Chapter 5 – SURVEYING AND MAPPING

TABLE OF CONTENTS

5.1 GENERAL 5-1
- 5.1.1 Surveying and Mapping Functions and Programs 5-1
- 5.1.2 Authority and Administration 5-2
- 5.1.3 Safety 5-2

5.2 GUIDANCE AND REFERENCES 5-4

5.3 SURVEY PLANNING 5-6
- 5.3.1 Survey Datum 5-6
  - 5.3.1.1 Horizontal Datum 5-6
  - 5.3.1.2 Vertical Datum 5-8
  - 5.3.1.3 Coordinate Projections 5-8
  - 5.3.1.4 Coordinate System Scale Factors 5-9
- 5.3.2 Survey Standards 5-11
  - 5.3.2.1 Accuracy and Precision 5-11
  - 5.3.2.2 Errors 5-12
  - 5.3.2.3 Control Survey Accuracy Classifications 5-13
  - 5.3.2.4 Mapping Accuracy Classification 5-14
  - 5.3.2.5 Units of Measurement 5-15
  - 5.3.2.6 Monumentation Standards 5-17

5.4 FIELD DATA COLLECTION AND PROCESSING 5-18
- 5.4.1 Control Surveys 5-18
  - 5.4.1.1 Horizontal and Vertical Control 5-18
  - 5.4.1.2 GPS- Derived Orthometric Heights 5-19
  - 5.4.1.3 Terrestrial Surveys 5-19
  - 5.4.1.4 Global Positioning System (GPS) 5-20
  - 5.4.1.5 Network Adjustments 5-22
- 5.4.2 Topographic Surveys - Aerial 5-22
  - 5.4.2.1 Flight Planning 5-23
  - 5.4.2.2 Ground Control 5-24
  - 5.4.2.3 LiDAR Mapping 5-24
- 5.4.3 Photogrammetry 5-27
  - 5.4.3.1 Photogrammetric Processes 5-27
  - 5.4.3.2 Aerial Photography 5-28
  - 5.4.3.3 Aerotriangulation 5-29
  - 5.4.3.4 Digital Terrain Compilation 5-30
- 5.4.4 Topographic Surveys - Terrestrial 5-31
  - 5.4.4.1 Terrain Surface Depiction 5-31
  - 5.4.4.2 Feature Location and Attributes 5-32
  - 5.4.4.3 Floodplain Mapping 5-32
  - 5.4.4.4 Bridge Site and Tributary Surveys 5-33
  - 5.4.4.5 Subsurface Utility Location 5-33
  - 5.4.4.6 Railroad-Highway Grade Crossings 5-34
  - 5.4.4.7 Data Processing/Map Compilation 5-34
- 5.4.5 Right-of-Way and Cadastral Surveys 5-35
  - 5.4.5.1 Records Research 5-35

TABLE OF CONTENTS (Continued)

5.4.5.2 Monument Recovery and Survey....................................5-36
5.4.5.3 Right-of-Way Survey Field Notes....................................5-36
5.4.5.4 Boundary Mapping and Data Compilation 5-37
5.4.5.5 Compile Title Search and Field Survey Data 5-37

5.5 FINAL DESIGN SURVEYS 5-38

5.5.1 Reference Hub Staking 5-38
5.5.2 Pavement and Bridge Grid Grades 5-39

5.6 RECORDS AND REPORTS 5-40

5.6.1 Purpose 5-40
5.6.2 Metadata Standards 5-40
5.6.3 Elements of Survey Field Notes 5-41

LIST OF EXHIBITS

Exhibit 5.1–A PROJECT DEVELOPMENT ELEMENTS 5-1

Exhibit 5.1–B FLH SURVEYING AND MAPPING FUNCTIONS 5-3

Exhibit 5.3–A GRID AND GROUND DISTANCES 5-7

Exhibit 5.3–B COMMON COORDINATE PROJECT SURFACES 5-10

Exhibit 5.3–C CONTROL SURVEY ACCURACY STANDARDS......................................5-13

Exhibit 5.3–D RECOMMENDED SCALES, CONTOUR INTERVALS AND ASSOCIATED POSITIONAL TOLERANCES FOR FLH MAPPING PROJECTS 5-16

Exhibit 5.4–A DERIVED ORTHOMETRIC HEIGHTS...5-19

Exhibit 5.4–B LiDAR SYSTEM COMPONENTS..5-25

This page intentionally left blank.

CHAPTER 5

SURVEYING AND MAPPING

5.1 GENERAL

This chapter provides policies, standards and criteria for surveying and mapping of Federal Lands Highway (FLH) projects. It is applicable to new or reconstructed highways, as well as Resurfacing, Restoration and Rehabilitation (RRR) improvements. It is written for surveyors, engineers, consultants and managers responsible for requesting and/or completing surveying and mapping activities. It also provides:

- FLH-specific guidelines, methods and practices to support development of quality surveying and mapping information; and
- Background and reference material containing necessary context and relevance for FLH work, including specific information concerning techniques, theory and specifications.

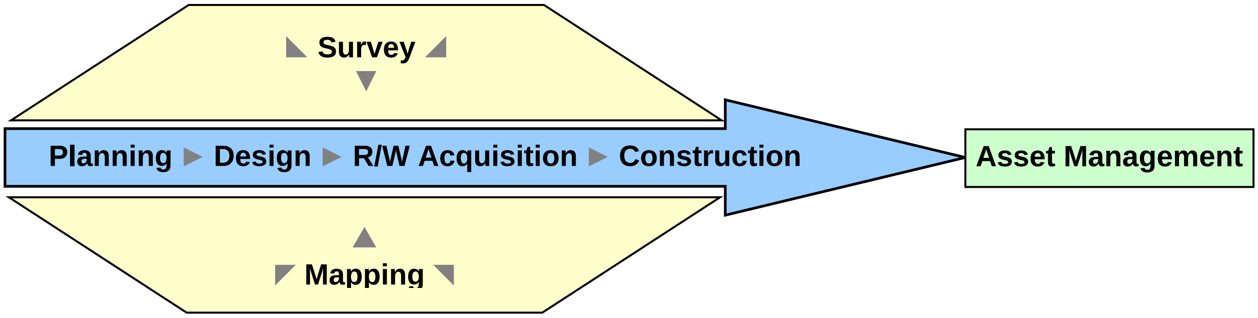
Refer to Section 1.1.1 for purpose and definitions of policy, standards, and guidance. Statements of FLH policy are shown in bold type. Statements regarding FLH Standard Practice are so indicated.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

5.1.1 SURVEYING AND MAPPING FUNCTIONS AND PROGRAMS

Surveying and mapping is fundamental to all civil engineering and roadway design work. It is a vital function linking the interdisciplinary elements of a project from planning through design, right-of-way acquisition and construction, to final asset management. Exhibit 5.1–A presents a graphic representation of the elements of project development and their interrelationships.

Exhibit 5.1–A PROJECT DEVELOPMENT ELEMENTS



Surveying and mapping connects the real world of site conditions, terrain and improvements to the virtual world of design concepts and calculations depicted in the CADD environment. To the implementation of designs in construction, surveying and mapping reverses that connection, taking the critical elements of design from CADD and accurately placing them in the context of the real world. Land surveying and right-of-way, a specialized aspect of surveying and mapping, considers the legal interpretation of evidence related to land boundaries and real property rights, to provide a comprehensive description of the physical and legal constraints to project development. Guidelines for activities specific to right-of-way acquisition documents are described in Chapter 12.

Exhibit 5.1–B lists typical surveying and mapping functions applicable to FLH projects.

5.1.2 AUTHORITY AND ADMINISTRATION

Surveying and mapping functions proceed under the authority and administration of the Division Offices of the FLH. Refer to Chapter 1 for the legislative authority as well as general policies, project development philosophy, and risk assessment.

Surveying and mapping is a professional-level practice that is generally governed by professional practice laws and regulations in each State. While Federal land surveying activities maybe exempted from some areas of land surveying by specific language in each State's legislation, these laws provide unique insight into local practices and customs.

5.1.3 SAFETY

The purpose of this section is to:

- Reinforce the importance of a safe work environment to the mission of FLH, and
- Provide guidelines to assist personnel, consultants and contractors to conduct their work in a safe and healthful manner.

Chapter 8 provides guidance for evaluating and developing highway safety alternatives for incorporation into roadway and structural designs.

Appendix 5A.1 contains a "Code of Safe Surveying Practices", outlining issues of particular concern to survey operations. Field surveyors, engineers and consultants must be familiar with these issues and take precautions to ensure that all work is conducted in a safe and healthful manner.

Exhibit 5.1–B FLH SURVEYING AND MAPPING FUNCTIONS

Function	Description	Activities
Geodetic Control	Obtaining horizontal and vertical measurements and analysis necessary to relate projects to defined local and national datum. Geodetic Control is a Federal requirement of Circular A-16.	• Global Positioning System (GPS) control • Precise Leveling • Least Squares Adjustment • Research and Recovery • Datum Modeling
Project Control	Obtaining existing and new monuments and data (measurements, computations, coordinates and elevations) needed to support project activities throughout planning design and construction.	• Monument Construction • Horizontal and Vertical Traverse • Real-Time GPS • Boundary Ties • Photogrammetric Ground Control
Deformation Monitoring	Monitoring for landslides, slopes, and constructed works, horizontal and/or vertical movement over time.	• Repeated Horizontal and Vertical Measurements • Continuous GPS • LiDAR and IFSAR or INSAR
Mapping	Depicting the configuration or relief of the earth’s surface (terrain), and the location of natural and artificial objects. Includes development of imagery and remote sensing data for enhanced understanding of existing site conditions.	• Aerial Photogrammetry • Airborne and Ground-Based LiDAR • Field Topography • Contour Mapping • Cross Sections • Subsurface Utility Investigation • Cultural Features • Hydrographic and bathymetric mapping
Boundary / Right-of-way	Determining property boundaries and real property rights that define the limitation of land title interests within a project. Includes developing maps and reports necessary for appraisal and acquisition of various real property rights.	• Land Title Investigation • Cadastral Surveys • Right-of-way Engineering • Appraisal Maps • Legal Descriptions
Construction	Locating and establishing ground-based alignment and grade of construction designs.	• Alignment Staking • Slope Staking • Improvements/Utility Staking • Quantity Surveys • As-Constructed Plans
Information Management	Preparing field notes and reports. Extracting and formatting design and staking data. Includes data analysis for continuity and accuracy, development of thematic maps, CADD files, and Geographic Information Systems.	• Records Research • File Formatting/Transfer • Database Design • Report Writing • Cartography

5.2 GUIDANCE AND REFERENCES

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. This list is not all-inclusive and there are numerous manuals, technical documents and journals that explain the techniques and formulas required to perform proper and accurate surveying and mapping. The user is assumed knowledgeable of basic procedures and current technology, or will consult the references for such purposes.

A glossary, including abbreviations and definitions, is described in Section 1.4. For detailed definitions on specific subjects, consult the glossaries in the references listed.

Reference should be made to State Department of Transportation Manuals for additional guidance applicable to individual projects.

