Introduction

What You Can Get From This Merit Badge

Did you know that three of the four presidents carved on Mount Rushmore were surveyors? George Washington, Thomas Jefferson, and Abraham Lincoln all worked as surveyors at some point in their lives. This shows how vital landownership has been to the development of this country.

As a landowner, you will need to know the boundary lines of your land so that someone else does not encroach or trespass on your property, and so you do not encroach on land that is not yours. While earning this merit badge, you will discover how land is measured and how it is described so that others can know where boundary lines are. You will have a chance to use some fine measuring instruments, apply advanced mathematics, operate computing equipment, and create a survey map.

For thousands of years, surveyors have used certain principles to mark and define property boundaries to coincide with written documents that describe the limits of landownership.

Surveying principles are used in mapping land features and to lay out the positions for what is to be built on land (buildings, parking lots, houses, etc.). Applying these principles of measurement, mathematics, and law, along with the professional expertise of retracing and reproducing recorded written descriptions of land, is the responsibility of the *surveyor.*

While earning this badge, you will barely scratch the surface of surveying. Becoming a surveyor generally takes several years of study in college and even more years of training and experience. Furthermore, surveying involves extensive knowledge of law as well as measurements and mathematics. Your experience might, however, entice you to learn more about it in college or at a summer job. You also will learn about other fields that use surveying instruments and methods. Best of all, earning the Surveying merit badge will expose you to hand's-on use of surveying instruments and methods.

Should You Earn This Badge?

If you like mathematics, you will enjoy working on this merit badge. You will learn how to apply geometry and trigonometry in the field. If you have not yet studied geometry in school, you can learn how to solve surveying problems graphically. You might also be able to learn the necessary mathematics from your merit badge counselor. Discuss your math background with your counselor before you begin studying for this badge.

If you like outdoor work, fine instruments, computers, and mathematics, this badge is for you.

This badge might open doors to a summer job or a career in surveying or related field. Years from now, you might use surveying to lay out your home or a campsite for your BSA local council. You might survey parts of the ocean floor or map a city from space. Your counselor can tell you more about areas of surveying that appeal to your particular interests.

Research

What do surveyors do? If your answer is, "Measure things," you are only partly correct. In many ways, surveyors are a lot like detectives. When they make measurements in the field, they are gathering evidence for the survey that they are preparing. Most surveys require more evidence than just the field measurements. Surveyors also gather documents such as deeds, wills, easements, right-of-way maps, flood maps, utility maps, and old surveys that provide information about the land that they are surveying.

Surveyors gather many documents and talk with several people to understand the character of the land before they begin their field measurements.

Deeds, wills, and easements describe the land and give information about who owns it and who has rights to it. These documents usually are found at the records office in the county where the land is located. Sometimes, the landowner or a local title attorney will provide these documents.

Right-of-way maps, flood maps, and utility maps help to show what things affect the land. Right-of-way maps show any roads on the land. Flood maps show how much of the land lies within flood hazard areas, which can affect what you are allowed to build on the land. Utility maps show where various utilities are suppose to be, including those buried underground.

Some of the documents surveyors gather include old surveys, deeds, and right-of-way maps.

Old surveys are very helpful because they show what other surveyors have found in past years. Many states require that surveyors file copies of their boundary surveys with the county recorder. In states that do not have this requirement, surveyors can find copies of old surveys by contacting landowners and other surveyors.

Finding a Surveying Merit Badge Counselor

Your Scoutmaster can help you find a counselor for the Surveying merit badge by contacting your local council. If no counselor is available, your Scout leader should contact a local surveying company or a civil engineering firm that specializes in surveying and ask whether they can refer you to a licensed professional surveyor to serve as a merit badge counselor. If that doesn't work, your leader may contact the American Congress on Surveying and Mapping at the address listed in the resources section at the back of this pamphlet.

At least three people—including yourself (but not your counselor, who must be free to coach other Scouts)—are needed to complete the requirements for this badge. Each will take a turn operating the instruments, holding the prism pole and the leveling rod, and recording field notes.

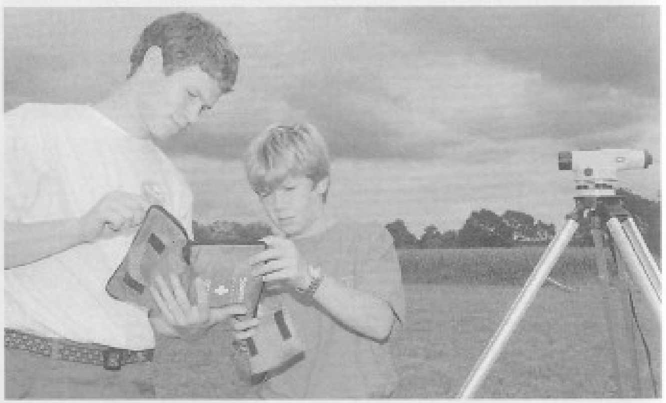
A Word About This Pamphlet

This pamphlet is not a self-teaching course in surveying or the Surveying merit badge—the vast amount of information on surveying cannot fit into a book of this size. Also, so many different models of surveying instruments exist, and surveying is changing so fast that a merit badge pamphlet cannot always keep up with the latest developments. Therefore, you must rely heavily on your counselor to show you how to use the instruments available, make the measurements, and plot the results. This merit badge pamphlet will show you the basic principles of surveying, whet your surveying "appetite," and expose you to the sort of work that surveyors do.

Safety

In the field, surveyors work in all kinds of weather and environments for long periods and sometimes in remote places or high-traffic areas. Surveyors must be aware of their surroundings so that they can conduct their work safely and apply the appropriate first aid when necessary.

While surveying in the field, you must take great precautions regarding traffic safety. A bright, fluorescent reflective vest is a must so that you remain visible to vehicular traffic at all times.



First, know the weather and environmental conditions where you will be working. Dress appropriately and bring extra clothing in case the weather changes. Some important items to remember include sunglasses and sunscreen, long pants and long-sleeved shirts, and a hooded jacket. It is a good idea to wear reflective vests to make yourself visible at all times. Protective helmets are necessary when surveying near roadways of any kind. Remember to bring plenty of food and water.

Heat-Related Injuries

Common heat-related injuries include dehydration, heat exhaustion, heatstroke, and sunburn. Preventing heat-related injuries begins with drinking enough water, up to 2 cups every 15 to 20 minutes. Do not wait until you feel thirsty. Thirst is an early sign of dehydration. Once the body becomes dehydrated, it cannot cool itself as well. This could lead to heat exhaustion or heatstroke.

Prevent sunburn by wearing loose-fitting clothes that completely cover the arms and legs. Remember to apply sunscreen to exposed areas, including your neck and ears.

Heat Exhaustion

As a result of dehydration, the body overheats because its cooling methods fail. Watch for these signs: elevated body temperature (between 98.6 and 102 degrees); pale and clammy skin that may be cool to the touch; heavy sweating; nausea, dizziness, and fainting; pronounced weakness and tiredness; headache, muscle cramps. To treat heat exhaustion, have the victim lie down in a shady, cool spot with the feet raised. Loosen the clothing. Apply cool damp cloths to the skin or use a fan. Have the victim sip water.

Heatstroke

Heatstroke (sunstroke) is far more serious but less common than heat exhaustion. It is life-threatening because the body's heat-control system has failed. Watch for these signs: body temperature above 102 degrees; red, hot, and dry skin; no sweating; extremely rapid pulse; confusion, disorientation; fainting or unconsciousness; convulsions. The victim must be cooled immediately. Place the victim in a cool, shady spot face-up with head and shoulders raised. Remove outer clothing, sponge the bare skin with cool water, and soak underclothing with cool water. Apply cold packs, use a fan, or place the victim in a tub of cool water. Dry the skin after the body temperature drops to 101 degrees. Seek medical help immediately.

Hypothermia

Hypothermia occurs when the body's core temperature drops so low that it cannot stay warm. Cool, windy, and rainy weather are particularly dangerous, but hypothermia can happen in relatively mild weather, too. To prevent hypothermia, keep warm and stay dry, and eat plenty of energy foods.

Early signs of hypothermia include shivering. As the victim becomes colder, however, the shivering will stop. Other symptoms may include irritability, disorientation, sleepiness, incoherence, and the inability to think clearly or rationally. Rewarm the victim and prevent further heat loss by moving the victim to a shelter, removing damp clothing, and warming the person with blankets until body temperature returns to normal. Cover the head with a warm hat or other covering, and offer hot drinks.

Cuts and Scratches

Minor injuries usually require little attention other than cleansing with soap, water, and disinfectant. Leave them to heal in the air, or cover them lightly with a dry, sterile dressing. Unless a cut is serious, bleeding probably will stop on its own or with slight pressure on the wound. If the bleeding does not stop immediately, apply direct and firm pressure to the wound with a sterile dressing or compress; raise the injured limb above heart-level. Clean and disinfect the wound, then cover with a sterile bandage.

