provide details consistent with these Standards that are specific to this project.

1. **Inventory positional accuracy.** The required horizontal and vertical accuracy of water and sewer system point features is given in Table 1. These accuracies must be achieved at the 95% confidence level in order to receive final payment.

Table 1. Accuracy requirements for water and sewer system inventory point features (accuracies are at 95% confidence per NSSDA).

General feature type	Example features	Accuracy	
		Horizontal	Vertical
Very well-defined occupation points	Survey control points (NGS, GDACS, control established for project), other survey monuments, property corners	**0.1 ft**	**0.2 ft**
Moderately well-defined occupation point, vertical accuracy important (e.g., for hydraulic modeling of unconfined flow)	Gravity sewer and stormdrain manholes, culvert inverts and crowns (at a specific horizontal location), weirs [Note: Manhole center shall be occupied unless manhole rim or cover is inclined at slope greater than 10%, in which case three equally spaced points on the rim shall be occupied]	**0.5 ft**	**0.2 ft**
Moderately well-defined occupation point, vertical accuracy not important (e.g., pressurized flow)	Water valves, water meters, force main manholes	**0.5 ft**	**0.5 ft**
Poorly defined occupation point and features that cannot be directly occupied	Water hydrants, water sample stations, above-grade valve assemblies, poles, tanks, towers	**1.0 ft**	**1.0 ft**

2. **Control check points.** Control check points shall consist of NGS stations with published accuracies of better than or equal to 0.1 ft (3 cm) horizontally and 0.2 ft (6 cm) vertically, or approved control points from the City database (a list is included with this document). Control check points can also be established by the firm performing data collection, but this control shall be directly referenced to the aforementioned control, and the firm must be able to demonstrate the accuracies achieved are better than or equal to 0.1 ft (3 cm) horizontally

and 0.2 ft (6 cm) vertically. For GNSS methods, a minimum of two separate observations not less than two hours apart are required for establishing control check points. For total stations, observations from at least two different setup points are required. In both cases, final check point coordinates may be determined using least-squares adjustment or the mean (or weighted mean) coordinate value, but the individual observations used shall not differ by more than the required accuracy values. Setup and backsight points for total stations may be established with GNSS using the same method as required for establishing control check points.

3. **Data validation.** A three-part comprehensive and independent data validation program is required. The combined results of these three data validation methods will be used to determine whether the required positional accuracies in Table 1 have been achieved.

   a. <u>Control check observations</u>. All firms shall occupy stations with known high-accuracy coordinates in the same manner as the inventory features. For local (temporary) GNSS base and optical total station setups, a minimum of two control check observations per setup is required, near the beginning and end of fieldwork for that setup. For permanent GNSS bases (either single or part of a network), a minimum of one control check observation per day per GNSS rover is required. For total stations, control check points can be used for the instrument setup and backsight points.

   b. <u>Reoccupation of features by data collection firm</u>. The last two inventory features collected each day per crew shall be re-observed at the beginning of the following day of data collection. These checked positions shall be stored in a feature class separate from the inventory points and shall be provided to the City as part of the project submittal.

   c. <u>Random independent field checking</u>. An independent field validation campaign shall be performed by the City (or a designated representative) to verify both positional and attribute accuracy, as well as data completeness. This will be done by selecting representative sample areas for performing a validation inventory. The sample size shall not be less than 2% of the total number of features submitted. The City reserves the right to retain the services of a private firm for performing the validation, but any such firm selected shall not perform inventory data collection for this project

4. **Coordinate System.** The coordinate system for all project spatial data deliverables shall be the State Plane Coordinate System of 1983, Arizona Central Zone (0202) referenced to the NAD 83(NSRS2007) datum. The linear unit shall be the international foot (both horizontally and vertically). For GNSS data, the coordinates must be computed directly from the geodetic coordinates without rotation, translation, or scaling of the projected coordinates.

5. **Vertical Datum.** The vertical datum for all project spatial data deliverables shall be NAVD 88. The orthometric heights shall be referenced to published NAVD 88 heights (or approved City control). NAVD 88 heights derived using the NGS program VERTCON shall not be used. For GNSS data collection, geoid height variation over the project shall be modeled using GEOID03. Any vertical offsets or planar corrections used to correct for bias in GEOID03 must be documented.

