Land measurement and survey

AN INTRODUCTION FOR WOODLAND OWNERS

J. J. Holmberg

Land measurement and survey relate to most areas of forest management. Knowing how land is measured and how to use maps and surveys is a necessary part of planning and implementing forest management activities.

Survey types and uses

Generally, surveying means gathering and processing information about the physical earth. It's the science of determining relative positions of existing points on the earth's surface or of establishing such points. Methods range from aerial and satellite systems to conventional ground methods. Survey professionals use a variety of methods to produce easy-to-use maps that are essential for effective land management. Surveys help you locate property boundaries, roads, structures, watercourses, and other physical characteristics of the land.

Familiarity with how property lines are marked is valuable. For example, when property lines cross roads, reference tags often indicate the location where the line and road intersect. Other important points often are marked in the forest with corner posts and with blazed, flagged, or posted lines between them.

Here we'll consider *plane surveys*. In plane surveying, the earth is assumed to be a flat horizontal surface (a plane). The calculations involved in plane surveying are relatively simple. For most purposes, plane surveys' level of accuracy is sufficient. When putting in a new road or logging 40 acres, for example, it generally doesn't matter if you are off by a fraction of a foot.

When surveying a large area, surveyors will calculate to compensate for the curvature of the earth's surface. This is called *geodetic surveying*. It is a technique used to determine relative positions of widely spaced points, and it takes into account the size and shape of the earth.

Another type of survey is *photogrammetric surveying,* which uses data obtained by cameras and other sensors. Photogrammetry has been used in natural-resource management for decades, and aerial photography is a must for planning purposes today.

Remote sensing, or use of satellite data, is a newer tool. Other survey types include:

- *Control surveys,* which serve as a reference framework for other surveys
- *Construction surveys,* which are used in civil engineering projects
- *Property surveys,* which establish property corners, lines, and areas of parcels
- *Cadastral surveys,* which are the most common type of property survey. They create, restore, mark, and define property lines of parcels of land to describe individual ownership. The official survey plat is a graphic representation drawn to scale that depicts the actual survey as described in the official field notes. The plat illustrates lot sizes and locations, bearings and distances, and corners, courses, and distances of surveyed lines. Most townships in the Northwest have one or more cadastral survey plats.

Joseph J. Holmberg, Extension forestry outreach educator, Oregon State University. Some material for this publication was drawn from the 2000 edition of *Watershed Stewardship: A Learning Guide* (Oregon State University Extension publication EM 8714), by Flaxen Conway, Derek Godwin, and Michael Cloughesy.

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- *Topographic surveys,* which are used to create the topographic maps commonly used in natural resource work
- *Route surveys,* which usually are required prior to construction of highways, railroads, pipelines, power lines, etc.
- *Hydrographic surveys,* which result in navigational charts and other maps of water bodies

Rectangular survey system

Most of the United States (outside the 13 original colonies) has been surveyed using the *rectangular survey system* or the *Public Land Survey System.* This is the kind of survey you'll be most likely to work with.

In 1785, the Congress of the Confederation enacted a Land Ordinance for the public lands northwest of the Ohio River. The law provided for the survey of public lands into townships of 36 square miles each. The Ordinance also established the use of the Cadastral Survey Plat, a system for recording land patents and related records essential to the chain of title. The rectangular survey system and, in 1800, the tract book system for permanently recording titles became the standard for transferring public lands into private ownership as western migration progressed.

In 1789, Congress established the Treasury Department and gave it responsibility for overseeing the sale of public lands. The General Land Office (GLO) was created in 1812 within the Treasury Department to oversee the sale and transfer of public lands into private hands. The GLO was transferred to the new Department of Interior in 1849. In 1946, the Bureau of Land Management (BLM) was created by merging the GLO and the Grazing Service.

BLM cadastral surveyors still must perform and review surveys of all federal lands being transferred by sale, donation, acquisition, or exchange. The BLM continues to provide GLO land and mineral recordation services for federal lands. The Oregon State Office of the BLM maintains a complete collection of all land status records, cadastral survey records, and mining claim records for Oregon and Washington. The Idaho State Office maintains records for Idaho.

BLM status records are current only for federal lands. Once land leaves federal ownership, subsequent private title transfers, rights, and restrictions are recorded in the appropriate county assessor's office.

How the rectangular system works

The rectangular system sets up a grid, with the objective of obtaining approximately square *sections* of 1 square mile each (1 mile on a side). One mile = 5,280 feet.

To understand the rectangular survey system, you need to know about meridians and baselines. *Meridians* are north–south lines, and baselines are east–west lines. A *principal meridian* is a true north–south line that runs through an initial point to the limits of the area being covered. At 37 locations in the United States, an initial point has been established where a principal meridian and a baseline intersect. These points were located through astronomical observations and don't change. Using these 37 points, control can be established for surveys anywhere in the continental United States.