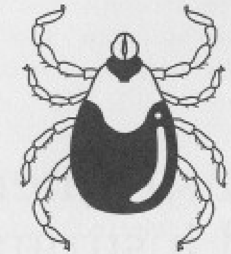
Poisonous Plants and Poisonous Animals

Surveyors come in contact with a wide variety of plants and domestic and wild animals while working in the field. For this reason, surveyors must be familiar with the poisonous plants and poisonous animals in the area and should know and carry the appropriate first-aid treatments. Because surveyors also sometimes work in locations where larger predatory animals (bears, mountain lions) exist, they must be aware of the possible dangers in those areas.

Stings and Bites

The best prevention is to pay attention where you walk and step, but despite all precautions you might get stung or bit by a bee, wasp, fire ant, scorpion, or spider. Treat ordinary insect stings by scraping out the stinger with the blade of a knife. Do not squeeze it; that will force more venom into the skin. Elevate the affected part, gently wash the area, and apply hydrocortisone cream. Bee and scorpion stings and spider bites can be treated with ice to help reduce swelling.

Ticks can carry diseases such as Lyme disease and Rocky Mountain spotted fever. Remove a tick as soon as it is discovered by grasping its head as close to the skin as possible with tweezers or gloved fingertips. Gently tease the tick from the wound. If you squeeze, twist, or jerk the tick, it could break off mouth parts, which would remain in the skin. Wash the wound carefully with soap and water. Apply antiseptic. Wash your hands thoroughly, to prevent disease.



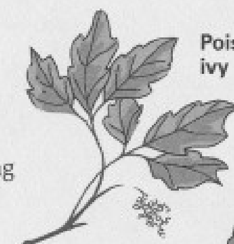
Tick

Snakebite, venomous spider bites, and venomous scorpion stings are serious, but not common. If stung or bitten by one of these creatures, seek medical help immediately.

Poisonous Plants

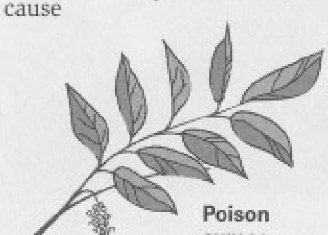
You can prevent most problems with poisonous plants by being able to identify them and by being careful. Poison ivy, poison oak, and poison sumac are the three most common troublemakers; learn how to identify and avoid these plants.

If you have touched or just brushed against one of these plants, immediately wash the skin thoroughly with soap and water to help prevent the rash from developing; the sap must be on your skin for 10 to 20 minutes before it starts causing problems. Further cleanse the area with rubbing alcohol. If a rash develops, apply a 0.5 percent hydrocortisone cream. Scratching the area will cause the irritation to spread.



Poison ivy

Poison oak



Poison sumac

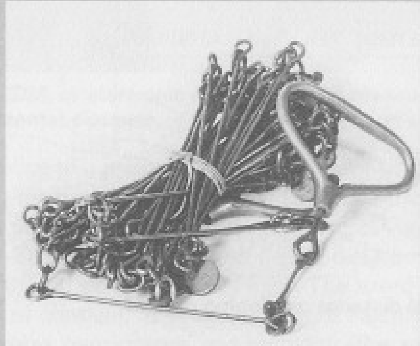
Surveying instruments are expensive and delicate. Listen carefully to your merit badge counselor's instructions for handling these instruments. Work slowly and carefully, even if it takes extra time.

Measurements and Instruments

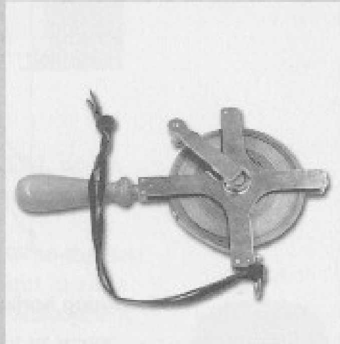
Surveying involves measuring horizontal and vertical distances and angles. It also involves extensive computation (much of which is done with a computer) and map drawing (much of which is done with a computer-controlled printer or plotter).

The Global Positioning System (GPS) uses artificial Earth satellites and portable computers equipped with receivers. GPS receivers process signals from the satellites to calculate location. This allows you to find your position (latitude, longitude, and elevation) almost anywhere on Earth, quickly and accurately, in almost any weather. Using GPS, latitude and longitude can be measured directly, without having to measure distances and angles between points. This is especially useful when the nearest survey monuments are far away. Your merit badge counselor might be able to demonstrate surveying using GPS.

Before modern instruments and computers made it possible to measure distances electronically, surveyors measured distances with flexible steel tapes. Before the flexible steel tapes, surveyors used steel chains, called Gunter's chains. Such chains were expensive, and the links deteriorated, thus altering the length of the chain. When steel band tapes became available, they replaced these chains. By tradition, though, surveyors still called length-measuring devices "chains," and many land descriptions still list distances in "chains."



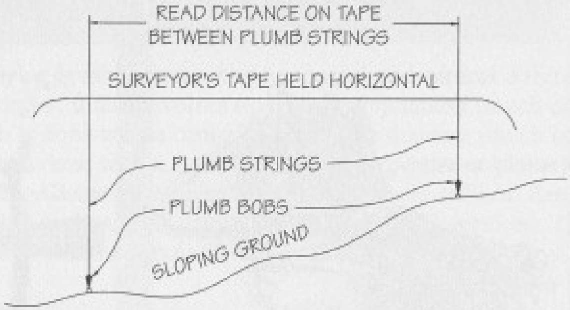
A Gunter's chain measured the wilderness of the United States. Chainmen laid out the chain and pulled on the handles to measure 66 feet.



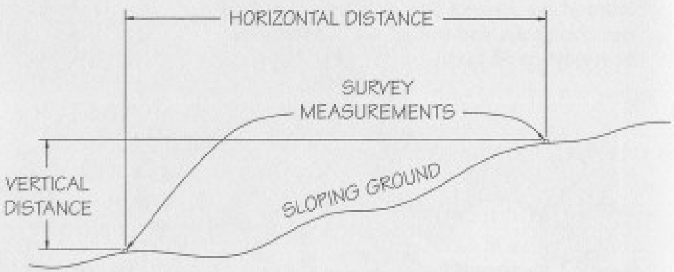
High-quality surveyor's tape

Horizontal Distances

Property boundaries are described using horizontal distances, even on sloping land. The illustrations here show how horizontal distance is described on sloping ground. Surveyors' instruments may measure the horizontal distance directly, or they may measure the slope angle and distance, and convert the slope distance mathematically to horizontal and vertical distances.

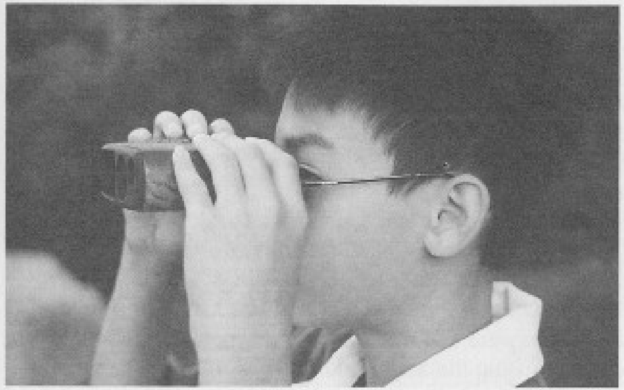


Measuring horizontal distance on sloping ground



Horizontal and vertical distances on sloping ground

Horizontal distances generally are measured with an electronic distance meter (EDM) or by GPS. The EDM measures distance by measuring the time needed for a light beam to travel between two points. The EDM is placed at one of the two points between which the distance is to be measured. The meter generates a light or infrared beam that travels across the



An EDM, or electronic distance meter, measures horizontal distance.

distance to a *prism* (reflector) and back to the EDM, which then measures the length of time it took the beam to travel that distance.

The time depends both on the distance between the two points and on the speed of light. The speed of light in air is almost constant, although it depends slightly on atmospheric pressure, temperature, and humidity (the amount of water vapor in the air). Some EDMs automatically measure these quantities and use the measured values to compute the distance precisely. With an EDM, distance measurement usually is more accurate and faster than with a chain. Most modern EDM's are incorporated into the surveyor's *total station.*

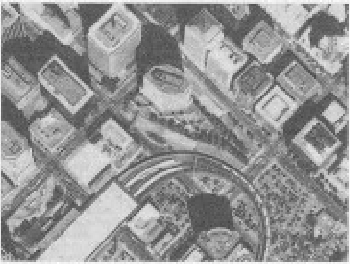
Total stations are instruments that have an onboard EDM to measure the distance to the prism and a telescope for sighting the prism. Total stations also can electronically measure the vertical angle to the prism. Most total stations have onboard computers to record all of the survey measures taken during the day. This function is called the *data collector.*

Horizontal distances also can be measured using GPS. To do this, a surveyor sets up a GPS receiver at one point and records the satellite data for that position. Then, the surveyor sets up the GPS receiver at the next point and records the satellite data for that position. After data has been recorded for all points, it is downloaded into a computer. GPS software uses the data to compute distances between all points measured.

