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Forest Service Handbook 2409.12 – Timber Cruising Handbook
Chapter 50 - Area Determination

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Digest: Following is an explanation of the changes throughout the directive by section.

50: Revises and updates entire chapter. More specific changes are set forth in the following sections.

50.2: Establishes code, caption, and sets forth "Objective" statements.

50.3: Establishes code, caption, and sets forth "Policy" statements.

50.4: Establishes code, caption, and sets forth direction for "Responsibilities".

50.5: Establishes code, caption, and sets forth new "Definitions" terminology.

50.6: Establishes code, caption "Practicality," and sets forth direction for the use of 'reasonable judgment' when applying applications.

52: Removes captions and obsolete direction for "Traverse" and establishes new captions and sets forth direction for "Training" in this section.

53: Removes captions and obsolete direction for "Aerial Photography and Mapping Methods" and establishes new captions and sets forth direction for "Survey Methods" in this section.

54: Removes captions and obsolete direction for "Additional Equipment" and establishes new captions and sets forth direction for "Point Accuracy Estimations" in this section.

55: Establishes codes, captions, and sets forth direction for "Area Error Estimations and Limits" in this section.

56: Establishes code, caption "Equipment", and sets forth direction for the use of approved and appropriate equipment.

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50.2 - Objectives

An accurate area determination is required in area-dependent sampling to calculate sale volume. Accurate acreage measurements are required for non-volume operations such as timber sale appraisal, contract preparation, reporting and monitoring, various post-sale activities, and resource measurement activities, such as archeology, wetlands assessment, or similar activities.

Defined limits for GPS and orthophotography surveys are given in section 55 of this handbook. Defined limits for direction-distance methods are given in section 55.1 of this handbook. Other references to limits are explained throughout the handbook and are repeated in some sections for clarity.

50.3 - Policy

Determine areas by approved methods, such as: direction-distance traverse, GPS surveying, orthophotography, or similar methods derived from evolving technologies.

50.4 - Responsibility

Regional foresters may approve exceptions for:

1. Area determination using modified or other techniques,

2. Area accuracy exceptions in specific situations, and

3. Specific equipment or other equipment as appropriate for a forest or project.

The regional forester may delegate authority to a regional staff director responsible for forest management, who may further delegate the authority to a regional measurement specialist.

It is the responsibility of the regional forester to approve the use of orthophotography (aerial volume estimates) for area-expanded volume estimates. This authority may not be delegated. However, orthophotography may be used for inspection or for missing data processes as explained in section 51.4 without such approval.

50.5 - Definitions

The following definitions apply to timber cruising operations. Other definitions may exist outside this discipline.

<u>Accuracy</u>. Closeness of an estimated value to a standard or accepted value (truth).

<u>Accuracy (absolute)</u>. Closeness of an estimated value to a global or universal standard or accepted value; for example, the absolute accuracy of a point relative to a location on the Earth.

Accuracy (expected). Long-run average value of a variable over many independent repetitions of an experiment.

Accuracy (relative). Closeness of an estimated value to a standard or accepted value relative to a local region or concern. For example, the relative accuracy of the points to each other in one unit (polygon) though the location on the Earth may be unknown.

Angle point. The points along a boundary or navigation survey where there is a distinct change of direction and which are observed by steadying the GPS receiver in one position for a period of time in order to average a number of observations at that common location.

Area-error. The difference in the measured area and the accepted "true" area. For example, if the measured area is 11 acres and the known area is 10 acres, the area-error is 1 acre.

Area-error (percent). Area-error is often expressed as a percentage. For example, 1 acre of area-error in a 10-acre unit gives an area-error of 10 percent (1/10).

Azimuth. A horizontal angle reckoned clockwise from North. Measurements are typically given in degrees: 0 degrees is North, 90 degrees is East, 180 degrees is South, 270 degrees is west, and 360 degrees is North again. North references may be true, magnetic, grid, or another method.

Beginning point. Point of Beginning (POB). The starting point of a direction-distance traverse; it is often the same point upon which the traverse ends.

Blunder. A mistake caused by mental confusion, carelessness, or ignorance. This is different from an error. See Error.

Boundary Point. Location point defining the perimeter of a land parcel.

Burst (GPS NMEA). A series of digital strings [values] sent from a GPS receiver to a recorder. The series constitutes one location measurement. Bursts are usually averaged to obtain a more reliable location measurement. Also called fix, hit, or ping.

Canopy closure. The proportion of the sky hemisphere obscured by vegetation when viewed from one point on the ground.

Closing error. The amount by which a series of survey measurements fails to yield a theoretical or previously determined value at a desired survey quality. The distance between the coordinates of a terminal point of a direction-distance traverse compared to the accepted (true) coordinates of the point being measured to or closed upon. Common terms for closing error are "closing distance," "traverse error," "traverse closure," "traverse closing error," "error of closure," and "misclosure". Closing error is not a blunder but a geometric value from measurement.

Common point accuracy. The accuracy value assigned to all points of a polygon.

Continuous Operating Reference Station (CORS). The system of base reference stations with known locations used in GPS location augmentation operations and post-processing operations.

Datum. A set of constants specifying the system used for calculating coordinates of points on the Earth. Such definition are NAD27 (North American Datum of 1927), NAD83, WGS84 (World Geodetic System 1983), and ITRF (International Terrestrial Reference Frame).

Digital Elevation Model (DEM). A raster surface where each pixel represents an elevation.

Differential Global Positioning System (DGPS). An enhancement to GPS that uses a network of fixed, ground-based reference stations (for example, CORS) to determine the difference between positions indicated by the satellite systems and known fixed positions. See Nationwide Differential Global Positioning System (NDGPS).

Digitize. Selecting points on a map or drawing and recording the coordinate values of the locations. This can be performed manually or by automated means and results put into digital or hardcopy form.

Differential correction. The process of enhancing measured GPS positions with corrections to the Global Navigation Satellite System (GNSS) (such as the Global Positioning System) that use a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions.

Direction. The angle between a measured line and a reference line. Azimuth is the direction of a line relative to North measured clockwise. Azimuth directions are commonly used in timber cruising (see Azimuth). (Some geodetic activities measure azimuth from the south; that is not done in timber cruising. Bearings are directions measured east or west of North or South with angles of 0 to 90 degrees. The bearing quadrants are: 1=NE, 2=SE, 3=SW, 4=NW. Bearings are seldom used in cruising.)

Direction-distance traverse. The process of surveying or measuring vectors around a unit or between control points (that is, GPS points). Vectors are defined by direction and distance.

Distance. The measured or calculated interval between two points. Horizontal distances are used in timber cruising area determination.

Estimated maximum area-error (EMAE). (See Area-error). Estimates are approximations of measurements. This estimation is expected to be at the 95 percent confidence level for timber cruising.

End point. The terminal point of a survey. End point is often used as the terminal point of a direction-distance traverse. Point of beginning (POB) is the start of a direction-distance traverse.

Error. The difference between the observed value of a quantity and the theoretical or defined value of the quantity. Error is not a mistake or blunder; it has statistical meaning. See Blunder.

Error of closure. See closing error.

Ephemeris. A table of the locations and related data of a celestial body (satellite) for given dates at uniform intervals of time. The precise ephemeris is the ephemeris of a satellite computed by adjustment of observations obtained from a worldwide tracking network in order to obtain maximum accuracy.

Filtered information. Processed data from satellite communications that has been reduced to meet selected criteria, such as using only 3D GPS calculations or limiting values of Horizontal Dilution of Precision (HDOP).

Fix, Fixes. Coordinate values determined by the GPS receiver from satellite signals. Usually, a number of fixed coordinates are averaged to determine a location or position. Other terms include: hits, bursts, and pings. See Burst.

Forest Management Service Center (FMSC). Located in Fort Collins, CO, FMSC is a sub-staff of the U.S. Forest Service, National Forest Management Staff, Washington Office. For more information, go to www.fs.fed.us/fmsc.

Geographic Coordinate System (GCS). A reference system that uses latitude and longitude to define the locations of points on the surface of a sphere or spheroid. A geographic coordinate system includes a datum, prime meridian, and angular unit.

Geo-referenced data. Aligning geographic information to a known coordinate system so that it can be viewed, queried, and compared to other geographic data. Geo-referencing may involve shifting, rotating, scaling, skewing, and in some cases, warping, rubber sheeting, or orthorectifying the data.

Geographic Information System (GIS). An integrated collection of computer software, processes, and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed.

Global Navigation Satellite System (GNSS). "Global navigation satellite system" is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. A GNSS allows electronic receivers to determine longitude, latitude, and elevation of the receiver on the Earth's surface.

Global Positioning System (GPS). Radio-emitting and -receiving satellites used to determine the location of points on Earth. The orbiting satellites transmit signals that allow a GPS receiver anywhere on Earth to calculate its own location through trilateration. Developed and operated by the U.S. Department of Defense, the system is used in navigation, mapping, surveying, and other applications in which precise positioning is necessary. GPS is a part of GNSS.

GPS angle-point. GPS points (vertices) at distinct changes of direction between lines defining the unit, generally with considerable spacing between each point.

GPS Walk. A unit's boundary determined by GPS points that are closely spaced, such as an interval of a few steps.

Ground control points. Positions of known value on which the location and accuracy of other measurements depend; for example:

1. Surveyed points on the ground serve to locate aerial imagery, and

2. GPS points can control direction-distance traverses.

Horizontal Dilution of Precision (HDOP). Measurements of the geometric quality (strength of figure) of a GPS satellite configuration in the sky. HDOP is concerned only with horizontal measurement precision. The smaller the dilution of precision number, the better the geometry.

Hit. See Bursts.

Inertial Navigation System Survey. An inertial navigation system survey uses an instrument which is ordinarily composed of motion sensors (accelerometers) and/or rotation sensors (gyroscopes) to measure direction and distance between survey points. This process is sometimes called dead-reckoning.

Least Count. The least count is the smallest subdivision markings on a measuring tool. For example, a tape marked with tenths of an inch can be used to measure to the tenth of an inch by reading the markings directly. A tenth of an inch is the least count on the tape. Estimation is required to measure to the nearest hundredth of an inch. Another example is a compass rose marked in degrees that can be read directly to a degree, making one degree the least count of the compass. Parts of a degree must be estimated.

Leg. A term for a line or vector used to measure a boundary or to navigate. A leg can be a line defined by two end points or a line defined by direction and distance.

Magnetic declination. The angle between magnetic North and true North observed from a point on Earth. Magnetic declination varies from place to place, changes over time, and is subject to local anomalies. Magnetic variation is sometimes used for this term in timber cruising operations.

Metadata. Data (information) about the data. Metadata describes the overall history of specific data, including content, quality, condition, and other characteristics. For more information go to: http://www.fs.fed.us/gac/metadata/

Misclosure. See closing error.

Mosaic. Several maps of adjacent areas with the same spatial reference and scale whose boundaries have been matched and dissolved.

MTDC Accuracy Matrix. Missoula Technology and Development Center (MTDC) spreadsheet of GPS accuracy measurements for given GPS receiver and antenna configurations, measurement procedures, and forest conditions, such as canopy closure. MTDC follows National Standards for Spatial Data Accuracy (NSSDA) for stated accuracies.

Multipath errors. Errors caused when a satellite signal reaches the receiver from two or more paths, one directly from the satellite and the others reflected from the boles of trees, nearby structures, or other surfaces. This error is particularly troublesome for forest surveyors who unknowingly measure the bounced signal while the direct signal is blocked.

NAD83. See Datum.

National Agriculture Imagery Program (NAIP). NAIP acquires aerial imagery. A primary goal of the NAIP program is to make digital orthophotography available to governmental agencies and the public.

Nationwide Differential Global Positioning System (NDGPS). NDGPS service is organized by the U.S. Department of Transportation. This service uses ground reference stations to determine the differential between the GPS solution and the true solution. This differential is then broadcast on a low frequency carrier for users to access, free of direct user charge. See Differential Global Positioning System.

National Marine and Electronics Association (NMEA). A nonprofit association composed of manufacturers, distributors, dealers, educational institutions, and others interested in peripheral marine electronics occupations. The NMEA has created a standard that defines an electrical interface and data protocol for communications between marine instrumentation that has been adopted as an industry standard by the GPS industry. GPS receivers receive and send NMEA strings to recorders with appropriate software to perform location and mapping functions.

Offset. A line running parallel to the line being measured. Sometimes this term is erroneously substituted for sideshot. See Sideshot.

Orthophotograph. A vertical aerial photograph from which distortions due to camera tilt and ground relief have been removed. An orthophotograph has the same scale throughout and can be used as a map. The scale is only true at ground level.

Orthophotography surveying requires digitizing orthophotographs for coordinates. Common short names are orthos and orthophoto.

Positional Dilution of Precision (PDOP). A measure of the geometric quality (strength of figure) of a GPS satellite configuration in the sky. PDOP is a measurement using horizontal and vertical components. The smaller the DOP number, the better the geometry. See Horizontal Dilution of Precision.

Photo-identifiable point (photo ident point). A spot on an orthophotograph, aerial photograph, or similar remotely sensed imagery from which a feature on the natural ground can be inferred, such as road intersections, ant hills, or utility covers. See Ground control point.

Ping. See Bursts.

Post-Processing. Correcting GPS observations after the surveying is complete. Post-processing uses Differential GPS to obtain precise positions of unknown points by relating them to known points such as Continuous Operating Reference Stations.

Precision. The tendency of a set of random numbers to cluster around a number determined by the set, such as the mean of the set. Precision measures the quality of the method used, not the quality of the results (accuracy). Standard deviation is the statistical measurement usually used to report precision. A set of measurements whose range is small is relatively more precise than a comparable set whose range is large.

Projection. A method by which the curved surface of the earth is portrayed on a flat surface. This generally requires a systematic mathematical transformation of the earth's arcs of longitude and latitude onto a plane. Some projections can be visualized as a transparent globe with a light bulb at its center (though not all projections use the globe's center), casting lines of latitude and longitude onto a sheet of paper. The common methods have the paper flat and placed tangent to or cutting through a portion of the globe (a planar or azimuthal projection) or formed into a cone or cylinder and placed over the globe (cylindrical and conical projections). Every map projection distorts distance, area, shape, direction, or some combination thereof.

Root mean square error (RMSE/RMS error). A measure of the difference between locations that are known or considered to be true compared with locations that have been interpolated or digitized. RMS error is derived by squaring the differences between known and unknown points, adding those together, dividing that by the number of test points, and then taking the square root of that result. The FMSC (and timber cruisers) use this process to determine the accuracy of orthophotography for surveying and for determining the quality of GPS observations against known values on GPS test courses.

Real-Time Kinematic/Real-Time Navigation (RTK/RTN). A technique used in survey based on the use of carrier phase measurements of the GPS (GNSS) signals in which a

single reference station provides the real-time corrections, providing up to centimeter-level accuracy.

Satellite-Based Augmentation System (SBAS). Nationwide Differential Global Positioning System (NDGPS) and Wide Area Augmentation System (WAAS) are examples of satellite-based augmentation systems for GPS. See NDGPS and WAAS.

Sideshot. A sighting or measurement from a survey point to locate a point which is not intended to extend the traverse line. A sideshot is often made to determine a location of an inaccessible object or a point obscured to GPS observations.

Static angle-points. See Angle point.

Traverse. Historically the term *traverse* means a direction-distance survey (chain and compass). Colloquialism use has extended the term *traverse* to sometimes mean any type of survey, including GPS surveys.