1.	Definitions of Surveying	*Definitions of Surveying and Associated and Associated Terms*, American Congress on Surveying and Mapping, 1978, Reprinted 1999.
2.	Standard Handbook for Civil Engineers	*Standard Handbook for Civil Engineers*, 5th Edition, Ricketts, Loftin & Merritt, McGraw Hill Professional, 2003.
3.	CE Reference Manual	*Civil Engineering Reference Manual for the PE Exam*, 9th Edition, M.R. Lindeburg, Professional Publications, 2003
4.	Surveying	*Surveying*, 10th Edition, F.H. Moffitt, & J.D. Bossler, Harpercollins College Div, 1997.
5.	Adjustment Computations	*Adjustment Computations*, 3rd Edition, P.R. Wolf & C.D. Ghilani, Wiley-Interscience, 1997.
6.	GPS for Land Surveyors	*GPS for Land Surveyors*, 2nd Edition, Van Sickle, Jan, CRC Press, 2001.
7.	Tech Bulletin No. 6	*Manual of Surveying Instructions*, Technical Bulletin No. 6., Department of the Interior, Bureau of Land Management, 1973.
8.	Lost or Obliterated Corners	*Restoration of Lost or Obliterated Corners and Subdivision of Sections*, Department of the Interior, Bureau of Land Management. 1974.
9.	Glossary of BLM Surveying	*Glossary of BLM Surveying and Mapping Terms*, Department of the Interior, Bureau of Land Management, 1980.
10.	Boundary Location	*Evidence and Procedure for Boundary Location*, 4th Edition, W.G. Robillard & D.A. Wilson, Wiley, 2001.
11.	Boundary Control	*Brown's Boundary Control and Legal Principles*, 5th Edition, C.M. Brown, D.A. Wilson & W.G. Robillard, Wiley, 2003.

12.	Elements of Photogrammetry	*Elements of Photogrammetry*, 3rd Edition, P.R. Wolf, McGraw Hill Science/Engineering/Math, 2000.
13.	Accuracy Standards for Large-Scale Maps	*ASPRS Accuracy Standards for Large-Scale Maps*, American Society of Photogrammetry and Remote Sensing (ASPRS), 1990.
14.	FGDC-STD-007.2-1998	Geospatial Positioning Accuracy Standard, Part 2, *Geodetic Control Networks*, Federal Geographic Data Committee, FGDC-STD-007.2-1998.
15.	NSSDA	Geospatial Positioning Accuracy Standard, Part 3, *National Standard for Spatial Data Accuracy* (NSSDA), Federal Geographic Data Committee, FGDC-STD-007.3-1998
16.	FGDC-STD-001-1998	*Content Standard for Digital Geospatial Metadata* (version 2.0), Federal Geographic Data Committee, FGDC-STD-001-1998.
17.	Vertical Accuracy Reporting for LiDAR Data	ASPRS Guidelines: Vertical Accuracy Reporting for LiDAR Data, 2004.
18.	NOS NGS-05	*National Geodetic Survey NOAA Technical Memorandum NOS NGS-05*, State Plane Coordinate System of 1983, January 1989, Reprinted with minor corrections March 1990.
19.	NOS NGS-58	National Geodetic Survey NOAA Technical Memorandum NOS NGS-58, *Guidelines for Establishing GPS-derived Ellipsoidal Heights (Standards: 2 cm and 5 cm)*, Version 4.3.
20.	Circular A-16	*Office of Management and Budget Circular A-16*, Revised August 19, 2002.

5.3 SURVEY PLANNING

5.3.1 SURVEY DATUM

Multi-disciplined, partner agency project delivery efforts require the use of a common, accurate horizontal and vertical survey datum as the basis for planning design and construction. This ensures all project elements (e.g., base topographic mapping, rights-of-way, special studies, designs, and locations of fixed works) can be related throughout project development and delivery phases. Increased use of Geographic Information Systems (GIS) for the efficient sharing of both engineering and surveying data within FLH and with agency partners makes the use of a universally accepted and understood horizontal and vertical reference system even more important. The importance of a common reference frame is recognized by Circular A-16 wherein lead Federal agencies are required to implement and contribute to the National Spatial Data Infrastructure (NSDI).

As applicable, and as specifically detailed in the project plan, cooperate with the National Geodetic Survey (NGS) and others to monitor, maintain and enhance the NSDI and its geodetic survey element, the National Spatial Reference System by:

- Establishing new geodetic reference marks in accordance with NGS policies and procedures,
- Reporting on the condition of local geodetic control,
- Participating in geodetic survey observation campaigns, and
- Developing methodologies and advanced technologies to promote implementation of the NSDI.

5.3.1.1 Horizontal Datum

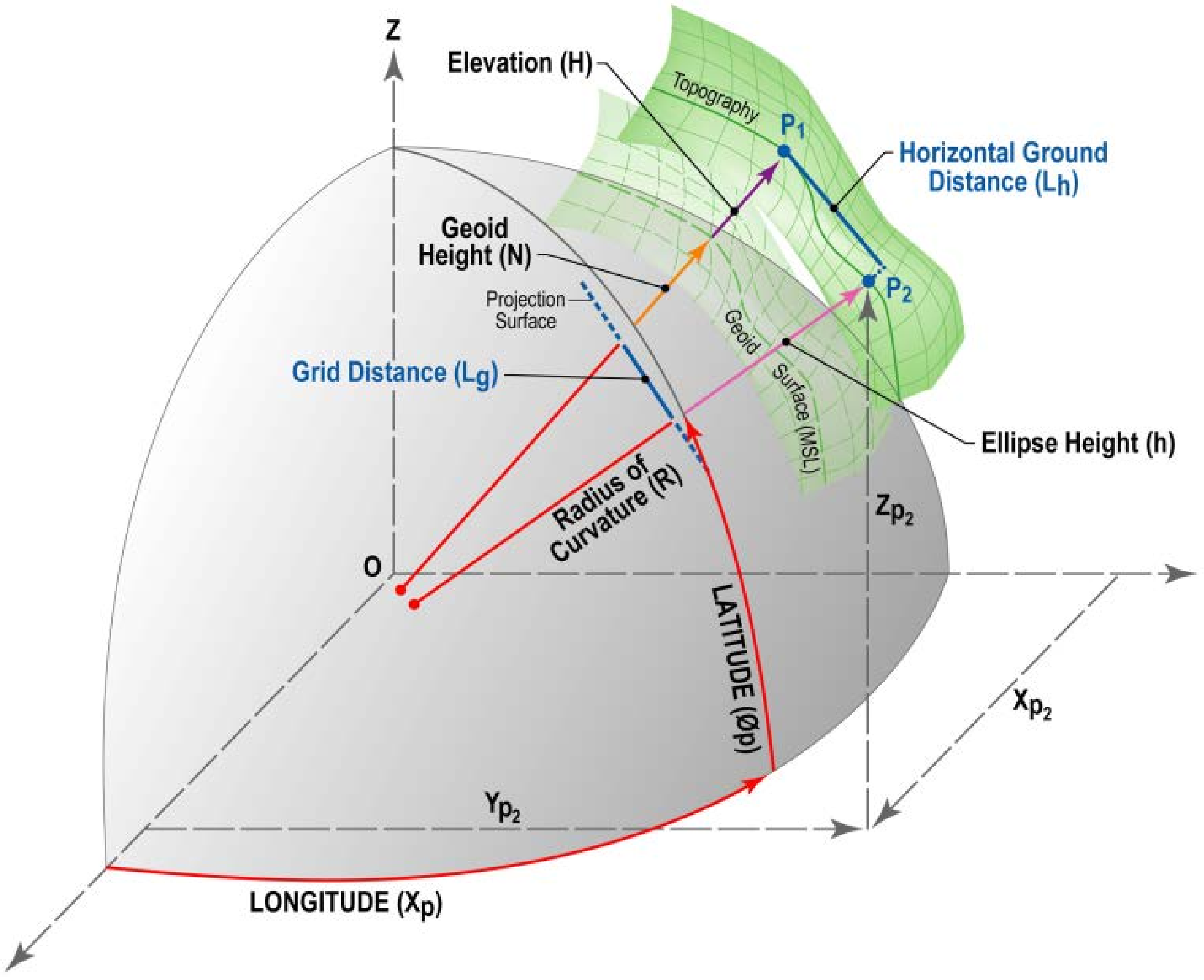
All surveying and mapping work, planning, studies and engineering designs must be based upon a common well-understood horizontal datum. **Unless unique circumstances prescribe use of an alternate reference system, the horizontal datum standard for all mapping, planning, design, right-of-way and construction on FLH projects shall be the North American Datum of 1983 (NAD83) as defined by the National Geodetic Survey (NGS).** Use of the most current realization of NAD83, from High Accuracy Reference Networks (HARN), Continuous Operating Reference Stations (CORS) or both is encouraged. Use of the *NGS Online Positioning User Service (OPUS)* is a convenient and efficient method of establishing the required horizontal control datum Project coordinates (northings and eastings) for mapping and design shall be expressed in terms of the State plane coordinate system zone in which the project exists. Definition of the State plane coordinate projections can be found in *NGS publication* NOS NGS-05.

State Plane Coordinates (SPC) are geodetic coordinates projected onto a geometric surface using a defined set of mathematical parameters and computations. Each geometric surface and the parameters defining the SPC zones are made to coincide with the NAD83 reference ellipsoid, the Geodetic Reference System of 1980 (GRS80), meaning the SPC reference surface will rarely be identical to the ground surface. Use the standard formula, contained in NGS publication *NOS NGS-05* and written into most modern surveying and mapping software, to compute the:

- Grid scale factor, variable due to location within the particular SPC zone;
- Height scale factor, dependent upon the distance above or below the SPC reference surface; and
- Combined factor, which is the product of the two.

The combined factor is the ratio of a distance measured on the grid surface to the same distance measured on the ground. Graphically and algebraically, the relationship is shown in the Exhibit 5.3–A.

Exhibit 5.3–A GRID AND GROUND DISTANCES



Differences between grid and ground distances should rarely exceed 1:10,000 at elevations near sea level. At this level, only the most exacting design elements (e.g., manufactured bridge structural members) will need to consider the variation between grid and ground distances. When, in unique situations, it is not practical to obtain State Plane Coordinates, the local ground coordinate system shall be constructed in such a way that it can never be confused with the typical number values found in the SPC zone.

5.3.1.2 Vertical Datum

All engineering work (e.g., mapping, planning, design, right-of-way engineering, and construction) for each transportation improvement project shall be based on a common vertical datum.

The vertical datum for all mapping, planning, design, right-of-way engineering and construction on transportation improvement projects, shall be the North American Vertical Datum of 1988 (NAVD88), as defined by the National Geodetic Survey (NGS). Exceptions to this policy, as determined by the Division Survey Manager in consultation with the Project Manager, are permitted for:

- Projects of small size and scope;
- Projects in remote, isolated locations;
- Maintenance, traffic safety and rehabilitation projects controlled by existing fixed works;
- Projects for which establishment of NAVD88 vertical control is cost prohibitive;
- Expedited projects for which establishment of NAVD88 vertical control is not feasible;
- Projects contiguous to the National Geodetic Vertical Datum of 1929 (NGVD29), which States that uniformity is desirable; and
- Projects in the immediate vicinity of harbors and wharfs, where tidal datum control the mapping and fixed works

Generally, the only acceptable alternate datum is NGVD29. For project locations where published NAVD88 data is not locally available, GPS survey methods using the latest approved geoid model should be considered. Assumed datum should only be considered as a last resort.

5.3.1.3 Coordinate Projections

Because geodetic surveying calculations are complex and most surveying projects are limited scope, surveyors generally prefer plane surveying to geodetic surveying methods. For local projects, plane surveying yields accurate results, but for large surveying networks, local plane surveying systems are inaccurate over large areas and cannot be easily related to other local systems.

In response to the needs of local surveyors for an accurate plane-surveying datum useful over relatively large areas, the US Coast and Geodetic Survey (the predecessor of NGS) developed the State Plane Coordinate System. The State Plane Coordinate System was established to provide a means for transferring the geodetic positions of monumented points to plane coordinates that would permit the use of these monuments in plane surveying over relatively large areas without introducing significant error.

A plane-rectangular coordinate system is by definition a flat surface. Geodetic positions on the curved surface of the earth must be “projected to their corresponding plane coordinate positions. Projecting the curved surface onto a plane requires some form of deformation. Imagine the stretching and tearing necessary to flatten a piece of orange peel.

