Chapter 2
Overview of Topographic Surveying Techniques and Methods

2-1. Purpose

This chapter provides an overview of the types of surveys and equipment that are used for performing control and topographic surveys. It covers the various types of engineering surveys used to support facility design and construction, the different survey equipment and instruments, and the general field and office procedures that are performed.

Figure 2-1. Topographic survey at Prompton Dam, PA (Philadelphia District--April 2005)

2-2. General Definitions

"Topographic surveying" encompasses a broad range of surveying and mapping products, ranging from aerial mapping to ground and underground surveys. "Control surveying" likewise can cover wide area geodetic surveys to construction stakeout. The following definitions from the Florida Administrative Code (FAC 2003) illustrates how topographic and control surveying falls under the overall "surveying and mapping" field:

> "Surveying and Mapping: a process of direct measurement and analysis specifically designed to document the existence, the identity, the location, and the dimension or size of natural or artificial features on land or in the air, space or water for the purpose of producing accurate and reliable maps, suitable for visualization if needed, of such documentation."

> "Topographic Survey: a survey of selected natural and artificial features of a part of theearth's surface to determine horizontal and vertical spatial relations."

> "Control Survey: a survey which provides horizontal or vertical position data for the support or control of subordinate surveys or for mapping."

Anderson and Mikhail 1998 define topographic surveys as follows:

> "A topographic map shows, through the use of suitable symbols, (1) the spatial characteristics of the earth's surface, with such features as hills and valleys, vegetation and rivers, and (2) constructed features such as buildings, roads, canals, and cultivation. The distinguishing characteristic of a topographic map, as compared with other maps, is the representation of the terrain relief."

As outlined in the scope in Chapter 1, the guidance and instructions in this manual will focus on the performance of site plan surveys required for the design and construction of military facilities and civil works projects. Control survey methods will focus on those surveys required to support detailed site mapping. ERDC/ITL 1999b defines installation map products as:

> "Maps are tools that provide the commanders with timely, complete, and accurate information about our installation. They have three primary uses on the installation: locate places and features, show patterns of distribution (natural and physical phenomena), and compare and contrast map information by visualizing the relationships between these phenomena. A map is a representation of reality comprised of selected features needed to meet the maps intended purpose."

2-3. Generic Considerations Applicable to all Drawings and Maps

There are some differences between topographic maps and plans (or engineering drawings). In general, maps are usually developed at a smaller scale, whereas detailed site plan drawings are at much larger scales. The following table (from Kavanagh 1997) illustrates this distinction:

Table 2-1. Map Scales Used for Various Engineering Drawings

Scale	Typical Uses
1" = 1' to 1" = 8'	Large scale detail drawings, architectural plans
1" = 20' -30'- 50' to 1" = 100'	Engineering site plans, facility design
1" = 100' to 1" = 800'	Intermediate scale: planning studies, drainage, route planning
1" = 1,000' and smaller	Small scale: topographic maps, USGS quad maps, NOAA charts

In general, map scales greater than 1 inch = 100 ft are intended for detailed design purposes. Smaller scales between than 1 inch = 100 ft and 1 inch = 1,000 ft are used for general planning purposes. To assure convenience of use and to derive full benefit from maps and plans, the data on various types of the above project drawings should contain the following criteria:

a. State Plane Coordinate System. It is desirable that the surveys and construction drawings for different projects be correlated with each other and with other Federal agencies. This is accomplished by the use of the State Plane Coordinate System as the coordinate system of the project, and insuring that this grid reference is adequately tied in to a nationwide geodetic reference system. In some cases, an arbitrary or artificial coordinate system may be used.

b. Coordinate grid lines. To enable proper correlation between the various project maps and plans, there must be drawn on all project maps (or CADD sheet files) the coordinate grid lines of the project coordinate system. These lines should be spaced five (5) inches apart; the outside coordinate lines should be the match lines for adjacent map sheets.

c. Determination of plan scales. The scale of topographic maps should be chosen so that these maps may serve as base maps over which subsequent project drawings can be drawn at the same scale. Reference Table 6-1 for guidance on selecting map scales. Thus, the scale of a reconnaissance topographic survey is chosen at a convenient scale so that it may serve as base over which the preliminary site studies and approved site plan may be prepared. The detailed topographic maps will also serve as a base upon which to prepare detailed utility maps.

d. Outside sources of information. Full use should be made of surveying and mapping information available in the various Federal, state, local agencies, and geospatial data clearinghouses prescribed in Corps regulations. USACE Commands are required by ER 1110-1-8156 to perform clearinghouse searches.

e. Accuracy. The type of survey, map scale, and contour interval should be selected in each case to interpret the character of the terrain most suitably for the purpose, and the tolerance of permissible error should be prescribed in each instance. It is not necessary that reconnaissance topographic surveys be of the same degree of accuracy as detailed topographic surveys, nor should they show the topographic data with the same degree of detail.

f. Control to be shown on Plans. The coordinate grid, horizontal control stations, benchmarks, and related reference datums should be shown on all maps and plans--see Chapter 5 for specific details. This is of particular importance in detailed layout plans of building areas drawn at the larger scales of 1 inch = 100 ft or 1 inch = 50 ft. The data are vital to speed and accuracy in subsequent location survey work.

SECTION I
Types of Surveys

The following types of products are covered by this manual, all of which are assumed to fall under the broad definition of "topographic surveying":

- Reconnaissance Topographic Surveys
- Detailed Topographic Surveys and Maps
- Utility Surveys and Maps
- As-built Drawings
- Boundary Surveys and Reservation Maps
- Reservoir Clearing Surveys
- Upland Disposal Area Surveys
- Channel Improvement and Cutoff Surveys
- Post-Flood High Water Mark Surveys
- Bridge Surveys
- Artillery Surveys
- Airport Obstruction and NAVAID Surveys
- Site Plans (Hydrographic, Beach, Levee, Route, Quantity, Structure, etc.)
- Army Installation Drawings

Some of the above surveying and mapping applications will overlap in practice and definitions will vary from District to District. Aerial topographic mapping products are excluded from this manual, as are high-order geodetic control surveys.

2-4. Reconnaissance Topographic Surveys

Topographic surveys have various definitions by different agencies and publications. These may include everything from photogrammetric mapping to hydrographic surveys. The reconnaissance topographic surveys described below relate to smaller scale preliminary mapping performed in advance of engineering and design, and are often called preliminary surveys. Following are the important considerations in connection with reconnaissance topographic surveys:

a. Purpose of reconnaissance surveys. The reconnaissance survey is the basis for a general study or a decision as to the construction suitability of areas. It may also be used for preliminary site layouts. Reconnaissance surveys are useful in showing the general location of roads, building areas, and utilities; and to establish an acceptable site layout which must be approved by authorized officers before detailed layout plans can be made. Such surveys also enable the proper selection of those areas, relatively limited in extent, which should be covered by the more time-consuming and costly detailed topographic surveys. In some instances the US Geological Survey (USGS) topographic quadrangle sheets may be enlarged and used for this purpose. The success of such use will be dependent upon the contour interval, whether the USGS maps are of recent date, the character of the terrain, and the nature of the project.

b. Map scales and contour intervals. Dependent upon the size and shape of the area and upon the nature of the terrain, i.e., density of culture and steepness of slope, reconnaissance surveys may be at scales varying from 1 inch = 400 ft to 1 inch = 1,000 ft. In cases where the project is of limited size, a scale of 1 inch = 200 ft may be used. Contour intervals of either five feet or ten feet may be used. The five-foot interval is the more serviceable and should be used except where steepness of slope makes the ten-foot interval advisable. When areas contain both flat and very steep slopes a ten-foot interval may be adopted as the contour interval of the map. On the flat areas, one-half interval contour (e.g., five foot) may be shown, discontinuing them wherever the slopes become steep or uniform. Contours having different intervals should not be shown by the same symbol on the same map. In extremely flat areas, a one- or two-foot contour interval may be required to adequately represent the terrain.

c. Accuracy and degree of detail. Extreme accuracy of position is not necessary and minutiae of detail are not desirable. The map should show all pertinent physical features such as roads, railroads, streams, cleared and wooded areas, houses, bridges, cemeteries, orchards, lakes, ponds, and fence lines. Elevations should be shown by contours and spot elevations at road intersections, bridges, water surfaces, tops of summits and bottoms of depressions.

d. Datum. When practical and feasible, it is desirable for these surveys to be referenced to an established NSRS datum, rather than some arbitrary grid system.

2-5. Detailed Topographic Surveys

Following are the important considerations in connection with detailed topographic surveys. Further guidance is contained in Chapter 6.

a. Purpose of detailed topographic surveys. Detailed topographic surveys are the basis for detailed plans showing the site layout and utilities. The area to be covered by detailed surveys should be kept to a minimum to serve the requirements of the actual building area and should not be made where reconnaissance surveys will serve. Detailed topographic surveys may be made by plane table, total station, GPS, laser scanning, and/or photogrammetry.

b. Map scales and contour intervals. Detailed topographic surveys should be at a map scale of 1 inch = 100 ft or 1 inch = 200 ft, with contour intervals of two feet, depending on the convenient size to be established for detailed site plans and utility maps. A scale of 1 inch = 50 ft is also used on small projects.

c. Accuracy and degree of detail. Upon the map sheets there shall be shown all control points and bench marks with their designating numbers and their elevations, all roads, railroads, streams, fence lines, utilities, poles, isolated trees ten inches or more in diameter, boundaries of timbered areas rock ledges or boulders, wells, buildings, cemeteries and any other physical data that will affect planning. In addition to elevations shown by the contours, there should be shown spot elevations at all summits, bottoms of depressions, tops of banks, stream or water surfaces, roads and railroad lines at breaks of grade, intersections, bridges, bases of isolated trees, first-floor elevation of existing buildings, and ground surfaces at wells. The contours should faithfully express the relief detail and topographic shapes. Accuracy standards for topographic mapping features are detailed in Chapter 4.

d. Horizontal control. There should be established a system of monumented horizontal control originating from and closing upon existing NSRS control points. Since this control should also serve the needs of subsequent site layouts and utility maps, the selection of its position and frequency must give due weight to these needs. In areas where there is to be intensive development, the lines of control circuits should ideally not be more than 2,000 to 2,500 feet apart in one direction, but may be of any convenient dimension in the other direction. Control points should generally not be more than 800 to 1000 feet apart along the line of the circuit and should be intervisible. In order to serve property survey needs, the outside control circuits should have control points within 300 or 400 feet of probable property boundary corners. Where topography is to be taken by plane table, a sheet layout should first be made and the control circuits selected near two sheet borders so that the line may be platted on both sheets.

e. Vertical control. Vertical control should consist of levels run in circuits originating from and closing upon Federal Government benchmarks. The closure error of these circuits should be predicated on the character and scope of construction involved. The elevation of each traverse station monument should be determined. Other permanent benchmarks as deemed necessary should be set.

f. Reference datum. When practical and feasible, it is desirable for these surveys to be referenced to an established NSRS datum, rather than some arbitrary grid or vertical reference system.

2-6. Utility Surveys

There are several kinds of utility surveys, but principally they can be divided into two major types. One type is performed for the layout of new systems, and the other is the location of existing systems. Typical utilities that are located include communications lines, electrical lines, and buried pipe systems including gas, sewers, and water lines. The layout of new systems can be described as a specialized type of route surveying, in that they have alignment and profiles and rights-of-ways similar to roads, railroads, canals, etc. In reality, utilities are transportation systems in their own right. Utilities are special in that they may have problems regarding right-of-way above or below ground. A great portion of utility surveying involves the location of existing utilities for construction planning, facility alteration, road relocations, and other similar projects. This is a very important part of the preliminary surveys necessary for most of these projects.

a. Purpose of utility maps. To a greater degree than any other drawings prepared in the field, utility maps serve two main purposes: (1) as construction drawings, and (2) as permanent record of the utilities, i.e. "as built." Their value to the Facility or Public Works Engineer in the proper operation and maintenance of the project is such as to require complete information on all pertinent features of each utility. For the purpose of recording "as built" construction in the most readily usable form, two sets of utility maps are usually found most practicable: General Utility Maps at small scale (1 inch = 400 ft or 1 inch = 200 ft and Detailed Utility Maps (sometimes referred to as unit layout maps) at a larger scale (1 inch = 100 ft or 1 inch = 50 ft) as described below.

b. General survey procedure. Utilities are usually located for record by tying in their location to a baseline or control traverse. It may be more convenient to locate them with relation to an existing structure, perhaps the one that they serve.

(1) Aboveground utilities are usually easily spotted and are easier to locate than the subsurface variety. Therefore, they should present little difficulty in being tied to existing surveys. Pole lines are easy to spot and tie in. Consulting with local utility companies before the survey has begun will save much work in the end. Any plats, plans, maps, and diagrams that can be assembled will make the work easier. If all else fails, the memory of a resident or nearby interested party can be of great help.

(2) Proper identification of utilities sometimes takes an expert, particularly regarding buried pipes. There are many types of wire lines on poles and in below ground conduits--this can lead to identification problems. Where once only power and telephone lines were of concern, now cable TV, burglar alarms, and even other wire or fiber optic line types must be considered.

