APPENDIX B — GEOSPATIAL ACCURACY STANDARDS

Accuracy vs. Precision. The following definitions are from Appendix 1-A, Glossary of Terms, of FGDC-STD-007.1-1998, Geospatial Positioning Accuracy Standards. "*Accuracy* - closeness of an estimated (e.g., measured or computed) value to a standard or accepted [true] value of a particular quantity. NOTE: Because the true value is not known, but only estimated, the accuracy of the measured quantity is also unknown. Therefore, accuracy of coordinate information can only be estimated … *Precision* - in statistics, a measure of the tendency of a set of random numbers to cluster about a number determined by the set. NOTE: If appropriate steps are taken to eliminate or correct for biases in positional data, precision measures may also be a useful means of representing accuracy."

Precision essentially defines the consistency of multiple measurements as those measured values cluster about a number determined by those same measurements. But when these multiple measurements include systematic errors or biases, highly precise measurements may nonetheless yield highly inaccurate results. For example, suppose benchmark A (see *) has a published value of 100.00 ft in elevation, and the difference in elevation between benchmark A and new benchmark B is measured 10 times by differential leveling. If all 10 measurements indicate that benchmark B is between 0.99 ft and 1.01 ft higher than benchmark A, it is logical to conclude that benchmark B has an elevation of 101.00 ft (and some people would say 101.00 ft ±0.01 ft). Although "±0.01 ft" may be a measure of *precision* in this example, it may be very misleading if erroneously understood to represent *accuracy*, especially if it is later determined that the elevation of benchmark A is really 98.26 ft, for example, instead of 100.00 ft. When correcting for the systematic error or bias of 1.74 ft, then the true elevation of benchmark B would be 99.26 ft instead of 101.00 ft, assuming there were no other systematic errors in the measurements.

* Note, a benchmark is a relatively permanent, natural or artificial, material object bearing a marked point whose elevation above or below an adopted vertical datum is known; a benchmark surveyed with differential leveling normally does not have surveyed geographic coordinates, latitude and longitude, as has a survey monument surveyed with GPS. A survey monument may either be a 2-D monument (latitude and longitude only) or a 3-D monument (latitude, longitude, and elevation).

Relative and Absolute Accuracy. As defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) in "Digital Elevation Model Technologies and Applications: The DEM Users Manual," page 471, *Relative accuracy* is a "measure that accounts for random errors in a data set. Relative accuracy may also be referred to as point-to-point accuracy. The general measure of relative accuracy is an evaluation of the random errors … in determining the positional orientation (e.g., distance, azimuth) of one point or feature with respect to another." In construction surveying for example, it is important for construction stakes to have good accuracy relative to the boundary markers used to define the corners of the lot on which the construction is to occur, but it may be immaterial whether or not the corner boundary markers are accurately surveyed relative to the geodetic datum so long as the boundary markers are authoritative and define legal ownership rights. Similarly, ASPRS defines *absolute accuracy* as "a measure that accounts for all systematic and random errors in a data set. Absolute accuracy is stated with respect to a defined datum or reference system." When the "reference system" is the National Spatial Reference System (NSRS), the "defined datum" is the North American Vertical Datum of 1988 (NAVD 88) for elevation surveys and the North American Datum of 1983 (NAD 83) for horizontal surveys. Both NAVD 88 and NAD 83 are geodetic datums used to control the surveying and mapping of North America. NAD 83 is based on the Geodetic Reference System of 1980 (GRS 80) ellipsoid which is nearly identical to the World Geodetic System of 1984 (WGS 84) ellipsoid used internationally in conjunction with the Global Positioning System (GPS) which is based on the WGS 84 ellipsoid and datum.

All ECs are surveyed with relative accuracy — relative to a survey monument or benchmark from which elevations are derived.