Traverse closing error (TCE). See closing error.

Unit. An area defined by a closed boundary: for example, a forest unit, polygon area, or project site.

Vertex. See Angle point.

Vertical Displacement. In aerial photographs, the outward dislocation from the center (nadir) of the top of a tree relative to the base of the same tree. The same condition can occur for elevated ground positions but is not noticeable because there is no base for reference.

Wide Area Augmentation System (WAAS). WAAS corrects GPS signal errors caused by ionosphere disturbances, timing, and satellite orbit errors. It provides vital integrity information regarding the health of each GPS satellite. A WAAS-capable receiver can yield a position accuracy of better than 3 meters, 95 percent of the time, in open sky conditions. There is no fee to use WAAS. For more information, go to: http://www8.garmin.com/aboutGPS/waas.html.

For additional definitions refer to the GIS Dictionary at: http://resources.arcgis.com/glossary.

50.6 - Practicality

Natural resource area measurements do not typically follow straight lines or occur on flat ground. Strict adherence to the following rules may not be practical; reasonable judgment should be applied. Operations following the intent of this section are allowable.

For example, boundary lines marked by painted trees usually do not fall in a straight line but are frequently represented by a straight line. It is practical to represent these trees in a straight line

as long as the trees fall equally on either side of the line. Lines representing tight curves need to reference each marked tree to represent the curve well.

In another situation, a large unit may need to be broken into sub-units for payment purposes. It is appropriate to measure the area of the total unit to meet the area-error standard. Then, the unit may be broken into sections. Area differences in the sub-units are compensated for when all sub-units are completed, of course, this requires that all the sub-units are completed; if there is a possibility this might not happen or if the prescriptions for the sub-units are quite different, then each sub-unit must be addressed independently.

Still another example would involve a unit intruded by a riparian corridor. It is appropriate to measure the area of the unit first without concern for the corridor. A poly-line for the thread of the stream can be determined by any survey method explained herein. Then, the width of the corridor along the stream-thread may be used to determine the area of the riparian area and subtracted from the total area of the unit.

These examples may be extrapolated to other applications demonstrating what practically may be done. The intent of this section is not to give an open license to ignore procedures, but allows common sense to be applied

51 - Requirements

The following metadata are required for area-based sampling methods in timber cruising.

51.1 - General Requirement for All Survey Methods

1. Document acreage determinations, calculations, and methods used; also include a map of the area.

2. Include information about the data and process (metadata). Metadata should include:

    a. Thoroughly document the collection procedure or reference the standard procedure/process that was used.

    b. Document the data sufficiently to allow users to determine the accuracy, value, purpose, restrictions, and sufficiency of the information.

    c. Include equipment details, such as: type, measurement units, least count, and other similar information associated with the data or data collection.

    d. Include information about: personnel directing or authorizing the work and procedure, crews performing the survey, field situations, personnel checking and verifying the field work, personnel processing the data, and so forth.

    e. Forest, region, district, time, date, sale, and so forth.

    f. Mapping projection, coordinate system, and datum used.

g. Adjustments made, such as: GIS modification of GPS features, office corrections to the original data, and transformations or conversions of coordinates.

h. Special conditions that might influence the outcome of the survey.

i. Differential GPS augmentation methods or similar operations (if used).

j. Software programs used for data collection, processing, and so forth. Store appropriate data files used for processing and keep common readable files showing the same general information with the project. These files need to be in readable form, such as text, ASCII, or *.doc files.

3. Involve field personnel in the review and validation process.

Coordinates for determining area may be calculated in any appropriate coordinate system, datum, and projection. The mapping projection, coordinate system, and datum used must always be associated with the coordinates. The process used must be clearly identified for each and every operation, such as data collection, calculations, mapping values, and any conversions or translations performed. Methods of conversion or translations between different systems must be documented. The USDA Forest Service presently requires data be reported in the NAD 83 datum for official mapping operations. Additional information can be found on the Forest Management Service Center (FMSC) Web site at http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml

All measurements include error; therefore, area measurements include error. Estimates of the maximum amount of difference between the true area and the measured area are determined by the estimated accuracy of the points defining a boundary. All methods determine area-error by using point accuracy values for GPS surveys (including orthophotography or similar methods), the closing-distance value of a direction-distance traverse or a similar accuracy metric. The GPS methods estimate the accuracy by using the Missoula Technology and Development Center (MTDC) Accuracy Matrix monitored by FMSC, or using procedures that are similar to or produced the Accuracy Matrix. Metadata must document which procedures are used for each project. For additional information go to http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

51.2 - Direction-distance Survey Method

In addition to the general requirements, document the following:

1. Type of equipment used to measure direction.

2. Magnetic declination determination and application or similar direction rotation procedures.

3. Type of equipment used to measure distance, such as laser, chain, or other tool.

4. Type of vertical or inclination angle tool and other significant tools.

5. The means used to change slope to horizontal distance.

51.3 - GPS Walk and GPS Angle-Point Survey Methods

In addition to the general requirements, document the following:

1. GPS receiver type, model, and serial number.

2. Native datum, native projection, or geodetic system.

3. Precision indicators, geometric strength indicators (such as Horizontal Dilution of Precision (HDOP)), filters or masks, and so forth.

4. Possible error sources that may cause interference, such as signal attenuation, multipath, or blockage.

51.4 - Orthophotography Survey Method

This method of determining area for area-expanded cruises can only be used with approval from the regional forester. However, there are no restrictions for the use of orthophotography for inspection of other survey methods as stated in sections 53.2 paragraph 8d, or for incidental determination of corners due to missing/lost data in GPS or direction-distance traverses, or corridor lengths, or similar operations were the area determination is only supplemented by orthophotograhy positions.

Orthophotography used to gain boundary coordinates must meet or exceed the following conditions to be acceptable for timber cruising work. The source and use of such information must be documented:

1. For USDA Forest Service timber cruising purposes, the pixel size should be one meter or less, unless otherwise authorized. Be aware that the size of the pixel is the precision of resolution of the image and not the accuracy of the point the pixel represents.

2. Orthophotography imagery meeting National Mapping Standards does not necessarily guarantee that digitized (or measured) coordinates are suitable for the project. Be sure the imagery is from an approved source, and even then, perform checks to verify the accuracy of the image's geo-referencing.

3. Check the accuracy of the orthophotography if there is any question about the quality of the source materials. Verify orthophotography imagery accuracy by comparing selected control points across the imagery with superior control, such as GPS points or previously validated imagery. Additional information available at: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

4. Obtain or define the metadata documenting the orthophotography source, resolution, accuracy, projection, datum, photography date, and other relevant details. When possible, use Forest Service-approved orthophotography.

5. Two different measurement accuracies concern the timber cruiser. For cruising area-determination purposes, the relative accuracy should be used. This is the accuracy of the pixel points with regard to each other, but not how well all the related points are geographically referenced. At this time, the range of relative accuracy from approved sources is from one to about fifteen meters. (This is appropriate for most area and area-error determination.)

6. The geographic coordinate absolute accuracy ranges from about 3 meters to 17 meters. (This is applicable for absolute geographic location in most timber activities.) There is frequently more distortion on the orthophotography where the images are joined (mosaic lines). Skilled and trained personnel are needed to use imagery when mosaic lines are inside the unit being measured.

7. Generally, for one-meter resolution orthophotography, the relative accuracy is less than 8 meters and quite possibly as accurate as 3 meters.

52 - Training

52.1 - All Survey Methods Training

Train all crew members in the correct use and care of appropriate equipment for the appointed task. Training should go beyond the proper use of equipment by including proper application and calibration of the equipment. Furthermore, since determining area involves measurement, mapping, and navigation, the cruiser should be trained in the knowledge of: equipment precision, accuracy, mapping, and proper recording of relevant information in the metadata.

52.2 - Direction-Distance Survey Method Training

In addition to the general training requirements, conducting a direction-distance traverse requires training in:

1. Use of the sighting compass.
See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

2. Azimuth and magnetic declination.

3. Significance of traverse closing errors and adjustments (sec. 54.1)

4. Slope chaining and inclination measurements.

5. Use of a distance meter (such as a laser).

6. Other devices or systems that produce line vectors, if used.

7. Observer alertness to avoid measurement blunders.

52.3 - GPS (GNSS) Survey Methods Training

In addition to the general training requirements, conducting a GPS or satellite-navigation-system survey requires training in:

1. Awareness of datum and projections.

2. Units of measurement and conversion.

3. Unit formats.

4. Proper setting to collect three-dimensional positions.

5. Satellite geometry and associated satellite observation errors.

6. Knowledge of GPS receiver peripherals, such as antennas and recorders.

7. Location accuracy augmentation methods (such as WAAS or any other SBAS, satellite based augmentation system, or NDGPS—National Differential Global Positioning System).

8. Knowledge of differential correction procedures and data export (if used).

9. Observer alertness to avoid obvious measurement blunders.

52.4 - Orthophotography Survey Method Training

In addition to the general training requirements, train all crew members in appropriate methodology for determining survey points from orthophotography. The forester shall have photogrammetric training, be able to understand aerial photography distortions and errors, and be able to use proper photographic interpretation procedures. The person digitizing the location shall understand and recognize image error. Train crewmembers in using only appropriate imagery and verifying the accuracy of an image.

Individuals should have orienteering map skills to help analyze objects in the photography. They should have knowledge of how the terrain at the project site is uniquely portrayed. Different areas of the country may demand new terrain familiarization to perform accurate photo-identification.

Train observers to be alert to see possible problems and avoid measurement blunders.

53 - Survey Methods

53.1 - Direction-Distance Survey Method

The distance-direction traverse employs traditional survey techniques to measure area using directions (angles, bearings, or azimuths) and distance. Originally, a directions-distance traverse

encompassed an entire unit and had to meet the 20-acre rule. Expanding the original process allows a direction-distance traverse between control points using the 5,000-foot rule (see sec. 55.1).
Use instruments capable of meeting accuracy standards. Record all raw measurements. Document all techniques used and the results of calculations. Inertial navigation system surveys may use procedures explained by this method.

53.2 - GPS (GNSS) Survey Methods

The Global Positioning System (GPS) utilizes signals transmitted from satellites to determine the coordinate location (X, Y, and Z) of points on the ground. Only the X and Y coordinate values are relevant to area determination. When these points are located on the perimeter of a closed traverse, they form a polygon whose area can be calculated. The Global Navigation Satellite System (GNSS) refers to international point-navigation-time satellites systems of which GPS is the United States of American part.

1. Boundary angle-points are determined by the GPS position (or sideshot or traverse points relative to the GPS position). The boundary of the unit is determined by the lines (legs) that join these boundary angle-points.

2. Before taking measurements, allow the GPS receiver to "warm up" for a sufficient amount of time to download a current GPS ephemeris. This may take as long as ten minutes and may be done while walking to the site if the antenna is kept in view of the satellites (avoid heavy canopy closure and obstacles).

3. During measurements, position the antenna of the GPS receiver above local obstacles (including the body) as much as possible. Take care to avoid situations that could cause multipath errors (reflected, redirected, or bounced signals) such as proximity to cliffs, large rocks, buildings, trucks, signs, power lines, and nearby large tree boles. If these situations cannot be avoided, consider alternative methods of measuring the boundary.

4. GPS receivers calculate a position when they receive signals from satellites. Any interference with these signals can cause errors in positioning. The optimal observing environment is a clear, open sky with little or no canopy closure.

5. Use only approved GPS receivers (see sec. 56) that meet the accuracy requirement necessary for determining the desired area accuracy.
See: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml. (The required accuracy standards needed for each application are explained throughout this handbook.)

6. Re-collect the data if the established standards are not met. Data may be collected for different portions of the boundary on separate dates or times.

7. Report area in the accepted Forest Service-required datum. Unless otherwise required, use the NAD 83 datum. The metadata must show in which datum and projection the survey was collected and in which datum and projection the report is made.

8. Include with the project:

a. Data files containing the position fixes or results from those fixes (such as, *.ssf , *.cor, *.inf, *.txt, *.tt, *.gpx, or similar file types).

b. Data files that are readable, such as text files and spatial files like Shapefiles (*.shp, *.dbf, *.shx, or *.prj). These files should be populated with all relevant attributes.

c. Method used for area calculations and any software used.

d. Plot of the survey in a digital format. Overlaying the plot on an orthophotography image is strongly suggested for checking purposes.

e. Date and name of the persons who collected the data.

f. Only filtered information from a GPS receiver is adequate for area-determination measurements. Filtered information means satellite information that has been inspected, ordinarily by software, before acceptance into a position calculation. The filtering process checks whether criteria such as HDOP limits and 3D mode are being met. Signals not meeting defined criteria are rejected for measurement. Some GPS receivers can filter satellite information as it is collected: this type of information does not need further filtering. For GPS receivers that do not do this, software to filter GPS information data or similar procedures can be used. This second situation usually requires that the GPS receiver have an internal operating system or be connected to a data recorder with an operating system that can run filtering software. Programs like TwoTrails© and ArcPad© can be configured to meet this requirement. See: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

9. Use only three-dimensional GPS measurements. This requires a minimum of four satellites. (Note: GPS satellite measurements are made in the 3D mode but area measurements are made in horizontal 2D space. These are essentially two different definitions for different applications.)

10. HDOP may be set to maximum productivity. Setting the HDOP to 20 or less is simply good practice; setting it to 6 or less may improve accuracy if that is needed to meet area-error limitations. Future setting may change as technology develops. See: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

11. SBAS (Satellite Based Augmentation Systems) should be used where available, such as WAAS (Wide Area Augmentation System for GPS).

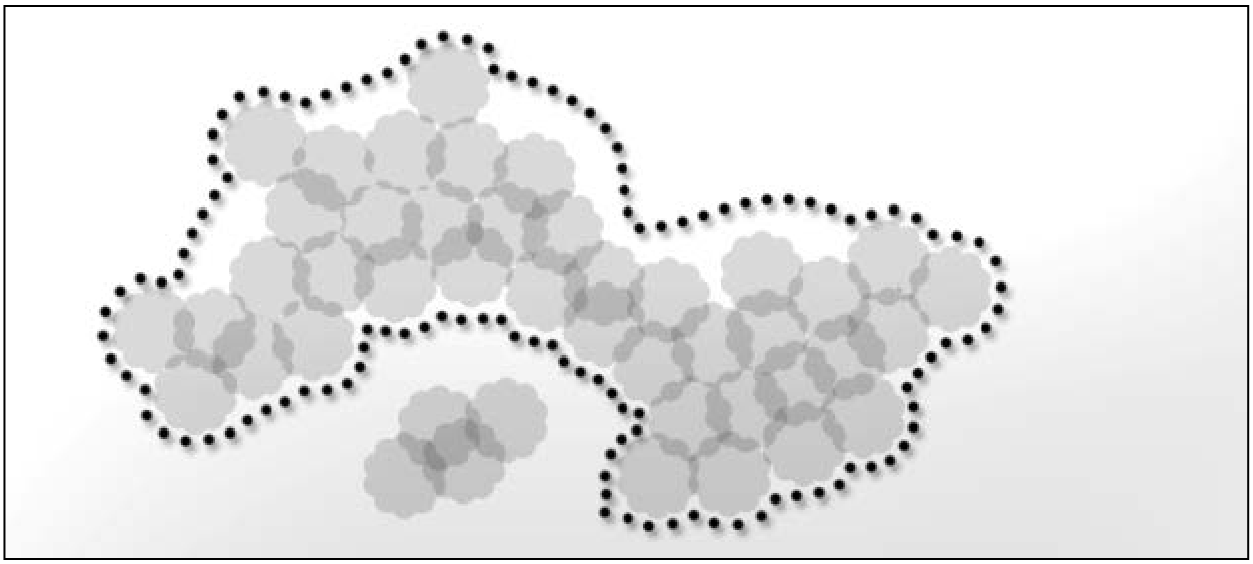
12. See GPS Augmentation (sec. 53.24) for possible additional observation restrictions.