In Oregon and Washington, the rectangular survey system is referenced to the north–south Willamette Meridian and to the east–west Willamette Baseline. These two lines cross at an initial point called the Willamette Stone, located in the west hills of Portland. In Idaho, the system is referenced to the Boise Meridian and Baseline, the initial point of which is in Meridian, Idaho.

Townships are approximately 6 miles on each side. They're numbered from the baseline, starting with Township 1 North (T1N) north to the Canadian border and Township I South (TIS) south to the California and Nevada state lines. Ranges are numbered from the meridian west (e.g., R1W) and east (e.g., RIE).

From each initial point, a grid of townships is established north and south of the baseline and east and west of the principal meridian.

Thus, a township six grid locations north of the baseline and two grid locations west of the principal meridian would be designated as T6N, R2W Similarly, a township three grid locations south of the baseline and six grid locations east of the principal meridian would be designated as T3S, R6E (Figure 1).

Normal townships contain 36 sections. Each section is approximately 1 mile square and contains 640 acres. (One acre = 43,560 square feet.) All townships use the same system for numbering the sections within them. Sections are numbered beginning with number 1 in the northeast corner, going west to number 6, then south to 7, east to 12, south to 13, and so on (Figure 2).

Every section has four quarter corners, which usually are the midpoint on each of the lines forming the boundaries of the section. Sections can be divided into *quarters* and *halves* by connecting these points. With a line drawn north–south or east–west through the center of a section to connect two quarter corners, the section is divided into halves. Each half is identified by its location in the section (north half, south half, east half, or west half).

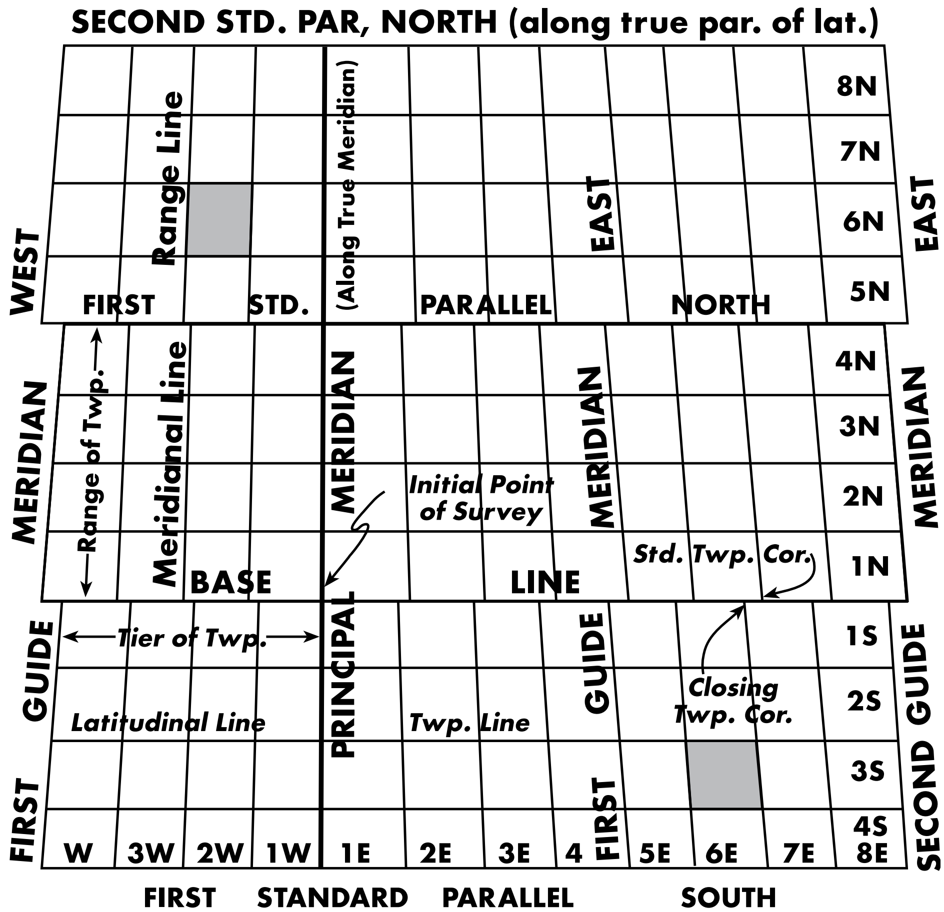

Figure 1.—An example of township and range numbering.