6. **Documentation and metadata.** A project report and feature-level metadata are required as part of the final submittal. The feature-level metadata shall adhere to the content requirements of the Spatial Attributes table provided by the City, and shall be included as

part of the feature geodatabases submitted for this project. The report shall include, at the minimum:

a. An executive summary.

b. Description of the project area, including map(s).

c. Narrative of the data collection effort, including equipment and software used, field and office procedures, problems encountered and how they were resolved.

d. Estimated accuracy of the features collected based on control checks and repeated observations, organized by feature type accuracy group and provided in tabular and/or graphical form.

e. List of existing control stations used for referencing the data and performing check observations, and list of additional control established for the project (if applicable), descriptions as to how this control was established, and supporting documentation demonstrating its accuracy.

f. Conclusions and recommendations, including those for future inventory projects.

Example A2: Establishing Horizontal and Vertical Geodetic Control Using GNSS

The primary and secondary control surveys performed for this project shall conform to the *Arizona Spatial Data Accuracy and Georeferencing Standards*, version 3.1 (November 8, 2008), referred to herein as the "Standards", and these shall apply unless specifically stated otherwise. The following items provide details consistent with these Standards specific to this project.

1. **Positional accuracy.** The positional error values for any point in the survey shall not exceed the values given below at the 95% confidence level, and these values shall be based on the correctly weighted *a posteriori* point variance-covariance matrices from the constrained least-squares adjustment:

	Error ellipse semi-major axis	Ellipsoid height	Orthometric height
Primary	1.5 cm	2 cm	3 cm
Secondary	3 cm	5 cm	5 cm

In addition, residuals shall not exceed 2 cm horizontally or 5 cm up for the final free or constrained adjustments of any primary or secondary network observation.

Payment of the final 10% of the contract price for this project will be withheld until the required accuracies are achieved as described herein. In the event these requirements are not achieved despite following the procedures specified herein, the City shall work with the Consultant to negotiate a fee for supporting additional field observations and the resulting additional data processing and analysis.

2. **Planning and execution.** The National Geodetic Survey (NGS) Arizona Geodetic Advisor shall be involved in the planning and execution of this survey to ensure that the results will be published in the NGS Integrated Data Base.

3. **Equipment.** All GNSS receivers used for the project must be dual-frequency, full-wavelength with geodetic-quality antennas. All control station occupations shall be performed using fixed-height poles (collapsible poles are permitted), and the height and correct bubble collimation of all poles shall be verified immediately prior to the survey.

4. **Field methods.** A minimum of three (3) occupations are required for each control station. The minimum occupation time for primary control stations is five (5) hours and all occupations must be performed simultaneously. The minimum occupation time for secondary control stations is one (1) hour, and it is not necessary that these all be performed simultaneously. It is recommended that the secondary station occupations be performed simultaneously with the primary occupations if possible based on the equipment and field personnel available.

5. **Methodology.** The survey shall be performed using GNSS equipment and adhere to guidelines in *NOAA Technical Memorandum NOS NGS-58* (1997) and the draft version of *NOAA Technical Memorandum NOS NGS-59* (2005) currently entitled "DRAFT Guidelines for Establishing GPS-derived Orthometric Heights (Standards: 2 cm and 5 cm)", with the following exceptions:

a. Vectors for the secondary control survey may be determined using sequential baseline processing software.

b. The minimum set of three occupations per station need not be done on three separate days. However, the start time of one primary session must differ from the other primary session start times by at least five (5) hours, and the start time of one secondary session must differ from the other secondary session start times by at least two (2) hours.

c. The maximum root mean square error for baseline solutions used shall not exceed 3 cm.

6. **Baseline processing.** Session processing software, such as the latest available version of the NGS program PAGE-NT, shall be used for processing vectors for the primary survey. Any session or sequential baseline processing software may be used for the secondary survey, but must meet the requirements listed in item 5.

7. **Network adjustment.** The network adjustment of both the primary and secondary surveys shall be performed using the latest available version of the NGS program ADJUST (or its successor). Both surveys shall be tied to appropriate horizontal and vertical control based on a survey plan developed in cooperation with the Arizona Geodetic Advisor. The primary survey shall be tied to not less than two (2) NGS Continuously Operating Reference Stations. The results of the primary survey shall be used to constrain the secondary survey.