GPS equipment quickly is becoming a more economical and affordable method for measuring distances, and it is simpler to use than the expensive and delicate total station. However, its use is limited because a GPS receiver cannot receive data when something stands between the receiver and the satellites. Surveying using GPS will not work indoors or under trees.

Horizontal and vertical distances also can be measured from aerial photographs (taken from an airplane) and satellite photographs taken from space. Before airborne GPS, aerial photography required that some points be surveyed on the ground; these were called *ground control points*. This method involved adjusting the aerial photographs to fit the surveys done on the ground. However, using airborne GPS, no adjustments are needed.

Aerial photography allows large areas to be mapped rapidly and accurately. The United States Geological Survey (USGS) maps, which are used extensively in Scouting, are made using aerial photography.



Aerial photography allows professionals to survey large sections like this metropolitan area.

Vertical Distances

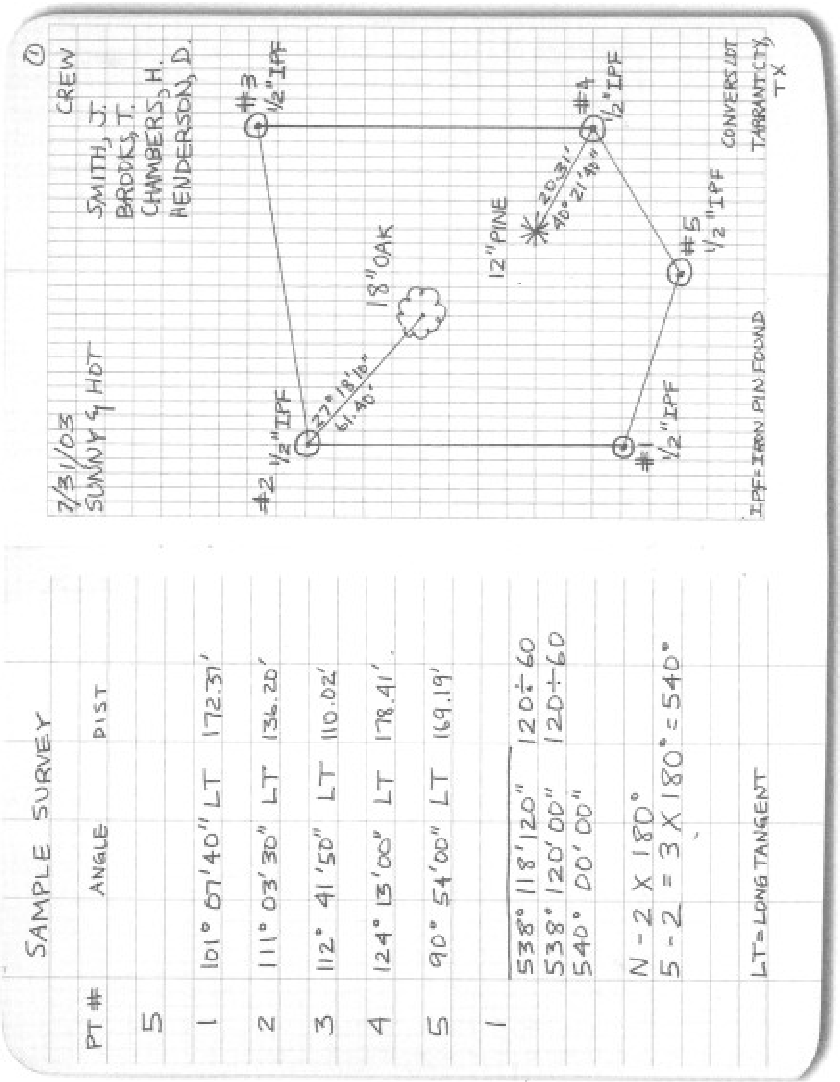
Vertical distances generally are measured in one of two ways: by sighting along a horizontal line toward a leveling rod, or by measuring slope angle and distance with an EDM and then converting the slope distance mathematically to vertical distance.

We will use the first method to measure the elevations in requirement 5. If you enjoy math, your counselor can show you how to use the second method.

For rough mapping of large areas, approximate land elevations sometimes are measured by special barometers. These barometers measure atmospheric pressure, which in turn depends on the elevation and the weather. For most measurements, however, GPS technology has replaced barometric pressure measurements.

Sample Survey Lot

Use this example to help you understand how surveyors calculate measurements when surveying a lot. It will help guide you as you work on requirement 3.



Distance Units

In surveying, distances are expressed either in meters or feet. To simplify the arithmetic, decimal fractions are used. (Inches normally are not used in surveying.) In the United States, most surveying measurements are expressed in feet.

In surveying, the *meter* is defined by law in terms of the wavelength of a particular form of light that can be generated in a laboratory. This is safer than defining the meter by a physical ruler that might be accidentally destroyed. In the United States, for long-distance control surveys, the foot is defined as exactly 0.3048 meters. This measurement is known as the *international foot* because it is used by countries in which survey systems are based on meters. For modern surveying to be consistent with old measurements, however, a survey foot is defined as exactly 1200/3937 meters. This measurement is called the *United States survey foot.* For the purposes of earning the Surveying merit badge, the difference between the United States survey foot and the international foot does not matter.

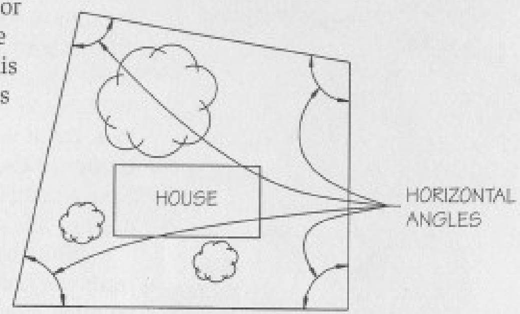
Distance Units Comparison Chart (Table of equivalents)

1 U.S. survey foot	=	0.304806 meters
1 international foot	=	0.3048000 meters
1 mile	=	5,280 U.S. survey feet
1 mile	=	80 Gunter's chains
1 mile	=	1.609344 kilometers
1 Gunter's chain	=	66 U.S. survey feet
1 Gunter's chain	=	100 links
1 Gunter's chain	=	4 poles/rods
1 Gunter's chain	=	22 yards
1 link	=	0.66 U.S. survey foot
1 pole/perch/rod	=	16.5 U.S. survey feet
1 yard	=	3 U.S. survey feet
1 acre	=	43,560 square feet
1 square mile	=	640 acres

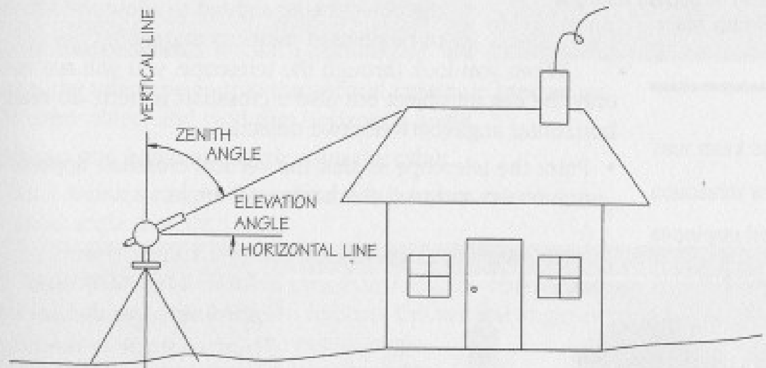
An old unit of length is the *chain,* which is 66 feet or 1/80 mile. This was the length of the old-fashioned Gunter's chain. A chain had 100 links of equal length. Some old land records and even a few modern deeds state distances in numbers of chains and links. If such units are used in your area, your merit badge counselor can tell you how modern surveyors handle them.

Horizontal and Vertical Angles

A horizontal angle is simply the difference between two *bearings,* or *azimuths,* which you can measure with a compass. While earning this merit badge, you will measure this difference much more accurately than you can with a compass. A vertical angle is a measure of how far an object is above the horizon (the *elevation angle*) or how far an object is below the point directly overhead (the *zenith angle*).



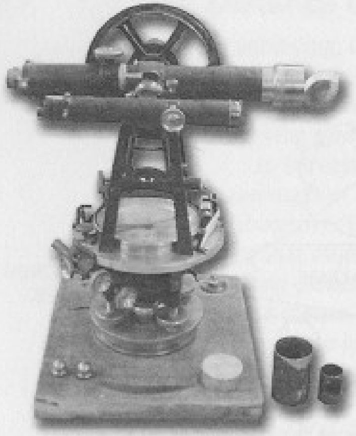
Horizontal angles at the corners of a lot



Vertical angles

Measuring Horizontal and Vertical Angles

In surveying, angles are measured directly with a total station, which measures the angles and distances automatically. This information is stored automatically in the total station or in an external data collector, or the surveyor writes it in a notebook. The readings are then loaded, sometimes electronically, into a computer for later use. Older surveying equipment such as transits and theodolites require surveyors to read and record the measurements manually.