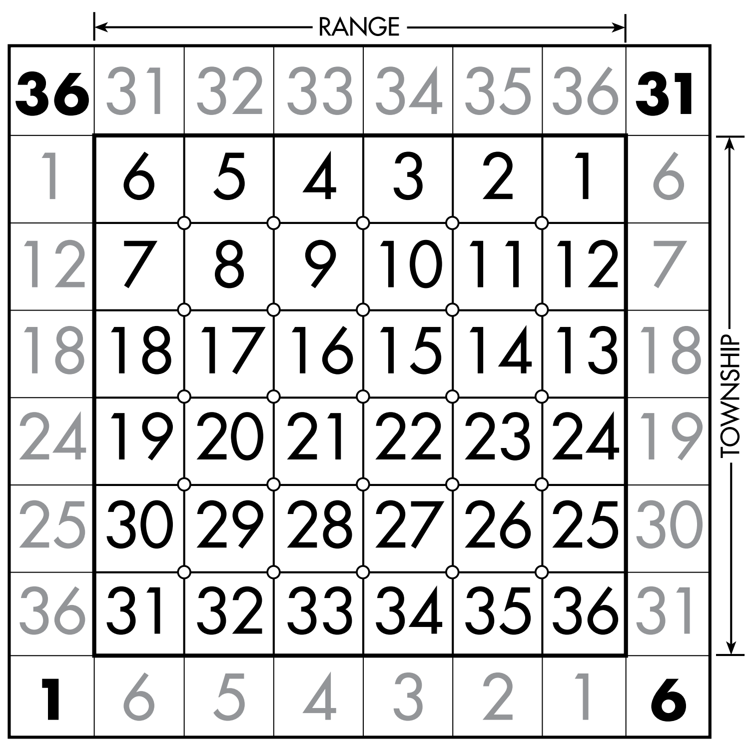

Figure 2.—Standard township plat.