The following provides brief descriptions of the three most common geometric surfaces used to develop coordinate projections:

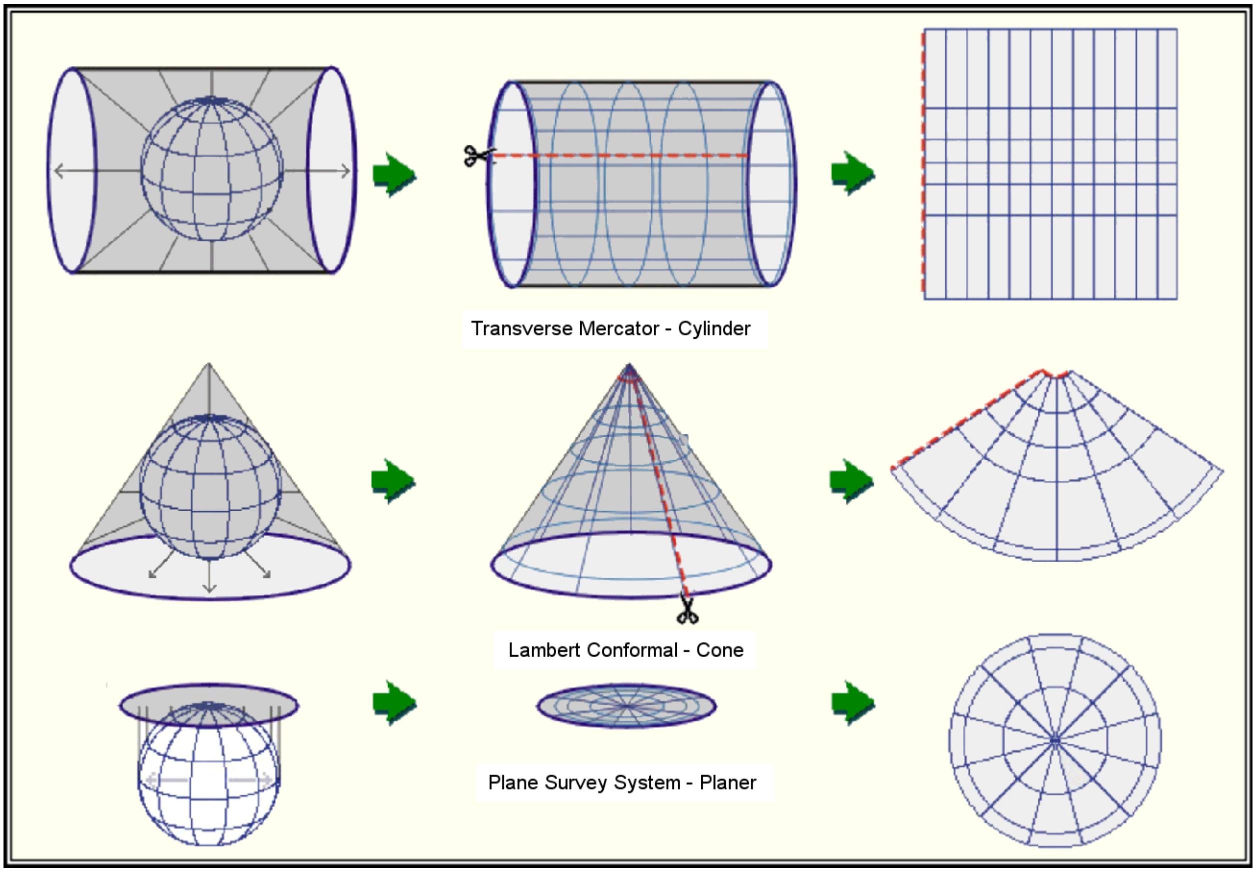
1. **Transverse Mercator.** In the Mercator projection, a cylinder intersects the ellipsoid to develop the projection surface. The cylinder is most often rotated 90 degrees so the axis of the cylinder is perpendicular to the axis of rotation of the datum surface, hence becoming a “transverse” Mercator projection. Occasionally, the cylinder is rotated into a predefined azimuth, creating an “oblique” Mercator projection. Conceptually, this is how one SPCS zone in Alaska was designed.
2. **Lambert Conformal.** The Lambert Conformal projection is illustrated by a cone that intersects the ellipsoid along two parallels of latitude. These latitudes are known as the standard parallels for the projection. Distances lying along the standard parallels are the same on both the ellipsoid and the cone. Between the standard parallels, distances projected from the ellipsoid to the conic surface become smaller. Outside the standard parallels, distances projected from the ellipsoid to the conic surface become larger. Scale factors are used to reduce and increase distances when converting between the projected surface and the ellipsoid surface. The scale factor is exactly one (1.000000) on the standard parallels, greater than one (>1.000000) outside them and less than one (<1.000000) between them. The Lambert Conformal projection provides the closest approximation to the geodetic datum surface for rectangular zones greatest in an east-west direction.
3. **Secant Cylinder.** The secant cylinder is defined by specifying the central meridian, plus the desired grid scale factor on the central meridian. The ellipses of intersection are standard lines. Their location is a function of the selected central meridian grid scale factor. The specification of the latitude-longitude of the grid origin and the linear grid values assigned to that origin are all that remain to uniquely define a zone of either the Lambert or transverse Mercator projection.

Exhibit 5.3–B provides a graphic illustration of the three most common geometric surfaces.

5.3.1.4 Coordinate System Scale Factors

The limits of each projection are generally chosen so that grid scale factors will be less than 1.00010 and greater than 0.99990 so that even if scale factors are disregarded discrepancies between ground measurements at sea level and distances on the grid will be within 1:10,000.

Exhibit 5.3–B COMMON COORDINATE PROJECT SURFACES



Distances measured on the surface of the Earth must be scaled to corresponding length on the ellipsoid. This ellipsoidal or elevation factor (generically referred to as the “height scale” factor) varies with the elevation at which the distance is measured. As the elevation of the measured line increases, the distance (radius) from the surface of the earth to its center increases, which correspondingly increases the length of the measured line. Thus, distances must be reduced in proportion to the change in radius between the ellipsoid and the radius of the Earth’s surface where the measurement is made. For example, a 3280.00 ft [1000.000 m] distance measured on the ground at an approximate elevation of 10,000.00 ft [3000.000 m], will project to an approximate distance on the projection surface of 3,279.30 ft [999.520 m]. This is a change between measured and projected of 480 ppm or 1:2083.

Normally, the height scale factor (in NAD27, it is called the sea level factor) and the grid scale factor are combined by multiplication into a combined factor. Distances measured on the earth’s surface are converted to grid distances by multiplying by the combined factor. Grid distances are converted to ground distances by dividing the grid distance by the combined factor.

As applicable for each project, determine the appropriate combined factor and document it for use in design and construction, including the basis for coordinate projection and method for project measurements and layout.

5.3.2 SURVEY STANDARDS

This section provides accuracy standards for project control, engineering drawings, maps and surveys used to support FLH transportation systems and related projects. This standard defines accuracy criteria, accuracy testing methodology and accuracy reporting criteria for features depicted on spatial data products and related control surveys. Using the standards and guidance contained in this section, end users of survey and mapping products (e.g., planners, designers, constructors) can specify surveying and mapping accuracy requirements needed for their projects or specific CADD/GIS layers, levels or entities. From these specifications, data producers (e.g., surveyors, cartographers, photogrammetrists) can determine the instrumentation, procedures and quality control processes required to obtain and verify the defined accuracies.

The value of any geographic data set depends on its fitness for a particular purpose. A critical measure of that fitness is data quality. When used in design and analysis, a data set's quality significantly affects confidence in the results. Unknown data quality leads to tentative decisions, increased liability and lost productivity. Decisions based on known data quality are made with greater confidence and are more easily explained and defended. Federal standards that assist in documenting and transferring data sets emphasize five important components of data quality:

1. **Positional Accuracy**. How closely the coordinate descriptions of features compare to their actual location.
2. **Attribute Accuracy**. How thoroughly and correctly the features in the data set are described.
3. **Logical Consistency**. The extent to which geometric problems and drafting inconsistencies exist within the data set.
4. **Completeness**. The decisions that determine what are contained in the data set.
5. **Lineage**. What sources are used to construct the data set and what steps are taken to process the data?

Considered together, these characteristics indicate the overall quality of a geographic database or map. The information contained in the section focuses on the first characteristic, positional accuracy.

5.3.2.1 Accuracy and Precision

Two terms common to surveying are accuracy and precision. They are commonly used without a true distinction between them. The National Geodetic Survey defines them as:

1. **Accuracy**. The degree of conformity with a standard.
2. **Precision**. The degree of refinement in the performance of an operation or in the statement of a result.

Accuracy relates to the degree of perfection obtained, and is a function of the quality of the result and the quality of the operation used to obtain the result. Accuracy is a function of precise methods, precise instruments, precise procedures, and most of all, good planning. While precise instruments are not a necessity, the use of less precise instruments may require increased time spent at a station and require more observations to achieve accurate results. Good planning and a reconnaissance trip will save many man-hours later.

Precision relates to the degree of perfection used (technique) and is a function of proper instrumentation (tools), procedures (methods), and observations. Accuracy is the degree of perfection obtained (results). Actual results must be used to compute accuracy. When the results do not compare favorably with the estimated results, it should be assumed that errors exist which should be corrected.

The accuracy of a field survey depends directly upon its precision. Although by chance (for example, compensating error) surveys with high order accuracies might be attained without high order precision, such accuracies are not valid. Therefore, all measurements and results should be shown with the number of significant figures that are commensurate with the precision used to attain the results. For instance, distances measured with an EDM should typically be shown to the nearest 0.003 ft [millimeter], while distances scaled on a USGS 7½′ quad map should typically be shown to the nearest 30 ft [10 m]. Similarly, all surveys must be performed with a precision that ensures that the desired accuracy is attained.

For each project survey, establish the appropriate levels of accuracy and precision that will meet the project requirements.

5.3.2.2 Errors

There are three general types of errors:

1. **Blunder**. A blunder is a mistake in determination of a value. Eliminating blunders is one of the most important elements in surveying. Apply the following basic rules for eliminating blunders:
    - Every value recorded in the field must be checked by some other field observations,
    - Once this check indicates that there are no blunders, the field records must never be changed, and
    - An overall check must be applied to every control survey. As many checks as practical should be programmed in the planning of the project.
2. **Systematic**. Systematic errors, or bias, are errors that, under the same conditions, will always remain the same in size and sign. These errors can only be located by recognizing conditions that create them; they are therefore very problematic. Make every effort to recognize any conditions that cause them and take the necessary steps to neutralize them. Most surveying equipment, when properly calibrated and used with the proper procedures, will automatically cancel most of these errors. Evaluate the errors that cannot be eliminated and determine the conditions that cause them.

3. **Random**. Random errors represent the limit of precision for a particular measurement technique in the determination of a true value. They obey the laws of probability. Errors of a properly conducted survey can be treated as random.

For each project survey, strive to minimize the level of errors that may occur throughout the process; and document errors that are detected during the course of the work.

5.3.2.3 Control Survey Accuracy Classifications

The classification standard for geodetic networks is based on accuracy as defined by the Federal Geographic Data Committee (FGDC). FGDC Accuracies are categorized separately according to Exhibit 5.3–C for horizontal, ellipsoid height and orthometric height.