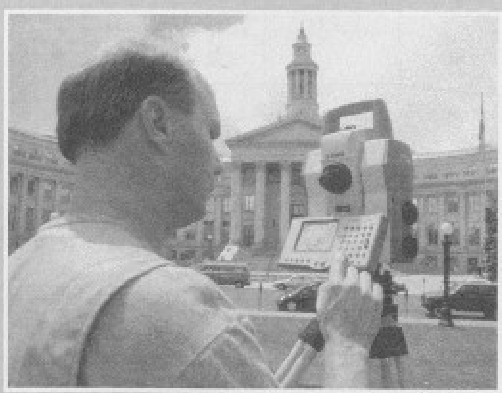
Surveyors once used transits like this one to measure horizontal and vertical angles using a magnifying glass.

A good total station is a delicate and complex instrument, and many controls must be operated on the total station to obtain accurate angle readings. All models are slightly different. Your merit badge counselor will show you how to use the total station that is available to you for this badge. There is a lot to it, but it is not hard to learn. This is your chance to use a very fine instrument, and you have a counselor to show you how. Make the most of this opportunity.

When using a total station, the surveyor reads the horizontal and vertical angles by pointing a telescope at the object from which a measurement is to be taken. The angle-indicating mechanism indicates the horizontal and vertical angles of the telescope. The telescope provides a magnified view of the object being sighted to allow the telescope to be pointed more accurately.

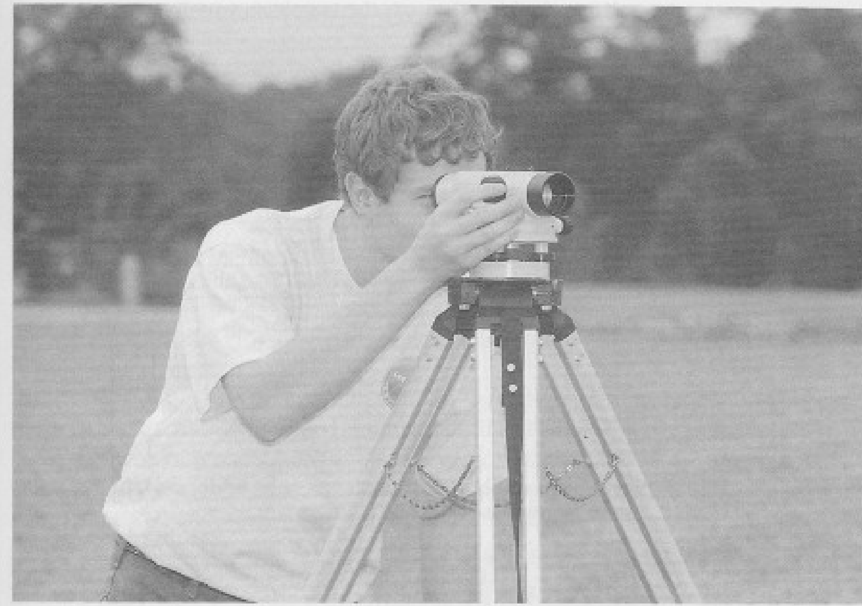
When you look through the telescope, you will see not only the distant object but also a crosshair pattern. To read the horizontal angle between two objects:

- Point the telescope so that the vertical crosshair appears on one object and read the horizontal angle.



Total stations almost eliminate the danger of human error in reading and writing numbers, although surveyors must still use the instrument correctly to have it read the proper angles.

Surveyors today use a total station to measure horizontal and vertical angles automatically.



- Move the telescope so that the vertical crosshair appears on the other object and read that horizontal angle.
- Subtract one horizontal angle from the other.

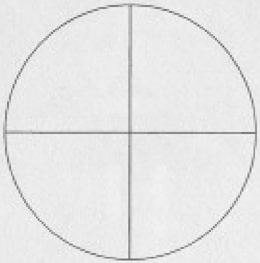
Total stations can do the subtraction for you and read the horizontal angle directly.

To read the vertical angle of an object, simply point the telescope so that the horizontal crosshair is on the object, and read the angle. Total stations can indicate the vertical angle as either the elevation angle or the zenith angle.

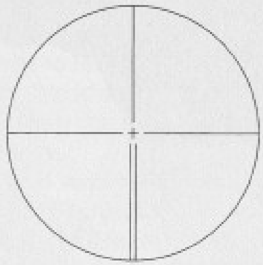
Total stations have a pendulum (back-and-forth) mechanism, called a *vertical compensator,* which automatically gives the correct vertical angle even if the total station is slightly tilted (not leveled on its tripod). In other words, the vertical compensator "corrects" the vertical angle even when the total station is not level. Tilt also causes slight errors in measuring horizontal angles and a total station's built-in compensator can correct this, too. However, if the total station is tilted too far, the compensator will not function, and the vertical angles must be remeasured. Total stations provide a way to check the compensator, which should be done every time you set up the instrument.

Your merit badge counselor will show you how to check the compensator on the particular total station you use.

When looking through the eyepiece, usually one or both crosshairs will be double (bifilar). A small object can be centered more accurately between two closely spaced crosshairs than behind a single crosshair.



Simple crosshair pattern as seen through a telescope



Bifilar crosshairs

> If you focus incorrectly, you may get incorrect readings without noticing that anything is wrong. Your merit badge counselor will show you how to focus the telescope on the particular instrument that you use and explain why that method is necessary. Generally, the ocular needs to be focused only once for your own eyes, but you might need to focus separately on each distant object. When another person looks through the telescope, it might need to be refocused completely.

Total stations and levels, and older surveying equipment such as transits and theodolites, have two focusing adjustments—one for the crosshairs and one for the distant object. First, focus the eyepiece, or *ocular,* so that you see the crosshairs clearly. Disregard the distant object completely during this adjustment; it may help to defocus the distant object or point the telescope at the sky, away from the sun. After the ocular is focused on the crosshairs, point the telescope at the distant object, and use the object-focusing adjustment to focus on the distant object. The crosshairs should remain in focus as you

> On some transits and theodolites, the telescope inverts the image, so the view is upside down. For the particular instrument that you use, your merit badge counselor will show you how to carry it, set it up precisely, and operate it.

focus on the distant object. Then, move your head slightly sideways while looking through the telescope, and verify that the crosshair pattern does not appear to move across the distant object. If the crosshair pattern does move, the telescope is not focused properly.

Total stations, transits, and theodolites vary greatly in the way their scales are marked, numbered, and read; in the basic methods of reading horizontal and vertical angles; and even in the methods of carrying and setting up the instruments. A few transits—and most total stations and theodolites—have *optical plummets,* which greatly simplify the task of placing the instrument directly over the point from which you want to measure.

Angle Units

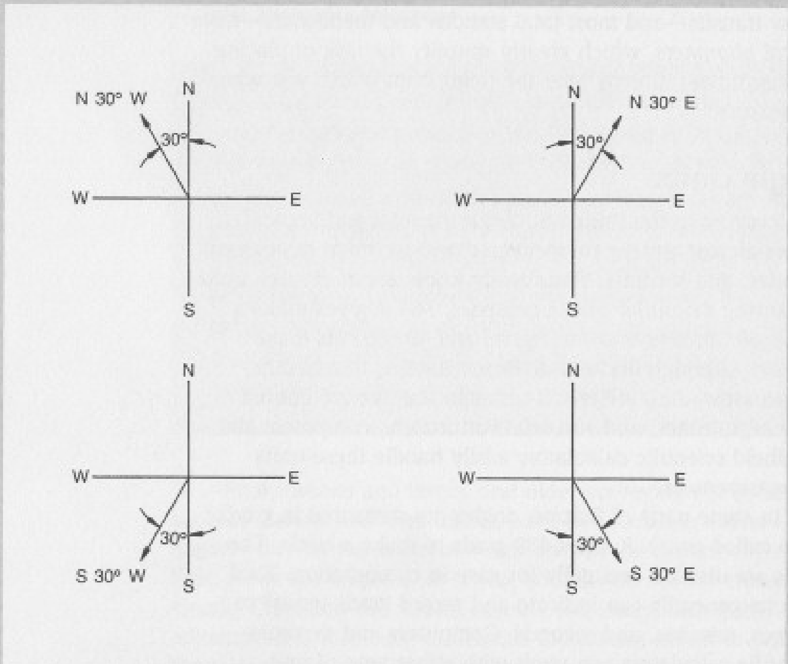
In surveying in the United States, horizontal and vertical angles almost always are measured and recorded in degrees, minutes, and seconds. You already know about degrees from measuring azimuths with a compass: 360 degrees make a circle, 60 minutes make a degree, and 60 seconds make a minute. Although decimal divisions (tenths, hundredths, thousandths, etc.) are much easier to use, we are limited to degrees, minutes, and seconds. Fortunately, computers and handheld scientific calculators easily handle these units of measurement.

In some parts of Europe, angles are measured in *grads* (also called *gons*). It takes 400 grads to make a circle. The grads are divided decimally for ease in computation. Total stations generally can indicate and record grads (gons) or degrees, minutes, and seconds. Computers and versatile scientific calculators can work with either type of unit.