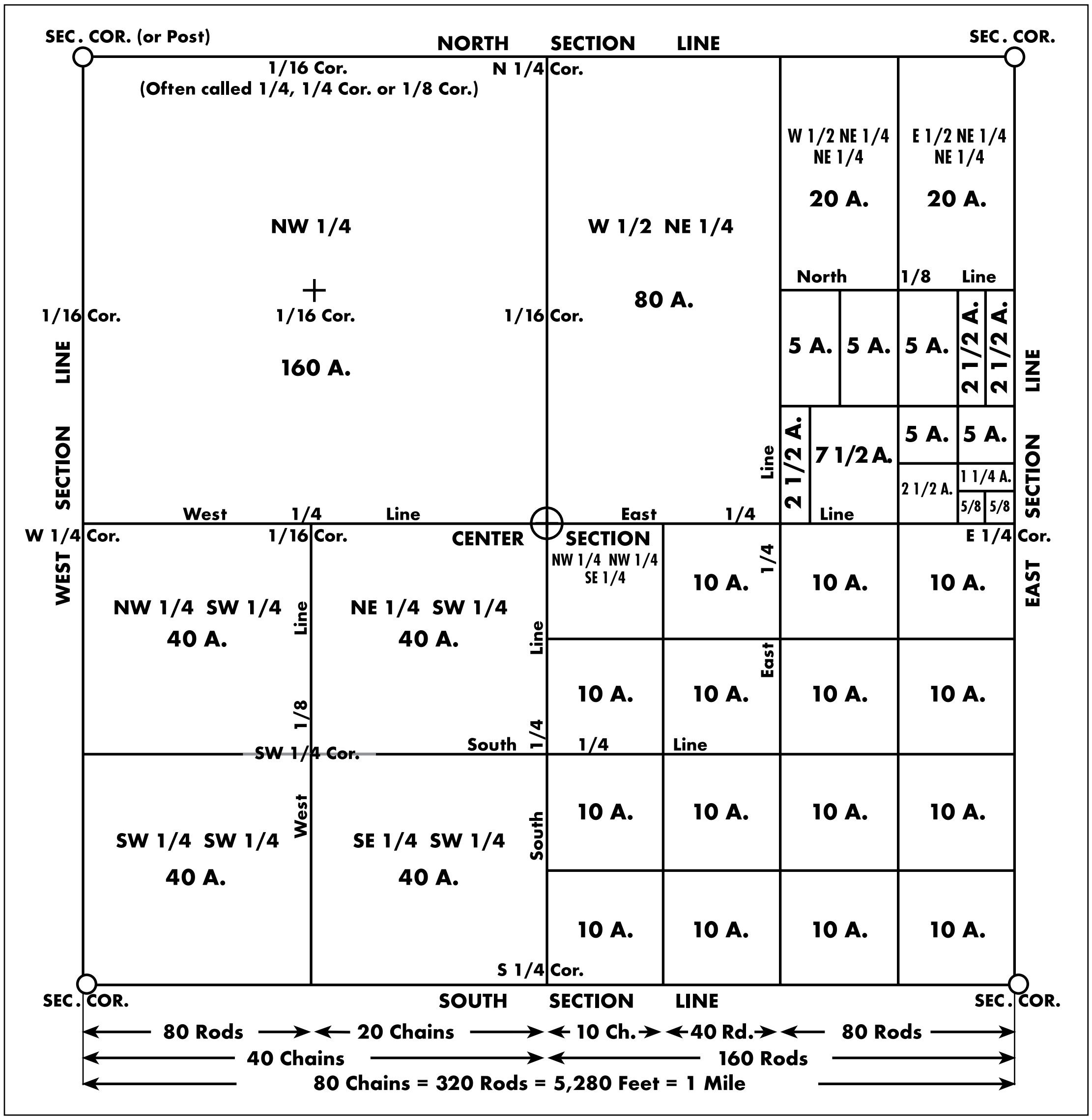

Figure 3.—Section of land (640 acres) showing minor subdivisions and corners.

With lines drawn north–south *and* east–west through the center of a section to connect all four quarter corners, the section is divided into quarters (Figure 3). Again, each quarter is identified by its location in the section (northeast quarter, southeast quarter, northwest quarter, or southwest quarter).

Halves and quarters can be subdivided further. Thus, a 40-acre block might be identified as SW1/4 NW1/4, Sec. 14, T2S, R3W, Willamette Meridian. A legal description then follows in parentheses. The legal description for small ownerships often includes a block identification that may not match the quarters of a section.

Sometimes the grid isn't perfect. For example, although every section basically is square and has four corners, these corners may or may not be shared with the adjoining section. And although each section should be 1 square mile and there are 640 acres in 1 square mile, not all sections have 640 acres. How can this be? The reason is that it can be difficult to match edges of adjoining townships if the townships were surveyed at different times. There also need to be adjustments because of the curvature of the earth. Often we have offset corners that act as a kind of "fudge factor" to avoid overlapping ownerships; then, the result is sections that don't have exactly 640 acres. These sections generally are along the western edge of the township.

The Legal Basis for Surveys

The federal survey system is based on two principles that provide the legal background for establishing land lines. The first principle is "Boundaries of public lands established and returned by duly appointed surveyors are unchangeable." In other words, if your land adjoins federal lands, and the federal land is surveyed correctly, the property line won't change, no matter what your licensed surveyor may say.

The second principle is "Original township and section corners established by surveyors must stand as the true corners which they were intended to represent, whether in the place shown by the field notes or not." This principle is required because interior lines are established off the section lines. Thus, if an original section line isn't correct, no other lines are correct.

For a survey to be legally binding, it needs to be conducted by a licensed cadastral surveyor and tied into an established corner.

Reading maps

This section will help you learn to use maps to locate on-the-ground features at a scale typical of forest management projects.

Most project work requires you to use a variety of maps. You use large-scale maps to make landscape-level plans. After you determine the need for a project and see how it fits into the broader landscape, you'll need stand-level maps.

We'll discuss two kinds of stand-level maps: transportation maps and topographic maps.

Transportation maps

Although a *transportation* map (Figure 4) typically covers a large area such as an entire state or county, it's also a stand-level tool because you can use it to locate areas where project work occurs.

Transportation maps vary in design depending on who owns the land. Each government agency usually uses a consistent design, but there's little consistency across agencies and even less among maps of private and public lands.

Typically, Forest Service maps concentrate on roads on National Forest lands and might not show other connecting roads. BLM maps do the same for BLM lands. This inconsistency can be a problem if you're working in an area with checkerboard ownership. Forest Service and BLM transportation maps are available at National Forest ranger districts and BLM district offices.