Exhibit 5.3–C CONTROL SURVEY ACCURACY STANDARDS

Control Survey Accuracy Standards
Horizontal, Ellipsoid Height, and Orthometric Height

	Measurement	Less Than or Equal to:	
	1-Millimeter	0.001 meters	[0.003 ft]
	2-Millimeter	0.002 meters	[0.006 ft]
	5-Millimeter	0.005 meters	[0.016 ft]
FLH SURVEY PROJECTS TYPICALLY FALL INTO THIS RANGE	**1-Centimeter**	**0.010 meters**	**[0.03 ft]**
	2-Centimeter	**0.020 meters**	**[0.06 ft]**
	5-Centimeter	**0.050 meters**	**[0.16 ft]**
	1-Decimeter	0.100 meters	[0.3 ft]
	2-Decimeter	0.200 meters	[0.6 ft]
	5-Decimeter	0.500 meters	[1.6 ft]
RESOURCE MAPPING PROJECTS TYPICALLY FALL INTO THIS RANGE	**1-Meter**	**1.000 meters**	**[3.3 ft]**
	2-Meter	**2.000 meters**	**[6.6 ft]**
	5-Meter	**5.000 meters**	**[16 ft]**
	10-Meter	**10.00 meters**	**[33 ft]**

When control points in a survey are classified, they have been verified as being consistent with all other points in the network, not merely those within that particular survey. It is not observation closures within a survey that are used to classify control points, but the ability of that survey to duplicate already established control values. This comparison takes into account models of crustal motion, refraction, and any other systematic effects known to influence survey measurements.

Refer to Appendix 5A.2 for FLH standard accuracy classifications for typical survey control levels, and recommended procedures and documentation to support the survey data.

5.3.2.4 Mapping Accuracy Classification

Determine mapping accuracy by comparing the mapped location of selected well-defined points to their "true" location as determined by a method known to produce more accurate results (e.g., conventional field survey to check photogrammetry). Mapping accuracy standards classify a map as meeting a certain statistical level of accuracy. Horizontal (or planimetric) map accuracy is usually expressed in terms of two-dimensional radial positional error measures (i.e., the root mean square (RMS) statistic) and is frequently related to plotting scale. Vertical map accuracy is expressed in terms of one-dimensional RMS elevation errors, and is frequently related to contour interval.

Maps, surveys and related geospatial data that are tested and found to comply with a specified standard shall have a certification statement that clearly indicates the target map scale and contour interval of the data layer. Project documentation will include testing procedures and statistical summary of the accuracy assessment. Horizontal and vertical accuracy classification of features is reported at the 95 percent confidence level by converting RMS error statistics by Equations 5.3(1) and 5.3(2).

Horizontal (two-dimensional) 95% confidence = RMS error * 1.7308 Equation 5.3(1)

Vertical (one-dimensional) 95% confidence = RMS error * 1.9600 Equation 5.3(2)

Project specifications will specify the geographic extent of data to be tested and the amount of testing (if any) to be conducted. Due to the high cost of testing and the varying applications for mapping data, not all map products should be tested. In these cases, the statement shall indicate that the mapping procedures were designed and performed under conditions known to meet a certain level of accuracy, but that the accuracy classification is estimated. An estimated accuracy statement is especially applicable to CADD and GIS databases that may be compiled from a variety of sources containing known or unknown accuracy reliability.

Mapping accuracy standards are associated with the final development of both the target horizontal plotting scale and contour interval. Photogrammetric flying height and ground survey density requirements are specified based upon the design target scale and contour interval. The use of Computer Aided Drafting and Design (CADD) and/or Geographic Information Systems (GIS) allows planimetric features and topographic elevations to be readily separated onto various layers and depicted at any scale or contour interval. Therefore, it is critical that these spatial data layers contain descriptor information identifying the original source and mapping accuracy classification.

The FLH standard for topographic mapping is the FGDC *National Standard for Spatial Data Accuracy* (NSSDA) and the ASPRS *Accuracy Standards for Large-Scale Maps*. This standard was developed, and remains generally recognized, by the photogrammetric industry. The ASPRS accuracy standards and statistical testing criteria can also be used to truth and classify topographic mapping compiled by other methods (e.g., terrestrial field survey, LiDAR).

Exhibit 5.3–D depicts recommended scales, contour intervals and associated positional tolerances for FLH mapping projects. Functional activities are generally divided into design and

construction tasks, and planning-level tasks. For most projects, identification of the type of project is the only design assumption required.

5.3.2.5 Units of Measurement

Article I, Section 8 of the US Constitution gives Congress the power to “fix the standard of weights and measures” for the nation. The First Congress, meeting in 1789, took up the question of weights and measures. In 1832, Congress directed the Treasury Department to standardize the measures used by customs officials at US ports. The Department adopted a report describing the traditional system, and Congress allowed this report to stand without taking any formal action. This is the closest the US has ever come to adopting a single system of measurement. The US Congress passed the *Metric Conversion Act* of 1975, Public Law (PL) 94-168, to encourage the use of the metric system of measurement throughout the US. In 1988, Congress passed the *Omnibus Trade and Competitiveness Act*, which designates “the metric system of measurement as the preferred system of weights and measures for United States trade and commerce.” The 1995 *Transportation Equity Act* for the 21st Century (TEA-21) relaxed certain requirements for State transportation agencies to employ International System of Measurements (SI) units on federally funded projects. These and other decisions make the decision to use metric (SI) or United States Customary Units (USCU) unique to a given project.

Surveying and mapping operations are easily adaptable to the use of either metric or USCU of measure. Care must be exercised to ensure that the required units of measurement are clearly identified in the project scope of work and work plan, and that all maps and reports note the correct units to avoid confusion.

Use of USCU with NAD83 State Plane Coordinates brings a unique issue with the appropriate conversion from coordinates in SI units (the defining system of the SPC system) and USCU. The adopted distance of a uniform foot has two official definitions in the US as follows:

1. **Survey Foot**. $1 \text{ US Survey Ft} = \frac{12}{39.37 \text{ m}}$
2. **International Foot**. 1 International Ft = 0.3048 m

The difference between the two definitions is approximately 6 ppm in a converting to USCU. This will produce differing coordinate values of approximately 3 ft in northing and 13 ft in easting for typical State Plane Coordinates. The difference is negligible for the actual measured distances between points. FLH standard practice is to use the US Survey Foot conversion. Most States have adopted official conversion definitions as part of the State’s plane coordinate legislation. Where official conversion definitions have been adopted by a State, FLH projects in USCU may conform to the adopted units of conversion (i.e., US Survey Foot or International Foot). **All maps and reports must clearly state the definition used to express project coordinates.**

Exhibit 5.3–D RECOMMENDED SCALES, CONTOUR INTERVALS AND ASSOCIATED POSITIONAL TOLERANCES FOR FLH MAPPING PROJECTS

Project or Activity	Target Map Scale Accuracy Classification	Contour Interval Accuracy Classification	ASPRS Map Accuracy Classification	Horizontal Tolerance (RMSE)	Vertical Tolerance (RMSE)	Horizontal Positional Confidence 95%	Vertical Position Confidence 95%
	1"= ___ ft 1:_____	_____ ft _____ m		_____ ft _____ m	_____ ft _____ m	_____ ft _____ m	_____ ft _____ m
Design and Construction of New Facilities (PS&E)							
General Site Plans and Topographic Detail	40	1	1	0.4	0.3	0.7	0.7
4R Final Design - As-Constructed - Pay Quantities	500	0.25		0.13	0.10	0.22	0.20
Building or Structure Design	40	1	1	0.4	0.3	0.7	0.7
Bridges - Structures - Culverts - Walls	500	0.25		0.13	0.10	0.22	0.20
Grading and Excavation Plans	40	2	1	0.4	0.7	0.7	1.3
4R Preliminary Design - Material Source	500	0.5		0.13	0.20	0.22	0.40
Planning and Feasibility Studies							
General Location Maps	200	5	2	3.3	3.3	5.8	6.5
Hydrology - Stream X-Sections - Geomorphology	2000	2		1.02	1.02	1.76	1.99
Flood Control Studies	400	4	2	8.3	2.7	14.4	5.2
Floodplain Mapping	5000	1		0.13	0.20	4.40	1.59
Environmental Assessment	400	N/A	3	12.5	N/A	21.6	N/A
Site Reconnaissance - Wetlands - Environmental Archeological - Route Studies	5000			3.81		6.59	

Special Studies and Maps

Cadastral, Property, and Right-of-Way	See Section 5.4.5 for surveying procedures.
Subsurface Utility Location	See Section 5.4.5.5 and Reference ASCE Publication C-I 38-02
Bathymetric	Reference US Army Corps of Engineers Publication EM 1110-2-103

5.3.2.6 Monumentation Standards

Provide reliable and stable survey monuments as necessary to preserve critical points of control for design and construction of FLH transportation facilities. The subset of survey points established to meet this purpose is known as Primary Project Control. Locate the coordinate and elevation control monuments along transportation corridors in secure locations. Select the station site with safety considerations for the surveyors and others given highest priority. Where possible, select sites outside of the proposed improvements, and in areas not subject to probable disturbance. Monuments should be accessible to the public, preferably in a public right-of-way or easement. **Monuments must be constructed to ensure horizontal and vertical stability.** Choose the monument type to suit the local conditions and application. Refer to Appendix 5A.3.1 for physical standards for control monuments.

Document all controlling survey monuments that are either found or placed, with recovery notes describing the monument location, character, condition and accessibility. See Exhibit 5A.3-A for an example survey monument record form.

5.4 FIELD DATA COLLECTION AND PROCESSING

5.4.1 CONTROL SURVEYS

Perform control surveys to establish the following:

- Geodetic networks of primary control stations to provide a common datum for planning design and construction projects, mapping products and Geographic Information System (GIS) applications.
- Boundary control for land title and right-of-way mapping.
- Aerial control for photogrammetry used in engineering design, right-of-way analysis, environmental constraints and planning studies.

Refer to Appendix 5A.3 for specifications for performing control surveys.

5.4.1.1 Horizontal and Vertical Control

FLH standard practice for establishing geodetic horizontal control is by the use of GPS static methods. These methods establish the relative positions of control points by observing radio signals from a constellation of satellites orbiting the earth. In relative positioning, two or more GPS geodetic receivers receive signals simultaneously from the same set of satellites. These observations are processed to obtain the components of the baseline vectors between observing stations. When the coordinates for one or more stations are known, the coordinates for new points can be determined after adjusting for the systematic differences between the reference system of GPS and the local geodetic network control. Fast static or kinematic GPS methods, or precise total station traverse methods, may be used to increase density of horizontal control, or to establish control in areas inaccessible to GPS.

