Introduction

The following document provides supplemental procedures to EFH Part 650.0115 for performing accurate surveys with a Survey Grade GPS system. Minimum accuracy class standards for different survey applications are summarized below and listed in table format at the end of the document.

Survey Requirements by Job Classification

Survey for Engineering Job Class VI-VIII shall have an OPUS correction performed on the base point, or the survey shall be tied to a National Geodetic Survey benchmark. See http://www.ngs.noaa.gov/OPUS/. The minimum observation time for an OPUS solution at the base point is 4 hours. If geospatial software is available on a personal computer or controller, all survey points shall be corrected to the adjusted base position prior to the start of design work. If geospatial software is not available, the OPUS solution shall be held in reserve and used to re-establish the base point if it is damaged or removed. The OPUS solution minimizes the risk of losing survey control after substantial resources are invested in a professional or independent review.

Engineering Job Class I-V may use an autonomous (HERE command) point under the base station. Survey point locations will be relative to the initial autonomous base point. They are not reproducible if the base point and associated benchmarks are obliterated. Only ONE (HERE command) autonomous base point will be used at the start of a survey. All subsequent surveys shall be based off the metadata of the initial autonomous base point.

Grid versus Ground Coordinates for Orthographic Images and Stakeout

Data collectors can be set up to reference GRID or GROUND coordinates. GPS survey recorded as GRID coordinates on a UTM map projection will typically ensure the best fit with underlying orthographic images (photos or topo maps), USGS DEM, and LIDAR data sets.

GPS survey points should NEVER be rotated or translated to match/align with the coordinate system of underlying orthographic images. If GPS survey coordinates do not match an orthographic image, the orthographic image should be transposed to the coordinate system used in the survey. An image can be scaled, rotated, or translated as needed to match/align with survey points.

GPS survey that will be combined with USGS DEM or commercial LIDAR survey shall be recorded in the same GRID coordinate system or transposed to the same system using survey software.

A horizontal distance measured in the field with GRID coordinates will be shorter than the same horizontal distance measured in the field with GROUND coordinates (as verified with a total station, tape or chain). Since a UTM or USSP map projection is a planar or flat grid surface at sea level, it can be simply stated that lengths on the grid surface are shorter than lengths on the ground surface, particularly at high elevations over long distances (see EFH, Chapter 1, Part 650.0115, Satellite-based surveying).

Although the spatial difference between GRID and GROUND coordinates is typically small, surveyors should be aware of this spatial difference during survey, stakeout, and quantity estimation. As a rule of thumb, there is roughly 0.1 foot of horizontal difference between a GRID and GROUND coordinate per 1,000 feet in elevation per mile. [Example: A 5,280-foot pipeline staked in GRID coordinates at an average elevation of 4,500 feet would actually measure 5,280.45 feet as GROUND coordinates with a GPS, total station, tape, or chain.]

In Utah, jobs should be surveyed, designed, and staked in GRID coordinates to avoid confusion. Although GRID coordinates may introduce subtle differences in distances and material quantities, the spatial differences often cancel out in most aspects of the job.

If jobs are surveyed in GRID coordinates, but will be staked with a total station, tape, or chain, the effect of GRID versus GROUND distances should be considered. If the differential is substantial, all topo, design, and stakeout coordinates should be transposed to GROUND coordinates with survey software. A combined scale factor will be applied to the entire job to move the geodetic coordinates off the planar map projection. Metadata should reflect that survey data or stakeout coordinates are to GRID or GROUND coordinates and include the combined scale factor.

Project Control

Engineering Job Class VI-VIII shall have project control with Accuracy Class RT1 ($\geq$ 2 base points and $\geq$ 4 benchmarks).

Engineering Job Class I-V shall have project control with Accuracy Class RT2 ($\geq$ 1 base point and $\geq$ 2 benchmarks).

Project Monumentation/Benchmarks

The minimum number of benchmarks for Engineering Job Class VI-VIII surveys shall be 4. At least 2 of those benchmarks shall have a line of sight. Benchmark material shall be 18 inches long, No. 4 rebar at minimum or equivalent. Mark the center of the rebar or apply a survey cap for point accuracy.

The minimum number of benchmarks for Engineering Job Class I-V shall be 2. At least 2 of those benchmarks shall have a line of sight. Survey and construction expected to last more than 24 months shall incorporate benchmarks that consist of 18 inches long, No. 4 rebar at minimum or equivalent. Wood hubs (1” x 2” or 2” x 2”) may be used for survey and construction that will be completed within 24 months. Mark the center of the monument or apply a survey cap for point accuracy.