(3) The location of underground utilities by digging, drilling, or probing should be undertaken only as a last resort, and then only with the approval and supervision of the company involved. Some techniques that work are the use of a magnetic locator, ground penetrating radar, a dip needle, or even “witching” for pipes or lines underground.

c. General utility maps. At a scale of 1 inch = 400 ft, 1 inch = 300 ft, or on smaller projects at scales of 1 inch = 200 ft, the principal features of each utility are generally shown separately, each utility on a separate map, or CADD layer/level. As a base upon which to add the data for each utility it is normally most convenient to use the approved general site plan of the same scale. The amount of detail to be indicated on each general utility map should be limited to that consistent with the scale of the map. It is usually feasible, even at a scale of 1 inch = 400 ft, to indicate the location, material, pipe sizes, etc., of the main distribution and collection systems, leaving minor construction features (valves, service connections, etc.) to be shown at larger scale on the second set of maps (see Detailed Utility Maps below) or as attributes in a CADD facilities database. General Utility Maps will normally include the following:

- Water Distribution System.
- Sewers: Sanitary and Storm Water Collection Systems
- Electric Distribution System, including Fire Alarm System.
- Communication Systems (telephone, cable, computer, fiber optic, etc.)
- Gas System.
- Gasoline Storage and Fuel System.
- Steam distribution and domestic hot water system for hospitals and other areas. (Include compressed air system, if any)
- Target and Magazine Areas. (Where located at some distance from the general construction area, these may be shown on a separate map annotated to show the relation to the project)
- Rail Facilities, including access to serving railroad (unless shown in complete detail on site plans)

Figure 2-2 below is a typical CADD file showing a variety of different utility systems surveyed by Louisville District personnel at an Army Reserve Center. Each utility was coded in the field and placed on a separate MicroStation design file “level.” Normally, as shown below, each utility system is given a different color coding as well as a different level assignment. Turning off different utility levels (and assigning these levels to separate sheets) eliminates the apparent overprinting below.

d. Detailed utility maps (sometimes referred to as Unit Layout Maps). At a scale of 1 inch = 100 ft or 1 inch = 50 ft and normally on reproductions of the detailed site plans, the detailed utility maps for large or complicated projects are generally prepared showing the details of all utilities on each sheet rather than with each utility on a separate sheet. By this means, the Facility Engineer is informed as to the underground relationship of the various utilities; and avoids the danger, in repairing one utility, of damaging another. Even at the relatively large scale of 1 inch = 50 ft, the complexity of utility data at "busy" intersections may require that inserts be added to the map at still larger scale. The detailed utility maps will show the additional detailed data of all kinds which it was not feasible to show on the smaller-scale general utility maps (grades at ground and inverts of manholes, etc., location and sizes of valves, service connections, etc.) and will thus provide the Facility Engineer with complete data necessary for operation and maintenance. On small projects where it has been feasible to prepare the general utility maps at large scale (1 inch = 50 ft), it will be possible to add the necessary complete detailed utility data to these maps and thus to avoid the preparation of special detailed utility maps. They may also be omitted in cases where it is found feasible to show utility details on "strip" road plans, providing the strips are of sufficient width to show service connections to structures on both sides of the road.

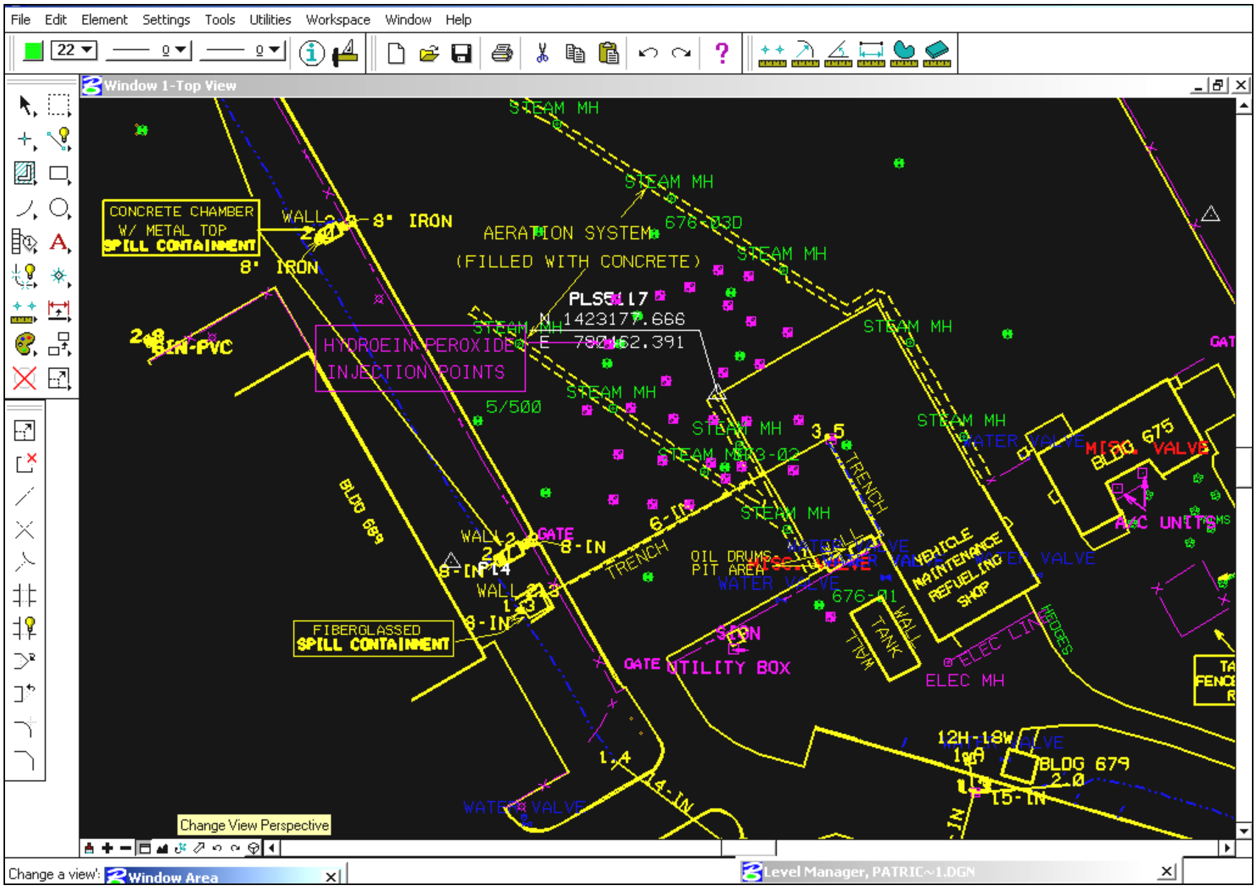

Figure 2-2. Utilities near a Vehicle Maintenance Refueling Facility at Patrick Air Force Base, Florida (Louisville District--2004)

2-7. As-Built Surveys

a. Purpose. As-built surveys are surveys compiled to show actual condition of completed projects as they exist for record purposes and/or payment. Since many field changes occur during construction, both authorized and clandestine, surveys are regularly completed to check the project against plans and specifications. As-built surveys are usually a modified version of the site plans that were originally required to plan the project. This is particularly true of road, railroad, or watercourse relocation projects. These projects are all of the route survey nature. The as-built survey, out of necessity, is this type also. Typical items checked are:

- Alignment.
- Profile or grade.
- Location of drainage structures.
- Correct dimensions of structures.
- Orientation of features.
- Earthwork quantities (occasionally).

b. Methodology. For route-survey-type projects a traverse is usually run and major features of the curve alignment are checked. Profiles may be run with particular attention paid to sags on paved roads or other areas where exact grades are critical. Major features of road projects that are often changed in the field and will require close attention are drainage structures. It is not uncommon for quickly changing streams to require modification of culvert design. Therefore, culvert and pipe checks are critical. Items that should be checked for all major drainage structures are:

- Size (culverts may not be square).
- Skew angle (several systems in use).
- Type or nomenclature (possibly changed from plans).
- Flow line elevations are very important and should be accurately checked.
- Station location of structure centerline with regard to traverse line should be carefully noted.

(1) Utilities that have been relocated should be carefully checked for compliance with plans and specifications. Incorrect identification of various pipes, tiles, and tubes can result in difficulties. Since the subject is somewhat complicated it is important to keep track of this type of information for the future.

(2) Project monumentation is sometimes a requirement of as-built surveys since it is common to monument traverse lines and baselines for major projects. Their location should be checked for accuracy. In many areas it is common for such monumentation to be done by maintenance people who are not at all familiar with surveying and therefore the work is not always as accurate as would be desired.

2-8. Reservation Boundary Surveys and Maps

a. Purpose. Boundary surveys of civil and military reservations, posts, bases, etc. should generally be performed by a professional land surveyor licensed in the state where the work is performed. Corps of Engineers boundary survey requirements and procedures are detailed in Chapter 3 (Mapping) of ER 405-1-12 (*Real Estate Handbook*). This chapter in ER 405-1-12 describes the procedures for providing maps, surveys, legal descriptions, and related material on a project or installation basis for planning, acquisition, management, disposal, and audit of lands and interests in lands acquired by the Corps of Engineers for Department of the Army military and civil works projects, for the Department of the Air Force, and as agent for other Federal agencies. The criteria, general format, forms development, approval authority, maintenance, and distribution of project maps reflecting graphic depiction of all lands acquired and disposed of are described in this regulation. Boundary surveys include parcel maps, subdivision maps, plats, and any other surveys that are officially recorded (filed) in a local County or State clerk's office. The following are the important considerations regarding boundary surveys:

b. Method and accuracy. The determination of the position of all points should be by transit or total station traverses originating from and closing upon points of the local horizontal control system. The error of survey as indicated by any such closure before adjustment should not exceed the standards specified for boundary surveys in the particular state--usually ranging from 1 part in 5,000 to 1 part in 10,000. Where applicable, procedures and standards in the "*Manual of Instruction for the Survey of the Public Lands of the United States*" (US Bureau of Land Management 1973) should be followed.

c. Reconciliation of conflicting data. Cases occur in which the data supplied by the field surveys do not agree with the deed description; where these conflict and cannot be reconciled legal advice may be necessary. However, it is a generally-accepted rule that where discrepancies exist between the boundary line, as described in the deed, and the boundary lines of possession as defined on the ground by physical objects such as fences, marked trees, boundary stones, boundary roads, and streams, the physical evidence should be held as correct, unless convincing evidence to the contrary is produced.

d. Boundary monuments. When boundary surveys are authorized, standard reinforced concrete monuments should be placed at all angle points on the exterior boundary. In long courses, such monuments should be placed along the line of intervals of 1,000 ft on level terrain and at prominent points (intervisible if possible) where the terrain is rolling. Where a monument replaces an old landmark it should be clearly so noted in the notes of the survey and on the property map. The notes should fully describe old monuments or landmarks. Monumentation guidance is contained in EM 1110-1-1002 (*Survey Markers and Monumentation*) and in ER 405-1-12 (*Real Estate Handbook*).

e. Scales and other details. Boundary maps may be platted at any convenient scale consistent with the size of the area involved. In the case of small projects the scale of the site plan will be a convenient one for the boundary map. These maps should show the bearings, referred to the meridian of the Government control point to which the survey is tied, and the lengths of property lines and rights-of-way, the names of property owners, and the acreage to the nearest one-hundredth of an acre. Where survey bearings and lengths differ from the deed description the latter should also be shown. The maps should also show the position of all old property marks or corners that were found. The project coordinate grid lines, control points, and the coordinate values of the beginning corner of the survey (POB) should be shown on the maps.

f. Metes and bounds description. A complete typewritten metes and bounds description will be prepared and will include the bearings and distances of all courses of the exterior boundary of the reservation including detached areas, if such exist, with type of markers placed at angle and intermediate points. The description will state the acreage, the county and state within which the area is situated, and the date of the survey. The description should also include metes and bounds of any excepted area within the reservation such as roads, railroads, and easements, with areas thereof.

g. Reservation maps. Reservation maps are required wherever the entire area of a reservation, or portion thereof, is held in fee title by the Government. The scale of the reservation map will depend upon the area involved, reliable information available, and on the scale of reservation maps in existence. Until such time as the boundary surveying and monumenting of properties acquired by purchase or condemnation are authorized, reservation maps will be usually comprised of a compilation of all available existing information in the form of deed descriptions, General Land Office survey data, metes and bounds descriptions if available, etc. The following data will be clearly set forth on the reservation map:

- All exterior boundary lines (based on certified and monumented surveys if prepared).
- Total acreage (computed, if a survey has been authorized), together with acreage of lands transferred by temporary agreement, if any.
- The exterior boundaries and acreage of all additions to existing military areas acquired since preparation of earlier reservation maps--to be indicated on original maps of the reservation if practicable, otherwise on segmental maps properly coordinated with the original maps.
- The metes and bounds survey description, if previously authorized, or the General Land Office survey description, if available.
- The approximate outline and designation of all outstanding areas of operation which are a part of the military reservation; for example, Cantonment Areas, Ordnance Areas, Airfield and Revetment Areas, Hospital Areas, Maneuver Areas, Depot Areas, Radio Sites, Target Range Areas, Bombing Areas, and other areas of importance.
- Rights-of-way for sewerage, water supply lines, and other utility rights-of-way. If prepared on segmental maps, these should be properly coordinated with the reservation map.
- The State and County or Counties within which the reservation is located.