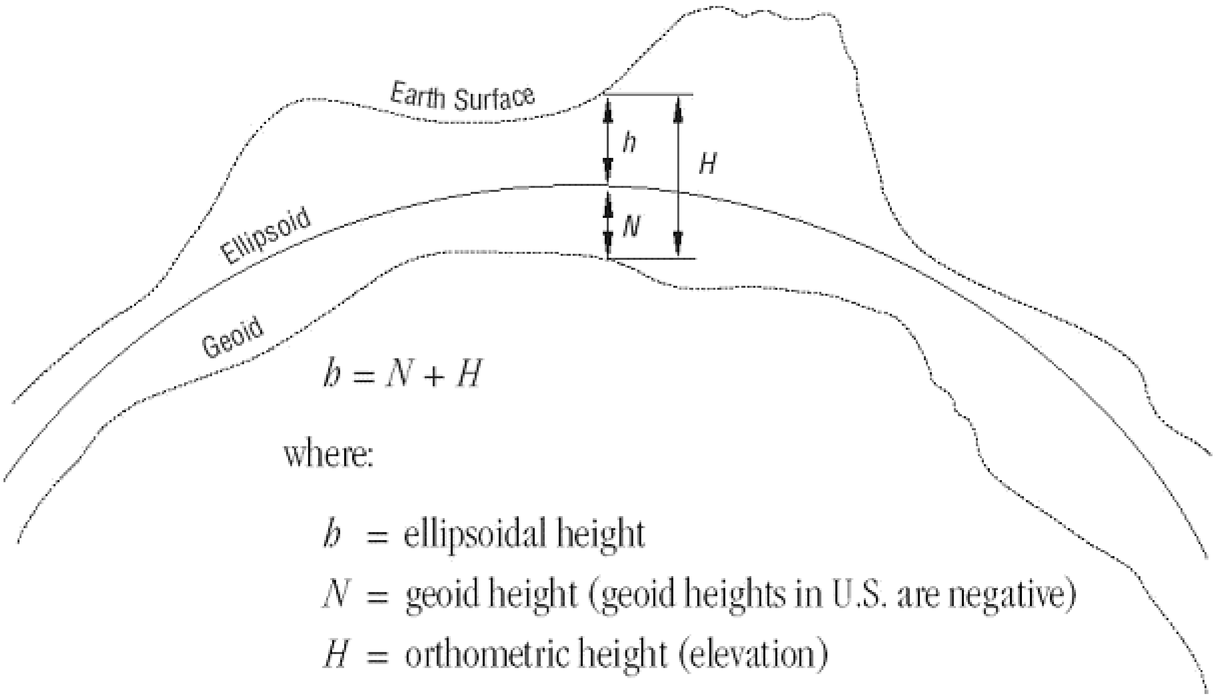
FLH standard practice for establishing geodetic vertical control is by conventional geodetic leveling. Geodetic leveling measures elevation differences observed between nearby rods. Leveling is used to extend vertical control within a project’s limits. New level runs are required to tie to existing network bench marks at the beginning and end of the leveling line. These network benchmarks must have an accuracy classification equivalent to or better than the intended accuracy of the new survey. When applicable, establish a standard project vertical datum on the existing network benchmarks by GPS-derived orthometric height surveying.

Appendix 5A.2 provides a table of standard accuracy classifications of horizontal and vertical control for FLH projects. Also refer to Section 5.3.2.3 to classify the accuracy of control points and survey networks.

5.4.1.2 GPS- Derived Orthometric Heights

GPS-derived orthometric heights (elevations) are compiled from ellipsoid heights (determined by GPS observations) and modeled geoid heights (using an acceptable geoid height model for the area) using Exhibit 5.4–A.

Exhibit 5.4–A DERIVED ORTHOMETRIC HEIGHTS



Because of distortions in vertical control networks and systematic errors in geoid height models, results can be difficult to validate; however, results comparable to those obtained using differential leveling techniques are obtainable. With proper care and analysis, FLH accuracy classifications “A-E” can be achieved from GPS-derived orthometric heights. Often the cost associated with bringing a vertical datum to remote project sites by conventional geodetic leveling methods can be prohibitive. If approved by the project’s technical representative, GPS-derived orthometric heights can be used to establish the vertical datum for a project, from which conventional geodetic leveling is used to extend the vertical control throughout the project. Vertical control so established can be classified primary control accuracy Classification “A” if all other requirements are met.

5.4.1.3 Terrestrial Surveys

Terrestrial Survey methods include an electronic theodolite, electronic distance measuring instrument (EDMI) and an electronic data collecting system. The system also includes tripods, tribrachs, prisms, targets and prism poles. Terrestrial survey methods of survey include traverse, resection, multiple ties and trigonometric leveling. Typical assignments can include horizontal and vertical control, boundary ties, topographic mapping and construction layout.

5.4.1.3.1 Redundancy

When proper procedures are followed, total station surveys achieve the accuracy standards for control surveys, meeting FLH Classification “B” (see Appendix 5A.2) horizontally. The proper procedures include redundancy of observations, thereby reducing the possibility of blunders. Also, redundant angles (multiple sets and/or reversed face) are observed whenever establishing or tying existing critical points such as control points and land net points. Redundant observations (e.g., multiple ties) should be observed to improve the information available from least squares adjustments and to strengthen survey networks.

5.4.1.3.2 Survey Adjustments

All control points, meeting accuracy classifications “A-E,” used for data gathering and stake out including photo control, shall be adjusted by the method of least squares.

5.4.1.4 Global Positioning System (GPS)

Where applicable, use Global Positioning System (GPS) surveying methods. The GPS methodologies used may vary in the type of equipment used, length of observation times and the computations and analysis required. GPS survey methods include, but are not limited to:

- Static GPS Surveys,
- Fast-static GPS Surveys,
- Real-time GPS Surveys (RTK), and
- Post-Processed Kinematic GPS Surveys.

GPS and other Global Navigation Satellite Systems (GNSS) surveying is an evolving technology. As GPS hardware and processing software are improved, new specifications will be developed and existing specifications will be changed. The specifications described in this section are intended to encourage application of the latest GPS methods and technologies that may be appropriate for individual projects.

5.4.1.4.1 Static GPS Surveys

Static GPS procedures allow various systematic errors to be resolved when high-accuracy positioning is required. Static procedures are used to measure baselines between stationary GPS receivers by recording data over an extended period of time during which the satellite geometry changes. GPS vectors are processed from raw GPS phase observations and the network of vectors is adjusted by least squares to compute coordinates, ellipsoid heights and elevations for the network points.

5.4.1.4.2 Fast-Static GPS Surveys

Fast-static GPS surveys are similar to static GPS surveys, but with shorter observation periods (approximately 5 to 10 min). Fast-static GPS survey procedures require more advanced equipment and data reduction techniques than static GPS methods require. Typically, fast-static GPS methods are limited to vector lengths of less than 6.2 miles [10 km].

5.4.1.4.3 Real-Time GPS Surveys (Real-Time Kinematic)

Kinematic GPS surveys make use of two or more GPS receivers. At least one receiver is set up over a known (reference) point and remains stationary, while another (rover) receiver is moved from point to point. All baselines are measured from the reference receiver to the roving receiver. Kinematic GPS surveys can be either continuous or “stop and go.” Stop-and-go station observation periods are of short duration, typically under two minutes. Real-time surveys are achieved with a radio or cellular data link between a reference receiver and the roving receiver. Measurement data from the reference receiver is transmitted to the roving receiver, enabling the rover to compute its position in real time. The distance between the reference receiver and the rover typically should not exceed 6.2 miles [10 km].

5.4.1.4.4 Post-Processed Kinematic GPS Surveys

Kinematic GPS surveying can also be conducted in a post-processed mode, where the phase observations are recorded in memory to process vectors and positions after the field work is complete. Also, modern GPS data collectors are capable of recording real-time Kinematic GPS vector data consisting of difference in position (delta X, Y and Z) and statistical information on the estimated reliability of that vector (co-variance/variance). In a post-processed mode, Kinematic GPS vectors can be adjusted in a least squares network to improve the analysis capability of establishing survey control with Kinematic GPS methods.

5.4.1.4.5 Leveling

Leveling is the surveying operation performed to:

- Determine elevations of points,
- Determine differences in elevations between points, and
- Control grades and roadway templates in construction surveys.

The traditional instrument used is a spirit level that establishes a horizontal line-of-sight by a telescope fitted with a set of cross hairs and a level bubble. Other instruments used for determining vertical distances are the transit, total station, aneroid barometer, and hand level. GPS may also provide sufficiently accurate elevations for many purposes.

When differences of elevation are determined either trigonometrically or by using a level and a rod, the effects of curvature and refraction must be considered. This is particularly true when the horizontal distances are long and when a high degree of precision is required. The curvature error results from measuring distances horizontally (flat) instead of measuring them along the arc or curvature of the earth. Refraction errors occur because the earth’s atmosphere bends light wave from the horizontal towards the earth’s surface.

The combined effects of curvature and refraction may be negated in differential leveling by balancing the length of foresights and back sights. They may also be negated by using the mean of the vertical angles looking both ahead and back when using trigonometric leveling. In situations where negating curvature and refraction is not practical, formulae for the corrections may be found in any standard surveying textbook.

Many modern automatic levels employ a laser scanning technique with a bar coded rod to observe and record differential level measurements digitally. Digital leveling has the advantage of decreased errors due to misreading the rod or manually recording the measurement, combined with improved accuracy due to the laser's ability to "read" the entire rod scale.

All differential leveling equipment must be properly maintained and regularly checked for accuracy. Systematic errors due to poorly maintained equipment must be eliminated to ensure valid survey adjustments.

5.4.1.5 Network Adjustments

After all blunders have been removed and the observation data has met the project requirements for accuracy and completeness, the FLH standard practice requires control survey observation data undergo analysis and adjustment both internally (i.e., minimally-constrained) for consistency and externally (i.e., fully-constrained) to local horizontal and vertical constraints. Least squares adjustment methods are standard practice for FLH control networks and are used to analyze and adjust all Primary Project Controls. Standard project reporting and metadata includes results from the minimally-constrained network adjustment used to quality control check the observation data and weighting strategy. The fully-constrained network adjustment, used to establish the final coordinate and elevation values is documented with a summary of final network constraints, observation residuals, variance of unit weight, and error ellipse values propagated at the 95 percent confidence level.

5.4.2 TOPOGRAPHIC SURVEYS - AERIAL

The choice of topographic survey by ground or aerial methods is determined by the needs of the project and cost considerations. Each project has a unique set of conditions that will determine which mapping techniques should be used.

Consider using photogrammetry where the needed benefits are:

- A cost-efficient surveying method for mapping large areas;
- May be safer than other surveying methods, especially in dangerous locations;
- Enables field crews to survey and map inaccessible areas;
- Creates a photographic record of the project site (referred to as a snapshot in time); and
- Produces useful digital products (e.g., orthophotos, Digital Terrain Models (DTM)).

Photogrammetry is not the best solution for all mapping situations. Photogrammetry may not be appropriate for conditions where:

- The accuracy required for a mapping project is greater than the accuracy achievable with photogrammetric methods;

- The density of vegetation is too great to provide a reasonable depiction of the ground surface;
- Conditions of light or weather preclude collection of usable photography; or
- The scope of the work is not large enough to justify the costs of surveying the photo control and performing the subsequent photogrammetric process. However, when unsafe field conditions are encountered, safety outweighs cost in the decision process.

Where applicable, utilize the following photogrammetric products:

- Stock aerial photography (existing or commercial),
- New aerial photography,
- Topographic mapping,
- Digital terrain models (DTM),
- Digital orthophotography,
- Satellite imagery, and
- Light Detection and Ranging (LiDAR).

5.4.2.1 Flight Planning

Fully define the scope of a photogrammetry project at the earliest stage possible, to minimize changes and expedite the entire process. Consider expanding the mapping limits in areas where there is some uncertainty in the needed coverage rather than potentially performing additional mapping later in the project life cycle.

The project flight plan should include specific information about the:

- Area to be mapped,
- Horizontal and vertical control datum,
- Potential safety problems,
- Plotting scale of the final mapping and/or imagery,
- The required contour interval, and
- Required photogrammetric deliverables and delivery dates.

The flight planning process should include:

- Obtaining maps depicting the location of the photo control, and
- Determining the beginning and ending of flight lines upon which aerial photography is to be obtained.

The goal of the flight planning process is to produce a flight plan that will provide the best balance between safety, accuracy and economy. This is accomplished by considering the:

- Location and amount of photo control to be set,
- Number of photographs to be obtained,
- Safety conditions of the project area, and
- Required accuracy of the photogrammetric products requested.

Exhibit 5A.4-A provides typical relationships between plotting scale, contour interval, aerial photography scale and pixel resolution.

5.4.2.2 Ground Control

The project flight plan identifies an appropriate control scheme. The necessary control scheme depends on the photogrammetric products produced and their required accuracy. Other considerations include:

- Safety factors,
- Size and shape of the area to be mapped,
- Addition of airborne positioning,
- Accuracy requirements of the photogrammetric products required,
- Terrain of the project area, and
- Accessibility to areas where the photo control is to be placed.