<u>Local and Network Accuracy</u>. Closely related to relative accuracy, the *local accuracy* of a control point, as defined in FGDC-STD-007.1-1998, is "a value that represents the uncertainty in the coordinates of the control point relative to the coordinates of other directly connected, adjacent control points at the 95-percent confidence level. The reported local accuracy is an approximate average of the individual local accuracy values between this control point and other observed control points used to establish the coordinates of the control point." Closely related to absolute accuracy, *network accuracy*, as defined by FGDC-STD-007.1-1998, "is a value that represents the uncertainty in the coordinates of the control point with respect to the geodetic datum at the 95-percent confidence level. For NSRS network accuracy classification, the datum is considered to be best expressed by the geodetic values at the Continuously Operating Reference Stations (CORS) supported by NGS. By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero."

Before the satellite era, geodesists were unable to establish a geocentric (center of earth) ellipsoid and datum, but current geodetic datums are geocentric because the center of the earth can be defined as that point about which satellites orbit, and GPS surveys can be referenced to the center of the earth as well as to multiple CORS stations on the earth's surface, surveyed so accurately that they are assumed to have absolute positioning errors of zero.

When using differential GPS survey procedures with survey-grade receivers, GPS surveys are normally tied directly or indirectly to CORS stations, providing both *local accuracy* and *network accuracy* of a few centimeters at the 95% confidence level. However, when using single, inexpensive mapping-grade GPS receivers, GPS surveys are not relative to any local survey monument or benchmark, and the network accuracy is on the order of 10-meters horizontally and 20-meters vertically at the 95% confidence level.

Land Surveying Standards. Traditional land surveying procedures yield *relative accuracy*, expressed in terms or *orders* and *classes* of surveys. Table B.1 shows how the various orders and classes of conventional vertical surveys have relative accuracies expressed in terms of the distance between two points, i.e., the reference benchmark and the newly surveyed point.

Table B.1 — Relative Accuracy Standards for Conventional Vertical Surveys

Vertical Survey Order	Vertical Survey Class	Relative Accuracy between directly connected points
1st	I	Standard Error = 0.5 mm $\sqrt{K}$
1st	II	Standard Error = 0.7 mm $\sqrt{K}$
2nd	I	Standard Error = 1.0 mm $\sqrt{K}$
2nd	II	Standard Error = 1.3 mm $\sqrt{K}$
3rd	N/A	Standard Error = 2.0 mm $\sqrt{K}$

where $\sqrt{K}$ is the square root of the distance K in kilometers between the two points

Table B.2 shows a similar distance-based relative accuracy standard for a survey method called *trilateration* which measures the distances of lines for horizontal positioning.

Table B.2 — Relative Accuracy Standards for Conventional Horizontal Surveys

Horizontal Survey Order	Horizontal Survey Class	Relative Accuracy between directly connected points
1st	N/A	Standard Error = 1 part in 1,000,000
2nd	I	Standard Error = 1 part in 750,000
2nd	II	Standard Error = 1 part in 450,000
3rd	I	Standard Error = 1 part in 250,000
3rd	II	Standard Error = 1 part in 150,000

Table B.3 shows a different distance-based relative accuracy standard for differential GPS surveys that measure distances to multiple satellites to compute baselines between a GPS base station and "rover," for both horizontal and vertical positioning.

Table B.3 — Relative Accuracy for GPS Horizontal Surveys

GPS Class	Local Accuracy at 95% Confidence Level
AA	0.3 cm + 1 part per 100,000,000
A	0.5 cm + 1 part per 10,000,000
B	0.8 cm + 1 part per 1,000,000
First	1.0 cm + 1 part per 100,000

When GPS surveys correctly use CORS or selected NSRS monuments as the GPS base stations for the differential surveys, then the network accuracies of the newly surveyed points can be estimated and centimeter-level accuracies can be achieved. But when only a single GPS receiver is used, errors are typically on the order of 10 meters horizontally and 20 meters vertically at the 95% confidence level.