53.21 - GPS (GNSS) Walk Method

1. To measure the boundary line, the field person must walk directly on the boundary (ex. 01 of this section) or use and note appropriate sideshots or offsets. Use another survey method if the desired accuracy is not possible by this method, such as working in canyons, heavy tree canopy, steep northern slopes, or cliffs.

53.21 - Exhibit 01

Walk Method Example.
Dots Depict Frequent Position Measurements While Walking the Unit



2. Any distance the field person walks off the boundary line that is not noted is improper and adds unknown inaccuracy to the boundary and, consequently, to the area. Both the inaccuracy of the GPS measurement plus the distance the observer is off-line contribute to error in measuring the area. This handbook describes methods to estimate the GPS accuracy; walking off the boundary without referencing it with an offset or sideshot is a blunder to be avoided.

3. Collect position fixes (coordinate values determined by the GPS receiver from satellite signals) while moving around the perimeter at a time interval that accurately defines the boundary. In general, a 5-second interval can be used for a walk file. However, if moving more rapidly, a more frequent interval may be suitable. Loss of position fixes (satellite signal) is acceptable for a short duration while moving in straight lines; however, position fixes must be acquired while moving through turning points (corners or curves) to portray the polygon correctly.

53.21 - Exhibit 01--continued

4. The receiver must be receiving and recording positions at major direction changes in the unit's boundary. Ensure this by walking slower around bends and monitoring the receiver. See that all fixes continually move forward and that they do not bounce backward relative to a previous fix. This can happen when the GPS inaccuracy is bigger than the actual distance covered between fixes.

5. Substantial spacing between position fixes indicates a loss of signal and the possibility of missing positions at critical turning points. The polygon shape must represent the boundary walked in the field. If not, the survey must be redone.

6. The field personnel should review the resulting map. The collected data must consist of a smooth string of fixes. The position fixes must lie in order, one after another, in a sequential pattern. GPS walk method boundaries of units are often jagged. Frequently, adjacent units have coincident sides that do not match. Allow only slight irregularities (such as jumping from side to side) in taking fixes.

7. When all measuring conditions are appropriately observed and the roughness of the boundary appears to be within positional tolerance defined for the project, it is allowable to smooth the lines. If some irregularities are obvious outliers, they may be deleted upon the advice of the field personnel. It is inappropriate to eliminate small irregularities without proper reason. Eliminated points should be noted.

8. If coincident boundaries of adjoining polygons are modified to match each other, comments must be placed in the metadata as to which boundary segments were maintained and which were modified.

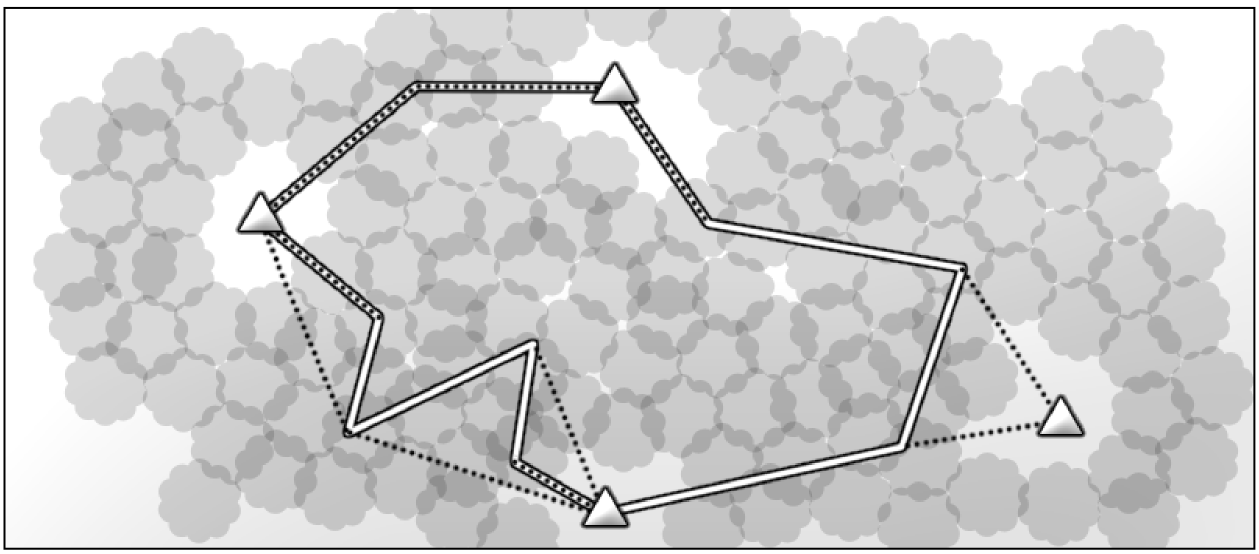
9. Boundaries may be constructed from separately measured polylines created by the GPS walk method taken at different times and in different directions.

53.22 - GPS Angle-Point Method

In this method, the observer measures the unit's boundary angle-points (vertices) by occupying only the points on or near a boundary direction change. The observer measures while on the boundary point or takes sideshots (or similar measurement) to the angle-points when they are near the boundary change (ex. 01 of this section).

53.22 - Exhibit 01

Triangles are GPS or Ortho Control -- Double Lines are Boundary -- Dashed Lines are Sideshots. The Southwest Points are Shown as Sideshots but They Could be Traversed Points if the Sideshots are Not Possible

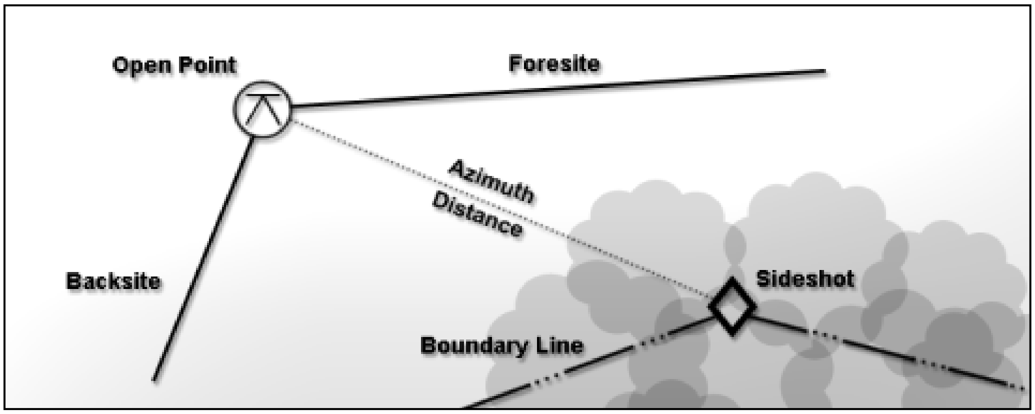


1. It is best to support the receiver's antenna in a stable manner, such as a tripod or staff, which is held reasonably steady while collecting satellite information. (This is not mandatory, but has proven to yield better results.) Natural resources surveying allows the receiver to be "wiggled" slightly, such as rotating the antenna around the survey pole or wrist.

2. Boundary angle-points located in poor environmental conditions suffer poor GPS signals. It is better to obtain a position in an open site and then take sideshots (or traverse) into the covered or blocked location (ex. 02 of this section).

53.22 - Exhibit 02

A Sideshot Diagram



3. Sideshot positions are created by measuring the direction and distance from a good GPS location to a nearby boundary point. The sideshot should be short, rarely more than 30 meters, because longer distances can produce greater error (for example: a 1-degree azimuth error in a 30-meter sideshot causes about a half meter position error at the sideshot point). Longer sideshots can be taken when the boundary point being determined by the sideshot is perpendicular to the boundary, as when measuring across a narrow strip unit. Observations should be taken very carefully when the sideshots involve sharp direction changes along the boundary.

4. Direction-distance traversing from an open-site GPS point into heavily canopied boundary points and back out to another good GPS control point is an excellent method to locate points where GPS signals are obscure. See section 53.4, exhibit 01.

5. Observe and average a sufficient number of good fixes. Good fixes meet filtering criteria such as 3D, appropriate HDOP, and so forth. Averaging 60 good GPS fixes has proven to be sufficient for positions that require more solid determinations. Lesser fixes may be averaged for more general measurement needs as explained in other sections of this chapter. See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml for changes in averaging requirements as new technology is developed.

6. Choose another survey method if the satellite signals are suffering error such as multi-path or being blocked. It is important that the observer continually monitor the quality of the fixes and only average appropriate values.

53.23 - GPS Receiver Always Active–Logging Only at Features (Points)

This method modifies and uses parts of the two previous methods. This method is quite efficient. Accuracy is quite good relative to the other methods and the time to observe a point is reduced greatly. The problem of the walk-method being off the line being measured is lessened in this method. Further, this method takes much less time than the angle-point-method.

Have the GPS receiver on but not logging as you walk to the point. Upon arriving at the point or feature, stabilize the receiver in an appropriate manner as explained in the previous sections (usually at head height over the point to be measured). Then immediately take 5-10 measurements and average them to determine the location coordinates.

When sideshots are used, make them after determining the GPS location. Be sure to leave the receiver active and orientate the antenna reasonably well, but do not log positions when moving between points or features. For more details and field reports, see http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

53.24 - GPS Augmentation

Using real-time differential methods to improve the GPS positional accuracy is encouraged. Examples of such methods are: WAAS, National Differential GPS, and real-time kinematics. Post-processing GPS surveys can be beneficial, but is not necessary or mandatory for timber cruising work. Studies by MTDC have shown that data collected with WAAS or NDGPS is rarely improved significantly with post-processing.

Real-time measurements are often used in field work, but later post-processing may be desired. Special requirements are necessary if post-processing is expected to be done at a later time to improve the measurements. If post-processing is expected, follow the manufactures guidelines to be sure the data collection is appropriately set for post-processing.

The following special requirements may be needed to properly post-process GPS information relative to a reference control station. These requirements are not necessary for data not post-processed. These or similar criteria are generally required by equipment manufactures to allow for proper post-processing.

1. Differentially correct all position fixes to a reference/base station that is within 500 kilometers (300 miles) and has an integrity index of 90 or higher. Collect position fixes by the remote GPS receiver under the following conditions:

    a. Minimum satellite elevation angle of 12 degrees.

    b. Minimum SNR level of 6 or a similar measure (such as C/N0 > 37).

2. Use a qualified reference/base station such as a continuous operating reference station (CORS) or agency base station. CORS stations should be used where available.

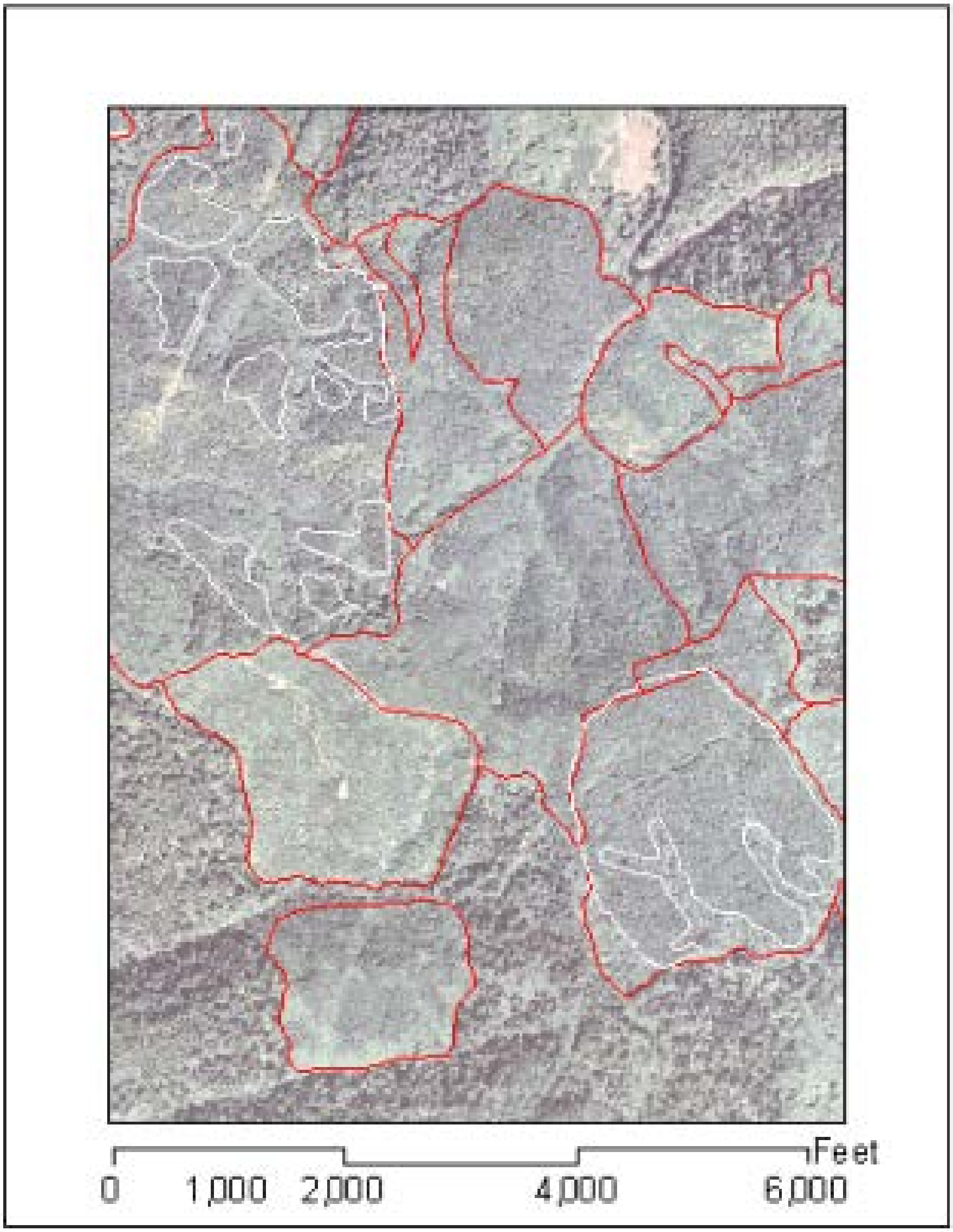
The above criteria will be modified at the FMSC website when changes are warranted and as technology advances. See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

53.3 - Orthophotography Survey Method

Photogrammetric methods and tools have improved dramatically and will continue to do so in the future, making orthophotography technology valuable for timber area and location measurements. Digital Elevation Models (DEM) are improving, allowing more accurate creation of orthophotography images (ex. 01 of this section). Consequently, orthophotography imagery is often available with suitable resolution to determine point coordinates to calculate timber-cruising unit boundaries. The crewmember doing the fieldwork is to be consulted on all maps and calculations produced. See section 50.4 of this chapter for required approvals to use this method.