Marking control points with targets before the flight is the most reliable and accurate way to establish photogrammetric ground control. Survey monuments in the primary control network can also be targeted to make them photo identifiable Premark targeting produces a well-defined image in the proper location.

Ground control targets are designed to produce the best possible photo control image point.

The main elements in target design are:

- Good color contrast,
- A symmetrical target that can be centered over the control point, and
- A target size that yields a satisfactory image on the resulting photographs.

Examples of control schemes information on the purpose of each is found in Appendix 5A.3.

5.4.2.3 LiDAR Mapping

Airborne Light Detection and Ranging (LiDAR) systems are increasingly applied on FLH projects due to their highly efficient capability of collecting digital elevation model (DEM) data. LiDAR is an active sensor system that uses laser light to measure distances. When mounted in an airborne platform (fixed wing or rotary wing), this device can rapidly measure distances between the sensor on the airborne platform and points on the ground, building, tree, etc., to collect and generate densely spaced and highly accurate elevation data. In order to achieve these accuracies, LiDAR systems rely on the Global Positioning System (GPS) and an Inertial Measurement Unit (IMU) to accurately position the sensor during flight. Three measurement components make up the LiDAR system:

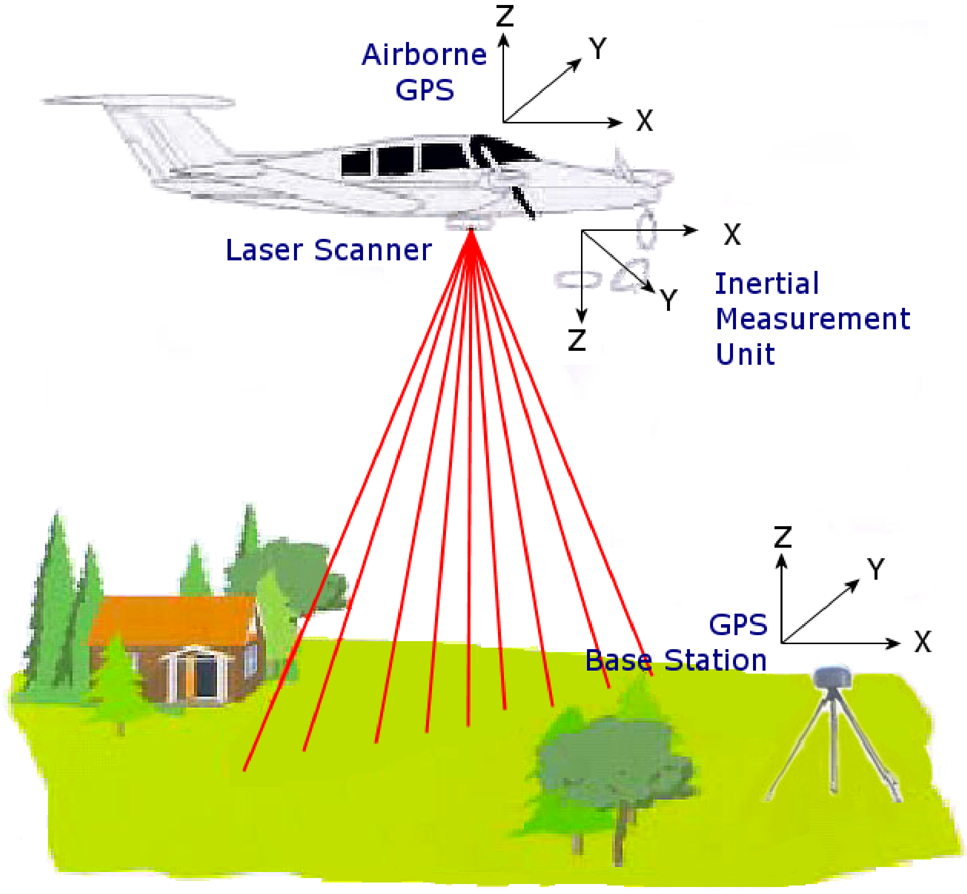
- GPS for horizontal and vertical position,
- Inertial Measurement Unit for angular attitude, and
- Laser scanner for ranging to points on the ground.

The LiDAR laser scanner is mounted in the bottom of an airplane (similar to an aerial camera) or helicopter, along with an Inertial Measurement Unit and GPS receiver and antenna. LiDAR systems record multiple returns for each laser pulse, along with the signal strength of the reflected light. The first pulse return (or 1st return) of LiDAR data measures the elevations of the canopy, building roof elevations and other unobstructed surfaces.

While in flight, the system gathers information on a massive base of scattered ground points and stores them in digital format. The Inertial Measurement Unit (IMU) records the pitch, roll and heading of the platform. Kinematic GPS provides spatial position of the aircraft. Additionally, many systems include a digital camera to capture photographic imagery of the terrain that is being scanned. Some systems have incorporated a video camera for reviewing areas collected. The raw LiDAR data are then combined with GPS positional data to georeference the data sets. Once the flight data is recorded, appropriate software processes the data that can be displayed on the computer monitor. This data can then be edited and processed to generate surface models, elevation models and contours.

Exhibit 5.4–B illustrates the LiDAR System Components.

Exhibit 5.4–B LiDAR SYSTEM COMPONENTS



LiDAR system tolerance for inclement weather conditions (e.g., high winds, wet snow, rain, fog high humidity, low cloud cover) is generally higher than that of other photogrammetric methods.

High point densities sometimes allow satisfactory data collection in areas of dense foliage where aerial photography would not produce satisfactory results. When planning missions, care must be taken regarding both natural (vegetative) and manmade (structure) ground cover. Pulse width, beam divergence, first and last pulse return discrimination, and choice of the post-processing algorithms may all affect the accuracy of LiDAR-derived data in areas of dense foliage.

Regardless of the data collection methods used (i.e., LiDAR, Aerial Photogrammetry, Ground Surveying), all topographic surveys for FLH projects are required to meet specific accuracy standards, as detailed in Section 5.3.2, with the same testing and reporting expectations.

In the following sections, considerations that are unique to LiDAR are described that should be evaluated in the project planning, data collection and testing.

5.4.2.3.1 GPS Base Stations

These active control stations must be located in the vicinity of the project site – typically within 18.6 miles [30 km] – and must be rigorously tied to the project horizontal and vertical control system. Multiple base stations are recommended to improve the confidence in a successful mission and to provide quality control processing of the kinematic GPS data.

5.4.2.3.2 System Calibration

LiDAR system optical components are subject to certain misalignments and calibration which must be accounted for in the project planning. Manufacture calibration certification and standard calibration test courses are often used to insure proper operation of the equipment.

5.4.2.3.3 Flight Planning

The LiDAR mission must be designed to cover the required project limits and mitigate potential error sources. Flying height and scan width should be planned to provide the required coverage and data posting in consideration of such factors as steep terrain and dense foliage. Multiple flight lines could be needed to provide the necessary verticality of laser pulses to successfully penetrate. Cross flights should be incorporated perpendicular to the project corridor at regular intervals for quality control purposes.

5.4.2.3.4 Inertial Measurement Data

Simultaneous solution of kinematic GPS and IMU data using advanced software processors is encouraged. The complementary nature of the two measurement systems, combined with advanced Kalman filtering algorithms provides a superior airborne position and attitude solution. Multiple high-speed on-board GPS receivers are also beginning to be used for dynamic positioning applications.

5.4.2.3.5 Data Voids

Regular posting of DEM points within the interval specified in the project plan is expected. Missing segments of data resulting from flight problems, system malfunction or ground conditions must be investigated. If warranted, ground surveying shall be conducted to fill in void areas and to verify DEM data in the surrounding areas.

5.4.2.3.6 Artifacts

Anomalous DEM points resulting from systematic errors, environmental conditions and remaining canopy points can adversely affect the quality of the resulting topographic mapping. Aerial imagery and ground truth surveying should be used to isolate and correct any artifacts in the DEM data.

5.4.2.3.7 Break Lines

LiDAR mapping by its self is unable to directly measure break lines and other linear features. Features not falling precisely at a regularly posted data point are practically invisible to LiDAR. FLH projects most often require accurate identification of edge of traveled way, flow lines and other break line features. For this reason, conventional aerial photogrammetry is often flown in conjunction with the LiDAR mission. Together the two systems are mutually supportive providing efficiency of DEM data collection with the accuracy and quality control of photogrammetry.

Though definitions in use sometimes vary, a digital elevation model (DEM) consists of a grid of regularly spaced points representing the irregular surface to be depicted. The distance between these points is referred to as the posting interval. A digital terrain model (DTM) includes mass points, as in a DEM, supplemented with three-dimensional break lines that depict linear surface features such as creeks, toe of slope or ridge lines. Topographic Mapping intended for use in design and construction of new facilities (see Exhibit 5.3–A) must be developed from a DTM including necessary break lines.

5.4.3 PHOTOGRAMMETRY

Photogrammetry is generally defined as the art and science of making accurate measurements from aerial photography. Aerial photographs, as they are initially exposed, do not allow accurate measurements. Distortions in the camera systems, combined with the curvature of the earth and irregular topography must be accounted for and eliminated. These photogrammetric processes allow the photogrammetrist to view, measure and plot three dimensions from a two-dimensional surface (aerial photograph).

5.4.3.1 Photogrammetric Processes

Photogrammetric mapping is achieved through four general processes known as:

- Imagery Acquisition (Aerial Photography),
- Ground Control Acquisition (covered in Section 5.4.2),
- Aerotriangulation and Model Set-up, and
- Digital Terrain Compilation and Planimetric Feature Compilation.

Each photogrammetric mapping project is unique. Each project is defined by spatial data collection for a unique piece of the earth with specific feature collection requirements (e.g., accuracy, feature types). The general processes listed above may involve several significant sub-processes based on the feature collection requirements for a specific project.

5.4.3.2 Aerial Photography

The success of all photogrammetric processes and the quality of the resulting products is largely dependent on the success of the aerial photography mission. The resulting photography must be checked to ensure sufficient coverage, adequate stereo overlap (lap) and image quality.

Aerial photography should be checked for image quality and correct end lap and side lap coverage between the photos. If the photography lacks adequate end lap and side lap coverage, the photography must be redone. Ideally, the end lap coverage will be 60 percent; however, end lap coverage ranging from 55 percent to 65 percent will produce adequate results. The side lap coverage percentages will vary with the photogrammetry job but most typically are planned for 40 percent over relatively flat terrain.

The photography should also be checked for stereo coverage within the project limits. It is important to have adequate stereo coverage since an object cannot be mapped if it only appears in one photograph.

Stereo coverage and end lap coverage can also be affected by the flight trajectory of the aircraft. These are most commonly manifested in either crab or drift. Crab occurs when constant corrections to the flight path cause the photos to twist with respect to one another. Drift occurs when the plane deviates from the intended flight line.

In steep terrain, the end lap coverage may need to be increased to avoid sliver shaped gaps in stereo coverage between exposures.

All aerial photographs must be checked to ensure image quality. Important aspects to inspect include:

1. **Image Motion**. Elongation of features on the photograph caused by the movement of the aircraft during exposure.
2. **Halation**. Spreading of an image beyond its proper boundaries, particularly common for bright or reflective objects.
3. **Graininess**. Large grain size resulting from poor developing techniques and decreasing the resolution of the photograph.

4. **Contrast**. Problems viewing details, especially in shadowy areas, caused by excessive or minimal density between the whitest and the blackest areas of the photograph.
5. **Hot Spots**. Bright areas of low detail caused by low sun angles.
6. **Fiducial Marks**. Marks imaged by the camera on each exposure and are used to orient photogrammetric instruments to the camera coordinate system. Fiducial marks are required for photogrammetric measurement.