8. **Deliverables and documentation.** All electronic and hard copy information necessary for publishing the results of this survey by the NGS shall be submitted as deliverables, including station descriptions and field logs. The project report shall include at the minimum:

   a. A project description, including map(s) of the project area.

   b. List of all horizontal and vertical control stations used.

   c. A map or sketch of the vector network for the secondary survey.

   d. Residuals of the free adjustment in tabular and/or graphical format, and the minimum, maximum, mean, and standard deviation of residuals for the free and constrained adjustments.

   e. Discussion of how the baseline processing and network adjustments were performed, including problems encountered and how they were resolved.

   f. Tabulations of estimated horizontal, ellipsoid height, and orthometric height accuracies based on the final constrained adjustments at 95% confidence. Horizontal accuracies shall include the error ellipse semi-major axis, semi-minor axis, and rotation angle.

   g. Vector loop closure analyses are required for the secondary survey, and other quality assurance measures used shall be documented, such as comparisons to existing control, or comparisons to Online Positioning User Service results.

   h. Recommendations for project control publication and a list of station coordinates based on the final results.

<u>Example A3</u>: Aerial Imagery and Topographic Surface Model

The imagery provided for this project shall have a pixel size of no greater than 0.5 foot and the contours derived from the surface model shall be at an interval of 2 feet. Spatial accuracy of the imagery and topographic surface models shall conform to the *Arizona Spatial Data Accuracy and Georeferencing Standards*, version 3.1 (November 8, 2008), referred to herein as the "Standards", and these shall apply unless specifically stated otherwise. The following items provide details consistent with these Standards that are specific to this project.

1. **Positional accuracy.** The spatial accuracy of the imagery and topographic surface model shall be assessed using not less than 20 independently determined check points in each of the five (5) project sub-areas, for a total of at least 100 check points. The sub-areas are identified in the map included with this document. The check point positions will be determined by the County using redundant Global Navigation Satellite System (GNSS) observations and the resulting coordinates shall be at least twice as accurate as that required for the project deliverables. The County (or a designated representative) will use these check points to independently assess accuracy of the project deliverables. Payment of the final 10% of the contract price for this project will be withheld until the required accuracies are achieved as described herein.
   a. <u>Imagery accuracy</u>. The positional accuracy of the imagery shall be equal to or better than 1.0 ft horizontally at 95% confidence. This shall be determined from the semi-major axis of the error ellipse computed using National Standard for Spatial Data Accuracy (NSSDA) methodology and horizontal covariance. In addition, the semi-minor axis of the error ellipse shall not be less than one-half the length of the semi-major axis.
   b. <u>Topographic surface model accuracy</u>. The vertical accuracy of the surface model shall be equal to or better than 1.0 ft at 95% confidence per NSSDA. This evaluation method may be augmented using the 95^{th} percentile method as described in the Standards.
2. **Coordinate System.** The coordinate system for the imagery and surface model shall be the Cochise County Coordinate System, overall County Zone (CC), referenced to the NAD 83 (NSRS2007) datum. The linear unit shall be the international foot (both horizontally and vertically). Accuracy assessments will be performed with respect to published control referenced to this coordinate system.
3. **Vertical Datum.** The vertical datum for the surface model shall be NAVD 88. The orthometric heights shall be referenced to NGS NAVD 88 heights published to the nearest centimeter (or approved County control). NAVD 88 heights derived using the NGS program VERTCON shall not be used for control. Accuracy assessments will be performed with respect to published control referenced to this vertical datum.
4. **Documentation.** A project report shall be submitted with the deliverables for this project, and shall include, at the minimum:
   a. Executive summary.
   b. A project description, including map(s) of the project area.
   c. Description as to how mapping control was established for the project, including a list of the published control stations referenced and estimated accuracy of the established mapping control.

d. Description of the procedures followed and methods used for georeferencing and generating the final products, including problems encountered and how they were resolved.

e. Results of the aerotriangulation adjustment, including residuals and a complete adjustment report (as an appendix).

f. Statement of product accuracies, including an error ellipse for the imagery and an error histogram for the surface model. The County check points will be provided for this purpose, and additional check points may also be used.

g. Conclusions and recommendations.