How Horizontal Angles Are Recorded

In Scouting and in most other fields, azimuth is measured as the horizontal angle from north, clockwise (looking down on earth), from 0 degrees to 360 degrees. But, in some types of surveying, azimuth is measured from south.

To avoid confusion, maps usually show bearing rather than azimuth. It looks complicated at first, but actually it is quite simple. *Bearing* is measured from either north or south, toward either east or west. (It always is written to show how it is measured.) The diagrams here show how it is done. Notice that the bearing angle never exceeds 90 degrees. Computers and scientific calculators can easily convert between bearing and azimuth. If it gives you trouble, ask your merit badge counselor for help.



The bearing of a line

Levels

Requirement 3 involves using a level and a leveling rod to determine the elevations of points on the ground. To do this, you generally do not need to measure vertical angles; you just want to be able to look along a level line at a leveling rod and use the leveling rod to measure vertical distances. You can do this with a total station by setting the telescope level. For leveling, however, a special-purpose instrument called a *level* is more accurate, easier to use, and less expensive.

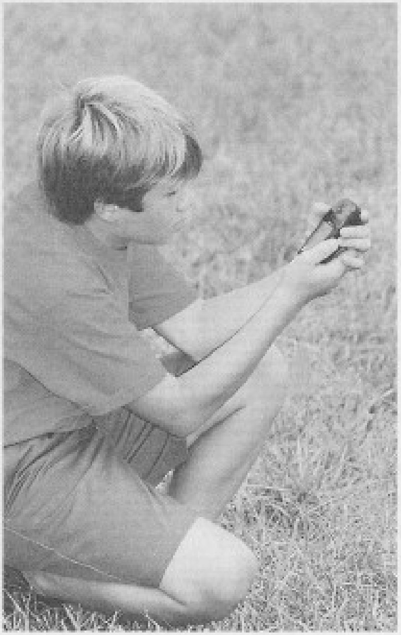
Surveyor's optical level

Optical levels have telescopes and crosshairs, but the crosshair patterns vary between levels and are designed for precise leveling rather than for measuring horizontal and vertical angles. Some levels can measure approximate horizontal angle.

Automatic optical levels have a vertical compensator, somewhat like those discussed earlier. In this case, the compensator slightly adjusts the telescope's line of sight so that the horizontal crosshair indicates a level line. As with total stations, the compensator does not function if the level is tilted too far. Make it a practice to check the compensator every time you set up the level. Your merit badge counselor will show you how to check the compensator, as well as how to set up and use the particular level you are using.

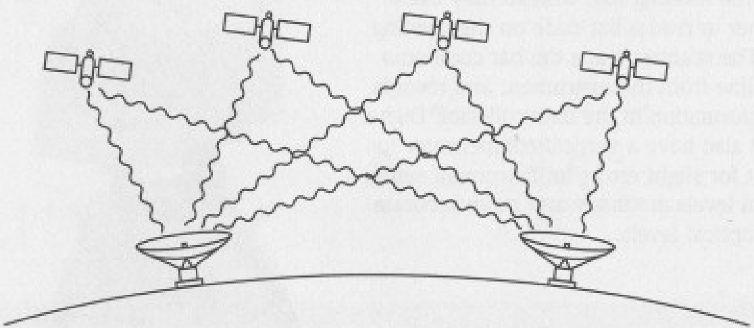
Digital levels do not use crosshairs to view the leveling rod. Instead they use a scanner to read a bar code on the leveling rod. The scanner reads the bar code on a level line from the instrument and records the information in the data collector. Digital levels also have a vertical compensator to adjust for slight errors in instrument setup. Digital levels are faster and more accurate than optical levels.

Surveyor's digital level



Global Positioning System Surveying

You probably have seen a GPS receiver in use, either one mounted in a car or a handheld model. Handheld GPS receivers tell you where you are and can be programmed to tell you how far and which direction to go to reach your destination. GPS receivers in cars and boats have a screen with a map that traces your progress and shows the distance to your destination. Some of these receivers can even tell you when to turn onto a particular street.



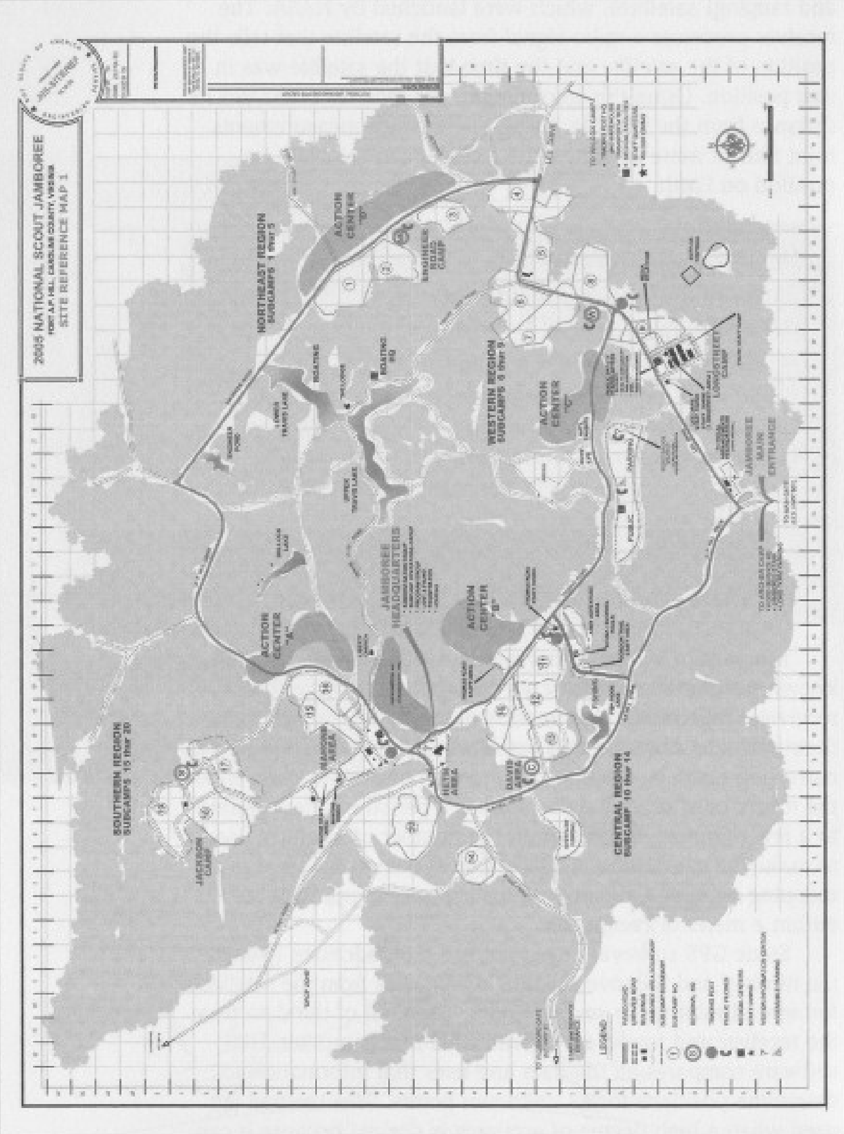
Satellite and receiver triangulation

GPS receivers use NAVSTAR (navigation system with timing and ranging) satellites, which were launched by NASA. The receiver processes a radio signal from the satellite that tells the position of the satellite and the time that the satellite was in that position. Using this information, the receiver calculates its distance from the satellite. Using the distance measurements from four or more satellites, the receiver can calculate its position on Earth.

Handheld GPS receivers are accurate to within 3 meters, but this is not accurate enough for most surveying tasks. To make their systems more accurate, surveyors place a receiver on a point for which the position is known. This receiver compares the known position to the position it computes from the satellites. The difference between the positions becomes the *correction factor,* or error of closure. Surveyors employ this correction method for two types of GPS surveying: *kinematic* and *static.*

Kinematic GPS surveying uses a receiver positioned at a known position to broadcast the correction factor to other GPS receivers, called rovers, at unknown points. Rovers determine their positions from the GPS satellites and apply the broadcast correction factor to calculate their actual positions. To do this, the rovers must occupy a position for a period of a few seconds to a few minutes, depending on the number of satellites used to make the calculation. This method is commonly used in mapping surveys and can produce measurements accurate to within a meter or centimeter.

Static GPS surveying does not use a broadcaster. Instead, the receiver and the rovers simply record data from the satellites for several minutes to several hours. Then, all of the data from the receiver and rovers are downloaded to a computer. GPS software compares all the data and uses that information to determine positions for all unknown points. This method is used when a high degree of accuracy is desired because it can produce measurements accurate to a millimeter.



How Land Is Described

When someone purchases land, the seller gives the buyer a deed. The deed, which includes a description of the land, is recorded in the county recorder's office. In this way, other people can know who owns the land and where its boundaries are.