5.4.3.3 Aerotriangulation

The process of adjusting the aerial photography to the earth is critical to the accuracy of final mapping products. Most projects are adjusted using aerotriangulation methods, which require fewer ground control points than other conventional adjustment methods.

Refer to Appendix 5A.5 for additional guidelines for analytical aerial triangulation.

5.4.3.3.1 Aerotriangulation Principles

Aerotriangulation is the simultaneous space resection and space intersection of image rays recorded by an aerial mapping camera. Image rays projected from two or more overlapping photographs intersect at the common ground points to define the three-dimensional space (3-D) coordinates of each point. The entire assembly of image rays is fit to known ground control points in an adjustment process. Thus, when the adjustment is complete, ground coordinates of unknown ground points and the precise orientation of each photographic image are determined by the intersection of adjusted image rays.

Aerotriangulation is essentially an interpolation tool, capable of extending control points to areas between ground survey control points using several contiguous uncontrolled stereo models. An aerotriangulation solution should never be extended or cantilevered beyond the ground control. Ground control should be located at the ends of single strips and along the perimeter of block configurations. Within a strip or block, ground control is added at intervals of several stereo models to limit error propagation in the adjusted pass point coordinates. Extending control by aerotriangulation methods is often referred to as bridging since the spatial image ray triangulation spans the gap between ground control.

5.4.3.3.2 Softcopy Methods

Aerotriangulation procedures that involve softcopy workstations must include fully analytical aerotriangulation software and high-resolution scanners. Diapositives are not required and all interior, exterior and control point mensuration are read from the scanned images. The elimination of diapositives eliminates the need to identify and drill mark the points for mensuration.

Softcopy aerotriangulation must follow procedures and use equipment that will enable the operator the ability to ascertain feature resolution at a level that will achieve the aerotriangulation accuracy required. A major advantage of softcopy aerotriangulation is that the software is generally interactive and thus provides excellent quality control. The results of point selection, measurements and weighting are shown to the operator immediately.

5.4.3.3.3 Aerotriangulation Adjustment

Measured positions of the photo control and the analytical points are processed in an independent unconstrained adjustment to determine if there are any problems with the photo mensuration.

Concerns with respect to the aerotriangulation measurements of the photo control and the analytic points should be resolved. Verified values of the photo control are applied in order to perform a constrained adjustment.

To complete the aerotriangulation process, the position and attitude, or tilt, of the aircraft at each exposure (or exposure station) is determined in the Aerotriangulation Solution by resecting the position from the known photo control. The values of the unknown analytic points are then determined by performing an intersection from two or more exposure stations through the analytic points to the ground.

5.4.3.4 Digital Terrain Compilation

Photogrammetric mapping generally considers topography compilation to include contours (lines of equal elevation), high and low points and lines defining abrupt changes in elevation break lines. The process of creating topographic data is typically done by generating mass points and break lines that, if desired, may be processed through software to generate contour lines. Direct digitizing of contours from the stereo model is occasionally used on FLH projects. The process chosen for topography compilation should be based on available compilation equipment, contour interval required, character of the area that is being mapped, available time and funding budget. Generally, terrain model development and processing are used for contour generation.

Digital Terrain Model surfaces compiled for FLH projects are expected to meet the accuracy classifications described in Section 5.3.2.3. Mass points and break lines must be collected from the stereo model, in sufficient detail and accuracy to ensure the required accuracy. The limiting Root Mean Square Error (RMSE) allowable under ASPRS Class 1 Standards is 1/3 the indicated contour interval. Spot elevations are restricted to an RMSE of 1/6 the contour interval. Regions of the project that cannot meet this accuracy requirement are required to be distinctly separated in the DTM surface and contour data files.

Additional guidelines and specifications for photogrammetric mapping are contained in Appendix 5A.4. Refer to Division Supplements for CADD file formats.

5.4.4 TOPOGRAPHIC SURVEYS - TERRESTRIAL

When applicable, perform topographic surveys using terrestrial methods to establish the following:

- Surface and subsurface features used in engineering design, right-of-way analysis, environmental constraints and planning studies;
- Areas that are not appropriate to aerial photogrammetric, LiDAR, or ground GPS surveys;
- Critical design areas;
- Floodplain mapping; and
- Bridge site and tributary mapping.

Refer to Appendix 5A.6 for additional guidelines for ground topography and planimetry.

5.4.4.1 Terrain Surface Depiction

Terrestrial survey methods for completing a topographic survey require the field collection of enough ground surface information to prepare a Digital Terrain Model (DTM). The use of the topographic survey will determine the appropriate amount of critical data collection. The limits of the survey will need to extend beyond the design area to complete the DTM.

A DTM is a representation of the surface of the earth using a Triangulated Irregular Network (TIN). The TIN models the surface with a series of triangular planes. Each of the vertices of an individual triangle is a coordinated (x, y, z) topographic data point. The triangles are formed from the data points by a computer program that creates a seamless, triangulated surface without gaps or overlaps between triangles. Triangles are created so that their sides do not cross breaklines. Triangles on each side of breaklines have common sides along the breakline.

Provide breaklines to define the points where slopes change in grade (the intersection of two planes). Examples of breaklines are the:

- Crown-of-pavement,
- Edge-of-pavement,
- Edge-of-shoulder,
- Flow line,
- Top-of-curb,
- Back-of-sidewalk,
- Toe-of-slope,
- Top-of-cut, and
- Top-of-bank.

Breaklines within existing highway rights-of-way should be clearly defined, while breaklines on natural ground may more difficult to determine.

DTMs are created by locating topographic data points that define breaklines and random spot elevation points. The data points are collected at random intervals along longitudinal break lines with observations spaced sufficiently close together to accurately define the profile of the breakline. Like contours, break lines do not cross themselves or other break lines. Cross-sections can be generated from the finished DTM for any given alignment.

When creating field-generated DTMs, gather data points along DTM breaklines and randomly at spot elevation points, using the total station survey methods. This method is called a DTM breakline survey. The number of breaklines actually surveyed can be reduced for objects of a constant shape (e.g., curbs). To do this, a standard cross section is sketched and made part of the field notes. Field-collected breaklines are identified by line numbers and noted on the sketch. With this information in the field notes, only selected breaklines need to be located in the field, while others are generated in the office based on the standard cross section.

Exercise skill to visualize in the field the TIN that must be created to accurately model the ground surface and where breaklines are needed to control placement of triangles. The following standard practices apply:

- Use proper feature codes, point numbering and line numbers;
- If ground around trees is uniform, tree locations may be used as DTM data points;
- Keep site distances to a length that will ensure that data point elevations meet desired accuracies; and
- Gather one extra line of terrain points 15 ft to 30 ft [5 m to 10 m] outside the work limits

5.4.4.2 Feature Location and Attributes

Terrestrial surveys for topographic mapping require a standard feature code format. Each FLH Division has developed standard survey feature code libraries for the common topographic survey assignments. Documentation of the feature code library, whether for standard FLH codes or for other codes, is required for every topographic mapping project. For all topographic data points collected assign a code relating to the feature being defined. Whenever possible, collect an elevation at the ground level for features with a vertical component so that the location can be used to compute the DTM. The horizontal component should be the center of the feature. For example, a power pole is recorded in the field data collector with a ground elevation of the power pole and then the center of the pole is then collected to obtain the horizontal location. The size, type, height, depth, width and other descriptive information is collected as an attribute along with the feature code.

5.4.4.3 Floodplain Mapping

Field surveying for floodplain mapping is uniquely different from topographic design surveys in that the data collected is not necessarily intended to describe a continuous DTM surface. Survey cross-sections are typically requested by hydraulic engineering in selected locations so as to depict the volumetric capacity of the flood valley. The following guidelines identify some of the typical requirements for floodplain mapping surveys:

- Proposed road alignments in parallel with adjacent rivers and their floodplains should have stream cross-sections taken every 500 ft to 1000 ft [150 m to 300 m]. Take a minimum of three stream cross-sections per location.
- Cross-sections must include the full width of the flood valley.
- Cross-section survey points are required at significant breaks in the ground line. The highest density of survey points will probably lie in the flow channels. Floodplain data points should emphasize the general slope of the plain and its width. For hydraulic purposes, a river's floodplain is defined using the 100-year flood event.
- Survey data is also required to define the edge-of-water, high-water marks, change in vegetation (tree lines), high points on gravel bars, top and bottom of channel banks, the stream thalweg (low point in the flow channels), and any other significant physical features (e.g., buildings). This information is useful in developing a comprehensive planimetric map of the area.
- Aerial photographs of the road and any adjacent rivers are often the best way to provide a complete depiction of the floodplain valley. A plan scale of 1:6000 [1:5000] should suffice in most cases. In some instances, a controlled aerial survey may prove more economical in getting flood plain survey data, particularly when aerial photogrammetry is being conducted as part of the roadway design. Consult with hydraulic engineering specialists in these instances to determine the limits of coverage desired.

5.4.4.4 Bridge Site and Tributary Surveys

The mainstream channel may influence bridges that cross its tributaries. In these situations, survey crews should take at least three river cross-sections on the main channel just downstream of the tributary confluence. Upstream of the tributary confluence, survey crews should take at least two river cross-sections on the main channel.

1. **Culverts**. Survey data collection should include the pipe length, the pipe inlet, the pipe condition and outlet elevations and the pipe area dimensions (e.g., diameter, span and rise) on all culverts within the project limits. For culverts crossing perennial streams, collect this data plus stream cross-sections 100 ft [30 m] upstream and 100 ft [30 m] downstream from the culvert inlet and outlet, taking cross-sections at 25 ft [10 m] intervals. Consult with the hydraulic engineering specialist to determine the preferred location and number of cross sections required for a specific project.
2. **Bridges**. Survey data collection should include stream cross-sections 500 ft [150 m] upstream and 500 ft [150 m] downstream of the proposed bridge site, taking cross-sections at 100 ft [30 m] intervals. Collect at least one section at the proposed bridge site, preferably two (e.g., upstream face, downstream face).

5.4.4.5 Subsurface Utility Location

Positive locations of all underground utilities are accomplished in accordance with the American Society of Civil Engineers (ASCE) National Consensus Standard titled ASCE C-I 38-02, Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data. Field surveying is required for Quality Levels C, B and A of the standards. Positive identification can be accomplished from visible above-ground features and as-built plans by electromagnetic detection instruments, potholing, probe or other acceptable methods. Combinations of methods may be more effective than a single method. The determinations of the proper methods are based specifically on identifying the type of facility being located and the accuracy needs of the horizontal and vertical position. These determinations are made through coordination with the design team and in accordance with the required Quality Level identified.

5.4.4.6 Railroad-Highway Grade Crossings

Coordinate with the railroad to obtain necessary safety and permit information.

Within the roadway corridor, survey and map each railroad structure and record the type of structure, the opening length and other information for comparison with railroad mapping. Tie railroad utilities or other utility poles and any facilities located on the railroad right-of-way. Show all utility poles and vertical clearance of utility lines at grade crossings.

When the project involves raising or lowering a railroad track, obtain the following data:

- Railroad alignment data (all tracks),
- All features along the centerline of railroad tracks through the entire area affected,
- Elevation of the roadway features along the highway, and
- Profile of each rail (top) for 500 ft [150 m] each side of highway centerline.

Refer to Section 9.3.15 for highway design considerations and requirements that need to be addressed by the survey and mapping activities.

5.4.4.7 Data Processing/Map Compilation

Data processing includes preparing and checking survey products. Supplemental control established during the topographic survey must be adjusted to fit the existing project control before calculating coordinates for topographic data points. The adjusted control is then used to compute three-dimensional coordinates for the data points. The adjusted coordinates are then edited for coding problems and then a draft DTM is prepared.