53.3 - Exhibit 01

Example of an Orthophotography Image



53.31 - Points at Ground Level

Orthophotography may be used to determine survey points and can be used similarly to (or in place of) GPS points when the following procedures are employed:

1. All crewmembers and the forester must have proper training for this method (see sec. 52.4).

2. Use the following procedures to get coordinate values for photo features that define or reference the boundary of the unit:

   a. Digitize (determine coordinates of) points on the orthophotography images that can be positively equated to physical ground points in the field. Use these digitized points just like GPS points discussed in earlier sections (sec. 53.2).

   b. Use stereo-viewing glasses and magnifying glasses to help analyze the aerial photograph stereo-pairs and individual photos in determining the location of the unit boundary. Extreme care must be taken in this identification, as it is subject to the same errors as any measurement. Nearby photo-features should be used to guarantee proper identification is being made of the photo identifiable point that is used to locate the boundary point.

   c. Appropriate large prints or digital orthophotography can be used in place of or with the aerial photograph stereo-pairs and aerial photos to locate positions.

   d. Use only ground-elevation points; do not use the top of any feature or structure for this method (see sec. 53.32 for situations relaxing this requirement).

3. Manually mark the unit boundary points from the field documents (such as aerial photographs or field sketches) on geo-referenced images in a Geographic Information System (GIS). The coordinates of these geo-referenced points can then be used to identify the boundary of the unit. Use mathematically correct methods to determine the area size of the unit. See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

4. Sideshots or direction-distance traversing from these orthophotography points is allowed when executed (as explained in section 53.2) on these subjects.

5. Marked photos, other media used, and field compilation notes documenting the point locations must be kept with the project materials.

6. The boundary of the unit is determined by the lines (legs) that join these boundary angle-points.

7. Newer technology that accomplishes the collection of the above information is allowed when it is proven it can accomplish the task with the same accuracy.

53.32 - Points Not at Ground Level

Measuring area using the top of trees instead of at ground level may be acceptable in some situations. Empirical work in closed canopy areas shows the size of an area can be determined reasonably well for large units. Considerable training in aerial photography properties and familiarity of the local forest types is necessary. The capability of the crew must be stated in the survey reports. Further, the exaggerated point location error and subsequent area-error must be clearly and distinctly stated with the measurement numbers. These issues are explained in section 54.32 on accuracy**.**

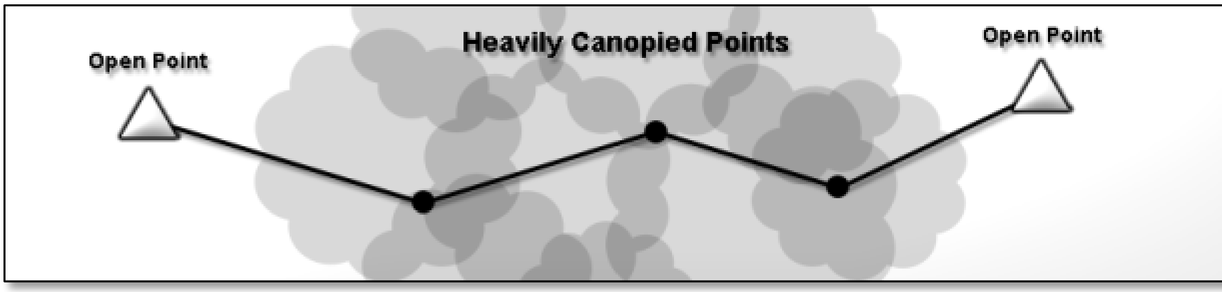
53.4 - Combined Survey Methods

This section describes how to combine direction-distance traverses with GPS control positions (or similar control positions such as orthographic image points).

Shown here (ex. 01), the traverse points are in the trees, blocked from good satellite observations. The GPS points (or orthographic image points) are in more open areas, where good measurements to unobstructed satellites can be made. This method combines the desirable features of "good control" from GPS plus the traverse operation, which is unaffected by canopy closure. This method is also effective when satellite signals are poor or unavailable because of canyons, steep north slopes, tunnels, dense tree canopy or stems, and similar situations.

53.4 – Exhibit 01

Combined Survey Method in Heavily Canopied Points



When combining these methods, the different processes remain essentially the same as explained for the independent operations.

1. All setup procedures, preparations, and similar operations explained in the individual methods apply respectively to the combined methods.

2. The GPS location of the boundary points can be determined by any method described in section 53 of this chapter. A control point (such as from GPS or orthophotogrammetry), as described in the angle-point method, is a good procedure at the place two types of surveys join.

3. Direction-distance traverse measurements (after applying appropriate angle or azimuth corrections) are adjusted between two control points, such as GPS or orthophotography positions. The closing error (traverse closing distance) limits are shown here:

   1:50 for traverses ≤ 5,000 feet between GPS or similar control points.

   1:100 for traverses > 5,000 feet between GPS or similar control points.

4. Apply appropriate adjustment methods to the traverse, such as the compass adjustment rule and azimuth corrections.

For additional support tools, guidance, and the derivation of the 5,000-foot rule, see http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

54 - Point Accuracy Estimations

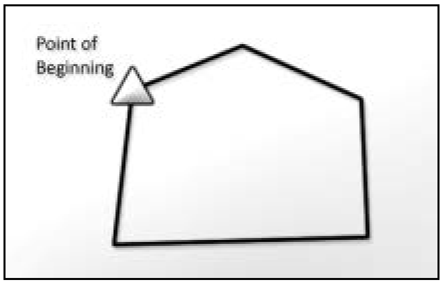
54.1 - Direction-distance Survey Accuracy Estimation

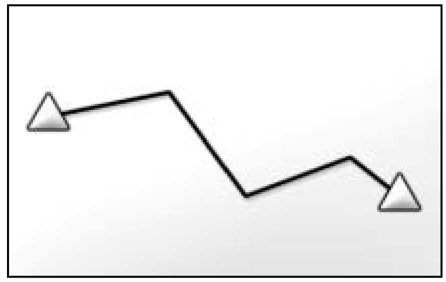
A modified "compass rule" is practiced by the timber cruising crews to adjust traverses. The common cruiser practice is to take a compass azimuth and measure a distance to create a vector between the occupied point and the observed point.

Connecting these vectors between two control points constitutes the closed traverse. The vectors of the traverse must be adjusted to get the correct location for each angle point along the traversed boundary. The traverse might start and end at the same point of beginning or it might run between two different known control points (ex. 01 of this section).

54.1 – Exhibit 01

Example of Different Techniques Used for the Direction-Distance Method



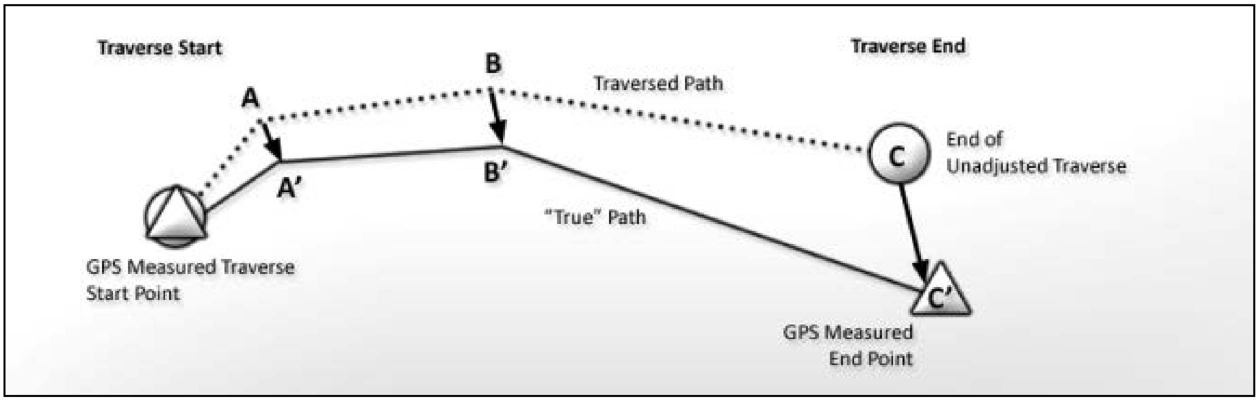


In higher order surveying, the **angles** at each traverse angle-point are adjusted. This is not the case in timber cruising as **azimuth, not angles**, are normally measured. Observing azimuth is acceptable in timber cruising. The magnetic declination should be applied to the magnetic azimuths to obtain true readings. The declination can be applied manually or by computer software. It is acceptable and common to apply local magnetic declinations.
See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

The calculation to convert raw coordinates to adjusted coordinates is fairly simple. The lineal error of closure (see definition of closing error, sec. 50.5) is distributed proportionately relative to the length along the traverse compared to the total length of the traverse. The lineal error of closure is first separated into its cardinal components; then, differences in northing and easting can be distributed proportionally (see ex. 02 of this section).

54.1 – Exhibit 02

Adjustment procedure for direction-distance traverse



The total closing error CC' is applied at C. The corrections at AA', BB' are proportional to their distance along the boundary from the start point.

In this example:

A is a quarter of the way to C;

B is half way to C;

There is a closing error of 2 meters in the X direction and 4 meters in the Y direction, as depicted in the diagram.

Then A is adjusted by ½ meter east and 1 meter south to A'

B is adjusted 1 meter east and 2 meters south to B'.

Of course, all the correction is applied to C to put it in on the closing point, C'.

54.2 - GPS Accuracy Estimation

This section describes how the location accuracy of GPS angle-points is estimated. The boundary of the unit is determined by the lines (legs) that join the boundary angle-points. Accordingly, the point estimates and the resulting lines between the points estimate the area-error of a unit, which is needed to determine volume.

The timber cruiser estimates the accuracy of the GPS points by using the Accuracy Matrix monitored by MTDC and FMSC. MTDC follows NSSDA (National Standard for Spatial Data Accuracy) methods for calculating the stated accuracies.

54.2 – Exhibit 01

Example of an Accuracy Table*

*The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service. The numbers in this exhibit are for illustration purposes only.

USDA Forest Service Global Positioning System: MTDC...

Global Positioning System > MTDC GPS Receiver Accuracy Reports

MTDC GPS Receiver Accuracy Reports

MTDC has been testing GPS receivers of various grades in order to determine their accuracy in different conditions, and, in some cases, differe
and model to see the accuracy reports for that receiver.

Manufacturer

Trimble

Model

Geo XT 2008 Series

Trimble Geo XT 2008 Series					Tested Accuracies By Canopy Type NSSDA(units in meters)		
External Antenna	Real Time Correction	Glonass	Post Process	# of Positions Averaged	Open	Light-Medium	Heavy-Closed
No	None	No	No	1	1.02	2.67	15.91
No	None	No	No	5	1.58	2.46	5.03
No	None	No	No	60	0.58	2.75	6.2
No	None	No	Yes	1	0.4	1.69	5.62
No	None	No	Yes	5	0.35	2.46	3.99
No	None	No	Yes	60	0.14	2.12	3.22
No	WAAS	No	No	1	0.47	4.42	3.79
No	WAAS	No	No	5	0.82	2.03	3.66
No	WAAS	No	No	60	1.01	2.18	4.43
No	WAAS	No	Yes	1	0.09	1.92	3.79
No	WAAS	No	Yes	5	0.26	1.35	3.66
No	WAAS	No	Yes	60	0.24	1.39	3.56
Yes	WAAS	No	No	1	0.45	1.49	2.24
Yes	WAAS	No	No	5	0.44	1.16	2.84
Yes	WAAS	No	No	60	0.53	1.1	4.07
Yes	WAAS	No	Yes	1	0.29	1.34	2.51
Yes	WAAS	No	Yes	5	0.17	1.39	2.23
Yes	WAAS	No	Yes	60	0.17	1.72	3.34

Note About Reports: (NSSDA = horiz RMS x 1.7308) Some results are an average of more than 1 test run, as of 6/19/2007 ranges listed instead of averages. Data collected afte
device to acquire a current almanac and ephimerus data.

Table of All Tested Accuracies– (346 kb)

<u># of Positions Averaged Legend</u>

1 is GPS Walk Method (Sec. 53.21)

5 is GPS Logging At Corners Only (Sec. 53.23)

60 is GPS Angle Point Method (Sec. 53.22)

Choose the value that best represents the type of equipment used and the canopy condition.

The values represent empirical accuracy determinations on control courses. Use these values for the accuracy parameter in area-error calculations. Appropriate interpolation (or even extrapolation) is allowed where values are missing in the table.

Blank cells in the matrix do not necessarily indicate missing information. They often mean the GPS signal is not available or is not usable in that condition, particularly under heavy canopy.

54.2 – Exhibit 01--continued

The MTDC matrix may change format, and the comments sections may be modified. Note the "Tested Accuracies" date in your reports. For explanation of changes, see http//www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

The field crew can estimate the accuracy for all the measured points of a unit by entering the Accuracy Matrix with the following parameters:

1. Equipment configuration.

2. "1 Position" is for Walk Method; "5 Position" is when receiver is active while moving between measured features and then averaging 5 measurements when arriving at the feature location; or "60 position ave." is for Static (angle-point) Method. Numbers may change as technology improves. See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

3. General forest canopy closure. In general, open canopy has 0 to 20 percent of the sky obscured; light-medium has 20 to 60 percent of the sky obscured; and heavy to closed has 60 to 100 percent of the sky obscured. http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

Then select the value from the table represented by these parameters. See section 54.2, exhibit 01.

Where the timber stand condition is similar throughout the unit, one single value can be used for all boundary points. When the timber stand conditions vary considerably, use appropriate and different values from the table for each point. If the stand conditions do not vary radically, apply an average value to all points.

Apply different accuracy values for different sections of the boundary perimeter where there are distinct changes in the timber stand conditions. The area-error from each section is combined into a total value for the unit. The worst-case accuracy is always acceptable to use, particularly where the area-error standard is still met.

Record your decisions and methods in the metadata. See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

54.3 - Orthophotography Survey Accuracy Estimation

54.31 - Points at Ground Level

The accuracy of location values from orthophotography is dependent on several factors. One factor is the pixel size of the image. For Forest Service timber cruising purposes, the pixel size should be 1 meter or less, unless otherwise authorized. The size of the pixel is the precision of resolution of the image, not the accuracy of each pixel to a correct geographic location. The smaller the pixel size, the clearer the images appear. Other factors determining accuracy are how well the images were processed and referenced to each other (relative spatial reference) and how true the process places each pixel to its true ground coordinates (absolute spatial geo-reference).

Orthophotography relative accuracy is generally less than 3 meters and less than 8 meters absolute accuracy from sanctioned imagery. These accuracies are comparable to GPS accuracies in open-sky conditions. It is imperative that the points chosen from the orthophoto correctly represent the boundary of the unit as marked on the ground. See earlier sections on training and skill requirements (sec. 52.4 and 54.31). This accuracy is applicable only to visible ground points. See following sections for points that are not on the ground (sec. 54.32).

The accuracy of the orthophotography to be reported with the survey needs to be verified with the source of the image (such as Forest Service Remote Sensing Applications Center—RSAC). The accuracy verification report must be included in the project's record. Using orthophotography meeting National Mapping Standards does not guarantee that digitized (or measured) coordinates are suitable for determining timber-cruise areas.
See: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

Orthophoto images suitable for timber cruising area work are available from the USDA Farm Service Agency, Aerial Photography Field Office. The images are "acquired at one-meter ground sample distance (GSD) with a horizontal accuracy that matches within six meters of photo-identifiable ground control points." The accuracy of 6 meters may be used as the appropriately explained why it is valid or it is proven by the method explained in the following paragraphs and as shown in section 54.31, exhibit 02.