When setting project benchmarks, set the receiver over the proposed benchmark with a fixed tripod or bipod. Measurements shall be stored as an Observed Control Point with accuracy class criteria set in the data collector.

Note: A benchmark is not established for project or job control until it has been closed upon with a redundant observation after a minimum survey interval of 4 hours. See “Closing a Survey” section.

Project Survey Measurement Requirements

When collecting points for topographic surveys, cross sections, etc., observations shall be taken according to the Accuracy Class RT3 or RT4 and stored as a Topo Point with accuracy class criteria set in the data collector. Topo Point observations may be made without the use of a bipod.

When a Rapid Point or Continuous Topo method is used to collect survey data, the measurements shall meet Accuracy Class RT4 criteria which can be set up in the data collector.

Starting Subsequent Surveys

After initial monumentation has been established, all subsequent surveys shall be started by checking into a known benchmark that has met the accuracy class requirements. Two options may be used to perform this check. The first option is to use the Stakeout Function to locate a known benchmark. A new Topo Point measurement shall be used to determine if the changes (deltas) in Northing, Easting, and Elevation fall within the accuracy class requirements. The second option is to take a measurement on a known benchmark using a Topo Point. An Inverse calculation between the known benchmark coordinate and the Topo Point coordinate shall be recorded to ensure the position differential falls within the accuracy class requirements.

Closing A Survey

All surveys shall be closed by taking a redundant observation on the required number of benchmarks that meet the accuracy class requirements.

The redundant observation(s) shall be recorded after the receiver has been re-initialized and the height of the receiver changed by more than 1 foot (remember to change rod HI in the data collector). The change in elevation will expose potential errors in wave length measurements. To re-initialize the rover, simply invert the rover pole for a few seconds to clear satellite configuration, and then revert the pole to receive a new satellite configuration and re-start the initialization process.

Two options may be used to record a redundant measurement. The first option uses the Stakeout Function to locate a known benchmark. A new Topo Point measurement shall be used to determine if the changes (deltas) in Northing, Easting, and Elevation fall within the accuracy class requirements. The second option is to take a measurement on a known benchmark using a Topo Point. An Inverse calculation between the known benchmark coordinate and the Topo Point coordinate shall be recorded to ensure the position differential falls within the accuracy class requirements.

A minimum survey interval of 4 hours should occur between the initial benchmark establishment and the redundant observation(s) to diversify the satellite configuration. Professional judgment can be applied on Engineering Job Class I-V if a short duration survey makes it difficult to achieve a 4-hour interval.

For Accuracy Class RT1, a redundant observation is required on a minimum of two benchmark points from two different base point locations. In order to complete the survey closure, the GPS base station needs to be moved to a second base point (i.e., an established benchmark redundantly observed from the first base point).

For Accuracy Class RT2, a redundant observation is required on 2 benchmark points (with or without moving the base station).

Survey Documentation

A hard copy of point locations and the following metadata shall be kept as a minimum on all surveys:

- Name and location of project
- Survey party, weather, date
- Units of survey (International Survey Feet)
- Vertical datum (e.g., NAVD 88)
- Reference ellipsoid (e.g., WGS 84)
- Coordinate system (e.g., UTM 11, 12, or 13)
- Geoid model (e.g., Geoid 12)
- GRID or GROUND coordinates with the combined scale factor.

An electronic copy of the Job File (a complete accounting of the GPS survey) shall be downloaded to an electronic job folder for Engineering Job Class VI-VIII. The Job File shall be maintained electronically for a period of 3 years beyond the life of the program contract. For perpetual easements, the Job File shall be maintained electronically for a period of 10 years after construction.

Survey with Multiple Rovers

If more than one GPS rover is used and the base point location is known, ensure that all data collectors have the same metadata for the base point. NEVER use the (HERE) command to start subsequent rovers. All rovers shall check into known benchmarks within the accuracy class requirements.

Site Calibration

A site calibration calculates parameters for transforming WGS-84 coordinates into local grid coordinates (N, E, E). It either calculates a horizontal and vertical adjustment or a transverse Mercator projection with a 3parameter datum transformation, depending on what has already been defined.

For accurate calibration, the site should be inside the survey envelope and have at least 4 control points with known 3-D grid coordinates.

For Accuracy Classes RT1─if a calibration has been performed, the base station must be inside the calibration envelope and must be tied to the nearest calibration control monument by a maximum horizontal tolerance of 0.033 ft^2 (1 cm) + 1 ppm (times the distance to nearest control monument) and a vertical tolerance of 0.066 ft^2 (2 cm) + 1 ppm (times the distance to nearest control monument).