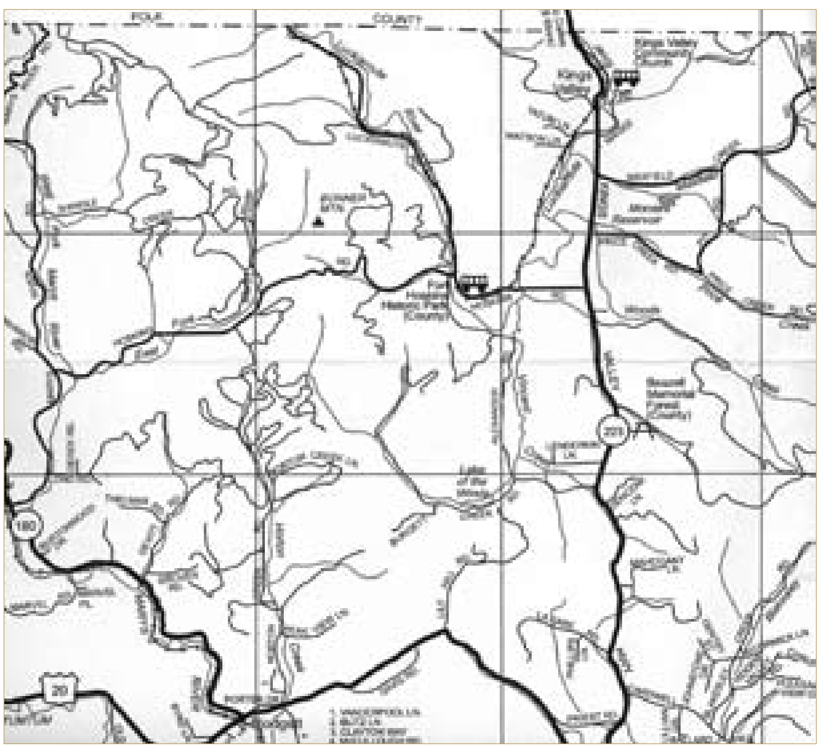

Figure 4.—An example of a transportation map.

Topographic maps

Topographic (topo) maps show relief, hydrology, vegetation, and human-made structures (Figure 5).

Topo maps and transportation maps show many of the same features, although each puts more detail into different elements. When comparing topographic and transportation maps, for example, you see topographic features such as ridges and valleys on each. These features are much better defined on topo maps, however. Because topo maps show roads, they can be used as transportation maps. However, most topo maps aren't updated as frequently as transportation maps are.

The U.S. Geological Survey (USGS) produces topographic maps. Oregon, for example, is represented by 1,925 USGS topo maps, which depict natural and cultural features of the landscape.

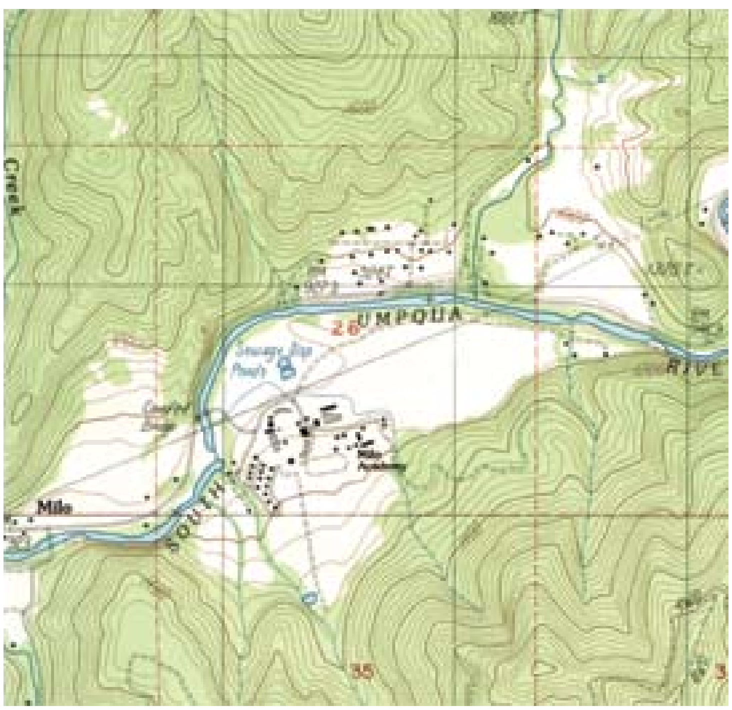

Figure 5.—An example of a topographic (topo) map.

Older USGS topo maps are available as 15-minute quadrangles (quads) with a scale of 1:48,000 (1 inch on the map represents 4,000 feet on the ground).

Newer USGS topo maps are available as 7.5-minute quads with a scale of 1:24,000 (1 inch on the map represents 2,000 feet on the ground). Please note that the 1:24,000 map is actually *twice* the scale of the 1:48,000 map, which might seem counterintuitive.

Map scales and distances

Distances measured from maps are accurate only if the map is drawn to scale. You also need to know the scale to convert map distance to ground distance.

Map scales are written either as a ratio (1:12,000) or a representation (1 inch = 1 mile). In the first case, 1 inch on the map represents 12,000 inches (1,000 feet) on the ground. In the second case, 1 inch on the map represents 1 mile on the ground. In either case, you can find the ground distance between two points on the map by measuring with a ruler and multiplying by the map scale.

To try this out, select two points on a topo map. Measure the map distance using a scale or ruler that shows inches and tenths of inches. Now multiply the measured distance by the map ratio. Convert inches to feet. You've calculated the horizontal ground distance between the two points.