As stated earlier, empirical tests demonstrate that for relative spatial referencing the accuracy may be around 3 meters. The following paragraphs explain how to verify orthophotography accuracies as well as how to field determine orthophoto accuracy.

The following example (ex. 01 of this section) demonstrates how to do the accuracy verification process of the orthophotography if the validation is questionable.

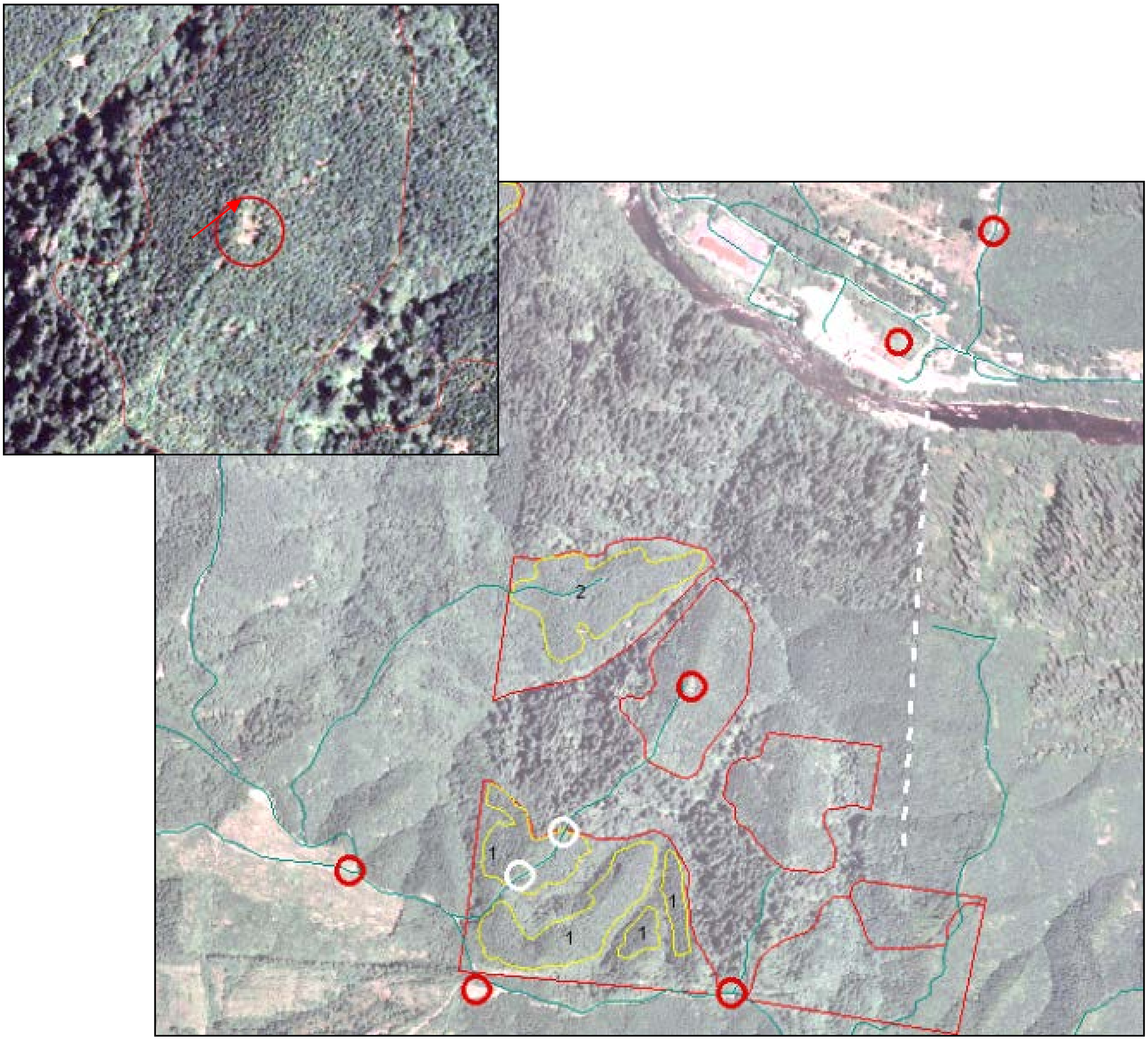
The black dot in the upper-left picture is a logical photo-identifiable point where a GPS observation can be made to compare with the digitized value from the photo. The circles in the larger photo show possible additional points to be measured with GPS. This will be discussed below, but first: some general information.

The sale units determined by digitizing are visible in the big orthophoto. The imagery is from an approved Forest Service source. Still, it is prudent to check our work wherever we can. Putting in several GPS points assures that we have good imagery, and gives us a chance to calculate the root mean square error (RMSE) for additional accuracy values or concurrence. The red circles show where GPS could be added across the entire project at easy-access sites. The white circles can be used for control or used as internal points to check GPS referencing calculations. The red circle at the northeast of the orthophoto is a poor choice because it is to the right of the white dashed line where the photos were joined to make the orthophoto. Sometimes, there is no choice, but if so, attempt to stay on one side of these join lines.

The small picture shows how the black spot in an open spot at the end of a road might be used to get GPS control. The center black dot is about 10 feet in diameter. With appropriate photo-identification skills, the selection place on the photo should be less than 3 feet or 1 meter. That digitized location from the orthophoto can then be compared to the GPS location at the same point.

54.31 – Exhibit 01

Orthophotography Showing Digitized (Or Measured) Coordinates



The accuracy of digitized orthophotography locations can be determined by comparison with the GPS locations. The GPS values are generally considered superior controls but also contain error and are not absolutely accurate.

The spread sheet (ex. 02) demonstrates how the photo coordinates compare to GPS control points. The result shows an accuracy of the photo compared to the GPS control to be 2.93 meters, RMSE for one standard deviation (65-percent level). Using a value of 4.5 meters is correct for this situation as it meets the 95-percent confidence level. That the orthophoto points have measurement variability (inaccuracy) of 4.5 meters can be reported and used for area-error calculations. See the discussion of RMSE at http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

54.31 - Exhibit 02

Orthophotography Showing Digitized (or Measured) Coordinates

	A	B	C	D	E	F
1	---------- Initial Data ----------					
2	Point ID	Photo UTM coordinates (meters)			Control UTM coordinates (meters)	
3		Xphoto	Xcontrol		Yphoto	Ycontrol
4						
5	9011	313963.2	313962.0908		5196431	5196429.333
6	9012	313891.6	313892.6461		5196438.4	5196435.451
7	9014	313903.6	313905.4477		5196305.3	5196305.907
8	9015	313941.4	313945.0969		5196272.3	5196273.992
9	9016	314001.7	313999.2166		5196301.6	5196300.052
10	9017	314011.9	314009.0015		5196364.7	5196364.011
11	pt7					
12	pt8					
13	pt9					
14	pt10					
15		6	- n			
16						
17		---------- Calculated Information ----------				
18		Photo X residual (poor to use if > 5)			squared	squared
19		Xphoto-Xcontrol	Yphoto-Ycontrol		X residual	Y residual
20	9011	1.11	1.67		1.23	2.78
21	9012	-1.05	2.95		1.09	8.70
22	9014	-1.85	-0.61		3.41	0.37
23	9015	-3.70	-1.69		13.67	2.86
24	9016	2.48	1.55		6.17	2.40
25	9017	2.90	0.69		8.40	0.47
26	pt7	0.00	0.00		0.00	0.00
27	pt8	0.00	0.00		0.00	0.00
28	pt9	0.00	0.00		0.00	0.00
29	pt10	0.00	0.00		0.00	0.00
30						
31	sum of the Xsuqred residuals /sum of the Ysquared residuals				33.97429256	17.577828
32	RMSEr - sq-root of sum of squared X, Y residuals				2.93	
33						
34						
35	Probability(error≤distance) = 1-e^-(distance/RSM_Error)2 *					
36						
37		4.5	distance (meters) per standard definition			
38		2.93	RMSEr			
39		0.95	Probability(error<3)		should be >.65 (65%)	
40						
41						
42	* David L. Wilson's GPS accuracy Web Page, 12 Aug, 2003					
43	htpp://users.erols.com/dlwilson/gpsacc.htm					
44	PhD., Mathematics, Kent State University					
45						

54.32 - Points Not at Ground Level

Using points at other than ground level introduce additional error to that described above (sec. 54.31) for ground-level points. Only points at ground level are correctly located by the orthophotography image creation process. Any coordinate determined from the orthophoto above or below ground elevation is not the same as that at ground level. Include information documenting that other than ground-level points were used and, because of this, there is greater point inaccuracy.

The picture (ex. 01 of this section) illustrates that the tops of trees are not in the same place as the bottoms of trees. The orthophoto is developed with the focus at ground level at the bottom of the trees. Locating positions from the tops of trees where the stumps are not visible adds considerable position error.

54.32 – Exhibit 01

<u>Photo Showing the Top of Trees are Not in the Same Place as the Bottom of Trees</u>

Near the edge of the photography the displacement from ground to top of tree is approximately 66 percent the tree height

Fig. 14-50. Image displacement increases radially from the principal point (nadir) on vertical imagery. (Courtesy of Forest Management Institute, Canadian Forestry Service, and Capital Air Surveys).

Using the tops of trees instead of ground level points upon which the orthophoto was made can introduce additional point accuracy error of approximately 66 percent times the average tree height in the project area. See: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

For example, if determining orthophoto points from the tops of 60-foot-tall trees, the additional treetop offset error is approximately 66 percent times 60 feet, which is 40 feet. If the orthophotography is accurate to 10 feet; then the final estimated inaccuracy for points measured at treetop is 40 feet plus 10 feet, which is 50 feet. This is the inaccuracy to be reported for each point digitized from the orthophotography imagery. For large units, this may be an acceptable error level. See the explanation of error limits in section 55. For additional information, go to: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

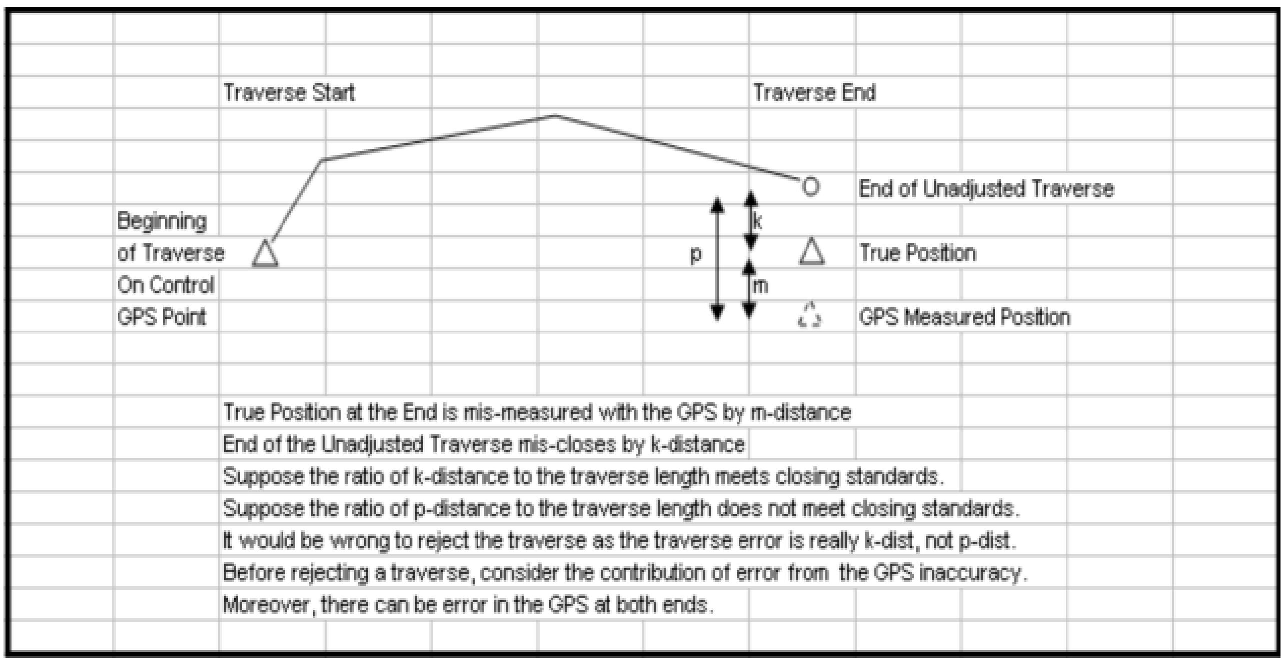
54.4 - Combined Survey Accuracy Estimation

Use the specific procedures for each method to calculate the point accuracy for that part of the survey (see ex.01 of this section).

Combining direction-distance traverses with GPS surveying requires some special considerations. Ordinarily, there is error in the control points upon which a traverse closes. Before rejecting a traverse that shows too much closing error, consider the accuracy of the control. The size of the traverse-closing error, reduced by the size of the likely control-point error, is probably a better number to use in place of the closing value and will more likely meet the required standard.

54.4 – Exhibit 01

Direction-distance Traverse Point Accuracy Estimation



Ordinarily, the direction-distance traverse and GPS (ortho) survey area-errors are added together. However, if the direction-distance traverse encloses the entire unit, then only the direction-distance traverse area-error is reported. The translation of the unit upon the ground does not affect the area calculation, only its placement on the map.

54.5 - Alternative Values for Accuracy

Alternative approved methods defining relative accuracy for points of a boundary may be used. Such values may be used in place of accuracies defined in other parts of the handbook, such as replacing GPS accuracy.

For example, survey only one side of a strip unit and establish the other side at a set distance off the surveyed line. In this case, the accuracy of measuring the offset line can be substituted for GPS accuracy or for the direction-distance traverse-closing error. The offset distance can be measured to less than a foot. For other examples, see section 50.6 and http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

54.6 - Precision of Measurement

Area measurements are to be reported to the nearest tenth of an acre along with a statement of the maximum expected area error.

Example 1: 27.6 acres, plus or minus 1.2 acres.

Example 2: 4.1 acres, plus or minus 0.3 acres.

Example of a modified form: 3.8 to 4.4 acres.

Other representations that are clear and consistent with these examples may be used.