2-9. Reservoir Clearing Surveys

a. Purpose. Reservoir clearing surveys will include the establishment and mapping of the upper clearing limit, the marking of pertinent portions of dredging spoil areas, the location of clearing and grubbing limits for channel cut offs and improvements, and the lay out and marking of boat channels through areas which will not be cleared. The upper clearing limit comprises the major portion of the job, and work on this item should be vigorously prosecuted most particularly during the winter months while the foliage is off the trees. The clearing limit contour will be established on the ground, painted, staked, and mapped for all parts of the reservoir except such areas as may be prescribed to leave nucleated. The following are typical examples:

- Areas for the enhancement of game and fish habitat.
- Upstream limits of creeks where pool is confined within the old channel or within steep banks.
- Within the river banks except for designated sections where clearing in the vicinity of public areas will be performed.
- Islands formed by the clearing limit contour will not be cleared and must be located and marked. This will probably require some exploratory surveying in the wider areas of the reservoir.
- Flowage easements.

b. Contour establishment and mapping. The clearing limit may frequently be located in low, flat terrain with numerous branchings, "finger" sloughs, swales, and may lie in no pattern whatsoever. The prime objective of this type survey is to locate, paint, and map the clearing line contour. In running the levels to locate the contour, the rodmen will be the key to progress. The instrumentman will maintain a hand or electronic notebook, recording all readings for turns. The contour will be temporarily marked when located until a closure has been made and the notes verified. Mapping will be accomplished at a target scale of usually 1 inch = 500 ft.

c. Coverage. It is most probable that long traverses will be required in the lower reaches of the reservoir. In the large heavily wooded areas there will be numerous "finger" sloughs, islands, and peninsulas formed by the contour. Lines, at approximately 1 mile intervals, originating on control at the river banks should be run more or less normal to river, cross section style, a sufficient distance outward to encompass the clearing limit contour and then tied together to form loops. In running these lines, all points where the contour is crossed should be flagged and control points left for continuance of surveys. These lines would serve a dual purpose to locate areas under the clearing limit contour and, after adjustment, as control from which the surveys can be extended. Open areas will be delineated on the map, with proper annotation, such as "cultivated," "pasture," "pasture with scattered trees," "scattered brush and trees," or whatever, so that a classification of type clearing can be made. In large cleared areas the contour can be shot directly on aerial photos, if desired.

d. Markings. Trees standing on or very near the clearing line will be marked in accordance with specifications. These markings shall be placed at intervals such that they are readily intervisible at distances commensurate with the woods cover. All abrupt changes in direction shall be well marked at the point of turn and other prominent trees nearby in both directions. The contour will be marked in open areas--generally at 500 ft to 1000 ft intervals--or closer when required to show important changes in direction. Points where the marked contour is discontinued or resumed (such as the contour entering stream banks or a wildlife and fish habitat area where marking is not required) will be prominently marked. One or more trees should a marked, or enough to insure that this point is readily visible and identifiable.

e. Miscellaneous. Where no surveying of the contour is required within the riverbanks, careful watch for breakouts must be maintained. This may require leveling along the riverbanks and exploration of the mouths of the streams, ditches, sloughs to ensure that the contour is also confined and, therefore, information is needed from which to make a rigid estimate of the acreage involved. In the course of the survey the contour will be outlined and this should be sufficient to determine the length of each area. The width, from the contour down to the timberline next to the water's edge, must be obtained at proper intervals to furnish an excellent average width. Points where these widths are obtained and the widths shall be plotted.

2-10. Upland Disposal Area Surveys

Disposal areas are usually acquired in fee simple and thus will be surveyed and monumented in accordance with state or local codes and standards. Clearing of these areas will be on a graduated basis and it will be necessary under the clearing limit to part off only the portions of the areas required for the original dredging. Limits of the required areas will be furnished to the survey party, and the survey work can be accomplished using the area boundary monuments as control. These limits will be defined on the ground by appropriate markings. The clearing in the disposal areas will be of lesser quality than the reservoir clearing, so that clearing contour marking will prevail and the contour should be marked in the spoil areas as elsewhere.

2-11. Channel Improvement and Cutoff Surveys

These areas require modified grubbing in addition to clearing and will have to be delineated differently from the normal reservoir clearing. The clearing and grubbing lines for these features are usually outlined in detail on the hydrographic maps and the cut off topographic maps. Using the existing ground control and these layouts, these limits will be established. All angle points in these limits will be marked on the nearest tree. Enough intervening trees to promote intervisibility will be marked. In order to furnish data for a close estimate of area of the channel improvement sites, the streamward edge of the timber shall be shown. Open areas within the cutoff confines will also be shown. This clearing will be of a higher grade and take precedence over the regular reservoir clearing. If it is found that the clearing contour passes through any other channel improvement clearing areas, and at the cutoff areas, marking should be discontinued at the intersection. No marking of the clearing limit contour will be done in the areas of clearing for channel improvement. Clearing maps will be presented as line drawn maps, using the reservoir mapping as a base and utilizing the cultural data, stream outlines, etc.

2-12. Post-Flood High Water Mark Surveys

High water marks are evidence of the highest stages reached by a flood. There are many different types of marks and the proper identification of them is the key to getting meaningful data. For this reason the most experienced man in the field party shall be used to locate the marks. High water marks tend to disappear rapidly after the flood peak. Thus, the survey should be started as soon as possible after the peak. Marks should be identified by means of stakes, flagging, paint, nails, crayon, etc., and field sketches made of locations to guide future survey work. Elevations can be obtained for the marks when time permits. Criteria for selecting high water marks are as follows:

- Marks should be selected on surfaces parallel to the line of flow so that they represent the water surface and not the energy grade line of the stream.
- Often small seeds of various plants will provide excellent high water marks, remaining in the crevices of bark or in cracks in fence posts or utility poles. The highest of such particles should be used.

- Mud or silt will often leave easily recognizable lines along banks or on trees, brush, rocks, buildings, etc.
- Excellent high water marks may be found on buildings within the flood plane. Excellent marks may be found on windowpanes or screens. However, care must be exercised not to select marks on the upstream side of the building, which may have been affected by velocity head.
- Residents may afford a valuable source of information when evidence has been cleaned up or destroyed by rain. Such information may be particularly reliable where the water has come into buildings on the premises.

Poorly defined high water marks:

- Drift found on bushes or trees in or near the channel may afford false information. On trees the buildup on the upstream side caused by current may cause an abnormally high reading, and conversely on the downstream side. Bushes may bend with the current and, after the slowdown, straighten up to lift the drift above the peak flood elevation.
- Foam lines, commonly found on bridge abutments, wingwalls, riprap, poles, trees, etc., may be affected by velocity head pileup.
- Wash lines are usually poor.
- Information from residents after passage of time and destruction of evidence, especially when remote from place of residence.

The type of marks should be fully described to facilitate recovery by others. Examples include "drift on bank," "drift on tree," "wash line," "silt line on post," etc. Marks should be rated as "excellent," "good," "fair," or "poor." Attribute data may include:

- Number, river or basin, bank of river.
- Month and year of flood.
- State, county, nearest town.
- Section, Township, Range, if possible.
- Specific location by description from nearest town, etc.
- Specific description of mark, e.g., "nail in post."
- Source of information.
- Type of mark.
- Sketch on right hand page of notebook.

If possible, mark may be tied to existing horizontal control. Otherwise, autonomous/differential GPS or spotting on quadrangle or other map may be the only available method of locating, especially in remote areas. All marks should be leveled to Third Order accuracy standards. Readings should be to nearest 0.01 ft. A TBM should be set in the vicinity to facilitate ties to any future comparative marks.

2-13. Route Surveys

Route surveys are most commonly used for levees, stream channels, highways, railways, canals, power transmission lines, pipelines, and other utilities. In general, route surveys consist of:

- Determining ground configuration and the location of objects within and along a proposed route.
- Establishing the linear or curvilinear alignment of the route.
- Determining volumes of earthwork required for construction.

After the initial staking of the alignment has been closed through a set of primary control points and adjustments have been made, center-line/baseline stationing will identify all points established on the route. Differential levels are established through the area from two benchmarks previously established. Cross-sections in the past were taken left and right of centerline. Today digital terrain models (DTM) or photogrammetry is used to produce cross-sections for design grades. Surveys may be conducted to check these sections at intermittent stations along the centerline. Ground elevations and features will be recorded as required.

2-14. Bridge Surveys

Bridge surveys are often required for navigation projects. In many instances, a plan of the bridge may be available from the highway department, county engineer, railroad, etc. When as-built drawings can be obtained, it may be substituted for portions of the data required herein. However, an accuracy check should be made in the field. Field survey measurements should include the elevation of bridge floor, low steel, and a ground section under bridge to present an accurate portrait of the bridge opening. Piers, bents, and piling should be located with widths or thicknesses being measured so that their volume can be computed and deducted from the effective opening under the bridge. Superstructure is not important and need not be shown. However, guardrail elevations should be obtained and the rails described as to whether they are of solid or open construction. A very brief description of bridge as to type of construction (wood, steel, concrete, etc.) and its general condition should be furnished. If wingwalls exist, minimum measurements should be made to draw them in proper perspective. Sketches of existing bridges may be required on many of the various types of surveys performed by a District. Obtain digital photographs of all bridges. All photographs should be carefully indexed, and a sketch made to show approximate position and angle of each exposure. In general, survey data to be included on bridge survey field notes should include:

- Direction facing bridge, whether upstream or downstream.
- Length of bridge, or stationing if established.
- Distances from center to center of piers or bents.
- Dimensions of piers or pilings including batter.
- Low chord (or steel) elevation over channel.
- Profile of bridge deck, roadway, handrail, etc.
- Sketch of plan of bridge, when required, showing deck dimensions including girder size and spacing.
- Sketch of typical bent, when required, including cap size.
- Sketch of wingwall, when required.
- Digital photographs from various aspects.
- Material of which constructed (wood, steel, concrete, prestressed concrete, etc.).
- Type of construction, such as truss, trestle, or girder.
- General condition of bridge.
- Alignment of bridge to channel, whether normal or at angle (may be shown on plan sketch).
- Alignment of piers or bents, whether normal or at angle.
- Composition of bents may be indicated on sketch.
- Designation of highway, road, street, railroad, etc., utilizing bridge--describe surface, if road.

An example of field notes for a typical bridge survey is shown in Chapter 12.

2-15. Artillery Surveys (FM 3-34.331)

The Field Artillery (FA) is a primary user of precise positioning and orientation information in a wartime environment. Topographic survey support must be provided to multiple launch rocket system (MLRS) units, Corps's general support units, and other nondivisional assets in the Corps area. The FA requires that topographic surveyors:

- Establish and recover monumented survey control points (SCPs)--horizontal and vertical--and azimuthal references for conventional and inertial FA survey teams.
- Coordinate the exact position of the high-order control with the Corps's survey officer.
- Augment FA survey sections when appropriate.

Topographic-engineer companies are the primary source of topographic support throughout the Echelons above Corps (EAC) and general support. Topographic companies support artillery surveys by:

- Extending horizontal and vertical control into the corps and division areas.
- Providing a survey planning and coordination element (SPCE) in support of the EAC.
- Providing mapping-survey control where required.
- Advising on topographic matters.
- Assisting in lower-level surveys to augment FA surveys.

Additional details on field artillery surveys are found in Chapter 9 of FM 3-34.331

2-16. Airport Obstruction and NAVAID Surveys (FM 3-34.331)

Airfield-obstruction and NAVAID surveying operations involve obtaining accurate and complete NAVAID (and associated airport/heliport-obstruction) and geodetic positioning data. Airport obstruction chart (AOC) surveys provide source information on:

- Runways and stopways.
- NAVAIDs.
- Federal Aviation Regulation defined obstructions.
- Aircraft-movement aprons.
- Prominent airport buildings.
- Selected roads and other traverse ways.
- Cultural and natural features of landmark value.
- Miscellaneous and special-request items.

a. NSRS connection requirements. AOC surveys also establish or verify geodetic control in the airport vicinity is accurately connected to the NSRS. This control and the NSRS connection ensure accurate relativity between these points on the airport and other surveyed points in the NSRS, including GPS navigational satellites. AOC data is used to:

- Develop instrument approach and departure procedures.
- Determine maximum takeoff weights.
- Certify airports for certain types of operations.
- Update official aeronautical publications.

- Provide geodetic control for engineering projects related to runway/taxiway construction, NAVAID positioning, obstruction clearing, and other airport improvements.
- Assist in airport planning and land-use studies.
- Support activities such as aircraft accident investigations and special projects.

b. Survey standards. Federal Aviation Administration Publication 405 (*Standards for Aeronautical Surveys and Related Products*, Fourth Edition., 1996.) and Federal Aviation Regulation 77 (*Objects Affecting Navigable Airspace*, 15 July 1996) outline the requirements for AOC surveys. Various areas, surfaces, reference points, dimensions, and specifications used in airfield surveys are described in these references.

c. Runway surveys. All length and width measurements are determined to the nearest foot. If the runway's threshold is displaced, the distance (in feet) is given from the beginning of the runway's surface. Determine the coordinates (latitude and longitude) of the runway's threshold and stop end at the runway's centerline. Elevations at the runway's threshold, stop end, and highest elevation (within the first 3,000 feet of each runway touchdown zone elevation [TDZE]) should be determined to the nearest 0.1 ft from the MSL. In addition, prepare runway profiles that show the elevations listed above, the runway's high and low points, grade changes, and gradients. Determine the elevation of a point on the instrumented runway's centerline nearest to the instrument landing system (ILS) and the glide-path transmitter to the nearest 0.1-ft MSL.

d. NAVAID surveys. Airports requiring airfield-obstruction and NAVAID surveys are instrumented runways. The exact point on the radar, the reflectors, the runway intercepts, and the instrument landing system (ILS) and microwave-landing-system (MLS) components depend on the survey type, the location, and the required accuracy. The requirement to verify the existing ILS/MLS, their proper description, and all components on or near the runway are mandatory. Obtain information for locating and describing all airfield features with help from airfield operation and maintenance section, and control tower personnel.

e. Obstruction surveys. An obstruction is an object or feature protruding through or above any navigational imaginary surface that poses a threat to the safe operation of aircraft. Navigational imaginary surfaces or obstruction identification surfaces are defined in Federal Aviation Regulation 77.

f. Reference. Additional details (including accuracy specifications) on airport obstruction and NAVAID surveys are found in Chapter 10 of FM 3-34.331

Figure 2-3. Airfield NAVAID positioning using Fast-Static GPS methods

2-17. Site Plan Engineering Drawings

An engineering site plan survey is a topographic (and, if necessary, hydrographic) survey from which a project is conceived, justified, designed, and built. Types of surveys that are performed for developing site plan drawings include:

- Hydrographic Surveys--surveys of USACE navigation, flood control, or reservoir projects (see EM 1110-2-1003 (*Hydrographic Surveying*).
- Beach Profile Surveys--surveys of renourishment projects, shore protection features, and structures.
- Levee Surveys--surveys of levees, revetments, and other related river control structures.
- Route Surveys--surveys of proposed or existing transportation routes.
- Quantity Surveys--surveys for construction measurement and payment.
- Structure Surveys--surveys of facilities, utilities, or structures.