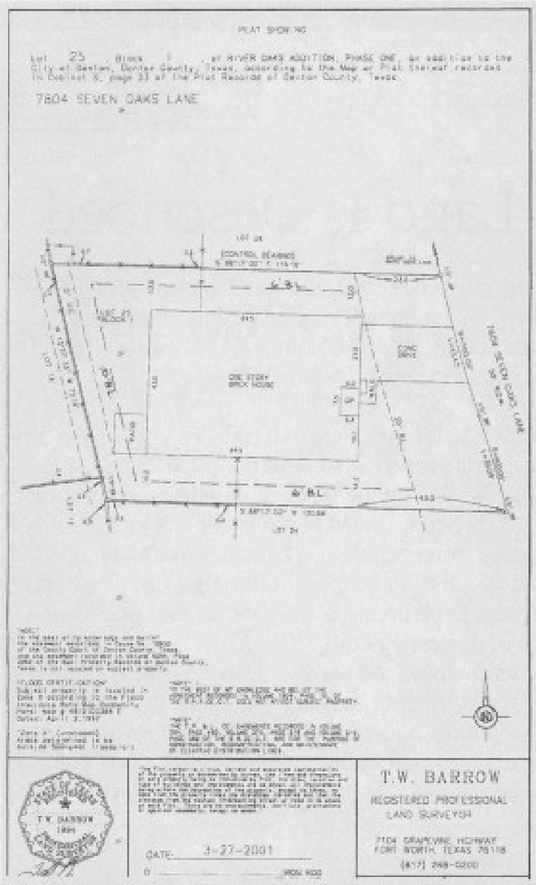
In the United States, there are two primary ways to describe land: the rectangular survey system of the public lands, and metes and bounds. The public lands of much of the Southern, Western, and Midwestern United States is laid out and described by the rectangular survey system. The metes and bounds system is used in the United States on the East Coast and in some other states. Wherever you live, you should understand both methods of describing land.

A few other methods are used to describe land boundaries. Examples are rivers, divides between watersheds, lines of latitude and longitude, and various artificial grid systems defined by law. Your merit badge counselor may show you examples of such boundary descriptions in your area.

Metes and Bounds

Using measurements along boundaries, a *metes and bounds* description begins at some specific point such as a durable surveyor's monument (a metal marker set firmly in concrete or stone is a good example) that can be located easily. If that point is not on the boundary of the property being described, the description directs you in some bearing (for example, N12° 34' 56" E) for some distance (for example, 123.45 feet) to a point of beginning on the boundary. Then, the description directs you around the boundary, one side at a time, back to the starting point. The boundary description may include descriptions of surveyors' monuments at the corners of the property and other information to avoid or minimize confusion in locating the property later.

Just for fun, your merit badge counselor may be able to show you the subdivision map that includes your home.



Boundary map with metes and bounds description

A deed may simply refer to a lot on a subdivision map filed in the county recorder's office, which shows all of the metes and bounds information for the whole subdivision. On the subdivision map, each block is numbered; within each block, each lot is numbered. Thus, a particular lot is described by the name of the subdivision map (and usually the deed book and page number where the map is filed in the county recorder's office), the block number, and the lot number. This method of description shows clearly the location of the lot in the subdivision, and avoids excessive copying and errors.

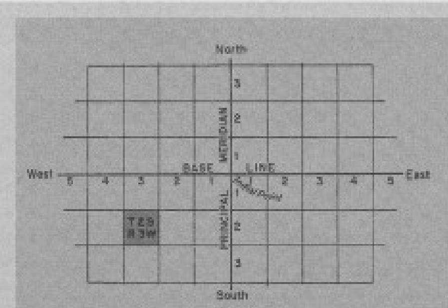
The Rectangular Survey System of the Public Lands

In the early days of America, a settler chose the land desired, marked the boundaries (by making piles of stone or blazing trees), hired a surveyor to measure the land, and bought the land from the government. Over the years, confusion arose over irregular shapes of land, gaps between adjoining lands, and lost or destroyed monuments (such as when a blazed tree fell or burned).

When the United States government opened its western land (the "public domain") for sale to settlers and for lease for grazing and timbering, the government used the *rectangular system of land surveys*. The land was surveyed and marked by durable monuments into an orderly arrangement of squares, all according to rigidly standardized directions from the government.

Various starting points were established throughout the western land. Through each point, an east-west line, called a *baseline*, was marked on the ground, usually for many tens or hundreds of miles in both directions. A north-south line, called a *meridian* or *range*, was similarly marked.

From the intersection of the baseline and the meridian, or range, six-mile squares, called *townships*, were laid out and monumented. Each township is identified by a "township" or "T" number according to how far north or south it is of the baseline, and by a "range" or "R" number according to how far east or west it is of the meridian. The terminology is a bit confusing, but the diagram here shows how it is done.



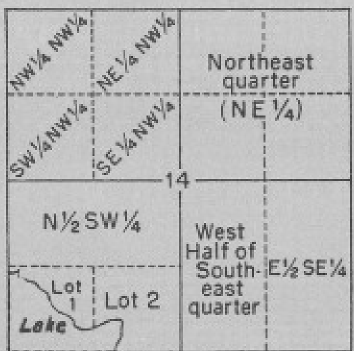
This diagram shows a township *grid*. These six-mile squares are identified by distance from the initial point. For instance, the shaded township is Township 2 South, Range 3 West.

Each township is divided into 36 one-mile squares, called *sections*, which are numbered as shown in the diagram shown here.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

This diagram shows the numbering of a township's 36 sections. Except in a few special cases, each section is approximately one mile square and contains approximately 640 acres.

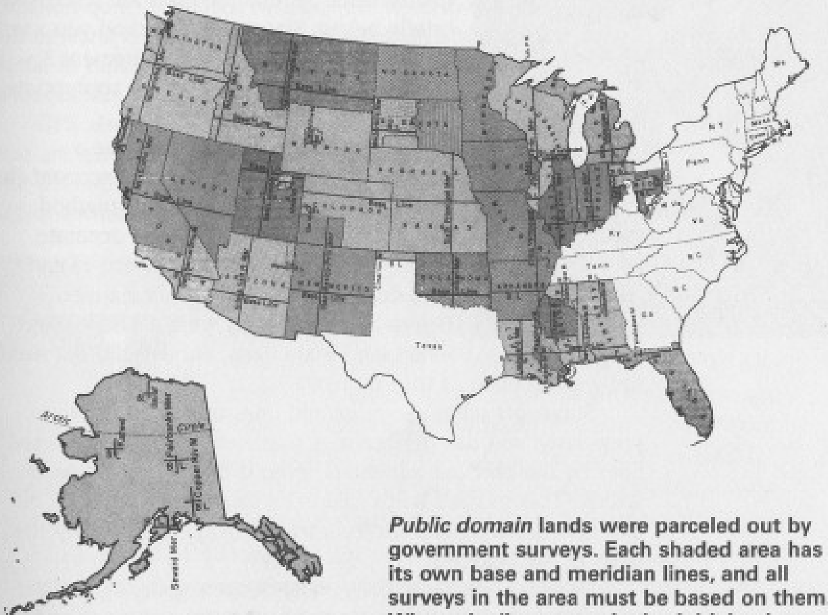
Each section may be divided into halves, quarters, and smaller subdivisions, all according to rigidly standardized directions from the government. Irregularly shaped subdivisions may be called *lots.* The following diagram shows how one particular section was divided according to the needs of the landowners.



This particular section is divided into eight approximately 40-acre 16th sections, three approximately 80-acre eighth sections, and two lake lots of less than 40 acres each.

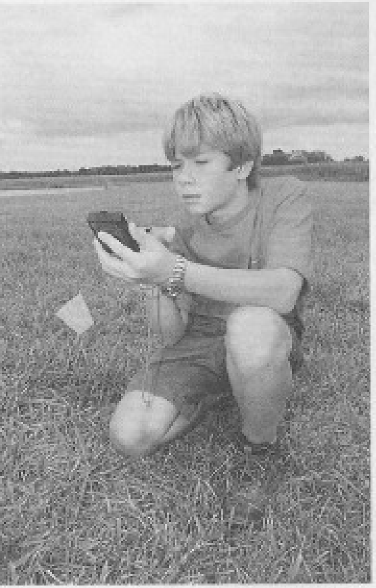
This system works well but is by no means perfect, and the imperfections can be troublesome unless you are aware of them. First, square townships and sections do not fit perfectly on the surface of our round planet. Second, in some places, surveys from different baselines and meridians meet and overlap. Third, when most of the public lands were surveyed into townships and sections, surveying instruments were primitive, and electronic instruments (calculators, computers, electronic distance meters, and satellites) were nonexistent. Much of the land was rugged and isolated. Therefore, a surveyor's errors tended to be large by modern standards. Fourth, some of the early surveyors were not fully competent, or, in a few cases, some were dishonest. Fifth, some of the monuments have disappeared.

These imperfections result in township and section boundary lines that are not quite north-south or east-west, township corners that do not fit together perfectly, sections that are not 1-mile squares, and monuments that are difficult to find or nonexistent. Your merit badge counselor can tell you how today's surveyors deal with these problems.