Enlarging maps using a photocopier provides an accuracy suitable for most woodland management applications. For example, a 1:24,000-scale USGS topo map can be enlarged 200 percent to a 1:12,000-scale topo map. Distortion can be a problem, but the price is very reasonable. By enlarging a map 200 percent and photocopying it onto acetate, you can make topographic overlays to use with 1:12,000-scale aerial photos. Caution: If the scale is too large or too small, the map may not be of much use.

Direction

Maps are made with direction in mind, and the top of a map usually is oriented to north. If you know how to read the direction between two points on a map, then you can use a compass to find the same direction on the ground and move from point to point.

Direction is measured as *azimuths* or *bearings*. Azimuths are based on the 360 degrees of the compass. North can be described as either zero degrees or 360 degrees. Azimuths are read clockwise from north, so east is 90 degrees, south is 180 degrees, and west is 270 degrees.

Bearings are based on four 90-degree quadrants. Beginning from a north–south line, bearings are read from north to either east or west *or* from south to either east or west. For example, a bearing of N 45 degrees W is the same as an azimuth of 315 degrees, and a bearing of S 30 degrees E is the same as an azimuth of 150 degrees. Bearings are no more than 90 degrees because each quadrant contains only 90 degrees.

A lot of map work is done in azimuths rather than in bearings because azimuths can be read more easily from a map using a 360-degree protractor. For example, select two points on a map and draw a line true north–south through one of the points and a line between the two points. Lay the protractor oriented north–south on the north–south line with the center of the protractor on the point. Where the line crosses the edge of the protractor, read the true azimuth from point to point.

Azimuths between points taken from maps are accurate only if the maps are drawn to scale. The scale used doesn't matter. In fact, you can measure the azimuth between two points on a map without knowing the map scale.

Figure 6.—An aerial photo.

Using aerial photographs

Aerial photographs (Figure 6) can be used like detailed maps, but they usually contain some distortions that you must recognize and account for.

Aerial photos are used by all types of natural resource workers, from timber sale layout personnel to wildlife biologists. Aerial photos can be used to divide the land base into stand-level units by identifying vegetative communities. Satellite photos are used for broad-based planning efforts that look at the largest landscape scales.

Early photos were black and white. Now, high-resolution color photos show species, density, tree height, and many other attributes of a forest, stream, or landscape.

The present industry standard for stand-level photo coverage is a 1:12,000-scale color photograph. At this scale, with the aid of a hand lens, you can recognize an individual tree or brush clump as small as 2 feet in diameter. Permanent inventory plots throughout the forest usually are established by marking locations on the photo with a pinprick and then finding those locations on the ground.

The detail visible on aerial photos is limited only by the eyesight of the user. People with poor eyesight or those who are color blind have difficulty interpreting aerial photographs. They have to make an extra effort to recognize what they are seeing.

Most photographs are oriented with the top of the photo to north. The top of the photo has information about the flight line number, photo number, date of flight, and land ownership. When ownership is a more-or-less rectangular block with the long axis oriented east–west, the photos may be oriented east–west as well. The three basic camera angles for aerial photography are vertical, high oblique, and low oblique. The kind of photos we discuss here use a vertical angle; that is, the camera is aimed straight down.

Seeing topographic features on aerial photos

A unique feature of aerial photography is the ability to see three-dimensional images of the land base, which makes it possible to see the topography of the land. This feature makes aerial photos extremely useful not only for planning purposes but also for locating on-the-ground features.

Most people need overlapping photos and a tool called a *stereoscope* to see three-dimensional images. Overlapping images are obtained by following a flight line across the land base and taking pictures at predetermined intervals. People with good stereo vision and eyes of equal strength often can see three-dimensional images without a stereoscope.

Photo scales and distances

Because aerial photographs are like detailed maps, the principles of scale and distance are similar to those for maps. However, photos can create problems when you use them to measure scale and distance.

Most scale variation results from changes in elevation of the ground's surface. The airplane's altitude is based on the average elevation of the ground to achieve the desired scale (1:12,000). The plane maintains that elevation for all flight lines in a photo series. As the ground comes closer to the camera or gets farther away because of elevation changes, the photo scale changes.

You can adjust each photo's scale using on-the-ground measurements. On a photo, find a straight stretch of road. Put a pinprick at both ends of the road on the photo and also mark them on the ground. Then measure the ground distance from one end of the road to the other. Measure the same distance on the photo. Then determine the ratio between the ground distance and the photo distance between the two pinpricks. Use this ratio to determine the true photo scale. Be sure to compare apples to apples; that is, either convert both measurements to feet or both to inches.

Images on aerial photos are displaced slightly, either toward or away from the center of the photo (the *principal point*). This displacement increases as you move away from the principal point. You can find the principal point by projecting horizontal and vertical lines from the fiducial marks on each edge of the photo (for example, see the black triangle on the right edge of Figure 6).