The methods used in performing an engineering survey can and sometimes will involve all of the equipment and techniques available. GPS survey techniques are covered in EM 1110-1-1003 (*NAVSTAR GPS Surveying*). Many of these GPS techniques are used in establishing control for topographic surveys. Photogrammetry may also be used to produce maps of almost any scale and corresponding contour interval--see EM 1110-1-1000 (*Photogrammetric Mapping*). Profiles and cross sections may also be obtained from aerial photos. The accuracy of the photogrammetric product varies directly with the flight altitude or photo scale--these factors must be considered when planning such a project. Surveys of structural deformations are not topographic surveys. These types of surveys are detailed in EM 1110-2-1009 (*Structural Deformation Surveying*). Preliminary, General, and Detailed Site Plans are often specified, as described below.

a. Preliminary Site Plans (Pre-engineering surveys). Based on reconnaissance surveys previously described, the first plans to be prepared are preliminary site studies showing in skeleton form only the general arrangement of areas where construction will take place, circulation between them and to training areas, public roads, and serving railroads. The most convenient scale for these studies on sizeable projects has usually been 1 inch = 400 ft; on smaller projects, 1 inch = 300 or 200 ft.

b. Approved General Site Plan. Upon the basis of these studies, a general site plan, at the same scale, is reached; and serves as basis for enlargement for detailed site plans and for general utility plans described below. This approved site plan will show:

- Grid System.
- Buildings (indicate types).
- Wooded Areas
- Roads and Fences (indicate roadway widths and types of base and surface).
- Service and Parking Areas.
- Rail Facilities, including access to serving railroad.
- Use Areas of all kinds (runways, aprons, firebreaks, parade grounds, etc.)

c. Detailed Site Plans. Based on the topographic surveys described above, and enlarged from the approved preliminary site plan, detailed site plans at the scale of 1 inch = 200 ft or larger are prepared. In the case of large developments such as cantonments, the detailed site plans often encompass an area about equal to that utilized by a regiment and may be drawn at as large a scale as 1 inch = 50 ft. The detailed site plans serve as a basis for detailed utility plans.

2-18. Army Installation Mapping Requirements

Each installation is guided by its respective service's comprehensive or master planning requirements. Each installation, depending on its mission, may have substantially more or fewer theme specific maps. It is the responsibility of the installation's planning, environmental operations, engineering, and administrative staff to understand the mapping needs for their installation. Each installation is unique and the specific quantity and type of maps required for an installation depend upon its individual features, conditions, and requirements. An installation will generally produce and maintain a set of maps to meet both its planning and operational needs. The following list (from ERDC/ITL 1999b--*CADD/GIS Technology Center Guidelines for Installation Mapping and Geospatial Data*) is representative of the geospatial map layers needed on a typical installation.

A-Natural and Cultural Resources
A-1 Areas of Critical Concern
- Historic Preservation and Archeology
- Threatened and Endangered Species
- Wetlands & Floodplains
- State Coastal Zones
- Lakes, Rivers, Streams, and Water Bodies
- Soil Borings & Soil Types
A-2 Management Areas
- Geology, including Surface Features
- Topography & Physiology
- Hydrology
- Vegetation Types
- Forest (Commercial Timber)
- Agriculture Grazing/Crops
- Fish and Wildlife
- Prime & Unique Soils
- Grounds Categories
- Climate & Weather
- Bird Aircraft Strike Hazard (BASH)
- Outdoor Recreation
- Pest Management

B-Environmental Quality
B-1 Environmental Regulatory
- Hazardous Waste Generation Points
- Permitted Hazardous Facilities
- Solid Waste Generation Points
- Solid Waste Disposal Locations
- Fuel Storage Tanks
- Installation Restoration Program (IRP)
B-2 Environmental Emissions
- Air Emission
- Waste Water NPDES Discharge
- Storm Water NPDES Discharge
- Drinking Water Supply Sources
- Electromagnetic and Radiation Sources
- Radon Sources

C-Layout and Vicinity Maps
C-1 Installation Layout
C-2 Off-base Sites
C-3 Regional Location
C-4 Vicinity Location
C-5 Aerial Photographs
C-6 Installation Boundary

D-Land Use
D-1 Existing Land Use
D-1.1 Future Land Use
D-2 Off-base Sites Land Use
D-2.1 Off-base Sites Future Land Use
D-3 Real Estate
D 4 Explosive Safety Quantity-Distance (QD) Arc
D-5 Hazard Analysis Constraints
D-6 Composite Installation Constraints and Opportunities
D-7 Area Development

E-Airfield Operations
E-1 On base Obstruction to Airfield and Airspace Criteria
E-2 Approach and Departure - Zone Obstructions to 10,000 Ft
E-3 Approach and Departure Zone Obstructions Beyond 10,000 Ft
E-4 Airspace Obstruction - Vicinity
E-5 Terminal Enroute Procedures (TERPS) Automation Plan
E-6 Airfield and Airspace Clearances
- Waivers
- Clear Zones
- Primary Surfaces
- Transitional Surface (7:1)
- Approach &Departure Surface (50:1)
- Approach and Taxiway Clearances
E-7 Airfield Pavement Plan
E-8 Airfield Pavement Details
E-9 Aircraft Parking Plan
E-9.1 Proposed Aircraft Parking Plan
E-10 Airfield Lighting Systems

F- Reserved
F-1 Reserved
F-2 Reserved

G-Utilities System Plan
G-1 Water Supply System
G-2 Sanitary Sewerage System
G-3 Storm Drainage System
G-4 Electrical Distribution System (Street & Airfield)
G-5 Central Heating and Cooling System
G-6 Natural Gas Distribution System
G-7 Liquid Fuel System
G-8 Cathodic Protection System
G-9 Cathodic Protection System Details
G-10 Industrial Waste and Drain System
G-11 Composite Utility System Constraints
G-11.1 Central Aircraft Support System
G-12 Other Utility Systems

H-Communication and NAVAID Systems
H-1 Installation Communication (Base and civilian communications units)
H-2 NAVAIDs and Weather Facilities

I-Transportation System
I-1 Community Network Access to Base
I-2 On-base Network
I-2.1 Future Transportation Plan

J-Energy Plan

K-Architectural Compatibility

L-Landscape Development Area

M-Future Development
M-1 Current Status
M-2 Short-Range Development
M-3 Long-Range Development

N-Reserved
N-1 Reserved
N-2 Reserved

O- Force Protection
O-1 Surge Capability (Beddown and Support of Deployed Forces)
O-2 Physical Security
O-3 Disaster Preparedness Crash Grid Map
O-4 Air Base Survivability and Theater-Specific Requirements

P - Ports and Harbors

R - Range and Training Areas

The CADD/GIS Technology Center schema (i.e., database structure/format) for installation maps uses "entity sets" to classify graphic (maps) and non-graphic data (tabular files, reports, database files. etc.). The overall structure is based upon the concept of features, attributes, and values. There are 26 entity sets listed in the latest release of the Spatial Data Standard for Facilities, Infrastructure, and Environment (SDSFIE):

Auditory
Boundary
Buildings
Cadastre
Climate
Common
Communications
Cultural
Demographics
Ecology
Environmental Hazards
Fauna
Flora
Future Projects
Geodetic
Geology
Hydrography
Improvement
Land Status
Landform
Military Operations
Olfactory
Soil
Transportation
Utilities
Visual

These 26 entity sets are further broken down into Entity Class, Entity Type, and Entity (attributes, descriptors, ranges, etc.), as shown for a typical feature in the plate below.

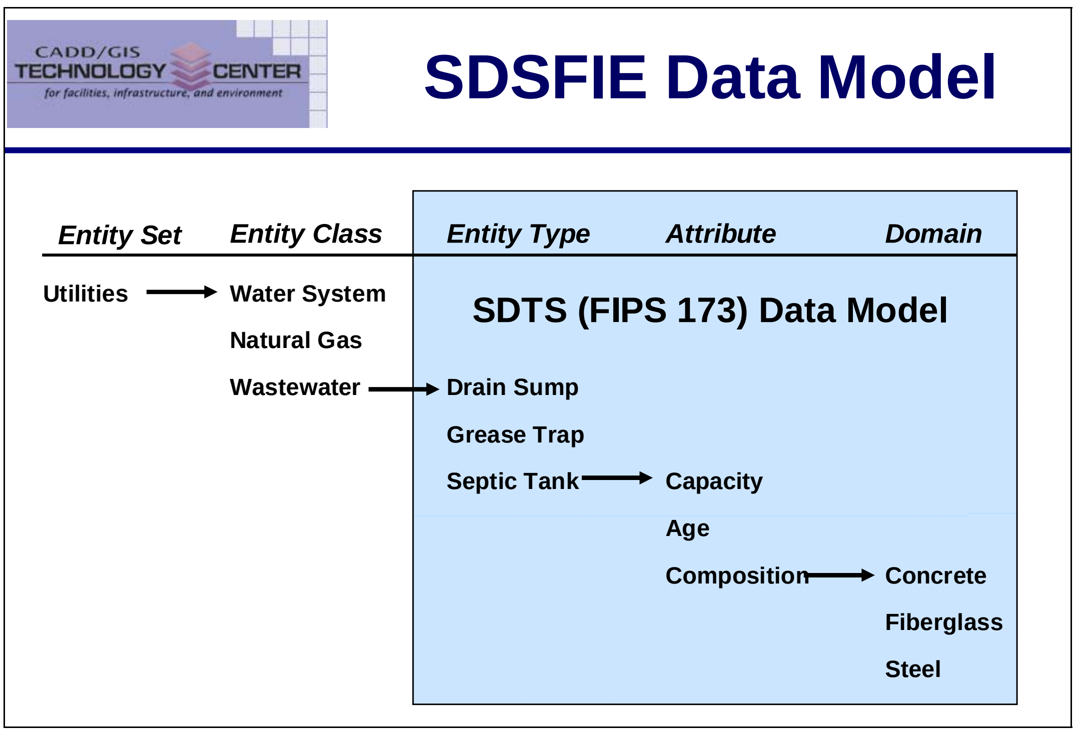

Figure 2-4. Spatial data feature and attribute breakdown for a septic tank (SDSFIE Release 2.300)

Maps supporting Army installations are expected to conform to the SDSFIE data model, and the related Facility Management Standard for Facilities, Infrastructure, and Environment (FMSFIE) non-graphic tables and elements.

SECTION II
Survey Methods and Techniques

This section provides an overview of the past and present instruments and methods used to perform topographic surveys of sites, facilities, or infrastructure.

2-19. Older Topographic Surveying Methods

Prior to the advent of total stations, GPS, LIDAR, and data collector systems, transit and plane table topographic surveying methods and instruments were once standard. They are rarely used today, other than perhaps for small surveys when a total station or RTK system is not available. However, the basic field considerations regarding detail and accuracy have not changed, and field observing methods with total stations or RTK are not significantly different from the older survey techniques briefly described in the following sections.

a. Transit-Tape (Chain). Transit tape topographic surveys can be used to locate points from which a map may be drawn. The method generally requires that all observed data be recorded in a field book and the map plotted in the office. Angles from a known station are measured from another known station or azimuth mark to the point to be located and the distance taped (or chained) from the instrument to the point. Transit-tape surveys typically set a baseline along which cross-section hubs were occupied and topographic features were shot in on each cross-section. The elevation of an offset point on a section is determined by vertical angle observations from the transit. The slope or horizontal distance to the offset point is obtained by chaining. The accuracy may be slightly better than the plane table-alidade method or very high (0.1 ft or less), depending upon the equipment combinations used. Transits are still used by some surveying and engineering firms, although on a declining basis if electronic total station equipment is available. Transit-tape surveys can be used for small jobs, such as staking out recreational fields, simple residential lot (mortgage) surveys, and aligning and setting grade for small construction projects. Assuming the project is small and an experienced operator is available, this type of survey method can be effective if no alternative positioning method is available. Detailed procedures for performing and recording transit tape topographic surveys can be found in most of the referenced survey texts listed at Section A-2.

b. Chaining. 100, 200, 300, or 500-foot steel tapes are used for manual distance measurement methods. Woven, cloth, and other types of tapes may also be used for lower accuracy measurements. Maintaining any level of accuracy (e.g., better than 1: 5,000) with a steel tape is a difficult process, and requires two experienced persons. Mistakes/blunders are common. Tapes must be accurately aligned over the points (using plumb bobs), held at a constant, measured tension, and held horizontally (using hand levels). Subsequent corrections for tape sag/tension, temperature, and slope may be necessary if a higher accuracy is required. Taping methods, errors, and corrections are not covered in this manual but may be found in any of the basic surveying texts listed at Appendix A-2.

c. Transit-Stadia. Transit-stadia topographic surveys are performed similarly to transit-tape surveys described above. The only difference is that distances to offset topographic points are measured by stadia "tacheometry" means-- i.e., using the distance proportionate ratio of the horizontal cross hairs in the transit telescope. The multiple horizontal crosshairs in the transit scope can be used to determine distance when observations are made on a level rod at the remote point. This distance measurement technique has been used for decades, and is also the basis of plane table survey distance measurement. The three horizontal crosshairs in the transit are spaced such that the upper and lower crosshair will read 1.0 ft on a rod 100 ft distant from the transit--a "stadia constant" ratio of 100 : 1. (Not all instruments have an even 100 : 1 stadia constant). The accuracy of a stadia-derived distance is not good--probably about 1 : 500 at best. Thus, a 500 ft shot could have an error of ± 1 ft. Additional errors (and corrections) result from inclined stadia measurements, i.e., when the shot is not horizontal. Reduction of the stadia intercept values to a nominal slope distance, then reduction to horizontal, requires significant computation or use of tables. Transit-stadia was often used like a modern day total station in that topo detail could be densified (typically using radial survey methods) from a single instrument setup. All observed data was recorded in a field book, and occasionally optionally plotted in the field. Transit-stadia techniques are likewise rarely performed today if a total station is available. Details on stadia measurement methods are found in any surveying textbook--e.g., Kavanagh 1997.

d. Transit/Theodolite-EDM. Electronic Distance Measurement (EDM) instruments were first developed in the 1950s, primarily for geodetic operations. In the 1970s, more compact EDM units were mounted atop or alongside transits and theodolites--thus replacing manual chaining or optical stadia distance measurement. Observed data were still recorded in field books for later office hand plotting. These crude transit-EDM combinations were the early forerunner of the modern total stations. During this time, methods were developed for automated drafting of observed features--after individual angles and distances and features were encoded on punch cards and input to a computer/plotter system.