Appendix B:

Surveying Spatial Data Documentation (Metadata) Examples

The documentation (metadata) examples in this appendix are meant to provide information on *only* the spatial component of surveying and engineering products. They are intended to be part of otherwise "traditional" surveying and engineering deliverables, such as plats, plans, and reports. The reason these examples are included in these Standards is that such information is often missing from traditional surveying and engineering deliverables. Without this type of information, it can be very difficult for others to make use of electronic versions of these deliverables.

These documentation examples are not intended to provide comprehensive information about the deliverables, or to serve as a replacement for the Federal Geographic Data Committee metadata standards used for electronic geospatial data. Instead, these examples represent documentation that is included as part of the surveying and engineering deliverables. Other information would also be part of the deliverables, such as the firm(s) that prepared the product, the registrant(s) in responsible charge (and their signed and dated seals), project information, the names of the client(s), applicable dates, use and purpose of the deliverables, certifications, approvals from government agencies, references to records and standards, details, notes, etc.

<u>Example B1</u>: Basis of Bearings and Coordinates (Gila Valley Area)

<u>Linear unit</u>: International foot (ift)

<u>Geodetic datum</u>: North American Datum of 1983 (1992)

<u>Vertical datum</u>: North American Vertical Datum of 1988 (see below)

<u>System</u>: Arizona LDP

<u>Zone</u>: Gila Valley

<u>Projection</u>: Transverse Mercator

Latitude of grid origin: 32° 20’ 00” N
Longitude of central meridian: 109° 48’ 00” W
Northing at grid origin: 0.000 ift
Easting at central meridian: 200,000.000 ift
Scale factor on central meridian: 1.00014 (exact)

All distances and bearings shown hereon are projected (grid) values based on the preceding projection definition. The projection was defined such that grid distances are equivalent to “ground” distances in the project area.

The basis of bearings is geodetic north. Note that the grid bearings shown hereon (or implied by grid coordinates) do not equal geodetic bearings due to meridian convergence.

Orthometric heights (elevations) were transferred to the site from NGS control station “P 439” (PID CY0725) using GPS with NGS geoid model “GEOID03” referenced to the current published NAVD 88 height of this station (889.460 m).

The survey was conducted using GPS referenced to the National Spatial Reference System. A partial list of point coordinates is given below (additional coordinates are available upon request). Local network accuracy estimates are given at the 95% confidence level and are based on an appropriately constrained least-squares adjustment of over-determined and statistically independent observations.

<u>Point #1 “SAFFORD BASE ARP”, permanent GPS base (off site)</u>

Latitude = 32° 48' 07.31561” N	Northing = 170,563.997 ift	*<u>Estimated accuracy</u>*
Longitude = 109° 42' 42.84664” W	Easting = 227,075.294 ift	Horizontal = Fixed
Ellipsoid height = 2945.423 ift	Elevation = 3033.826 ift	Vertical = Fixed

<u>Point #1002, 1/2” rebar with aluminum cap, derived coordinates (on site)</u>

Latitude = 32° 50' 06.81662" N	Northing = 182,643.211 ift	*<u>Estimated accuracy</u>*
Longitude = 109° 42' 47.90144" W	Easting = 226,633.861 ift	Horizontal = ±0.034 ift
Ellipsoid height = 2822.412 ift	Elevation = 2910.734 ift	Vertical = ±0.056 ift

<u>Point #1006, 1/2” rebar with plastic cap, derived coordinates (on site)</u>

Latitude = 32° 50' 16.89645" N	Northing = 183,662.115 ift	*<u>Estimated accuracy</u>*
Longitude = 109° 42' 47.93756" W	Easting = 226,629.942 ift	Horizontal = ±0.047 ift
Ellipsoid height = 2815.734 ift	Elevation = 2904.040 ift	Vertical = ±0.068 ift

<u>Registrant in responsible charge</u>: Michael Lamar Dennis, AZ RLS 46675, AZ PE 35882