***Public domain* lands were parceled out by government surveys. Each shaded area has its own base and meridian lines, and all surveys in the area must be based on them. Where the lines cross is the *initial point.* (Not to scale)**

Measuring True Azimuth or Bearing



For requirement 2, you need to lay out lines on the ground in the proper azimuths or bearings. This can be done in several ways. You and your merit badge counselor should select a method according to the accuracy requirements of the particular survey, your interest and mathematical background, and the capabilities of your counselor's instruments. Several methods are discussed briefly below. State which method you used on the map you draw for requirement 3; your counselor will suggest the appropriate wording for your type of map.

The simplest method is to use a magnetic compass and take into account the local magnetic declination. This method, while simple, is not sufficiently accurate for most modern surveying. Much of early America was surveyed in this manner. Before better methods were available, and when land was cheap, surveys did not need to be as accurate as they do now.

Surveyors often use or extend lines that were surveyed previously, and use the bearings that were assumed for those lines by the previous surveyors, even if those bearings were wrong. This method helps to ensure consistency between old and new surveys. The surveyor must always state clearly the basis of the bearings.

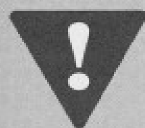
Celestial (heavenly body) observations generally are the most accurate. Polaris (the North Star) works well from northern tropical and middle northern latitudes. (Note that Polaris is not quite at true north; it moves around the north point in the sky, but true north can be computed from the direction of Polaris.) At far northern latitudes, Polaris is too high in the sky for convenient observation with a total station, and the measurement accuracy tends to be poor. Near the equator, Polaris is not always visible; and Polaris is not visible at all from the southern hemisphere. Other stars can be used almost as easily, without the latitude restrictions of Polaris. Obviously, stars can be used only at night.

While the sun is a convenient azimuth reference from most latitudes, you must be careful of your instruments. Most important, you must be extremely careful to properly protect your eyes and **never** look directly at the sun. For safety reasons, this method is not recommended.

Measuring true azimuth by celestial observations generally requires some elementary astronomy and some spherical trigonometry. If you like mathematics and you have had trigonometry, here is your chance to use it. Otherwise, you may want to use another method.

A gyroscopic compass, or *gyrocompass,* can indicate direction quite accurately without the need to observe the sun or stars. It is useful in cloudy weather, and is particularly useful in mines and tunnels. The main disadvantages of a gyrocompass are its high cost and heavy weight.

GPS also can be used to establish a true azimuth. GPS data are gathered at each end of an azimuth line and then the true azimuth and length of the line can be computed using GPS software.



WARNING: Never look directly at the sun. *Never, absolutely **NEVER**, look at the sun through a telescope, except through a proper sun filter.* Doing so will cause permanent and severe eye damage. Prolonged direct viewing of the sun, even through a filter made for that purpose, can cause eye damage. If you do look directly at the sun through a telescope with a proper filter, be absolutely sure that the filter is in place before you point the telescope at the sun. Have your merit badge counselor supervise you directly and carefully at all times when you are making sun observations.

Surveying a Lot

Requirement 2 requires you to perform a survey of a lot. This type of survey describes property in terms of *metes* (the bearings and distances or physical features that describe each line of the property's boundary) and *bounds* (the monuments that mark the corners of the property or points where the property line changes direction). Bounds can be iron pipes or stakes driven into the ground, trees, concrete monuments, fence posts, etc. Throughout history, the metes and bounds system has been used to describe property. In the United States today, all of the states that made up the original 13 colonies (as well as a few other states) use this system. All of the other states used this system to describe smaller tracts of land that were divided from the original rectangular survey system.

Here are two examples of metes and bounds descriptions:

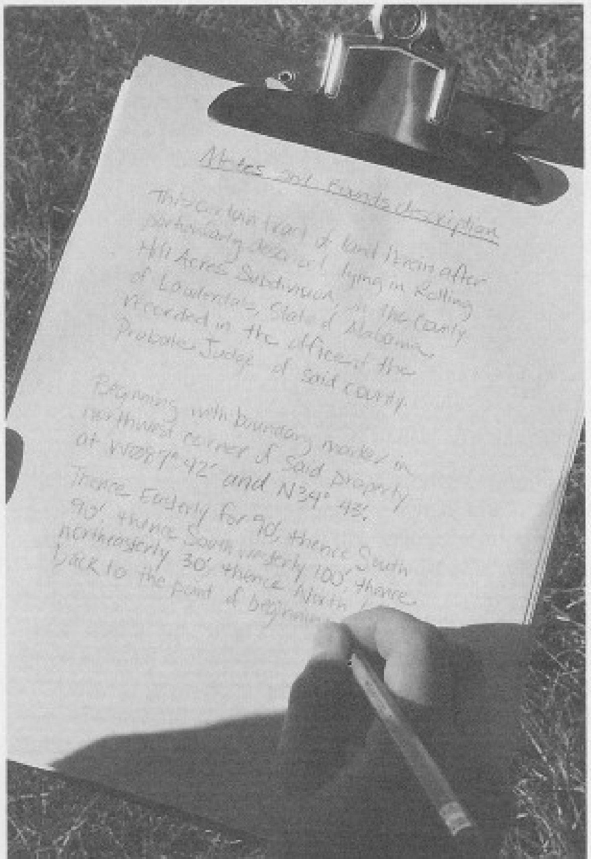
- Along the east edge of Crooked Creek to a 24-inch sycamore tree at the end of a fence, then in an easterly direction, with the fence, to a stone on top of a ridge.
- N 44° 10' 33" E 400.76 feet to an iron pipe at the southwest corner of property owned by Jones.

To fulfill requirement 2, your merit badge counselor will establish the points between which you will survey to describe the lot. Your counselor also will determine the meridian base for your survey, either by assuming a bearing or azimuth for the beginning line, or by establishing its bearing or azimuth by some other means. Along with the others in your group, you will take turns operating the survey instruments (total station), recording notes, giving backsights, and measuring the distances between the established points. When the work is completed, your counselor will show you how to check your precision by calculating the error of closure.

The *error of closure* is the difference between the measured location of a known point and the actual location of the known point.

The object of this exercise is to gather and record the data necessary to draw a map of the lot. Along with gathering the data for describing the boundaries of the lot, you will also record angles and distances measured to certain physical features (such as trees) to be shown on the map.

This procedure will be followed at each corner point of the lot until you have recorded angles and distances measured between every line of the lot boundary. Using the notes your team recorded, you will be able to check that your work was done properly and to draw a map of your survey. Your merit badge counselor will help you to accomplish this graphically or by using mathematics, depending on your level of knowledge.

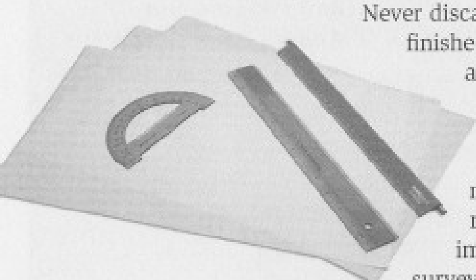


Sample Set-up Procedure

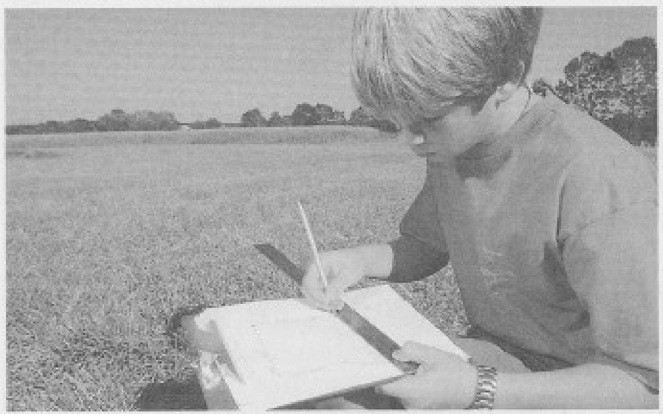
1. Position the tripod over the point.
2. Place the instrument on the tripod, and level it so that it is directly over the point. Your merit badge counselor will show you how to do this with the particular instrument you are using.
3. Observe the backsight being given by the person in charge of the rod.
4. Set the instrument's horizontal angle plate to zero (unless this is required before observing the backsight—your counselor will know this).
5. Measure the distance between the point where you are and the backsight point. This measurement should be made with a total station or an EDM, depending on the type of equipment used. Record this measurement in the notebook or call it out to the recorder.
6. Turn the total station or theodolite to the next corner point. (The procedure will be determined by the instrument used. Your counselor will show you what to do.)
7. Read the horizontal angle. (Most instruments display the angle as turned to the right of the backsight point.) Record this angle in the notebook or call it out to the recorder. To provide greater precision, you may wish to "double" the angle; your counselor will explain how this is done, and why.
8. In the notebook, record the distance measured between the point you are occupying and the next corner point, or call out the distance to the recorder.
9. If you can observe any of the physical features that need to be located, you will want to record angles turned to them from this point and the backsight point, and from the distances measured. You can measure the distances with tape or an EDM as directed by your counselor. To avoid confusion when compiling the data in your notebook, be sure to note which setup and backsight points are used. Record these angles and distances in the notebook, or call them out to the recorder.