Figure 2-5. Plane table and alidade--Wild T-2 theodolite at right (USC&GS, ca 1960s)

e. Plane table surveying. The plane table and alidade were once the most common tools used to produce detailed site plan maps in the field. The Egyptians are said to have been the first to use a plane table to make large-scale accurate survey maps to represent natural features and man-made structures. Plane table mapping is rarely done today--plane table surveying has, for most purposes, been replaced by aerial photogrammetry and total stations, but the final map is still similar. Plane table surveys were performed in the Corps well into the 1980s, and perhaps into the 1990s in some districts. A plane table survey system is described as follows: A blank map upon which control points and grid ticks have been plotted is mounted on the plane table. The table is mounted on a low tripod with a specially made head--see Figure 2-5 above. The head swivels so that it can be leveled, locked in the level position, and then be rotated so that the base map can be oriented. The base map is a scaled plot of the ground control stations.

Thus, with the table set up over one of the stations, it can be rotated so that the plotted stations lie in their true orientation relative to the points on the ground. Spot elevations and located features are located with an alidade, an instrument that uses optical stadia to determine distance (similar to the transit stadia). The error of a map produced with a plane table and alidade varies across the map as the error in stadia measurements varies with distance. Horizontal errors may range from 0.2 ft at 300 feet, to 10 ft or more at 1,000 feet. Since the elevation of the point is determined from the stadia measurement, relative errors in the vertical result. The plane table survey resulted in a “field-finished” map product, with all quality control and quality assurance performed in the field by the party chief/surveyor. The site plan map delivered from the plane table was immediately suitable for overlaying design detail. Modern day electronic survey and CADD systems are still attempting to attain the same level of “field-finish” capability that the plane table once produced. Older editions of this manual or the surveying textbooks listed in Section A-2 should be consulted if more detailed information on plane table survey techniques and alidade observations is needed.

Figure 2-6. Leica TCR 705 Reflectorless Total Station

2-20. Total Stations

Total stations were first developed in the 1980s by Hewlett-Packard (Brinker and Minnick 1995). These instruments sensed horizontal and vertical angles electronically instead of optically, and combined them with an EDM slope distance to output the X-Y-Z coordinates of a point relative to the instrument's X-Y-Z coordinates. Electronic theodolites operate in a manner similar to optical instruments. Angle readings can be to 1" with precision to 0.5". Digital readouts eliminate the uncertainty associated with reading and interpolating scale and micrometer data. The electronic angle-measurement system eliminates the horizontal- and vertical-angle errors that normally occur in conventional theodolites. Measurements are based on reading an integrated signal over the surface of the electronic device that produces a mean angular value and eliminates the inaccuracies from eccentricity and circle graduation. These instruments also are equipped with a dual-axis compensator, which automatically corrects both horizontal and vertical angles for any deviation in the plumb line. An EDM device is added to the theodolite and allows for the simultaneous measurements of the angle and the distance. With the addition of a data collector, the total station interfaces directly with onboard microprocessors, external PCs, and software. The ability to perform all measurements and to record the data with a single device has revolutionized surveying. Total stations perform the following basic functions:

Types of measurements:
- Slope distance
- Horizontal angle
- Vertical angle

Operator input to total station data collector:
- Text (date, job number, crew, etc.)
- Atmospheric corrections (PPM)
- Geodetic/grid definitions
- HI & HR
- Descriptor/attribute of setup point, backsight point, sideshot point, stakeout point, etc

In general, there are three types of total station operating modes:

- Reflector--total station requires a solid reflector or retroreflector signal return from the remote point to resolve digital angles and distances. Prisms are attached to a pole positioned over a feature. Requires two-man field crew--operator and rodman.

- Reflectorless--the total station will resolve (and coordinate) signal returns off natural features. Distances may be far more limited than those obtained from reflectors ... typically less than 1,000 ft. Allows for more economical one-man field crew operation.

- Robotic--total station self-tracks single operator/rodman at remote shot or stakeout points. One-man crew operation, with operator normally based at remote rod point.

Additional details on total stations are covered in Chapter 8. Total stations are also extensively covered in the text references listed at Appendix A-2--e.g., Wolf and Ghilani 2002.

Figure 2-7. RTK base station and radio link transmitter--and rover with backpack (Key West Harbor Dredging Project 2004--C&C Technologies, Inc. & Jacksonville District)

2-21. Real Time Kinematic (RTK) GPS

RTK survey methods have become widely used for accurate engineering and construction surveys, including topographic site plan mapping, construction stake out, construction equipment location, and hydrographic surveying. RTK survey systems operate in a similar fashion as the robotic total station, with one major exception being that a visual line of sight between the reference point and remote data collection point is not required. Both RTK and total stations use similar data collection routines and methods, and can perform identical COGO stake out functions. Kinematic surveying is a GPS carrier phase surveying technique that allows the user to rapidly and accurately measure baselines while moving from one point to the next, stopping only briefly at the unknown points, or in dynamic motion such as a survey boat or aircraft. A reference receiver is set up at a known station and a remote, or rover, receiver traverses between the unknown points to be positioned. The data is collected and processed (either in real-time or post-time) to obtain accurate positions to the centimeter level. Real-time kinematic solutions of X-Y-Z locations using the carrier (not code) phase are referred to as "real-time kinematic" (RTK) surveys. However, included in this definition are "post-processed real-time kinematic" (PPRTK) techniques where the kinematic solution is not actually performed in "real-time." RTK (or PPRTK) survey techniques require some form of initialization to resolve the carrier phase ambiguities. This is done in real-time using "On-the-Fly" (OTF) processing techniques. Periodic loss of satellite lock can be tolerated and no static initialization is required to regain the integers. This differs from other GPS techniques that require static initialization while the user is stationary. A communication link between the reference and rover receivers is required to maintain a real-time solution. Additional details on performing topographic surveys with RTK are covered in Chapter 9.

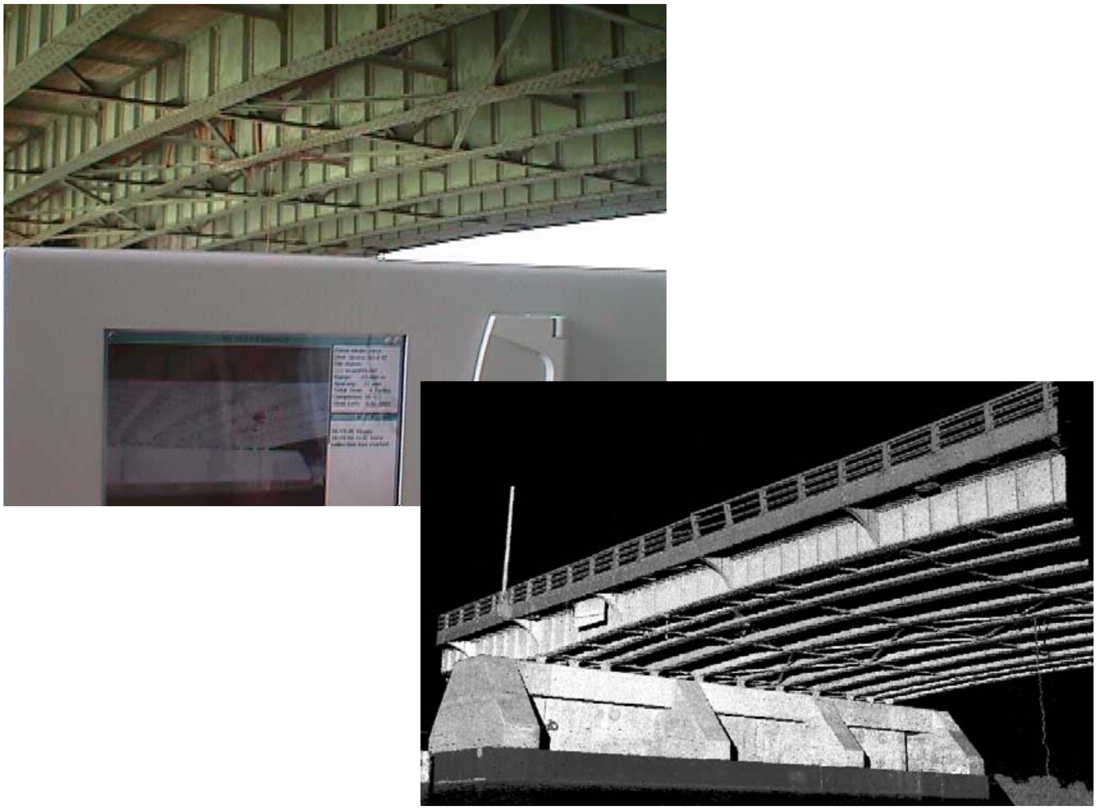

Figure 2-8. Optech LIDAR scanner and resultant image of underside of Kennedy Bridge (Arc Surveying & Mapping, Inc.--Puerto Rico 2002)

2-22. Terrestrial LIDAR (Laser) Scanning

Laser scanning instruments have been developed that will provide topographic detail of structures and facilities at an extremely high density, as shown in Figure 2-8 above. These tripod-mounted instruments operate similarly to a reflectorless total station. However, they are capable of scanning the entire field of view with centimeter-level pixel density in some cases. A full 3D model of a project site or facility results from the scan. This model must be edited and feature attributes added. See Chapter 10 for additional descriptions of terrestrial LIDAR survey procedures and applications.

2-23. Topographic Data Collection Procedures

Uniform operating procedures are needed to avoid confusion when collecting topographic survey data, especially for detailed utility surveys. The use of proper field procedures is essential to prevent confusion in generating the final site plan map. Collection of survey points in a meaningful pattern aids in identifying map features. The following guidelines are applicable to all types of topographic survey methods, including total stations and RTK systems.

a. Establish primary horizontal and vertical control for radial survey. This includes bringing control into the site and establishing setup points for the radial survey. Primary control is usually brought into the site from established NSRS monuments/benchmarks using static or kinematic GPS survey methods and/or differential leveling. Supplemental traverses between radial setup points can be conducted with a total station as the radial survey is being performed. A RTK system may require only one setup base; however, supplemental checkpoints may be required for site calibration. Elevations are established for the radial traverse points and/or RTK calibration points using conventional leveling techniques. Total station trigonometric elevations or RTK elevations may be used if vertical accuracy is not critical--i.e., ± 0.1 ft.

b. Perform radial surveys to obtain information for mapping. Set the total station or RTK base over control points established as described above. Measure and record the distance from the control point up to the electronic center of the instrument (HI), as well as the height of the prism or RTK antenna on the prism pole (HR). To prevent significant errors in the elevations, the surveyor must report and record any change in the height of the prism pole. For accuracy, use a suitable prism and target that matches optical and electrical offsets of the total station. Use of fixed-height (e.g., 2-meter) prism poles is recommended for total station or RTK observations, where practical.

c. Collect topographic feature data in a specific sequence. Collect planimetric features (roads, buildings, etc.) first. Enter ground elevation data points needed to fully define the topography. Observe and define break lines. Use the break lines in the process of interpolating the contours to establish regions for each interpolation set. Contour interpolation will not cross break lines. Assume that features such as road edges or streams are break lines. They do not need to be redefined. Enter any additional definition of ridges, vertical, fault lines, and other features.

d. Draw a sketch of planimetric features. A field book sketch or video of planimetric features is an essential ingredient to proper deciphering of field data. The sketch may also be made on a pen tablet PC. The sketch does not need to be drawn to scale and may be crude, but must be complete. Numbers listed on the sketch show point locations. The sketch helps the CADD operator who has probably never been to the jobsite confirm that the feature codes are correct by checking the sketch.

e. Obtain points in sequence. The translation of field data to a CADD program will connect points that have codes associated with linear features (such as the edge of road) if the points are obtained in sequence. For example, the surveyor should define an edge of a road by giving shots at intervals on one setup. Another point code, such as natural ground, will break the sequence and will stop formation of a line on the subsequent CADD file. The surveyor should then obtain the opposite road edge. Data collector software with "field-finish" capabilities will facilitate coding of continuous features.

f. Use proper collection techniques. Using proper techniques to collect planimetric features can give automatic definition of many of these features in the CADD design file. This basic picture helps in operation orientation and results in easier completion of the features on the map. Improper techniques can create problems for office personnel during analysis of the collected data. The function performed by the surveyor in determining which points to obtain and the order in which they are gathered is crucial. This task is often done by the party chief. Cross training in office procedures gives field personnel a better understanding of proper field techniques.

(1) Most crews will make and record 250 to over 1,000 measurements per day, depending on the shot point detail required. This includes any notes that must be put into the system to define what was measured. A learning curve is involved in the establishment of productivity standards. A crew usually has to complete five to six mapping projects to become confident enough with their equipment and the feature coding system to start reaching system potential.

(2) A one or two-person survey crew is most efficient when the spacing of the measurements is less than 50 feet. When working within this distance, the average rod person can acquire the next target during the time it takes the instrument operator to complete the measurement and input the codes to the data collector. The instrument operator usually spends about 20 seconds sighting a target and recording a

measurement and another 5-10 seconds coding the measurement. The same time sequences are applicable for a one-man topographic survey using a robotic total station or RTK.

(3) When the general spacing of the measurements exceeds 50 feet, having a second rod person may increase productivity. A second rod person allows the crew to have a target available for measurement when the instrument operator is ready to start another measurement coding sequence. Once the measurement is completed, the rod person can move to the next shot, and the instrument operator can code the measurement while the rod people are moving. If the distance of that move is 50 feet or greater, the instrument will be idle if you have only one rod person.

(4) Communication between rod person and instrument person is commonly done via radio or cell phone. The rodmen can work independently in taking ground shots or single features; or they can work together by leapfrogging along planimetric or topographic feature lines. When more than one rod person is used, crew members should switch jobs throughout the day. This helps to eliminate fatigue in the person operating the instrument.