Example B2: Survey Metadata Report (Phoenix Area)

```
Job# XXXX0001
Date: 07/03/2007
Surveyor:  Fisher, Brian S. (AZ LS # 39593)

____________________________________________________________________________
Basis of Bearing:
____________________________________________________________________________
The basis of bearing is geodetic north.  Note that the grid (mapping plane)
bearings shown hereon (or implied by grid coordinates) do not equal geodetic
bearings due to meridian convergence.  The following two on-site points are
listed below for convenience and to satisfy Arizona Boundary Survey Minimum
Standards rule 14.E.2.a.  These points and implied line are not meant to
supersede in importance the geodetic datum, survey control stations, or map
projection definition.

DESIGNATION -  Northeast Corner Section Six, T5S R4E G&SRM
DEA PID     -  5164
SITE COORDINATE:
  Northing  = 1,419,672.57  ift
  Easting   = 2,577,712.77  ift
  Elevation =     1,204.38  ift

DESIGNATION -  Southeast Corner Section Six, T5S R4E G&SRM
DEA PID     -  6169
SITE COORDINATE:
  Northing  = 1,414,270.14  ift
  Easting   = 2,577,704.61  ift
  Elevation =     1,216.75  ift

Measured grid bearing and distance between these two points is North 00
degrees 05' 12" East, 5402.44 ift
____________________________________________________________________________
Benchmark:
____________________________________________________________________________
DESIGNATION -  G 422
NGS PID     -  DV1226
SITE COORDINATE:
  Northing  = 1,422,135.579 ift
  Easting   = 2,572,086.950 ift
  Elevation =     1,199.626 ift
____________________________________________________________________________
Basis of Coordinates and Datum:
____________________________________________________________________________
Linear Unit:   "International Foot" (1 ift = 0.3048 meters exact)
Geodetic Datum:  North American Datum of 1983 National Spatial Reference
Reference Ellipsoid = Geodetic Reference System 1980 (GRS80):
  a = 6,378,137.0000 meters = 20,925,649.325 ift
  b = 6,356,752.3141 meters = 20,855,486.595 ift
  1/f = 298.257 222 101
System adjustment of 2007: NAD83(NSRS2007) or NAD83(2007)
Vertical Datum: NAVD88 Geoid03/NAD83(NSRS2007)
  Geoid Model Used: NGS Geoid03
  Vertical Transformation to Geoid Model: None
____________________________________________________________________________
HORIZONTAL/VERTICAL SURVEY CONTROL
```

```
PROJECT CONTROL  -  HELD FIXED HORIZONTAL (LLh) & VERTICAL (h+N)
DESIGNATION -  B 422
NGS PID     -  DV1227
NAD 83 (07) -  33d 03' 18.64687" (N)    112d 02' 48.27455" (W)
ELLIP HEIGHT-  327.220 (meters)
GEOID HEIGHT-  -30.438  (meters)     GEOID03
HORZ ORDER  -  A
ELLP ORDER  -  THIRD CLASS I

SITE COORDINATE:
  Northing  = 1,429,168.236 ift
  Easting   = 2,562,283.941 ift
  Elevation =     1,173.419 ift
```

```
VERTICAL SURVEY CONTROL
```

```
PROJECT CONTROL  -  FREE ADJUSTED HORIZONTAL (LLh) & VERTICAL (h+N)
DESIGNATION -  G 422
NGS PID     -  DV1226
NAVD 88     -  365.656  (meters)  [measured 365.646 (meters)]
VERT ORDER  -  FIRST CLASS II

SITE COORDINATE:
  Northing  = 1,422,135.579 ift
  Easting   = 2,572,086.950 ift
  Elevation =     1,199.626 ift
```

```
MAP PROJECTION PARAMETERS
```

Projection Type: Lambert Conformal Conic, single parallel

Note: In a single parallel conic, the North, South and Central Standard Parallels are all the same latitude. The latitude of the Grid Origin is also set at this Standard Parallel.

```
Standard Parallel/Grid Origin       =   33d 15' 00.00000" (N)
Central meridian                    =  112d 15' 00.00000" (W)
False northing (at grid origin)     =  1,500,000.000 ift
                                         457,200.000 meters
False easting (at central meridian) =  2,500,000.000 ift
                                         762,000.000 meters
Standard parallel scale factor
   (from the ellipsoid to the grid) =  1.000045 (exact)
```

All distances and bearings shown hereon are grid (mapping plane) values based on the preceding map projection and datum definition. The projection was defined such that grid distances are equivalent to surface (ground) measured distances in the projection zone (see the attached map, Maricopa_County_LDP_20ppm.pdf). The maximum design criterion for map plane distortion in the projection zone is +/- 40 ppm (shown in green on the attached map). The projection was designed to best minimize map distortions throughout Maricopa and part of Pinal Counties, Arizona. The projection zone is defined as any area having less than a 40 ppm distortion.