The draft DTM is reviewed for quality with check shots. Errors in field procedures and in the original collection files are identified and corrected. Potential sources of error are height-of-instrument, rod height, prism offset, improper labeling of breaklines and instrument or backsight occupation number mislabeling. The revised collector files are then rerun and a new draft contour map is created. This map should be reviewed for proper density of collected points, limits of survey and flow lines of pipes used in the DTM.

Final field verification of the topographic survey, if possible, is a valuable tool in confirming the quality of the survey before delivering it to the designer. Aerial photography, digital ground photos and/or video segments should be used to enhance the descriptive ability of the field survey and for quality review when field verification is not possible.

Additional guidelines and specifications for topographic surveys by ground methods are found in Appendix 5A.6.

5.4.5 RIGHT-OF-WAY AND CADASTRAL SURVEYS

Right-of-way and cadastral surveys are performed to gather data on existing property lines corners and monuments for use in conjunction with existing records and right-of-way requirements to determine, delineate, appraise, acquire, monument and map rights-of-way, in support of due process for appraisal and acquisition.

Cadastral surveying in support of right-of-way mapping is uniquely different from land surveying for boundary determination. The land net developed for right-of-way mapping must be sufficiently resolved to identify partial and whole land parcels impacted by the real property requirements for the transportation improvement project. Resolution of the land lines must be accurate enough to support appraisal, preparation of legal descriptions and acquisition of the necessary real property. Typically, record boundary information that is tied to some of the controlling land net corners is sufficient to fulfill these purposes. In certain circumstances (e.g., very high land values, close design tolerances, ambiguous land tenure, boundary conflicts), complete boundary determination survey of some or all affected parcels may be necessary.

5.4.5.1 Records Research

Thorough research of relevant land and survey records forms the foundation of a right-of-way and cadastral survey. Overall survey efficiency and quality of deliverables will be determined, in part, by the quality of the research. During the project planning phase, the overall scope of the project and specific project requirements will be determined. The project scoping and preliminary engineering planning is described in Section 4.3.2.

The record data search is the first action taken in the monument recovery process and provides the necessary survey and land ownership data required for the field survey and for analysis and mapping of the recovered land-net information. The goals of the record data search are:

- Identify ownership and existing rights,
- Identify controlling land net information, and
- Assemble all other information necessary for the right-of-way or cadastral survey.

Land and survey records are available in Government agencies, utility companies, title companies and other public/private entities. Research for a right-of-way and cadastral survey should be included within the research and planning for the overall transportation improvement project.

Typical sources of land survey records include:

- United State Geologic Survey (USGS) map sales – quad maps, county series and electronic Digital Ortho Quarter Quads (DOQQ) and Digital Raster Graphs (DRG);

- BLM State Office – master title plats, historical index, utility and road easements, GCDB, cadastral plats, mineral surveys, HES, field notes;
- US Forest Service, Regional Office – maps, plats, easements, special use permits;
- Forest Supervisor – maps, easements, special use permits, monument records;
- County Offices, Public Works, Recorder – tax assessor maps, index of owner/address, survey records, plats, monument records, as-builts, deeds, existing right-of-way;
- Court Records;
- Title Search;
- State Records – as-builts, State right-of-way plans and documents, land board records;
- Utilities;
- Railroads;
- Land Owners – plats, deeds; and
- Private Surveyors – plats.

5.4.5.2 Monument Recovery and Survey

The right-of-way and cadastral survey fieldwork will be coordinated with other transportation improvement project surveying activities. The right-of-way and cadastral fieldwork activities include:

- Cadastral monument research and recovery;
- Locating cadastral monuments, both record and non-record; and
- Locating physical features that may affect title (e.g., fences, roads, buildings).

Other survey activities include:

- Recovering and/or setting the project control,
- Performing photogrammetry control surveys,
- Performing topographic surveys, and
- Performing construction surveys.

The practical advantage of coordinating all transportation improvement project activities is to save time by reducing the number of trips to the field and to allow for a simultaneous adjustment of the survey data. Timing right-of-way and cadastral survey fieldwork to occur early in the process and synchronizing it with other transportation improvement project survey activities also allows for the early referencing of project control, land-net corners and lines of basic importance to ensure their perpetuation.

5.4.5.3 Right-of-Way Survey Field Notes

Field notes are a combination of electronically recorded measurement data and hand-written or computer generated notes that together represent an accurate, clear, complete and concise record of everything that occurred during the course of the right-of-way survey. The final quality of all record maps and documents depends on the quality of the information and data contained in these notes. Survey field notes are of such vital importance that they are at times called into review by courts. Field notes should include all evidence even if it may disagree with record data, a recovered monument, or with an analysis of its location.

5.4.5.4 Boundary Mapping and Data Compilation

Boundary mapping for right-of-way purposes begins with the collection and analysis of real property records and evidence necessary to develop the property lines, existing rights-of-way and easements that make up the land tenure within the project area. This base map of existing real property rights is known as the boundary compilation, and as noted earlier in this section, must be developed to a sufficient level of accuracy to support due process for right-of-way appraisal and acquisition. Boundary mapping continues through identification of necessary parcels for acquisition (i.e., fee simple title, deed restrictions, permanent easements, temporary construction easements) and the preparation and delivery of maps, descriptions and acquisition documents. Development of right-of-way documents for appraisal and acquisition is covered in Chapter 12.

5.4.5.5 Compile Title Search and Field Survey Data

The boundary compilation base file is compiled in the coordinate system and datum consistent with the horizontal control established for the project. This often requires that record boundary data be scaled to conform to grid distances (see Section 5.3.1 for information on horizontal coordinate systems). The final boundary compilation base file consists of a vector map in Computer Aided Design and Drafting (CADD) format. The boundary compilation includes a combination of field evidence, title information and surveying judgment to provide the user with a clear understanding of the data being depicted. Ambiguous or disputed boundaries need to be depicted and described so the acquiring agency can resolve these disputes and facilitate the acquisition process.

The final boundary compilation must provide an accurate portrayal of property lines, ownership, existing rights-of-way and other rights or interests that may be impacted by the project. The map will be used to determine the parcels necessary for right-of-way acquisition for the project and compensation due to the landowners. Adhere to applicable State statutes, professional standards and FLH standards and specifications in the development of this compilation and subsequent right-of-way plans and legal descriptions.

5.5 FINAL DESIGN SURVEYS

Before progressing to final design levels (e.g., 50 percent, 70 percent, 95 percent and 100 percent milestones), terrain verification and design location surveys may be necessary to ensure that the proposed design conforms to actual field conditions, and that critical tie-in points are known to a sufficient level of accuracy. Typical final design survey tasks include:

- Aerial topography check profiles,
- Ground truth field topography,
- Design centerline location,
- Reference hub or slope staking,
- Proposed right-of-way or utility location,
- Cross-section surveys, and
- Existing pavement and bridge grid grades.

As discussed in Section 5.3.2.2 and Section 5.4.3.3, all topographic mapping is tested by comparing mapped locations of selected well-defined points to their "true" location as determined by a method known to produce more accurate results. Field surveyed profiles, well distributed throughout the photogrammetric flight plan, are used for testing aerial topography compiled for concept studies and preliminary engineering. Check profile surveys are usually completed in conjunction with ground control surveying and the comparisons completed immediately following compilation. Following the preliminary (30 percent) design phase, additional ground truth topographic or planimetric survey tasks may be necessary to support final roadway design. For low-risk projects in generally flat and open areas, original ground check profiles along the proposed design centerline may be sufficient to facilitate the final design effort to proceed. Carefully review the site conditions, which will often reveal areas requiring additional attention. Areas of limited visibility from trees or brush may require additional field surveys to establish accurate topographic data. Areas where field topographic data is collected should be compiled and edited or merged into the original topographic surface so that the project topographic base file always reflects the most reliable data. Section 5.4.4 provides direction on how to conduct field topographic surveys.

Critical design features (e.g., existing drainage improvements, streams, tree-save areas and utilities) are often not identified as critical until after preliminary designs are complete. For these and similar issues, ground truth field topography of selected areas and features is frequently required. Comprehensive staking and cross-section surveys may be required in places where the final engineering has greater risk due to steep terrain, heavy tree cover or unsatisfactory ground truth found early in the project.

5.5.1 REFERENCE HUB STAKING

When required, set hubs and accompanying stakes to reference the preliminary design catch points for slope construction, either through slope staking methods, or at the fixed design distance from the roadway alignment. Define standard offsets from reference hubs to cut and fill slope catches and collect cross-section elevations between the reference hubs. Exercise care to ensure that cross-section points accurately depict the relief along the existing terrain line. This requires that all points of relief (e.g., toe-of-slope, flow line, crown) be collected, and that the cross-section be taken very closely in line to the design station. The cross-sections are used to develop or validate the final design independent of the original base topography. For this reason, cross-section data is not merged into the topographic base file.

At times, reference hubs, or reference stakes, or centerline staking, or combination thereof, is also required for some or all of a roadway alignment to facilitate site inspections or other engineering studies (e.g., geotechnical work). Cross-section surveys are not typically completed for these situations.

5.5.2 PAVEMENT AND BRIDGE GRID GRADES

On occasion, critical design elements are encountered that require extensive field survey efforts to depict existing conditions in sufficient detail. Highly detailed surveys for pavement design and bridges and drainage structures are more often encountered in urban roadway projects where matching proposed design grade lines with existing improvements become critical. Pavement and bridge design can impose some of the highest accuracy requirements for topographic mapping. Before beginning such detailed survey field work, closely coordinate with the design engineer to ensure a clear understanding of the required work and a well crafted work plan. The work plan should include sketches showing the features to be located and a written description of the required grade point interval and necessary mapping accuracy.

5.6 RECORDS AND REPORTS

5.6.1 PURPOSE

Document the surveying and mapping data, and maintain accurate project records in the form of field notes; correspondence, metadata and reports as an essential activity to provide the context, documentation and conclusions. Carefully prepare records and provide information to users at all stages of a project such that the resulting data is properly applied, questions can be resolved and decisions can be efficiently made. Regardless of the reporting format (e.g., digital files, hand drawn notes, illustrations, written reports), the goal of project reporting is to effectively communicate the necessary facts to a potentially unfamiliar user to correctly interpret and apply the surveying and mapping data.

Provide a project control report for all project control surveys. Refer to applicable Division Supplements for the report content and format.

5.6.2 METADATA STANDARDS

Metadata is descriptive information about the content, quality, condition and other characteristics of data. Formal Content Standards for Geospatial Metadata have been developed and adopted by the Federal Geographic Data Committee (FGDC). As a geospatial content provider, FLH is expected to comply with the guidelines and standards endorsed by FGDC. Metadata is contained in a standard digital file format (Text, HTML, XML) using some or all of the structured data tags included in the content standards. Metadata does not eliminate the need to complete and archive other project records; however, the metadata file should be diligently completed, and should answer the following questions related to surveying and mapping tasks:

1. What does the data set describe?
2. Who produced the data set?
3. Why was the data set created?
4. How was the data set created?
5. How reliable are the data and what problems remain in the data set?
6. How can someone get a copy of the data set?
7. Who wrote the metadata?

Appendix 5A.7 is an example metadata file, using a reduced set of data tags, applicable to typical FLH surveying and mapping projects.

5.6.3 ELEMENTS OF SURVEY FIELD NOTES

Whenever possible, apply electronic data collection methods that provide an efficient automated process for collecting and recording raw and processed survey measurements. Use electronic data collection to maintain the accuracy and consistency of survey measurement records. Carefully record electronic data in the field, using a well-understood process including standard point numbers and feature codes, such that the transfer of digital field data from the field survey to a finished map can be a seamless, nearly hands-free process.

Refer to applicable Division Supplements for the content and format of electronic data and manually recorded survey field notes and reports.