2-24. Automated Field Data Collection

Since the 1990s, survey data collection has progressed from hand recording to field-finish data processing. Prior to the implementation of data collectors, control survey data and topographic feature data were recorded in a standard field book for subsequent office adjustment, processing, and plotting. Modern data collectors can perform all these functions in the field. This includes least squares adjustments of control networks, full feature attributing, symbology assignment to features, and on-screen drafting/plotting capabilities. Data collectors either are built into a total station or are separate instruments. A separate (independent) data collector is advantageous in that it can be used for a variety of survey instruments--e.g., total station, digital level, GPS receiver. Field data collector files are downloaded to an office PC platform where the field data can be edited and modified so it can be directly input into a CADD or GIS software package for subsequent design and analysis uses. Many upgraded CADD/GIS software packages can directly download field data from the collector without going through interim software (e.g., CVTPC). Subsequent chapters in this manual (i.e. Chapters 7 and 11) provide additional information on data collectors and the transition of field collected data to office processing systems.

a. Field survey books. Even with fully automated data collection, field survey books are not obsolete. They must be used as a legal record of the survey, even though most of the observational data is referenced in a data file. Field books are used to certify work performed on a project (personnel, date, time, etc.). They are also necessary to record detailed sketches of facilities, utilities, or other features that cannot be easily developed (or sketched) in a data collector. When legal boundary surveys are performed that involve ties to corners, it is recommended that supplemental observations and notes be maintained in the field book, even though a data collector is used to record the observations.

b. Field Coordinate Geometry (COGO) computations. Most data collectors now have a full field capability to perform any surveying computation required. Some of the main field computational capabilities that are found on state-of-the-art data collectors include:

- Coordinate computations from radial direction-distance observations
- Multiple angle/direction adjustments
- Offset object correction (horizontal or vertical)
- EDM meteorological, slope, and sea level reductions
- Horizontal grid and datum transformations

- Vertical datum transformations
- GPS baseline reductions (static, kinematic)
- Traverse adjustments (various methods)
- Inverse and forward position computations
- Resections (2, 3 or more point adjustments)
- Level net adjustments (trig or differential)
- RTK site calibration adjustments (regression fits)
- Construction stake out (slope, horizontal & vertical curves, transition/spiral curves, etc.)

c. Feature coding and attributing. Data collectors are designed to encode observed topographic features with a systematic identification. Similar features will have the same descriptor code--e.g., "BS" for "backsight" and "EP" for "edge of pavement." Features that are recorded in the data collector can have additional attributes added. Attributes might include details about the feature being located (e.g., the number of lamps and height of a light pole).

d. Field graphic and symbology displays. Many field data collectors have symbology libraries which can be assigned to standard features, e.g., manholes, culverts, curb lines, etc. Plotted display of collected points with symbology can be viewed on the data collector display screen, or transferred to a portable laptop screen that has a larger viewing area. This allows for a visual view in the field of observed data in order to check for errors and omissions before departing the job site. This capability is, in effect, a modern day form of a plane table.

e. Data transfer. Digital survey data collected in the field is transferred from the data collector to a laptop or desktop PC for final processing and plotting in CADD (e.g., MicroStation, AutoCAD). Both original and processed data observations are transferred. Original (raw) data includes the unreduced slope distances, HIs, HRs, backsight and foresight directions, etc. Field processed data includes items such as reduced horizontal distances, adjusted coordinates, features, attributes, symbology, etc. Many field-finish software packages can generate level/layer assignments that will be compatible with CADD packages.

f. Reference. Additional details on data collectors and COGO are covered in Chapter 7 of this manual.

2-25. Methods of Delineating and Densifying Topographic Features

A variety of methods can be used to tie in planimetric features or measure ground elevations. Some type of systematic process is used to ensure full coverage of a job site--e.g., running cross-sections from a centerline baseline or a grid pattern. Feature accuracy will also vary: an invert elevation will be shot to 0.01 ft whereas ground shots on irregular terrain are recorded to the nearest 0.1 ft; the horizontal location of a building corner or road centerline will be to the nearest 0.01 ft but a tree can be positioned to the nearest foot.

a. Cross-section survey methods. Most site plan topographic surveys are performed relative to project baselines. This is often called the “right-angle offset technique” (Kavanagh 1997). A baseline is established along a planned or existing project axis (e.g., road centerline) using standard traverse control survey methods, as shown in Figure 2-9. Intermediate points are set and marked at regular intervals along the baseline (at 50-ft or 100-ft stations with intermediate stations added at critical points). The intermediate points are marked with 2x2 inch wooden hubs, PK nails, or temporary pins with flagging. Station hubs are occupied with a transit or total station and cross-sections are taken normal to the baseline alignment. Points along the cross-section offsets are shot for feature and/or elevation. Offset alignment is done either visually, with a right-angle glass, or transit, depending on the accuracy required. Distances along offsets are measured by chaining, stadia, or EDM (i.e., total station). Detailed notes and sketches of ground shots and planimetric features are recorded in a standard field book, electronic data collector, or both. Notekeeping formats will vary with the type of project and data being collected. General industry standard notekeeping formats should be used, such as those shown in any of the texts listed under Appendix A-2. Examples of selected topographic baseline notes are shown in Figures 2-10 and 2-11 and in Chapter 12.

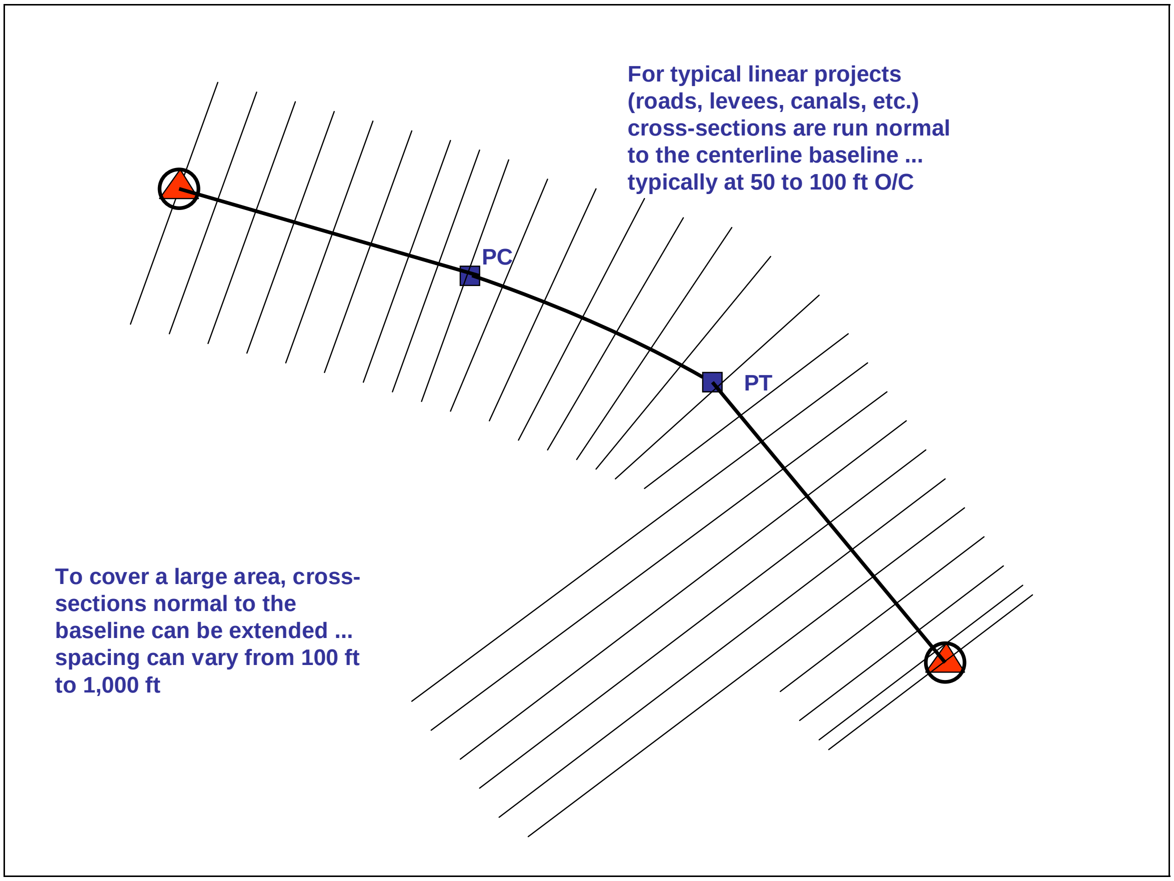

Figure 2-9. Illustration of cross-sections alignments run normal to established baselines

A grid pattern of cross-sections is also used for topographic survey of large areas, such as wetlands, orchards, swamps, etc. This is also illustrated in Figure 2-9 above where the cross-sections southeast of the PT extend a considerable distance from the baseline. In general, the maximum distance to extend the baseline is a function of the feature accuracy requirements and the precision of the survey instrument. For total stations, ground shots on a prism rod out to 1,000 ft and greater are usually acceptable. Transit stadia distances should not extend out beyond 500 ft. If coverage beyond 1,000 ft is needed, then additional baselines need to be run through the area and intermediate cross-sections should be connected between these baselines. (In current practice, this is rarely performed anymore--radial methods with a total station or RTK system are far more productive).

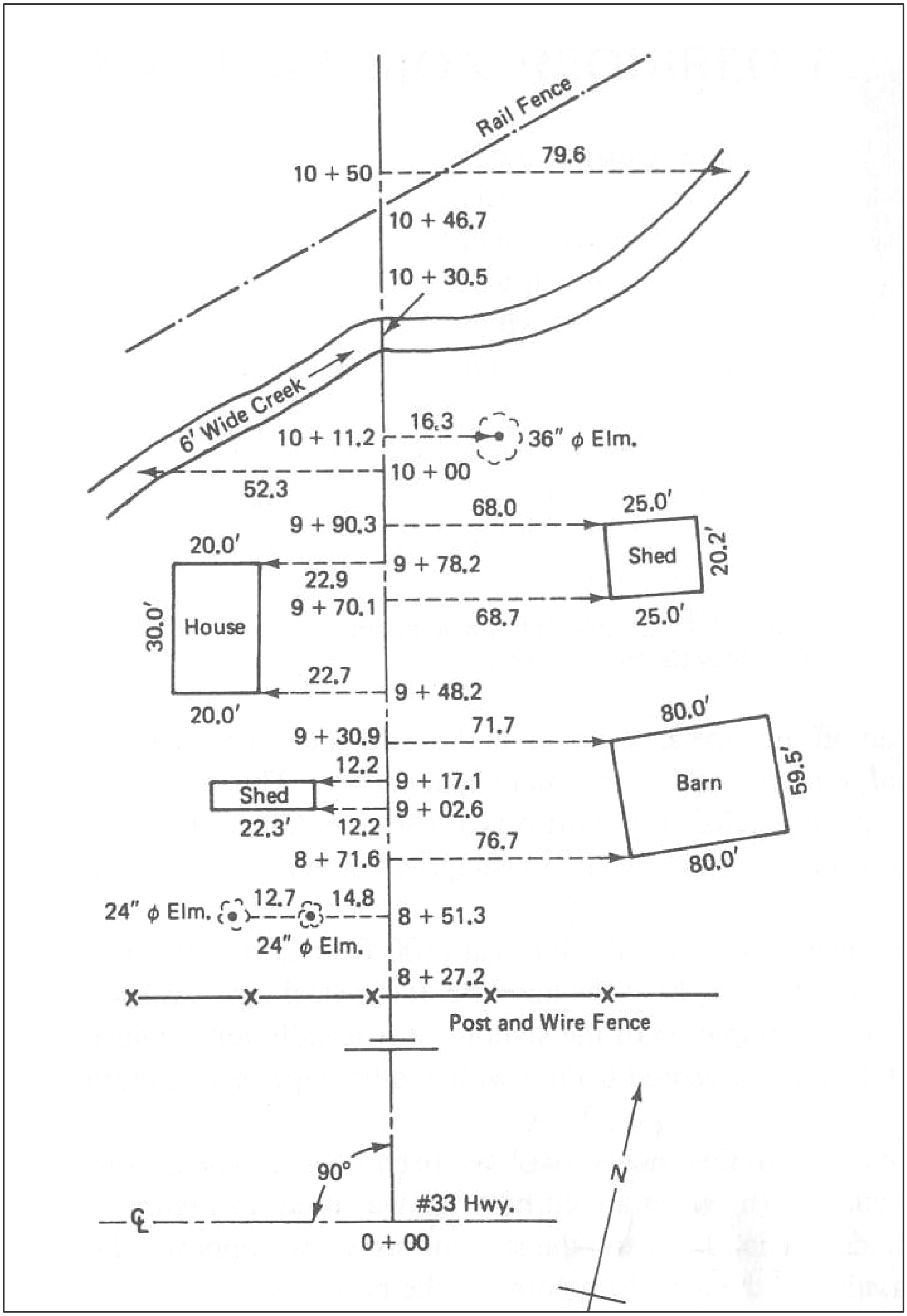

Figure 2-10. Sketch of profile line and cross-section (Kavanagh 1997)