When making measurements on a photo, it's important to use the center area near the principal point. For best accuracy, the two ends of the road or other line being measured should be on opposite sides of, and equally distant from, the principal point.

Distortions due to topography and camera tilt are removed in *orthophotographs*. Orthophotos look like any aerial photo, but directions and dimensions can be scaled from them.

Direction

Because aerial photographs are like detailed maps, you can obtain azimuths from photos just as you can from maps. However, be aware that most photos have some *crab* or *drift*. These are terms for misalignment that occurs when the camera or airplane is oriented incorrectly during aerial photography. This misalignment skews the orientation of the photo from true north–south or east–west.

You can determine a true baseline for each photo by finding a straight stretch of road, sighting down the road with a compass, and comparing the azimuth or bearing you read to the azimuth or bearing of the same stretch of road as measured from the photo.

Geographic information system (GIS)

GIS stands for *Geographic Information System*. GIS uses digital geographic information stored on computers to make maps. GIS ties information about various resources to a digital base map. Information on each type of resource is stored as a mapping layer, like layers of acetate laid over a base map. Resource layers commonly include the public land survey system, topography, transportation, water, vegetation, geology, and land ownership. This allows complex analysis and modeling.

GIS is generally an application for owners of large properties, but some owners of smaller properties are finding it useful. To do planning on a landscape level, land managers look at the distribution of elements in ecosystems through both space and time. To do so, they need to be able to manage and manipulate vast amounts of data. GIS gives them this capability.

Decisions on natural-resource issues related to forestry require data on transportation networks, hydrography, boundaries, and elevations. State and federal agencies and local and tribal governments provide these data for the Digital Map Library, which is operated by the USGS State Service Center for Geographic Information Systems. The partnership helps eliminate duplication of effort, and it funds new data collection. Some data are free to the public, allowing people in rural areas access to information which they otherwise wouldn't be able to obtain readily.

Global positioning system (GPS)

GPS stands for *Global Positioning System*. The GPS is a network of 24 satellites orbiting the earth, transmitting very precise time and position data day and night, in any weather, anywhere in the world. Signals from these satellites are broadcast to hand-held units on the ground. The hand-held receiver receives signals from three or more satellites and uses triangulation to determine the user's position on the earth.

Hand-held units vary in accuracy and cost as little as $100 or as much as $10,000. There are no setup or subscription fees to use GPS. The GPS receiver must receive the signal of at least three satellites to calculate latitude and longitude and from four or more satellites to determine altitude. Newer GPS receivers are accurate to within 1 meter or less.

GPS is changing rapidly and is updating geographic information systems; some hand-held GPS units feed land location data directly into GIS. As a botanist finds an endangered plant species, for example, he or she can enter its location into GIS using the GPS. A forester can use GPS to traverse a timber sale unit and feed that information directly into GIS. New applications are born daily in the GIS and GPS world.

SUMMARY

Forest managers need information on land measurement and survey. Surveys and maps help you locate property boundaries, roads, structures, and physical elements on the land.

Most of the United States has been surveyed using the rectangular survey system or the Public Land Survey system. The rectangular system sets up a grid, with the objective of obtaining approximately square sections of 1 square mile each. Sections can be divided further into halves and quarters.

Most forestry work requires you to use maps. You use large-scale maps to make landscape-level plans. After you see how your project area fits into the broader landscape, you'll use stand-level maps such as transportation maps and topographic maps.

Transportation maps are useful for locating areas where project work occurs. Maps are available from a variety of agencies, but they vary in design depending on who owns the land. Topographic (topo) maps show relief, hydrology, vegetation, and human-made structures. Topographic maps are available from the U.S. Geological Survey.

Distances measured from maps are accurate only if the map is drawn to scale. Map scales are written either as a ratio (1:12,000) or a representation (1 inch = 1 mile). You can find the ground distance between two points on the map by measuring with a ruler and multiplying by the map scale.

Direction is measured with azimuths and bearings. Azimuths are based on the 360 degrees of the compass, and bearings are based on four 90-degree quadrants. Most map work is done in azimuths because they can be read easily using a 360-degree protractor.

Aerial photographs can be used like detailed maps that show vegetation. With the aid of overlapping photos and a stereoscope, you can see three-dimensional images on aerial photos. However, aerial photos often contain distortions that you must recognize and account for.

Geographic information systems (GIS) use digital geographic information stored on computers to make maps. Information on each type of resource (e.g., topography, transportation, vegetation, or water) is stored as a mapping layer. GIS allows land managers to store and manipulate vast amounts of data that allow them to look at an ecosystem over both space and time.

Geographic positioning systems (GPS) use signals from satellites to locate a hand-held unit on the ground, thus determining the user's precise location.

For more information

Textbooks

Aerial Photography and Image Interpretation for Resource Management, by D.P. Paine (New York: Wiley, 1981).