For Accuracy Classes RT2─if a calibration has been performed, the base station must be inside the calibration envelope and must be tied to the nearest calibration control monument by a maximum horizontal tolerance of 0.066 ft^2 (2 cm) + 1 ppm (times the distance to nearest control monument) and vertical tolerance of 0.098 ft^2 (3 cm) + 1 ppm (times the distance to nearest control monument).

For Accuracy Classes RT3 and RT4─if a calibration has been performed, the base station must be inside the calibration envelope and should be tied to the nearest calibration control monument at the accuracy level of the survey.

Accuracy Classes Rationale

Listed below are data collection parameters to achieve various accuracies with a strong amount of confidence (95 percent level). The term “accuracy” in this case, actually refers to the precision from a base station correctly set over a monument held as truth. The accuracy of the rover positions will be less than the accuracy of the base station’s alignment to the user’s datum. These accuracies have been developed from years of best practices from the experiences of many RT users and are also reflected in some existing guidelines.

Class RT1 Precisions: typically **0.033-0.066 ft^2** (0.01-0.02 m) horizontal, **0.066-0.131 ft^2** (0.02-0.04 m) vertical (two sigma or 95 percent confidence), two or more redundant observations on the same point with a staggered time interval of 4 hours from different bases adjusted in the project control. Each RT location differs from the average no more than the accuracy requirement. Discard outliers and re-observe if necessary. Base stations should use fixed height tripods. Baselines ≤ 10 km (6 miles). Data collected at a 1-second interval for 3 minutes (180 epochs), PDOP ≤ 2.0, ≥ 7 satellites. No multi-path conditions observed.

Rover range pole must be firmly set and leveled with a shaded bubble before taking data. Use fixed height Rover pole with bipod or tripod for stability.

Class RT2 Precisions: typically **0.066-0.131 ft^2** (0.02-0.04 m) horizontal, **0.098-0.164 ft^2** (0.03-0.05 m) vertical (two sigma or 95 percent confidence), two or more redundant observations on the same point staggered at a 4hour interval, two different base locations recommended (not required), bases are within the project envelope, each location differs from the average no more than the accuracy requirement. Discard outliers and re-observe if necessary. Base stations should use fixed height tripods. Baselines ≤ 15 km (9 miles). Data collected at a 1-second interval for one minute (60 epochs). PDOP ≤ 3.0, ≥ 6 satellites. No multipath conditions observed. Rover range pole must be level before taking data. Use fixed height Rover pole with bipod or tripod for stability.

Class RT3 Precisions: typically **0.131-0.197 ft^2** (0.04-0.06 m) horizontal, **0.131-0.262 ft^2** (0.04-0.08 m) vertical (two sigma or 95 percent confidence). Redundant locations not necessary for typical locations, important vertical features such as pipe inverts, structure inverts, bridge abutments, etc., but RT horizontal locations are acceptable. Baselines ≤ 20 km (12 miles). Data collected at a 3 measurements for 5 seconds with a steady pole. PDOP ≤ 4.0, ≥ 5 satellites. Minimal multi-path conditions. OK to use Rover pole without bipod, try to keep pole steady and level during the location.

Class RT4 Precisions: typically **0.328-0.656 ft^2** (0.1-0.2 m) horizontal, **0.328-0.984 ft^2 (**0.1-0.3 m) vertical (two sigma or 95 percent confidence). Redundant locations not necessary for typical locations. Any baseline length okay as long as the solution is fixed. Data collected at a 1-measurement for 1 second (1 epochs, PDOP ≤ 6.0, ≥ 5 satellites, any environmental conditions for data collection are acceptable with the previous conditions met.

Chapter 1 - Surveying (Survey Grade GPS)