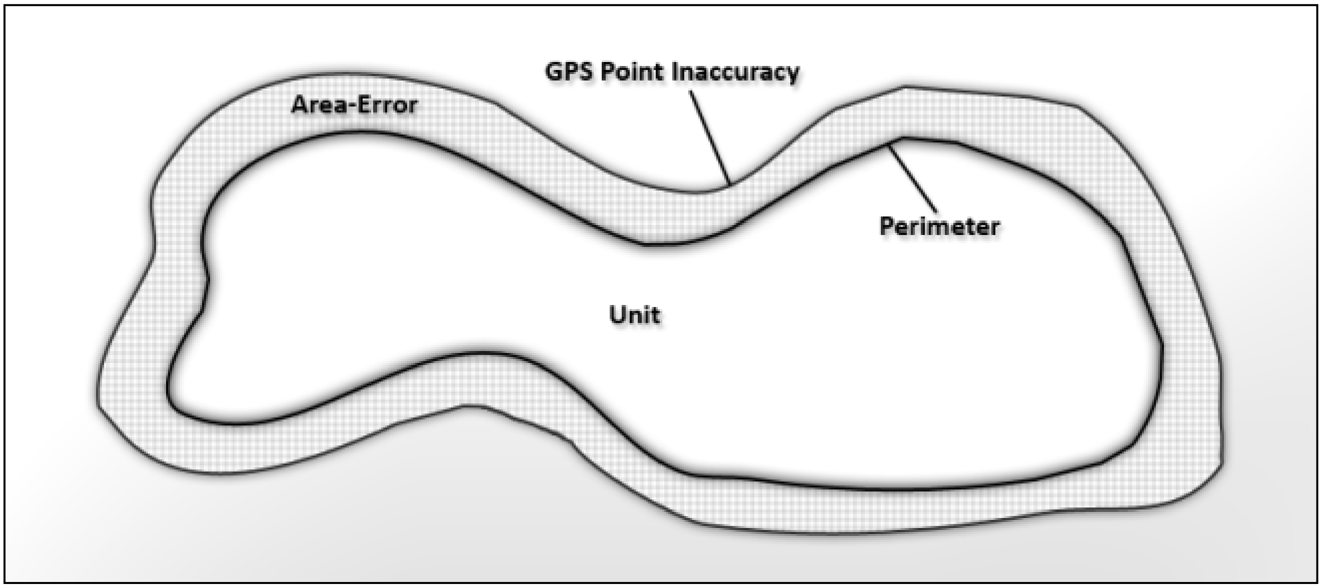
There may be cases in which reporting to the hundredth of an acre reduces rounding errors. This is allowable but not mandated. For example, the maximum expected area error is calculated by the unit's perimeter times the inaccuracy of points along the perimeter. The handbook explains this in great detail elsewhere, but for a simple example: a 1,000-foot perimeter with points accurate to 3 feet calculates the maximum expected area error to be 3,000 square feet or 0.06887 acres and can be reported as plus or minus 0.1 acre or 0.07 acres along with the unit's acres measured. Rounding the reported values to two decimals may be done and usually removes rounding problems. See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

55 - Area-Error Estimations And Limits

Measuring the area of a unit always has some error; the measurements are never exact. Measurement errors are not blunders; they are due simply to the physical inability to measure something perfectly. Area-error is to be less than 10 percent of the area measured for timber cruising in almost all cases. (The exceptions are explained in the rounding issues and in the superior rule of the closing error for direction-distance traverses). The following explains how to determine the area-error and some exceptions to the 10 percent rule. The regional forester may approve area accuracy exceptions for specific situations.

55 - Exhibit 01

Example of Measurement Error
The Maximum Area Error Occurs When All the GPS Error is on One Side of the Unit's Boundary



Calculating the amount of area-error can be complex because of the varying shapes that may define a unit. However, it is fairly simple to estimate the maximum area-error for a unit. All the GPS point errors applied to one side of the polygon creates the maximum area-error that is expected. For this diagram (ex. 01), the error is shown outside the polygon. The result is essentially the same if all the error is on the inside because the point inaccuracy is quite small compared to the length of the entire perimeter. The maximum area-error is estimated when the error is applied perpendicular to the boundary. When the point inaccuracy is not perpendicular to the boundary, there is less error, but the direction of the GPS inaccuracy is not known; therefore, only the maximum can be estimated.

Calculating the area-error of a unit is generally simple. The possible maximum area-error is estimated by multiplying the perimeter of the unit by the inaccuracy of the GPS boundary points. For example, given a 30 acre unit, a perimeter of 4,500 feet, and a GPS inaccuracy of 3 meters (~10 feet):

> Maximum area-error = 4,500 feet X 10 feet = 45,000 square feet.
>
> Area-error in percent = (45,000 square feet / (30 acres X 43,560 square feet)) X 100 = approximately 3 percent. The limit is to be less than 10 percent.

Calculating the area-error for a direction-distance traverse is similar except that the closing error (see sec. 50.5 for error of closure synonyms) is used in place of the GPS inaccuracy in the above algorithm. There is one more modification: there is no error at the beginning point of a traverse

55 - Exhibit 01--continued

(see 55.1 ex. 01); the closing error is at the end point of the traverse. The mean value of the errors of the starting point plus the ending point is half the closing error at the end point (mean of zero plus closing-error). For this reason, half the closing error value is substituted for the GPS inaccuracy. As all the error is applied to either the outside or the inside of the measured line, the actual area-error may be quite a bit smaller but it is rarely larger. This again estimates the largest area-error expected.

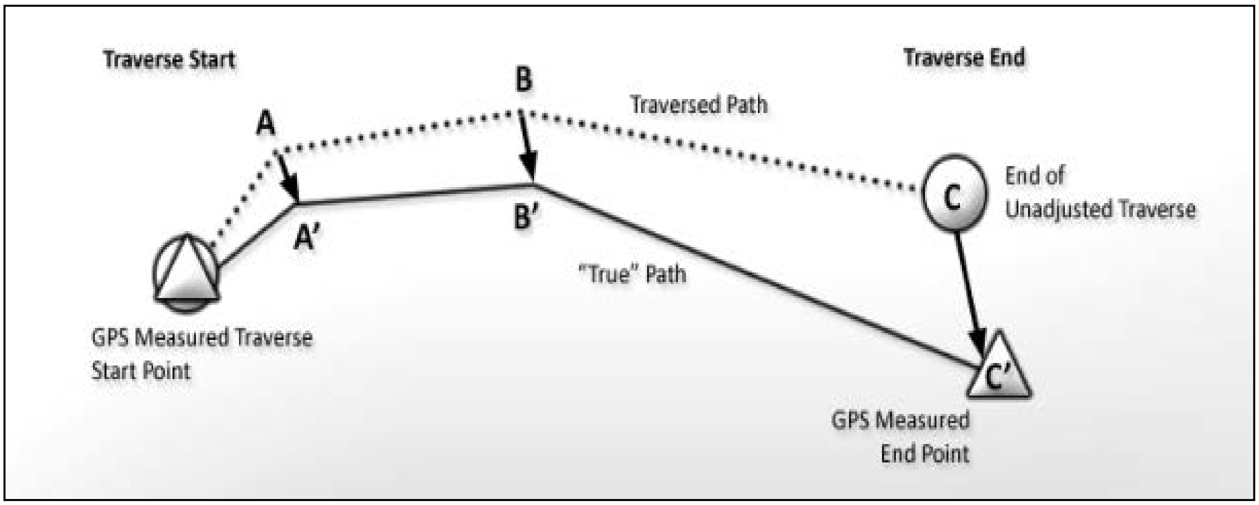
55.1 - Direction-distance Area-Error Estimation

The area of a unit is to be reported as the measured area plus or minus the estimated maximum area-error (EMAE). For this method, the maximum variation in area measurement is visualized in exhibit 01 of this section.

The simple diagram between two control points shows how the measurement points A, B, and C are adjusted to the corrected position, A', B', and C', as a proportion of the closing error, C-C', relative to the part of the total perimeter. Essentially, the maximum area-error expected is a triangle. This area is calculated as half the closing distance, C-C', times the length of the perimeter between the start and end points.

55.1 - Exhibit 01

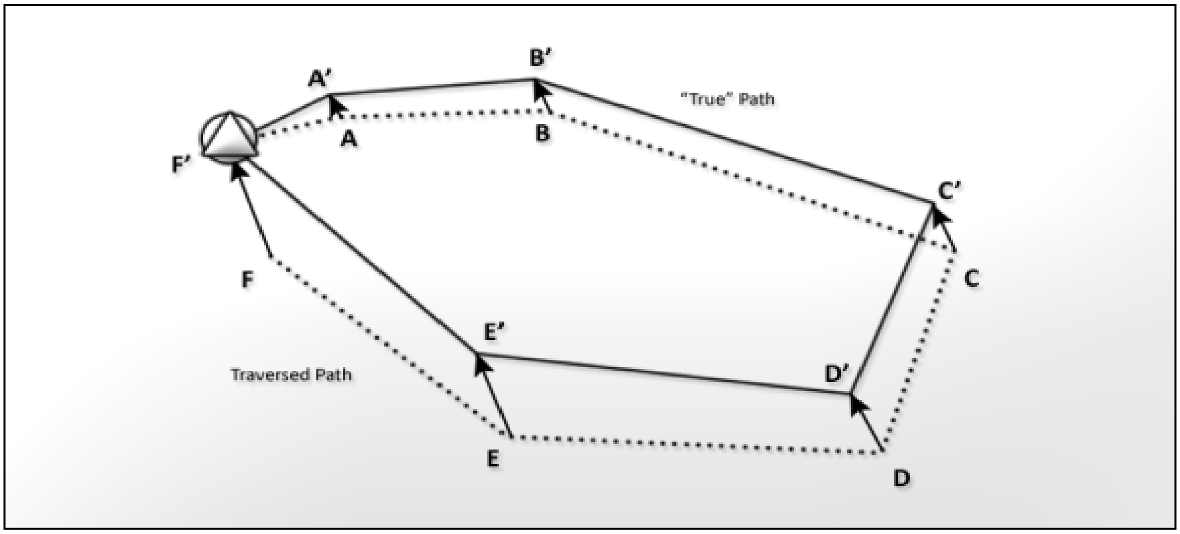
Diagram Between Two Control Points



This same algorithm is used for all traverses whether the traverse is between points as shown in exhibit 01 or for a closed traverse as shown in exhibit 02. The area error for a traverse around the entire unit does not form a simple triangle, but instead, there can be area-error inside the true unit and other area-error outside the unit. However, for simplicity of fieldwork and office calculations, this method represents the area reasonably well and is larger than the actual error expected (ex. 03). The direction-distance traverse closing error restrictions keeps the area-error in check.

55.1 - Exhibit 02

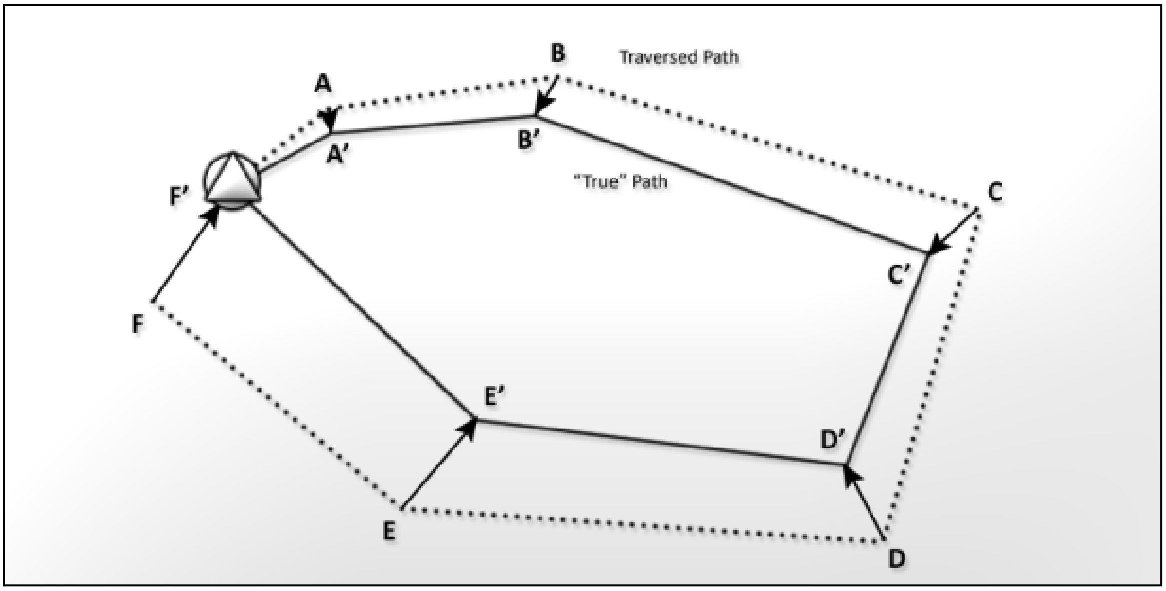
Diagram of Closed Traverse Around a Unit (Area-error May be Either Outside or Inside the Boundary)



Typical to all area-error calculations, the estimates are for the maximum error that might occur. For ease of calculations and to express the maximum error expected, the calculations for a closed traverse are the same as in the first example (ex. 01), being half the closing error, F-F', times the entire perimeter. The diagram in exhibit 03 depicts this. For methods to calculate the more complex area-error if needed or desired, see http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml. The less complex method shown in exhibit 03 of this section is sufficient in most cases when the error standards are met.

55.1 - Exhibit 03

Diagram of Maximum Error Expected (Area-error Calculated on One Side of the Boundary)



Restating this situation: if all the error is depicted on one side of the polygon, and the boundary lines are straightened, it would look similar to the first simple diagram (ex. 01 of this section). This error calculation is a larger value (a more generous value) than expected but it can be easily calculated. It is the method ordinarily used in this handbook for reporting the maximum area-error (variation) expected in a direction-distance traverse.

Area error is to be reported for direction-distance traverses. However, the acceptance of a direction-distance traverse is not limited by this reported area-error information, but by the superior rule of a traverse closure relative to 20 acres for a closed traverse around the unit or to the 5,000-foot rule between GPS or similar control points. As stated in the Responsibility section (sec. 50.4), the regional forester may set different standards for low-value or high-value product surveys.

Use instruments capable of meeting accuracy standards when measuring boundaries enclosing the area. The following are the accuracy standards:

55.1 - Exhibit 03--continued

1. Do not exceed the error of closure ratio (see sec. 50.5 for error of closure synonyms). The error of closure limit is dependent on the size of the unit being surveyed or by the distance between control points:

   a. Traverse around the entire unit;

      1:50 for area of 20 acres or less, or

      1:100 for areas greater than 20 acres.

   b. Traverse between control points;

      1:50 for boundary segments of 5,000 feet or less, or

      1:100 for boundary segments greater than 5,000 feet.

2. Adjust traverse for error of closure using direction-distance survey techniques (such as compass rule) after angle or azimuth adjustments are made.

3. Only accept a direction-distance traverse not meeting error of closure standards if it has one or more verification traverses in which the difference in acreage between the original survey and the verification survey is less than 10 percent. A different crew must run the verification traverse than performed the original survey.

Maximum area-error for a direction-distance traverse is calculated manually as described here:

1. Multiply half the traverse closing error by the perimeter of the unit to get the amount of area representing the maximum expected area-error.

2. Divide the area-error by the area of the unit to get the maximum estimated area-error, relative to the area of the unit, in decimal form.

3. Multiply by 100 to get the percent of estimated maximum area-error relative to unit size.

These three steps are shown in a simple formula, in which area, perimeter, and the traverse closing error are entered as known or estimated parameters.

Area:	The area of the unit (known or estimated).
Perimeter:	The length of the perimeter (known or estimated).
TCE:	Traverse closing error distance (known or estimated).
EMAE:	Estimated maximum area-error.

55.1 - Exhibit 03--continued

EMAE%: The percent estimated maximum area-error.

EMAE = 0.5 * TCE * Perimeter.

EMAE% = (EMAE / Area) * 100.

Units of measurement must be consistent, such as feet for distance and square feet for area or meters for distance and square meters for area (ex. 04 of this section).

55.1 - Exhibit 04

Estimated maximum area-error calculation for direction-distance traverse

For example:

Area = 30 acres

Perimeter = 4500 ft

Traverse Closing Error = 45 ft

(just meets the limit allowed for this perimeter which is 1:100 because the area is greater than 20.)

Now to calculate and show the area-error standard is met.