Elementary Surveying, 9th ed., by P.R. Wolf and R.C. Brinker (New York: Harper Collins, 1994).

Interpretation of Aerial Photographs, 4th ed., by T.E. Avery and G.L. Berlin (Minneapolis: Burgess Publishing, 1985).

Map and photo sources

Local U.S. Forest Service, U.S. Bureau of Land Management, and state Department of Forestry or Natural Resources offices have transportation and topographic maps that show private and public ownership. However, since there are large blocks of private ownership that don't adjoin federal lands, maps of these lands may not be available from federal sources. You may be able to obtain limited GIS maps from these agencies for cooperatively developed projects.

Most Forest Service and BLM offices have aerial photos of their lands, which also often cover adjoining private lands as well. You may be able to borrow these photos and make color copies for field use. Again, large blocks of private lands would not be available. Copies usually can be obtained at high-quality copy shops.

The Oregon Department of Forestry publishes Forest Protection District Maps for most forested areas of Oregon. These maps generally are at a scale of 0.5 inch = 1 mile, except for northeast Oregon, where the scale is 0.625 inch = 1 mile. Protection District Maps show: most public and many private roads; Forest Service, BLM, county, and private road numbers; townships, ranges, and sections; streams, rivers, and lakes; other major topographic features; and public land ownership. These maps are available folded, unfolded, and even laminated from:

Graphics Services
Oregon Department of Forestry
2600 State Street
Salem, OR 97310
Tel. 503-945-7336

The Washington Department of Natural Resources publishes 1:100,000-scale quadrangle maps which depict state and federal lands, highways, roads, trails, recreation sites, water features, and geographic names. These maps are available at:

Washington Department
of Natural Resources
902-C 79th Avenue SE
Tumwater, WA 98501
Tel. 360-586-6360

Idaho geographical information is available from:

Idaho Water Center
322 East Front Street
Boise, ID 83720
Tel. 208-287-4800

Color and black-and-white aerial photographs for most of Oregon are available at various scales. You can purchase them from:

W.A.C.
520 Conger Street
Eugene, OR 97402
Tel. 541-342-5169
From Washington and Idaho, contact Walker and Associates at 206-244-2300.

Every county courthouse has maps showing ownership of each tax lot. These maps usually don't show roads, and their large scale makes them inappropriate for stand-level planning. Some counties now have GIS available.

USGS topographic maps are sold at various specialty and outdoor stores and are available directly from:

USGS Information Services
P.O. Box 25286
Denver, CO 80225

USGS information is available by phone at 1-800-USA-MAPS or online at http://store.usgs.gov/ The USGS also maintains an information database of aerial photographic coverage of the United States and its territories that dates back to the 1940s. You can obtain information on this database from the USGS addresses and phone numbers above.

USGS regional Earth Science Information Centers (ESIC) offer information and sales service for USGS map and earth science publications. They provide information about geologic, hydrologic, topographic, and land-use maps; books and reports; aerial, satellite, and radar images and related products; earth science and map data in digital format and related applications software; and geodetic data.

Numerous websites and computer software packages provide topographic and aerial photographic information. Some of the Web-based information is free. Mapping software is available from suppliers such as Ben Meadows (benmeadows.com), Forestry Suppliers (forestry-suppliers.com), and Terra Tech (terratech.net)

The Regional ESIC serving the Northwest is:
Menlo-Park ESIC
345 Middlefield Road
Menlo Park, CA 94025-3591
Tel. 650-329-4309

The USGS, in cooperation with state agencies and universities, operates a national network of state ESICs that provide state and local information about earth science products and services. The following state ESICs serve the Pacific Northwest.

Oregon
Map and Aerial Photography Library
University of Oregon
1501 Kincaid Street
Eugene, OR 97403-1299
Phone: 541-346-3051

Oregon Department of Geology
and Mineral Industries
Nature of the Northwest Information Center
800 NE Oregon Street, Suite 177
Portland, OR 97232
Tel. 503-872-2750

Oregon Geospatial Enterprise Office
1225 Ferry Street SE, 2nd floor
Salem, OR 97301-2558
Tel. 503-378-2116

Washington
Washington Division of Geology
and Earth Resources
P.O. Box 47007
1111 Washington SE, Room 148
Olympia, WA 98504-7007
Tel. 360-902-1450

Map Collection and Cartographic Service
University of Washington Libraries
P.O. Box 352900
Seattle, WA 98196-2900
Tel. 206-543-9392

Idaho
University of Idaho Library Map Collection
Moscow, ID 83843-4144
Tel. 208-885-7552

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University of Idaho
http://info.ag.uidaho.edu

Washington State University
http://pubs.wsu.edu

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