ACCURACY CLASS SUMMARY TABLE (minimum requirements)				
	CLASS RT1	**CLASS RT2**	**CLASS RT3**	**CLASS RT4**
MINIMUM PRECISION	0.033 sft, Horizontal 0.066 sft, Vertical	0.066 sft, Horizontal 0.098 sft, Vertical	0.098 sft, Horizontal 0.131 sft, Vertical	0.164 sft, Horizontal 0.260 sft, Vertical
REDUNDANCY	≥ 2 Locations, 4-hour differential	≥ 2 Locations, 4-hour differential	NONE	NONE
BASE STATIONS	≥ 2, for Redundant Point Observation in Project Control Area	Recommend 2, for Redundant Point Observation in Project Control Area	≥ 1, in Project Control Area	≥ 1, in Project Control Area
PDOP	≤ 2.0	≤ 3.0	≤ 4.0	≤ 6.0
COLLECTION INTERVAL	1 second for 3 minutes	1 second for 1 minute	3 measurements for 5 seconds*	1 measurement for 1 second
SATELLITES	≥ 7	≥ 6	≥ 5	≥ 5
BASELINE DISTANCE	≤ 10 km (6 mi)	≤ 15 km (9mi)	≤ 20 km (12 mi)	Any with Fixed Solution
TYPICAL APPLICATIONS	Watershed Project Control Engineering Job Class VI-VIII Survey collaboration with external partners High hazard or significant property improvements Perpetual easements	Job Control Engineering Job Class I-V	Job Stakeout As-Builts Cross Sections Land Leveling Site Grading Canals and Ditches Canal Lining Critical points for structures or along pipeline routes	Continuous Topo Pipeline Routes Feedlots General Mapping Storage pools for reservoirs, ponds, wetland basins

*Advanced instruments may reach the desired precisions with less epochs.

Leave this page blank.

Introduction

Field tests with the Differential (beacon signal or satellite based) Global Positioning System (DGPS) have demonstrated an acceptable level of accuracy under certain conditions. In Utah, both the Garmin backpack units and the ProXYZ handheld units meet the DGPS requirement. Supervisors shall ensure employees have sufficient training and competency to use the DGPS system in collecting waypoints, measuring lengths, and measuring areas before using equipment for planning, design, practice certification, and quality assurance activities.

a. When collecting waypoints, it is recommended to use point averaging for a minimum of one minute to increase the accuracy of measurement.

b. GPS without differential correction is most often used in practice planning. It should not be used for design, layout, construction, practice (quantity) certification, or quality assurance activities. Measurements are inconsistent and the accuracy level can exceed 12 feet.

c. GPS with differential correction can be used conditionally for measurement of areas or lengths required for planning, practice certification, and quality assurance activities. It also can be used conditionally in practice design. See item (d).
Area Measurements. DGPS can be used to measure areas on slopes less than 15% provided the accuracy level calculated by the DGPS unit is 1 meter (3 feet) or less.

   Length Measurements. DGPS can be used to measure lengths on slopes less than 15% provided the accuracy level calculated by the DGPS unit is 1 meter (3 feet) or less.

   DGPS should not be used when the total length of the measured practice is less than 250 feet. Use another method.

   If slopes exceed 15% for a portion of the measurement, those length segments should be measured by another method or adjusted by using an appropriate slope adjustment factor as shown below (see example).

Slope Adjustment Factor = $\sqrt{(\frac{\%slope}{100})^2 + 1}$

% Slope	Slope Adjustment Factor
15	1.011
16	1.013
17	1.014
18	1.016
19	1.018
20	1.02
21	1.022
22	1.024
23	1.026
24	1.028
25	1.031
26	1.033
27	1.036
28	1.038
29	1.041
30	1.044
35	1.059
40	1.077
45	1.097
50	1.118

Example:

Pipeline planned downhill

Start of Pipeline = Elevation 8,000 Feet

End of Pipeline = Elevation 7,500 Feet

Distance measured with DGPS = 2,000 Feet

% Slope = $\frac{8{,}000-7{,}500}{2{,}000}(100)$ = 25%

Slope Adjustment Factor = 1.031

Actual Length of Pipeline = 2,000 x 1.031
= 2,062 Feet

d. DGPS can be used for vertical measurements provided the accuracy level calculated by the DGPS unit is 2 meters (6 feet) or less. For practices where a vertical error of twice the horizontal error (2 x 3 feet = 6 feet) is acceptable, the observed elevations may be used if appropriate steps are taken in the design process. For example, DGPS elevations may be used for the design of a livestock pipeline that would normally be designed from a topographic map, as long as the minimum pressure requirements at all locations can tolerate an error in static head of 6 feet.

e. Metadata for DGPS survey should be documented.

- Name and location of project
- Survey party, weather, date
- Units of survey (meters)
- Vertical datum (e.g., NAVD 88)
- Reference ellipsoid (e.g., WGS 84)
- Coordinate system (e.g., UTM 11, 12, or 13).

f. All area and length measurements obtained with DGPS should be downloaded using DNRGarmin, ArcPad, or other suitable software. Hard copies of the downloaded data should be placed in the administrative file along with the metadata, or an electronic version shall be kept in the customer file folder in Toolkit.