National Map Accuracy Standards (NMAS). Whereas surveying standards have traditionally referenced *relative accuracy*, mapping standards have traditionally referenced *absolute accuracy*. The NMAS, in use since 1947, defines absolute accuracy at the 90% confidence level. Horizontally, for large-scale maps, 90% of clearly defined checkpoints must be accurate within 1/30th of an inch at the publication scale of the map; there is no real limit on the 10% of errors that may be larger than 1/30th of an inch. Vertically, 90% of checkpoints used to validate the accuracy of contour lines should be accurate within ½ the contour interval with no errors larger than the full contour interval; and 90% of checkpoints used to validate the accuracy of spot heights should be accurate within ¼ the contour interval with no spot height errors larger than ½ the contour interval. Apparent vertical errors can be offset by permissible horizontal errors; this makes it difficult to perform vertical accuracy checks.

National Standard for Spatial Data Accuracy (NSSDA). Implemented in 1998 to replace the NMAS for all digital mapping products, the NSSDA defines absolute accuracy at the 95% confidence level, compared with the NMAS' 90% standard. This equates to the FGDC's definition of *network accuracy*. The FGDC has specified: "Federal agencies collecting or producing geospatial data, either directly or indirectly (e.g., through grants, partnerships, or contracts with other entities), shall ensure, prior to obligating funds for such activities, that data will be collected in a manner that meets all relevant standards adopted through the FGDC process" and specifically mandates that the "accuracy of new or revised spatial data will be reported according to the NSSDA."

According to FGDC-STD-007.1-1998, "The reporting standard in the horizontal component is the radius of a circle of uncertainty, such that the true or theoretical location of the point falls within that circle 95-percent of the time. The reporting standard in the vertical component is a linear uncertainty value, such that the true or theoretical location of the point falls within ± of that linear uncertainty value 95-percent of the time."

The NSSDA provides root-mean-square error (RMSE) criteria for computing accuracy values at the 95% confidence level, but only when errors are known to follow a normal error distribution. However, the National Digital Elevation Program (NDEP) has determined that many forms of elevation errors do not follow a normal error distribution (bell curve) and specifies that an alternative 95th percentile method be used to establish accuracy at the 95% confidence level. The ASPRS "DEM Users Manual" defines *percentile* as follows: "As used in this manual, a percentile is any of the values in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. Any of these groups can specify a specific percentile, e.g., the 95th percentile. The 95th percentile indicates that 95% of the errors will be of equal or lesser value and 5 percent of the errors will be of larger value."

In testing the accuracy of a dataset at the 95% confidence level, the NSSDA states: "A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications."

Table B.4 compares NMAS and NSSDA vertical accuracy standards for checking contours or digital terrain models or individual points based on their equivalent contour interval. The NMAS and NSSDA standards for spot heights are half the values shown in this Table. For example, for 2 ft equivalent contours, 95% of spot heights should be accurate within 0.6 ft.

Table B.4 — Comparison of NMAS/NSSDA Standards

NMAS Equivalent Contour Interval	NMAS Vertical Accuracy Standard 90% Confidence Level	NSSDA $RMSE_z$	NSSDA Vertical Accuracy at 95% Confidence Level
1 ft	0.5 ft	0.3 ft	0.6 ft
2 ft	1.0 ft	0.6 ft	1.2 ft
5 ft	2.5 ft	1.5 ft	3.0 ft
10 ft	5 ft	3.0 ft	6.0 ft
20 ft	10 ft	6.1 ft	11.9 ft

NOAA Technical Memorandum NOS NGS-58. Normally referred to as "NGS-58," the correct title of this document is NOAA Technical Memorandum NOS NGS-58, "Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)," November, 1997. This is the "bible" for GPS elevation surveys, and NOAA contracted with Dewberry in 2002 to perform research necessary to validate the various operational procedures necessary to ensure that 2 cm *local accuracy* , 5 cm *local accuracy*, or 5 cm *network accuracy* are achieved with specified baseline lengths, observation times, satellite configurations that control vertical accuracy, and other variables. Survey procedures consistent with NGS-58 were followed for all check surveys to establish "ground truth" for this study and the evaluation of various remote sensing technologies.