$EMAE = 0.5 * TCE * Perimeter = 0.5 * 45\text{ ft} * 4500\text{ ft} = 101250\text{ ft}^2 = 2.324\text{ acres}$

$EMAE\% = (EMAE / Area) * 100 = (101250\text{ ft}^2 / (30\text{ acres} * 43560\text{ ft}^2\text{/acre})) * 100 \approx 7.7\%$

Area reports should have information showing something like this:

The unit encloses 30 ± 2.3 acres

or the unit contains 30 acres, plus or minus 7.7 percent

Software that calculates the above, such as TwoTrails©, may be used.
See http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

The reverse calculation may be desired when trying to determine the accuracy requirements to get a specific percent of error. Knowing or estimating the area, perimeter, and what is allowable as area-error enables the determination of the closing error that will be allowed to meet a need. Therefore, the traverse closing error can be appropriately calculated by the amount of error allowable in the area. See exhibit 05 of this section for the reverse process formulae and examples.

55.1 - Exhibit 05

Reverse Example of the Above Calculations
Calculating How Large the Closing Error can be to Meet a Specified Estimated Maximum Area-error

EMAE = *Area* * (*EMAE%* / 100)
TCE = 2 * (*EMAE* / *Perimeter*)
For example:
Area = 30 acres
Perimeter = 4500 ft
Percent Estimated Maximum Area-Error (as allowed by the project manager) = 7.7%
EMAE = *Area* * (*EMAE%* / 100) = (30 acres * 43560 ft^2/acre) * (7.7 / 100) = 100624 ft^2
TCE = 2 * (*EMAE* / *Perimeter*) = 2 * (106224 ft^2 / 4500 ft) ≈ 44.7 ft

This example reverses the earlier forward calculation by beginning with the amount of area-error that will be allowed, then determining that TCE equals 45ft. Using the reverse calculation allows the manager to choose the distance for closing a traverse relative to the needs of the project. This matches the 45-foot closing error in the earlier example (forward calculation). If the desired estimate for area-error was 10 percent instead of 7.7 percent, then the acceptable traverse closing error could be as large as 58 feet. This determination may not respect the 20-acre rule limit, but may be more in line with the economics of the operation on the unit. Approval from the appropriate manager is needed and must be noted in the metadata. The 20-acre closing error rule is superior to the 10 percent area rule.

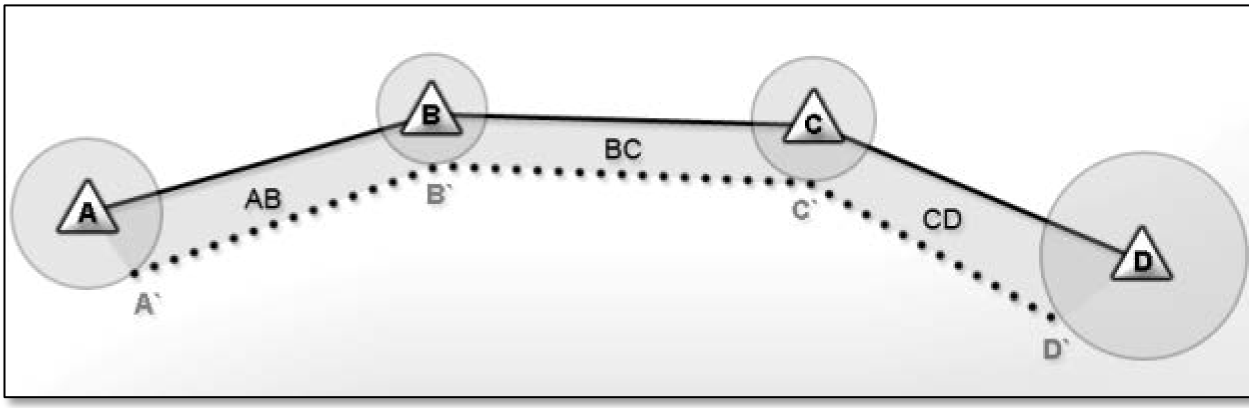
55.2 - GPS Walk and GPS Angle-Point Area-Error Estimation

Report the area of a unit as the measured area plus or minus the EMAE (estimated maximum area-error). The following sections show how to calculate the maximum error expected for a unit. The actual area-error is expected to be less than the calculated maximum error, EMAE, 95 percent of the time. This is a valuable statistic because this maximum expected error calculation is consistent and reports a conservative value. It also helps the forest manager to choose equipment and procedures that are suitable to the economics and management needs of the project.

The following (ex. 01) shows how the maximum area-error is calculated. The location error at any point can be in any direction. There is little area-error when the directions of the error-between two adjacent boundary points is parallel to the boundary path. The maximum area-error exists when both point location errors are perpendicular and to one side of the perimeter path.

55.2 - Exhibit 01

How Expected Maximum Area-error is Calculated



The size of the trapezoid area, AB, is calculated by multiplying the average value of the ends, AA' and BB', times the length, AB. Similarly, the area BC is (BC' + CC') divided by two multiplied by length BC, and so on. The total of the largest expected error for the unit is the sum of the areas (AB + BC + CD + …).

Equation 1 shows how to calculate area-error when the accuracy is different at each boundary point. See: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

> {Eq 1} Total Area-Error = [AB *(AA' + BB')/2] + [BC * (BB'+ CC')/2] + [CD * (CC' + DD')/2] + …

The calculation becomes much easier when the accuracy of the boundary points is the same at all locations. This is because AA' = BB' = CC' = DD'. Therefore, AA' times the length of the perimeter ABCD calculates the total expected maximum area-error. In other words, the width of the inaccuracy times the perimeter is the estimated maximum area-error.

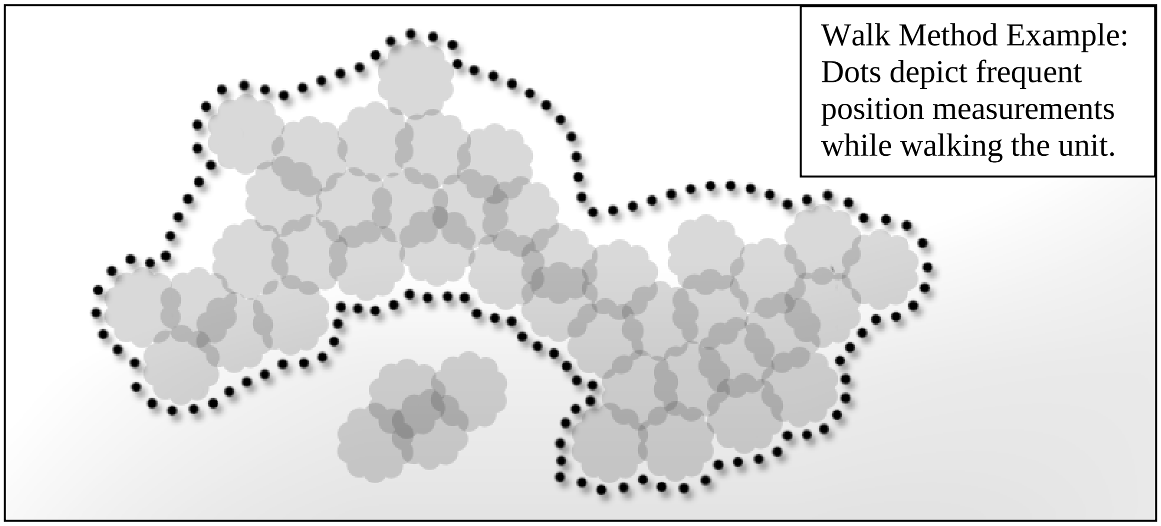
Equation 2 calculates expected maximum area-error when the accuracy is the same at each boundary point.

> {Eq 2} Total Area-Error = line AA' (the common point error) * line ABCD

The above equations work for all situations, whether the boundary points are close together (as in a walk session) or further apart at only the boundary direction change points (as in an angle-point session).

55.2 – Exhibit 02

Walk Method



Repeating for clarification: Equation 1 and 2 are appropriate to estimate the area-error when the boundary points are measured closely together, such as taking a GPS reading every few seconds while walking the boundary.

If the measurements are made less often, at only the angle-points of the unit (see ex. 03 of this section), then the expected error may be reduced by half. For more information, see: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

Even though the direction of the error is unknown, the error can only exist in one direction. That one direction, whatever it is, is used for area calculations of the line coming in and the line going out. Mathematically, this makes the forward and backward boundary calculations dependent, which allows the error to be reduced.

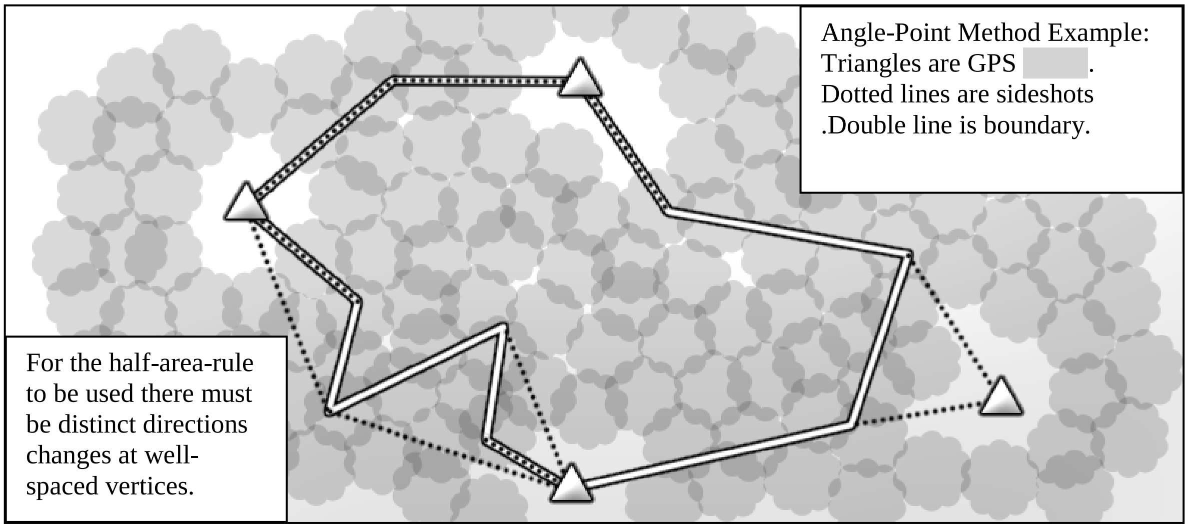
Whether the points-accuracy of the boundary points are all different or are all the same, the total area-error is multiplied by one-half, as shown in equation 3.

{Eq 3} Total Area-Error = {Eq 1} or {Eq 2} * 0.5

This calculation should only be applied when the deflection angles are generally greater than 45 degrees.

55.2 - Exhibit 03

Angle-Point Method



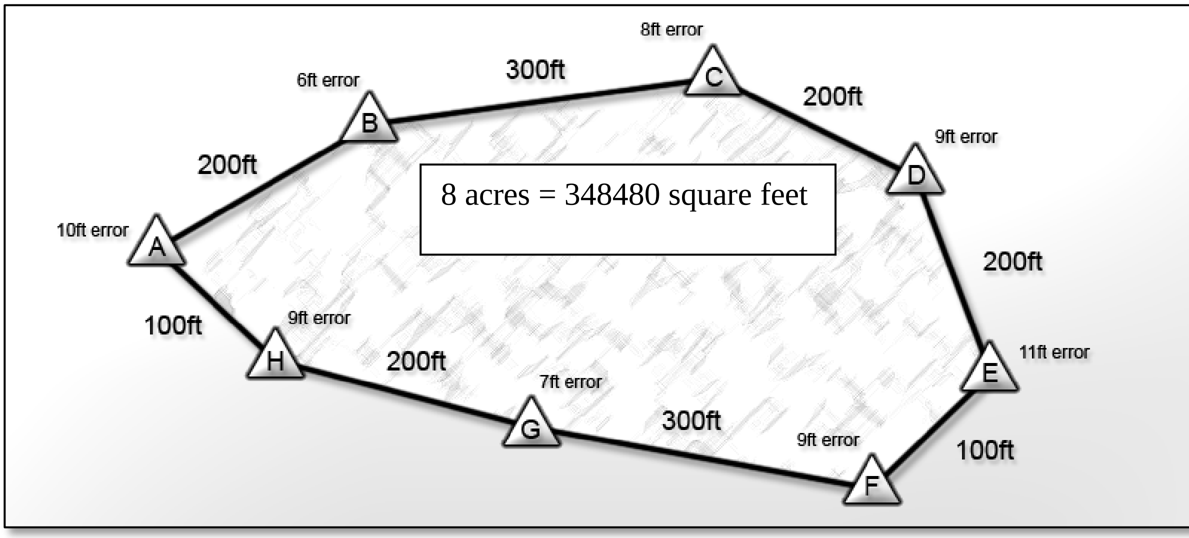
Choosing the Walk Method or Angle-Point Method calculation depends on whether the points are quite close together along the boundary or only measured at major angle-points. Use the Walk Method equation {Eq1} or {Eq2} for closely spaced points. If the points are only at the angle-points, {Eq3} can be used. If there is confusion as to which equation to use, do not use {Eq3}. By using {Eq1} or {Eq2}, the error estimation is generous and will likely include the true value being measured. However, when the Walk Method area-error amount results in too large of an error, consider using the Angle-Point Method equation, {Eq3}, or use superior equipment or other survey methods suitable for the difficult situation. This reduction of one-half should only be applied to the Angle-Point Method when the deflection angles are generally greater than 45 degrees.

The following examples (ex. 03 and ex. 04) explain the area-error calculations. Measurement units must be consistent, such as feet for distance and square feet for area (or meters for distance and square meters for area).

55.2 - Exhibit 04

Area-Error Calculation of Polygon from Vertices with Different Accuracy

Suppose you have an 8-acre plot and the GPS accuracy is different at each individual point along the boundary.



Using equation 1, the area-error for each leg in between points must be calculated individually:
Area Error(AB) = [(dist(AA') + dist(BB'))/2] * dist(AB) = [(10ft + 6ft)/2] * 200ft = 1600ft^2
Area Error(BC) = [(dist(BB') + dist(CC'))/2] * dist(BC) = [(6ft + 8ft)/2] * 300ft = 2100ft^2
Area Error(CD) = [(dist(CC') + dist(DD'))/2] * dist(CD) = [(8ft + 9ft)/2] * 200ft = 1700ft^2
Area Error(DE) = [(dist(DD') + dist(EE'))/2] * dist(DE) = [(9ft + 11ft)/2] * 200ft = 2000ft^2
Area Error(EF) = [(dist(EE') + dist(FF'))/2] * dist(EF) = [(11ft + 9ft)/2] * 100ft = 1000ft^2
Area Error(FG) = [(dist(FF') + dist(GG'))/2] * dist(FG) = [(9ft + 7ft)/2] * 300ft = 2400ft^2
Area Error(GH) = [(dist(GG') + dist(HH'))/2] * dist(GH) = [(7ft + 9ft)/2] *200ft = 1600ft^2
Area Error(HA) = [(dist(HH') + dist(AA'))/2] * dist(HA) = [(9ft + 10ft)/2] * 100ft = 950ft^2
To get the total area-error, sum the values to get 13350ft^2

When using the GPS Walk Method, the total area-error is 13350ft^2, and the percentage of error is:
% error = Total Area-Error/Unit Area = 13350ft^2 / 8 acres = 13350ft^2 / 348480ft^2 = 0.038 = 3.8%.