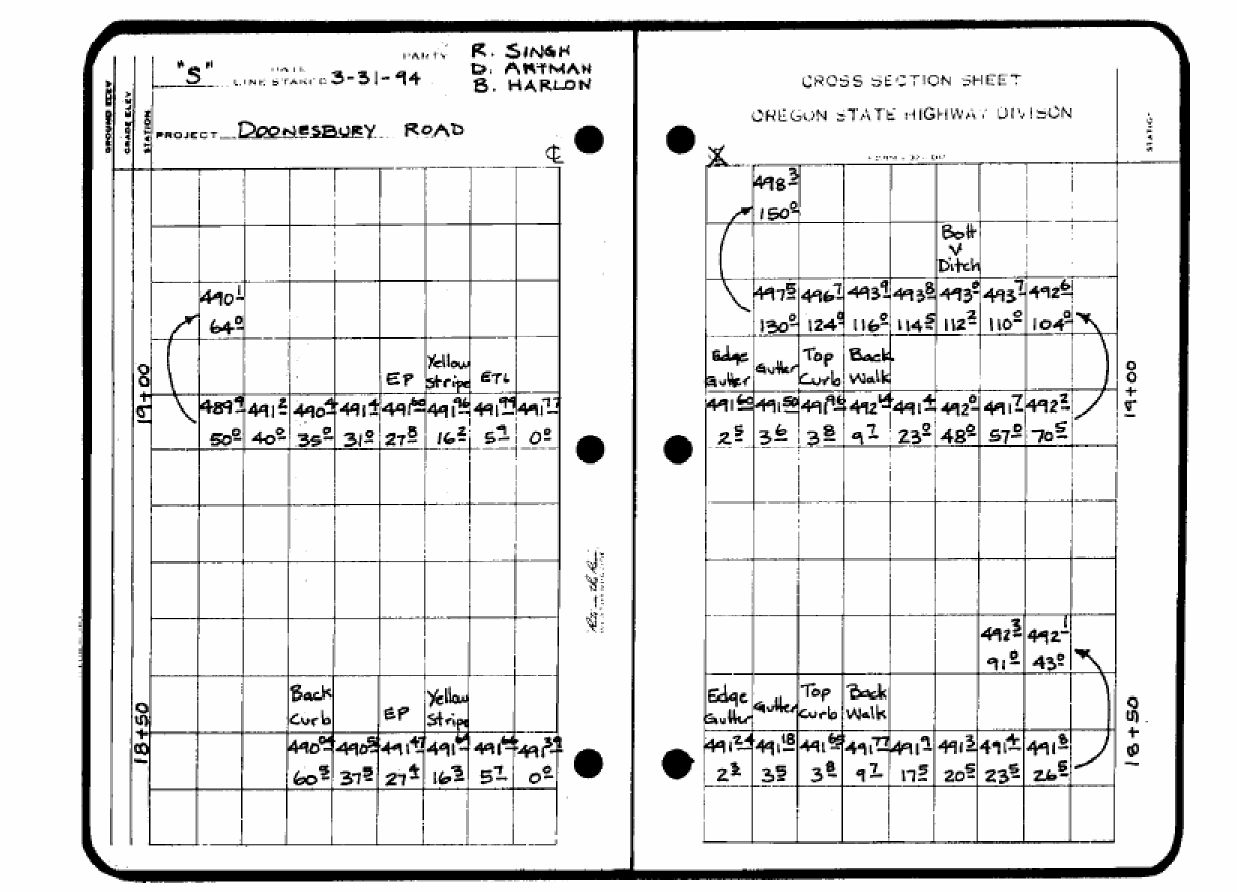

Figure 2-11. Example of field book notes showing location relative to centerline and elevation data from two cross-sections spaced 50-ft C/C (Oregon DOT 2000)

b. Radial survey methods. (Figure 2-12). Plane tables were especially suited to radial survey methods; thus, most surveys using total stations or RTK now utilize this technique. Radial observations are made with the instrument (total station or RTK base station) set up over a single point that has full project area visibility (or in the case of RTK, can encompass radio or cell phone ranges well beyond visible limitations with a total station). Thus, topographic features, baseline stakeout, and elevations can be surveyed without having to occupy separate stations along a fixed baseline. COGO packages will automatically compute radial distances and azimuths to linear or curved baseline stations, and visually guide the stakeout process. RTK surveys methods are a unique form of radial survey methods--RTK controller COGO packages are used to reduce GPS observations and guide alignment. Planimetric and ground elevation coverage is performed in a systematic pattern to ensure that the project site is adequately covered. This was straightforward on a plane table--the drawing could be viewed for omissions. On electronic data collector devices, verifying coverage before breaking down the instruments is not as easy. Data collector display screens are typically small and not all field data may have been collected using “field-finish” string (polyline) type coding.

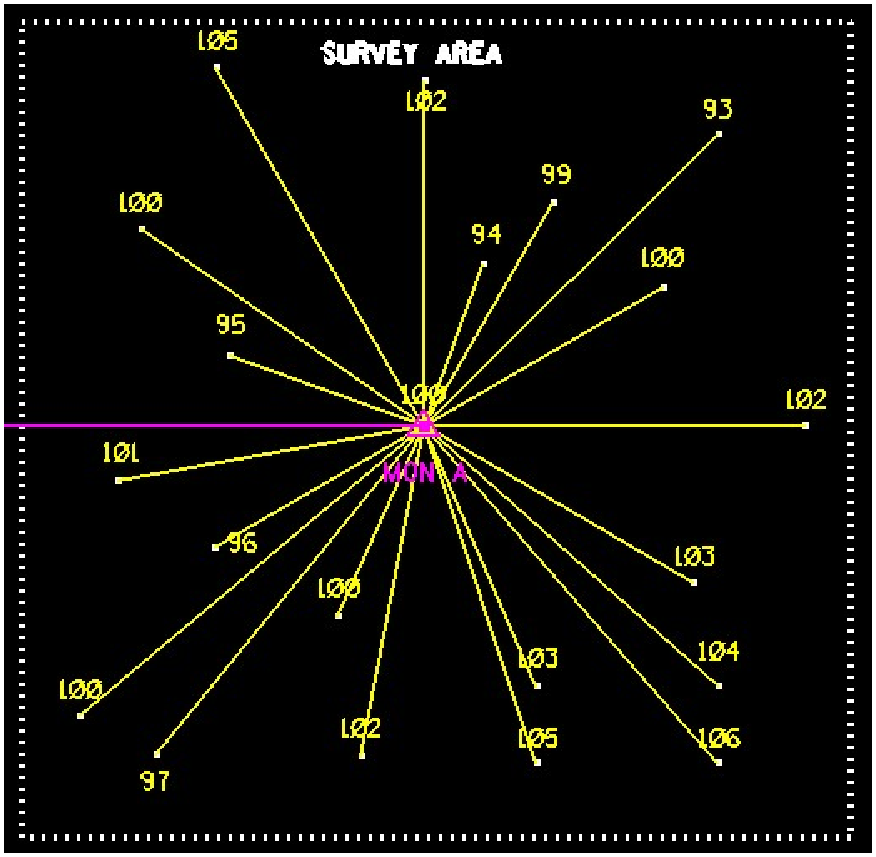

Figure 2-12. Topographic detail densification using radial survey methods--instrument set at point "MON A" and radial shot points (planimetric features or elevations) are observed

c. Planimetric features. Planimetric features are tied in using either cross-section or radial survey methods. The amount of detail required on a feature depends on the nature of the project and the size of the feature relative to the target scale. On small-scale topographic mapping projects, a generic symbol may be used to represent a feature; however, on a detailed drawing for this same project, the feature may be fully dimensioned. An example would be a 3 ft x 5 ft catch basin: on a 1inch = 400 ft scale map, this basin would be represented by a symbol at its center point but might be surveyed in detail (all four corner points located) on a 1inch = 30 ft site plan.

d. Topographic elevations and contours. A variety of survey methods are used to develop the terrain model for a given project area. The technique employed is a function of the type of survey equipment, the detail required, and specified elevation accuracy. In addition, the technique may depend on whether traditional contours or a digital terrain model (DTM) is required.

e. Contours from cross-sections. Contours can be directly surveyed on the ground or derived from a terrain model of spot elevations. When cross-section methods are employed, even contour intercepts along the offsets can be set in the field using a level rod. Alternatively, elevations can be taken at intervals along the cross-section where changes in grade or breaklines occur, and contour intercepts interpolated over the linear portions. If abrupt changes in grade (or breaks in grade) occur between cross-section stations, then supplemental cross-sections may be needed to better represent the terrain and provide more accurate cut/fill quantity takeoffs.

f. Contours from radial surveys--spot elevation matrices. It is often more efficient to generate contours from a DTM based on spot elevations taken over a project area. These surveys are normally done with a total station or RTK system; however, older transit-stadia or plane table methods will also provide the same result. The density of spot elevations is based on the desired contour interval and terrain gradient. In some instances, an evenly spaced grid of spot elevations may be specified (so-called "post" spacing). Flat areas require fewer spots to delineate the feature. Breaklines in the terrain are separately surveyed to ensure the final terrain model is correctly represented. Data points can be connected using triangular irregular network (TIN) methods and contours generated directly from the TIN in various CADD packages (MicroStation InRoads, AutoCAD, etc.). The generated DTM or TIN also provides a capability to perform "surface-to-surface" volume computations.

g. DTM generation from breakline survey technique. The following guidance is excerpted from the California Department of Transportation (CALTRANS) *Surveys Manual*. It describes a technique used by CALTRANS to develop DTMs on total station topographic surveys.

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 which creates a seamless, triangulated surface without gaps or overlaps between triangles. Triangles are created so that their sides do not cross breaklines. Triangles on either side of breaklines have common sides along the breakline.

Breaklines 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 are clearly defined, while breaklines on natural ground are 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 alignments.

Method: When creating field-generated DTMs, data points are gathered along DTM breaklines, and randomly at spot elevation points, using the total station radial survey method. This method is called a DTM breakline survey. Because the photogrammetric method in most cases is more cost effective, gathering data for DTMs using field methods should be limited to small areas or to provide supplemental information for photogrammetrically determined DTMs. The number of breaklines actually surveyed can be reduced for objects of a constant shape such as curbs. To do this, a standard cross section for such objects is sketched and made part of the field notes. Field-collected breaklines are identified by line numbers and type on the sketch along with distances and changes in elevation between the breaklines. 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. Advantages of DTM breakline surveys:

- *Safety of field crews is increased because need to continually cross traffic is eliminated.*
- *Observations at specific intervals (stations) are not required.*
- *New sets of cross sections can be easily created for each alignment change.*

DTM survey guidelines:

- *Remember to visualize the TIN that will be created to model the ground surface and how breaklines control placement of triangles.*
- *Use proper topo codes, point numbering, and line numbers.*
- *Use a special terrain code (e.g., 701) for critical points between breaklines, around drop inlets and culverts, and on natural ground in relatively level areas.*
- *Make a sketch of the area to be surveyed identifying breaklines by number.*
- *Do not change breakline codes without creating a new line.*
- *Take shots on breaklines at approximately 20 m intervals and at changes in grade.*
- *Locate data points at high points and low points and on a grid of approximately 20 m centers when the terrain cannot be defined by breaklines.*
- *If ground around trees is uniform, tree locations may be used as DTM data points by using a terrain code of 701.*
- *Keep site distances to a length that will ensure that data point elevations meet desired accuracies.*
- *Gather one extra line of terrain points 5 to 10 m outside the work limits.*

Accuracy Standard: Data points located on paved surfaces or any engineering works should be located within ±10 mm horizontally and ± 7 mm vertically. Data points on original ground should be located within ± 30 mm horizontally and vertically.

Checking: Check data points by various means including reviewing the resultant DTM, reviewing breaklines in profile, and locating some data points from more than one setup.

Products: The Surveys Branch is responsible for developing and delivering final, checked engineering survey products, including DTMs, to the survey requestors. Products can be tailored to the needs of the requestor whenever feasible, but normally should be kept in digital form and include the following items:

- *Converted and adjusted existing record alignments, as requested. (CAiCE project subdirectory)*
- *Surveyed digital alignments of existing roadways and similar facilities. (CAiCE project subdirectory)*
- *CAiCE DTM surface files. (CAiCE project subdirectory)*
- *2-D CADD MicroStation design files, .dgn format.*
- *Hard copy topographic map with border, title block, labeled contours, and planimetry.*
- *File of all surveyed points with coordinates and descriptions. (CTMED, .rpt, format)*

h. Utility survey detail methods. It is important to locate all significant utility facilities. Utilities are surveyed using either total station or RTK techniques. The CALTRANS *Surveys Manual* recommends that accuracy specifications for utilities that are data points located on paved surfaces or any engineering works should be located within ±10 mm horizontally and ±7 mm vertically. Data points on original ground should be located within ±30 mm horizontally and vertically. The following are lists of facilities and critical points to be located for various utilities--as recommended in the CALTRANS *Surveys Manual*.

Oil and Gas Pipelines

- *Intersection point with centerlines and/or right of way lines*

- *For lines parallel to right of way – location ties necessary to show relationship to the right of way lines*
- *Vents*
- *Angle points*
- *Meter vaults, valve pits, etc.*

Water and Sewer Lines
- *Intersection point with centerlines and/or right of way lines*
- *For lines parallel to right of way – location ties necessary to show relationship to the right of way lines*
- *Manholes, valve boxes, meter pits, crosses, tees, bends, etc.*
- *Elevation on waterlines, sewer inverts, and manhole rings*
- *Fire hydrants*
- *Curb stops*
- *Overhead Lines*
- *Supporting structures on each side of roadway with elevation of neutral or lowest conductor at each centerline crossing point.*
- *On lines parallel to roadway, supporting structures that may require relocation, including overhead guys, stubs, and anchors*

Underground Lines
- *Cables/lines (denote direct burial or conduit, if known), etc.*
- *Manholes, pull boxes, and transformer pads*
- *Crossing at centerline or right of way lines*
- *For lines parallel to right of way – location ties as necessary to show relationship to the right of way lines*

Railroads
- *Profile and location 60 m each side of the proposed roadway right of way lines*
- *Switch points, signal, railroad facilities, communication line locations, etc.*

Checking: Utility data should be checked by the following means:
- *Compare field collected data with existing utility maps*
- *Compare field collected data with the project topo map/DTM*
- *Review profiles of field collected data*
- *Include field collected data, which have elevations, in project DTM*
- *Locate some data points from more than one setup*

i. Archaeological Site/Environmentally Sensitive Area Surveys (CALTRANS). Archaeological and environmental site surveys are performed for planning and engineering studies. Surveys staff must work closely with the appropriate specialists and the survey requestor to correctly identify archeological and environmentally sensitive data points.

Method: Total station radial survey, GPS fast-static, kinematic, or RTK.

Accuracy Standard: Data points located on paved surfaces or engineering works should be located within ±10 mm horizontally and ±7 mm vertically. Data points on original grounds should be located within ±30 mm horizontally and vertically. Review field survey package for possible higher required accuracy.

Checking: Check data points by various means including, reviewing the resultant DTM, reviewing breaklines in profile, and locating some data points from more the one setup.

Products:
- *3-D digital graphic file of mapped area*
- *Hard copy topographic map with border, title block, and planimetry (contours and elevations only if specifically requested)*
- *File of all surveyed points with coordinates and descriptions*

j. Spot Location or Monitoring Surveys (CALTRANS). Monitoring surveys are undertaken for monitoring wells, bore hole sites, and other needs.