When using the GPS Angle-Point Method, the total area-error is one half times 13350ft^2 (6675ft^2) and the percentage of error is: % error = 6675ft^2 / 348480ft^2 = 0.019 = 1.9%.

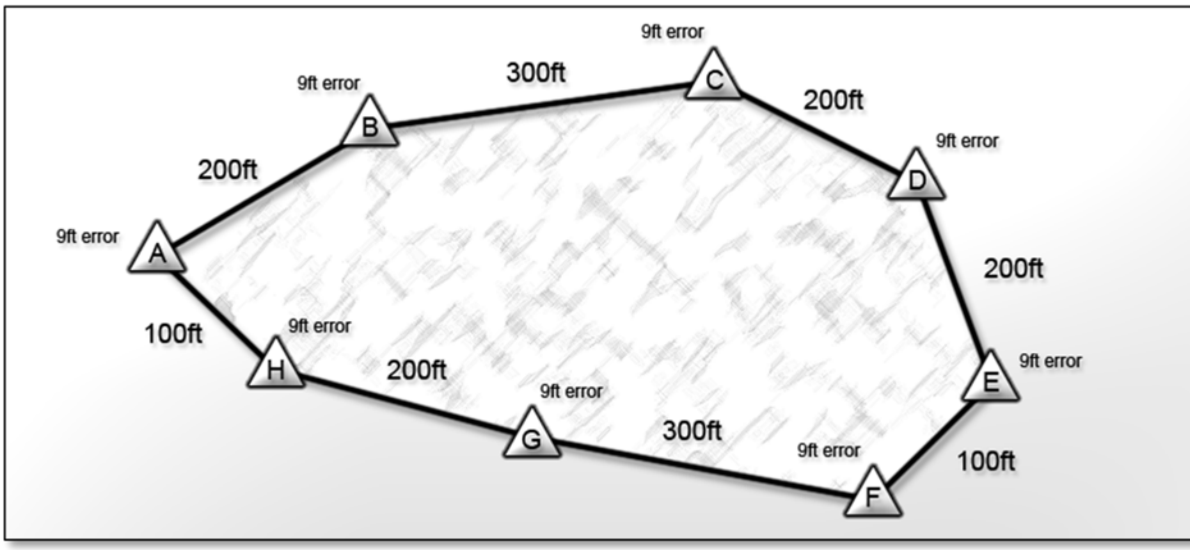
In this example, the errors at the points were: 10, 6, 8, 9, 11, 9, 7, and 9, which is about a 8.6-foot inaccuracy average around the unit, or rounded up, about 9 feet inaccuracy on the average.

Therefore, to achieve the above shown % error, the crew needs to use equipment and procedures that generally have better than 9ft point accuracy if using the GPS Walk Method. Equipment that generally gets 18ft point accuracy is appropriate if using the GPS Angle-Point Method.

55.2 – Exhibit 05

Area-Error Calculation for Polygon Where All the Boundary Points Have the Same Inaccuracy

Suppose you have an 8-acre plot and the GPS accuracy is the same at each individual point along the boundary.



Using equation 2, the area-error is the GPS inaccuracy times the perimeter:

Total Area Error = AA' * *Perimeter Length* = 9ft * 1600ft = 14400ft^{2}.

When using the GPS Walk Method, the total area-error is 14400ft^2, and the percentage of error is:

% error = Total Area-Error/Unit Area = 14400ft^2/8 acres = 0.041 = 4.1%.

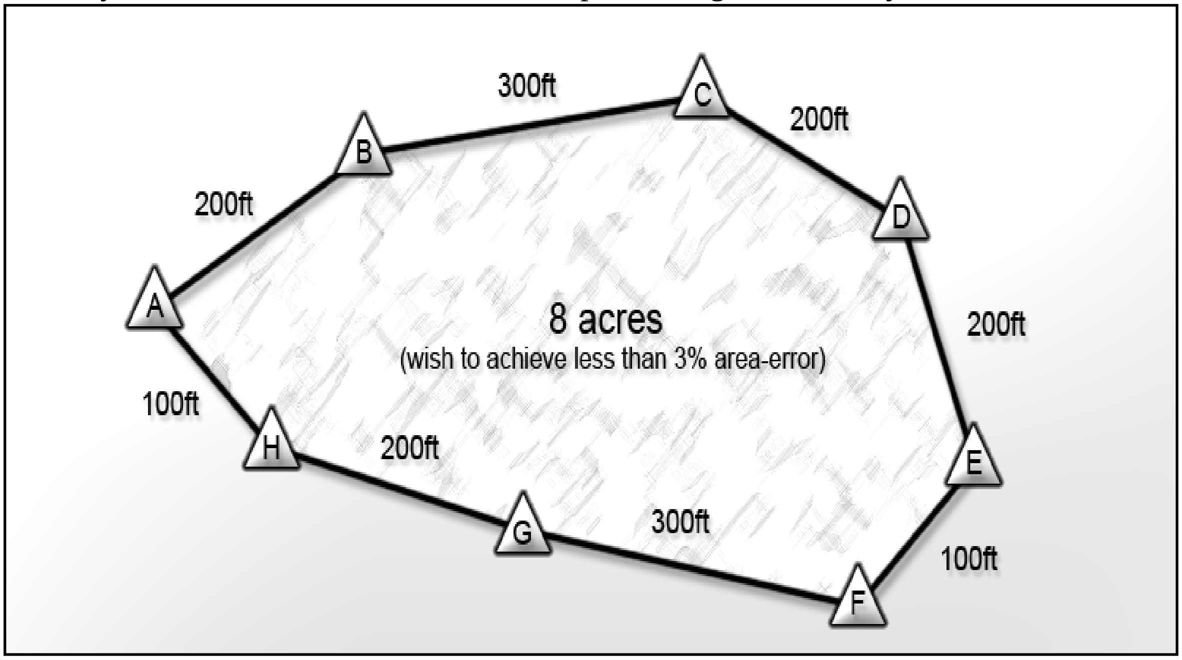
When using the GPS Angle-Point Method, the total area-error is one half times 14400ft^2 (7200ft^2) and the percentage of error is:

% error = Total Area-Error/Unit Area = 7200ft^2/8 acres = 0.021 = 2.1%.

Reversing the above calculation is what the project manager may want: that is, the ability to calculate how much accuracy is required at each boundary point to get a desired percent of area-error. This is the process: knowing or estimating the area, the perimeter, and the allowable area-error enables the manager to decide on the GPS accuracy required, and therefore, which procedure and equipment is most appropriate. The GPS accuracy can be appropriately limited by the amount of allowable area-error. An example of this follows (ex. 06).

Reverse Calculation Knowing the Size of the Area; Perimeter Length; and the Desired Percent of Error to Determine the Accuracy Needed for GPS

Reverse process to determine what the GPS accuracy needs to be such that we know or can guess the unit's size and perimeter length. Suppose you have an 8-acre unit and the GPS accuracy is to be the same at each individual point along the boundary.



This is the reverse process where the manager estimates the area to be 8 acres, the perimeter to be 1600ft, and the project is to have less than 3% error in the area:

For the GPS Walk Method:

GPS Accuracy Needed = % error * Total Area / *Perimeter Length* = 0.03 * 8 acres / 1600 feet ≈ 6.5 feet of accuracy.

For the GPS Angle-Point Method:

GPS Accuracy Needed = 2 * % error * Total Area / *Perimeter Length* = 2 * 0.03 * 8 acres / 1600 feet ≈ 13.0 feet of accuracy.

Therefore, the line officer knows that the crew needs to use equipment and procedures that have better than 6.5-ft accuracy if using the GPS Walk Method. Equipment and procedures that only get 13-ft accuracy can be used if the GPS Angle-Point Method is applied. Either way will achieve the desired 3 percent or less error in area determination.

55.2 – Exhibit 06--continued

These calculations allow the line officer to choose the process and equipment to meet design targets. A manager can weigh the accuracy expected relative to the economic needs of the operations. **Unless otherwise approved, limit the area-error to less than 10 percent of the unit's area when using GPS or similar satellite based surveys**. (This standard is defined in other sections).

Include the percent of error with the area size measurement for timber cruising operations. The amount of allowable error may be restricted by the appropriate authority reflecting the economics of the operations.

55.3 - Orthophotography Survey Area-Error Estimation

The maximum area-error for an orthophotography surveyed unit is estimated by the orthophotography point accuracy value. Calculate the area-error by substituting the orthophotography point accuracy for the GPS accuracy values explained in previous sections.

1. Ordinarily, the orthophotography points are selected at major angle changes along a boundary, which make the GPS Angle-Point Method appropriate.

2. If many close-spaced points along the boundary are chosen, then the GPS Walk Method is more appropriate.

3. Use the "common point accuracy" for the entire unit when the orthophotography point accuracy is the same for all points.

4. Use the "individual point" calculation method when the accuracy varies from point-to-point around the unit being measured.

Precision and accuracy values for orthophotography are continually changing. Updated information is maintained at http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml. This information explains and summarizes accuracy values for known photography, such as the National Agriculture Imagery Program (NAIP), as well as describing methods to determine accuracy for projects. See section 53.3 on how to determine boundary point accuracy from orthophotos.

Where possible, compare GPS points with orthophotography points (and vice-versa) as a redundant check for both systems. Report the source of your photography.

Orthophoto measurements taken at tree top must add the vertical displacement error to the ground inaccuracy orthophotography measurements.

If the trees are 60 feet tall, then two-thirds of this height (40 feet, or approximately 12 meters) is to be added to the expected ground error. If the ground error is 8 meters, then the resultant orthophotography point accuracy using tree-top photo points is 20 meters (8 meters plus 12 meters). Expressed as a formula:

> Orthophotography Point Accuracy = Estimated Ground Error + (0.66 * Tree Height) (see sec. 54.3 of this chapter.)

Additional information can be found at: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

Calculate area-error using the same process as explained for GPS points by substituting the orthophoto information for the GPS. The area error is the sum of the error along each leg of the boundary. Each leg's error is calculated as the product of the perimeter leg's length times the average of the inaccuracy of the orthophotography points at the end of the leg. Spread sheet

calculations or programs, such as TwoTrails©, may be used. For additional information, see: http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

55.4 - Combined Survey Area-Error Estimation

The area-error for a unit that is surveyed with more than one method combines the area-error calculation from each piece of the survey. Use the individual procedures specific to each method to calculate area-error for that part of the survey, and then sum the errors from each survey method.

Four methods of surveying are shown in the example (ex. 01 of this section). As an example, assume the orthophotography survey section has a 3-meter (approx. 10-foot) point accuracy and the perimeter length is 1,000 feet. The area-error for the ortho section is then 10 feet times 1,000 feet and equals 10,000 square feet.

The GPS angle-point section has 3-meter (approx. 10-foot) point accuracy also, and the perimeter length is 2,000 feet. The area-error for the GPS angle-point survey section is then 10 feet times 2,000 feet, and equals 20,000 square feet. As these boundary points are at sharp changes in the boundary, we only have half the error, 10,000 square feet.

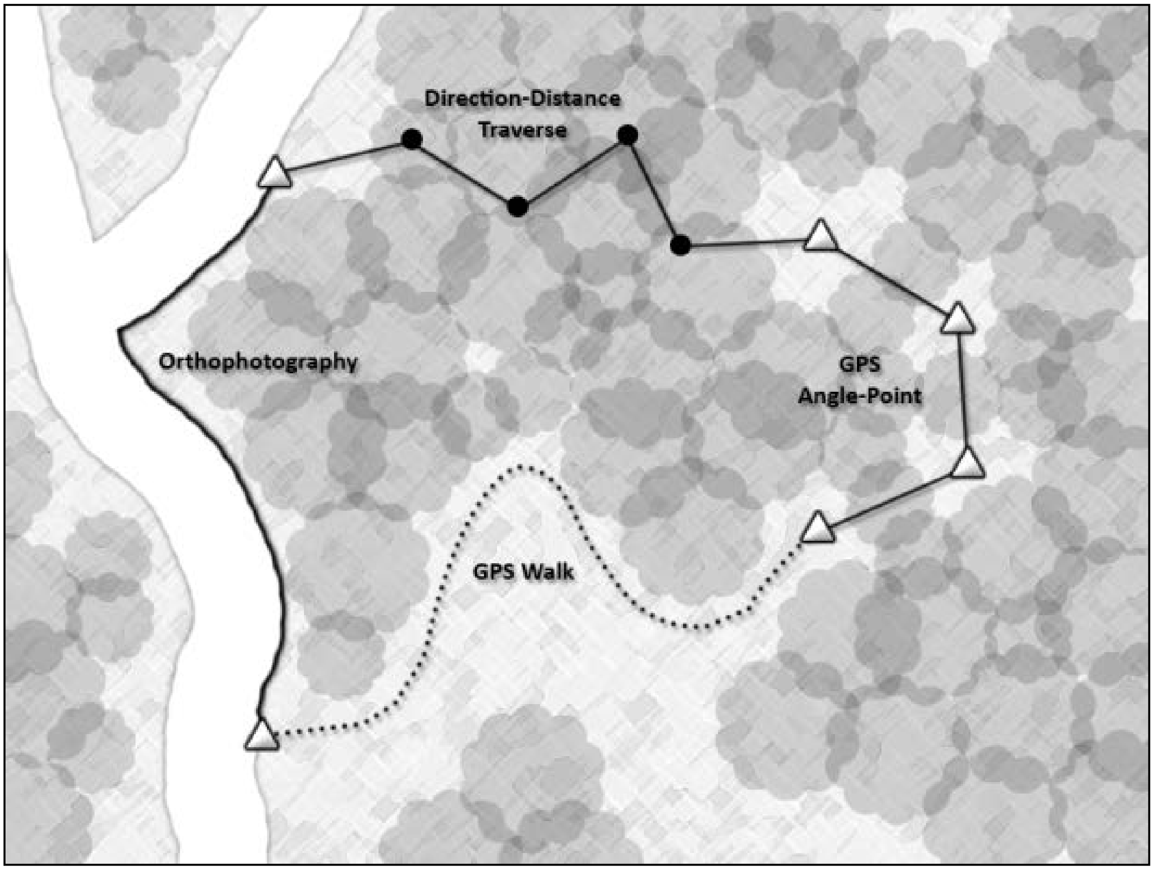
The GPS walk section has 6 meters (approx. 20 feet) point accuracy and the perimeter length is 3,000 feet. The area-error for the GPS walk survey section is then 20 feet times 3,000 feet, and equals 60,000 square feet.

The direction-distance traverse section has 15-foot closing error and the perimeter length is 1,000 feet. The area-error for the direction-distance survey section is then 15 feet times 1,000 divided by 2, and equals 7,500 square feet.

The area of the unit is 50 acres (2,178,000 square feet). The sum of the above area-errors is 87,500 square feet. There is approximately 4 percent area-error when the sum of the combined survey area-errors are divided by the unit's area. Additional tools are available at http://www.fs.fed.us/fmsc/measure/geospatial/index.shtml.

55.4 – Exhibit 01

Combined Methods of Surveying



56 - Equipment

The type and configurations of equipment is quite variable and changing. Information concerning approved and appropriate equipment is maintained by the MTDC and Forest Management Service Center in Fort Collins, Colorado, at http://www.fs.fed.us/forestmanagement/index.shtml and http://fsweb.ftcol.wo.fs.fed.us/frs/fmsc/measure/.

This site is updated as equipment changes with technological advances and procedural enhancements. Guides concerning equipment accuracy and procedures to be used in different forest conditions are also maintained here and are supplemental support to this handbook.