Method: Total station radial survey, GPS fast static or kinematic

Accuracy Standard: Data points located on paved surfaces or any engineering works should be located within ±10 mm horizontally and ±7 mm vertically. Data points on original ground should be located within ±30 mm horizontally and vertically.

Checking: Observe data points with multiple ties.

Products:
- *File of all surveyed points with coordinates and descriptions*
- *Sketch or map showing locations of data points*

k. Vertical Clearance Surveys (CALTRANS). Vertical clearance surveys are undertaken to measure vertical clearances for signs, overhead wires, and bridges.

Method: Total station radial method.

Accuracy Standard: Data points located on paved surfaces or any engineering works should be located within ±10 mm horizontally and ±7 mm vertically. Data points on original ground should be located within ±30 mm horizontally and vertically.

Checking: Observe data points with multiple ties.

Products:
- *File of all surveyed points with coordinates and descriptions*
- *Sketch or map showing vertical clearances*

2-26. General QC and QA Guidance on Topographic Data Collection and Drawings

The following guidance is excerpted from the Woolpert, Inc. "Survey Manual." It contains a "checklist" of critical features and attributes that must be collected for various types of utilities, roads, boundaries, facilities, HTRW sites, and other structures. It is followed by a "Drawing Annotation Checklist" that provides general guidance on attributing various features.

INTRODUCTION: Topographic surveys are the basis for the engineering, planning, and development plans. It is critical that the information shown on the plans be correct and complete. It is also very important to understand the intended use or accuracy requirements needed by the user of the plan along with the size of the project. This information can be useful to determine whether the project should be collected by aerial mapping of ground run surveys. If the plan is to be used for engineering design then the field survey will likely include pavement sections and utility locations.

ITEMS INCLUDED ON SURVEYS

Topography (General)
- *Performed by using trigonometric techniques with the Total Station or digitized by aerial photography.*
- *Provide and identify the natural relief of the ground, and man-made structures.*
- *Topography (Location)*
- *Natural*
- *Establish the location of "top of bank", "toe of slope," and centerline of all streams or creeks.*
- *Provide cross sections at specified intervals – typically 20 meters or 50 ft.*
- *Provide a "spot grade" shot +/- 30 ft away from "top of bank" at the cross section interval*
- *Provide a "top of water" shot at every 1000 ft interval – record date and time if tidal area or recent weather events if not tidal.*
- *Sizes of trees will be identified by common name and/or scientific name, and their diameter will be measured at DBH or "diameter at breast height."*
- *Provide location of isolated or cultivated trees*
- *Provide location of edge of woods at outside "drip line."*
- *Locate all high points and low points along ridges and valleys.*
- *Note: Some circumstances may require the location of: spoil piles, sink holes, standing water, caves, and unusual rock outcrops.*
- *Note: Some circumstances may require the locations of the "thread" or "thalweg line" when providing a profile of a stream.*
- *Wetlands*
- *Delineation of a wetland can be located only after flags have been set by an environmental scientist from either the Army Corps of Engineers or Department of Transportation.*

Ditches and Drainage Features
- *Establish the location of "top of bank", "toe of slope," and centerline of all ditches.*
- *Provide cross sections at specified intervals – typically 20 meters or 50 ft.*
- *Provide a "spot grade" shot – typically +/- 30 feet away from "top of bank" at the cross section interval.*

- *Locate any concrete or asphalt: flumes, V-ditches, UD – drains or channels.*
- *Locate all yard drop inlets and curb drop inlets.*
- *Locate all headwalls and wing walls.*
- *Measure the diameter and note the type of all pipes.*
- *Provide location and elevation on invert (flow line) of pipe.*

Storm and Gravity Sanitary Sewers

- *Obtain elevations and location on the tops of manholes or drop inlets.*
- *Measure readings (downs) from rim of manhole to inverts*
- *Locate and provide elevations on inverts and manholes on the next structure out of the limits.*
- *Obtain location and elevations on inverts on box culverts*
- *Obtain location and elevations on inverts on ends of flared-end-section pipes*
- *Locate sanitary sewer clean outs*
- *Locate and describe sanitary sewer pump stations (lift stations).*
- *Locate approximate areas of septic fields and tanks.*

Roads

- *Locate and measure all curb and gutter features: Back of curb, flow line, and edge of gutter pan.*
- *Note size and type of curb and gutter.*
- *Provide location of edge of pavement at specified intervals – typically 20 meters or 50 ft.*
- *Note size and type of pavement.*
- *Provide location of centerline or "crown" of road.*
- *Obtain and locate all entrances.*
- *If concrete pavement has been overlaid with asphalt, measure approximate depth of overlay.*
- *Locate and note types of guardrails.*
- *Locate and provide elevations at the base of Jersey barrier.*

Railroads

- *Provide location of tracks with elevations at specified intervals--typically 20 meters or 50 ft in a curve. Note: Some special circumstances may also include location and elevations for the ballast rock and railroad bed.*
- *Obtain location of all switches.*
- *Obtain location of all mileposts. Note: Most crossing signals provide distances to closest milepost. If a railroad milepost cannot be located, the closest railroad spur must be located and tied.*
- *Obtain location of all signal equipment.*
- *Obtain location of all Right-of-way monuments.*
- *Obtain location, size, and type of culverts under the railroad.*
- *Secure a copy of the railroad right-of-way map.*

Fences

- *Provide location, type, and height of fence.*
- *Common types of fences are split rail, wood privacy, chain link, woven wire, barbed wire, etc.*

Cemeteries
- *Location of cemetery boundary must be shown.*
- *Locate graves coincident with the Right-of-way and survey centerline.*
- *Provide an approximate count of the number of graves.*

Automobile Graveyards
- *Locate outside limits and note approximate number of automobiles.*

Signs
- *Locate and describe all overhead truss signs.*
- *Locate and describe all overhead cantilever signs.*
- *Locate and describe all breakaway I-beam traffic signs.*
- *Locate and describe all traffic signals.*
- *Locate and describe all historical markers – recording identity numbers.*
- *Locate, measure, and describe in detail all advertising signs or commercial billboards. It is imperative to note the owner and the license number.*

House & Building Location
- *Locate all dwellings and buildings at the wall or footer line and note/dimension the overhang.*
- *Describe as dwellings, buildings, restaurants, etc.*
- *Identify structure address: example) house or box number.*
- *Describe the height of structures: example) one story, two story, or split-level.*
- *Describe the type of construction: example) brick, wood frame.*
- *Locate and describe all porches, decks, carports, utility buildings, and driveways.*

Utility Items--Above Ground Utility Location
- *Utility poles and guy wire anchors – recording number and owner.*
- *Light poles – recording number and owner.*
- *Cable TV pedestals – recording number and owner.*
- *Electric – cabinet, transformer, junction box, hand hole, witness post, meter, transmission tower, and Sub-Stations (note: do not enter facility).*
- *Water meters, valves, vaults, manholes, blow off valves, fire hydrants and witness posts.*
- *Gas meters, valves, test stations, and witness posts.*
- *Force main air vents and witness posts along line as well as valves and emergency pump connections at pump station facility (note: do not enter facility).*
- *Steam pipes and steam manholes.*
- *Petroleum pipes, witness posts, and pumping stations (note: do not enter facility).*
- *Communication or telephone manholes, pedestals, hand holes, and witness posts – recording number and owner.*
- *Traffic control signals, manholes, cabinets, junction boxes, and hand holes.*

Political Boundaries & Road Names
- *Provide location of all monuments of city or town corporate limits.*
- *Obtain the location of all monuments pertaining to county or state lines.*
- *Locate all street name signs and route number identifiers.*

Government Survey Control

- *Locate all government benchmarks.*
- *Locate all government triangulation, trilateration, and traverse stations.*
- *Locate all government reference marks and azimuth marks.*
- *Locate all state Right-of-way monuments.*

Property Data – (If required)

- *Obtain Right-of-way plans from State Location and Design Engineer.*
- *Obtain pertinent data from court records such as; subdivision plats, parcel, or tract deeds and plats, and tax assessor's cards and maps.*
- *Provide location of all property monuments called for in the deed as needed per scope*
- *Provide location of all easements.*

Hazardous Material/Waste Sites

- *Typically, all hazardous waste sites or potential waste sites will be noted.*
- *Obtain site plan of suspected area*
- *Note and record pertinent information on location of underground storage tanks, filler caps, monitoring wells and caps.*

Set TBMs

- *Obtain and verify vertical datum as per scope: Assumed, City datum, NGVD29, or NAVD88.*
- *A minimum of two temporary benchmarks will be set on private topographic surveys.*
- *TBMs will be set an interval of 1000 ft. to 1500 ft. on typical corridor surveys.*

<u>DRAWING ANNOTATION CHECKLIST</u>

- *Advertising Signs (Billboards): Locate if needed and show license number and owner (small license plate).*

- *Automobile Graveyards: Locate the outside limits and annotate.*

- *Brush, shrubbery, woods: Annotate as dense, light, mixed, etc., and type. Example: (Tree types). Description of trees: describe the type of tree, not just hardwood and pine unless it cannot be identified. Use "Shrub" instead of "Bush" in all cases.*

- *Buildings: Locate at the overhangs and annotate type brick, frame, etc., the height (one story, two story, etc.), and name if commercial. Carports, porches, steps, walks, etc., will also be shown. Example: (1 Story frame dwelling #3098), (2 Story brick building #4139); Building numbers need to be shown. If no number is visible note that, do not leave it blank. Sheds are structures with a roof, and four support posts; Buildings are structures enclosed by four sides, and a door; a Dwelling is a structure that someone lives in; a Commercial Building is a business; and a Restaurant is a structure that someone eats in. The occupant of a Commercial building shall also be identified, i.e. Exxon or First Union Bank. Strip malls will be called out as such or by the name of the shopping center.*

- *Bridges: Annotate type, with deck.*

- *Curbs and Gutters: Annotate type and size.*

- *Cemeteries: Locate the extremities, the closest grave to the centerline and annotate the approximate number of graves.*

- *Concrete or Paved Ditches: Annotate type and width. Flow elevations and directions will be secured by a field survey.*

- *Concrete or Paved Flumes: Annotate type and width. Flow elevations and directions will be secured by a field survey.*

- *Curbs: Annotate type and size.*

- *Culverts: Annotate type, size, secure invert elevations, and direction of flow.*

- *Dams: Annotate type.*

- *Entrances: Annotate type (soil, gravel, asphalt, etc.).*

- *Electric Manholes and junction boxes: Annotate.*

- *Endwalls and Headwalls: Annotate type.*

- *Fences: Annotate Height and type (wood, wire, or chain link), no split rail or woven wire.*

- *Fire Hydrants: Annotate.*

- *Guardrails: Annotate type.*

- *Guy Wires: Need to be annotated and located (number and furthest wire if more than one).*

- *Government Benchmarks, Triangulation Stations, Traverse Stations, Azimuth Marks, and Reference Marks: Annotate.*

- *Historical Marks: Annotate identification numbers.*

- *High Voltage Transmission Lines: Annotate. Electric transmission lines should be shown on the survey. Show one Tower outside the limits. List the number of lines on each tower. We do not need to show the location of the overhead lines.*

- *Light poles: Should be described differently, based upon use. The light poles along roadways are to be called out as “Street Light”; the lights in a shopping center, at a service station, around a hotel are to be shown as “Security Light.” The light poles in someone’s yard would be shown as “Lamp Post” and ground lights illuminating signs, etc. would be shown as “Outdoor Lights.”*

- *Mile Markers: Annotate*

- *Names of all cities, towns, and villages must be annotated and all corporate limits, county and state lines located and annotated.*

- *Outlet Ditches: Annotate with directions of flow.*

- *Pavements: Annotate type and if concrete covered with asphalt, make notations.*

- *Pipes: Annotate type, size, invert elevations, and direction flow.*

- *Property Data: Corners will be located and annotated. All pins within the limits of the survey should be obtained if possible, especially each lot within a subdivision, not just pc and pt points on the subdivisions right-of-way.*

- *Ponds and Lakes: Annotate and collect DTM data inside the edge of water line styles.*

- *Roads: Annotate route numbers and street names and type.*

- *Right-of Way Monuments: Annotate.*

- *Railroads: Annotate owners, right-of-way, and distance to the nearest milepost.*

- *Sewage Disposal and Water Supply: Annotate for each individual developed property, privy, well, sewer clean outs, water meters, drain fields, septic tanks, etc. See homeowner if necessary.*

- *Special Signs: Annotate overhead truss, signal traffic lights, railroad protective devices, etc. (No street signs or speed limit signs are needed). Location and description of all other signs is required. Private signs should be picked up and described, as well as the type of supports, concrete pads or bases, and heights (especially the tall service station and restaurant signs that can be seen from the interstates). All green signs along interstate should be shown and described as on wood posts or steel breakaway posts, and if they are on concrete or not. Street signs should be picked up and identified as "Street Sign." Reflector posts, curve signs, speed limit signs, other delineator signs should not be picked up. If they show up in the mapping put an X through them.*

- *Storm and Sanitary Sewers: Annotate type. Example: SMH= Sanitary, SSMH=Storm, DI, etc. Secure rim elevations, inverts and/or flow lines of all structures. For curb drop inlets show elevation at low point of the throat, usually the center of actual box and measure the length of the throat.*

- *Telephone M.H.'s, pedestals, handholes: Annotate.*

- *Trees: Annotate type and size with the diameter measured three feet above the ground. If unsure of type, hardwood or pine will do.*

- *Utility Poles and Pedestals: Annotate number and owner initials. Include information if pole has light or transformer. Example: T-Ped-#R-1680, B.A. (Bell Atlantic) PP-AB-53, V.P. (Virginia Power).*

- *Walls: Annotate type, height, and width.*

- *Witness posts: annotate type.*

- *Identify gas station filler caps, monitoring wells and locate concrete pads around them.*

- *Identifying areas of possible hazardous materials and type of possible contamination.*

- *Use common sense…annotate, edit and/or revise areas not covered in the above and correct all discrepancies in mapping.*

- *Set TBM's or BM's approximately 1500 feet apart. They can be on the centerline. They should also be at all drainage crossings (canals, etc.) and bridges.*

- *Use discretion when setting nails in trees for references. Do not use ID caps on private property.*