Drawing Your Map

In requirement 2, you laid out a five-sided lot. You recorded field notes that show what you measured and the measurement results (distances, angles, and features like trees, shrubs, and rocks). You can now use those field notes to draw your map for requirement 3.



Never discard your field notes after the map is finished; your notes are your original and most accurate record. If you find a mistake on your map, you will need to review your original notes to determine the source of the error and the correct measurement data. Or, you might have recorded things which may become important later. Field notes, which surveyors generally keep on file, might also become important evidence in court.



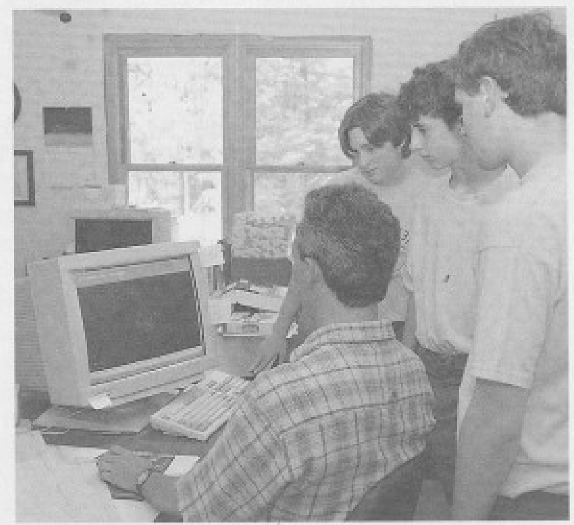
Work closely with your merit badge counselor as you draw your map. While you work, your merit badge counselor may point out errors that, if not caught in time, would require you to start over.

For your map, choose a paper size large enough (at least 11-by-17 inches) to allow you to show all of the necessary detail. If you use trigonometry to plot your map, grid-ruled paper is helpful. If you do not want the grid lines to show on your finished map, use drafting tracing paper with light blue grid lines, which do not reproduce in most industrial photographic processes, blueprints, and copiers.

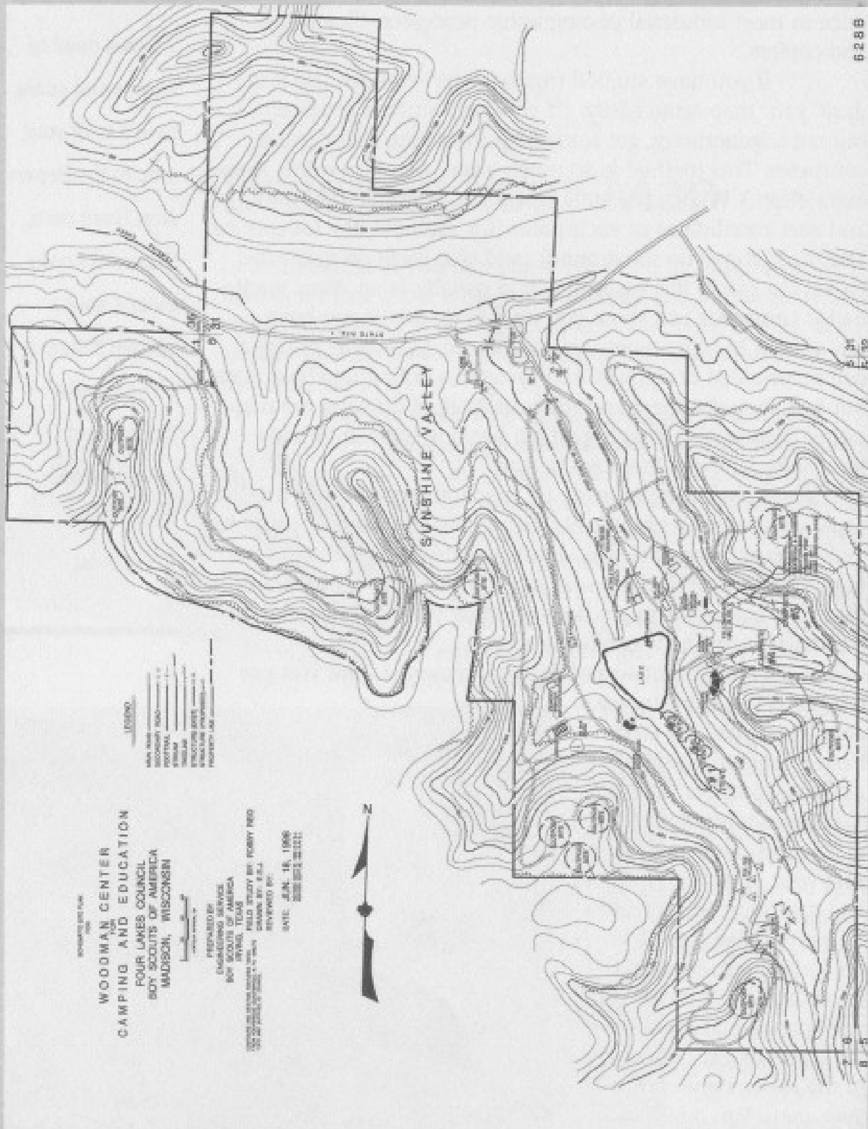
If you have studied trigonometry, you can use it to draw your map quite easily. (If you have studied geometry but not trigonometry, get some help from your merit badge counselor. This method is so much easier that it is worth some extra effort.) With a scientific calculator, compute the north and east coordinates of each point (for example, the lot corners and the features on the ground), and plot them on grid-ruled paper. On maps, the north direction usually is up. Your merit badge counselor can show you how to do this if you have not done it in trigonometry class. You might be able to use a computer-aided drafting (CAD) system to draw the whole map, but you should understand the principles of drawing the map, rather than merely learning which buttons to push to make the computer draw the map for you.

If you are not quite ready for trigonometry, you will need to draw your map geographically. Use grid-ruled paper if possible, and a separate straightedge, drafting scale, and protractor. So many versions of drafting scales and protractors are available that your counselor might need to show you how to use the particular instruments available to you.

If you did the lot survey for requirement 2, and you use trigonometry, you can use coordinates (which you need to compute for plotting) to calculate the maximum north-south extent and the maximum east-west extent of your lot. You can figure what scale to use to make the lot fit on your paper. Position the lot so that it fits nicely onto your paper, and leave room for a title block, preferably in the lower right corner of your map. You might want some help from your merit badge counselor the first time you do this.



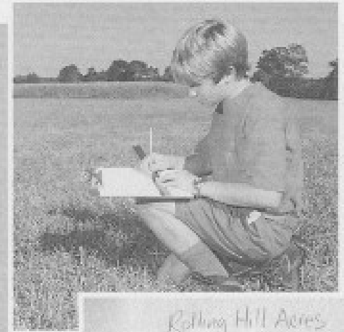
You will need to know what scale to use to fit your map to the paper size. Used here, the word *scale* means how a certain distance on your map corresponds to that same distance on the ground.

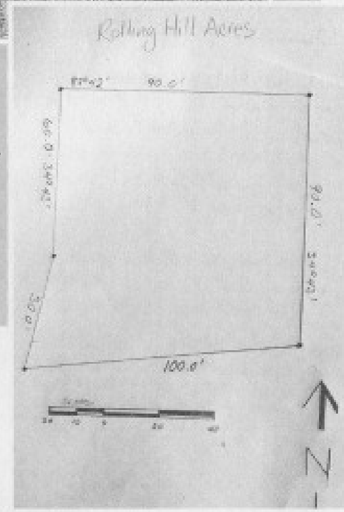


A professionally drawn CAD plot

To draw a map graphically, use a protractor to mark the bearing of each line, use a straightedge to draw the line in that bearing, and use a scale to determine the length of the line. Follow these steps to draw your map.

1. Put the protractor over the starting point with its zero mark aligned to the closest north-south grid line.
2. Mark the bearing of the line.
3. Use a straightedge to draw a line through the point at the required bearing.
4. Use a drafting scale to mark the right length on the line, and erase the rest of the line.





If you did not use trigonometry to survey the lot for requirement 2, you might need to experiment with scales to fit your map to the paper. Your counselor can help you. Regardless of how you draw the map, show your counselor your proposed layout before you invest a lot of work in drawing the details.

Use symbols, preferably like those on the USGS maps, to show the features you plotted on your map. If you surveyed a lot, write the bearing and distance of each side of the lot beside its boundary line on your map.

Draw a title block on your map, preferably near the lower right corner. Experiment first on scrap paper so you do not ruin your good map with excessive erasure. Include the name of the property (in this case, the land you surveyed for your Surveying merit badge), the location of the property (for example, the city or county, and state), a north arrow (usually in the upper left corner), a scale, the basis of the bearings (for example, celestial observations, a previous surveyor's bearing, or magnetic compass), your name and Scout troop number, and the date. Work closely with your merit badge counselor, as a beautifully drawn map is nearly worthless if essential information is missing.

Leveling

Select a starting point for leveling. Your counselor should approve your starting point before you begin measuring.

In requirement 5, an elevation of 100 feet is assumed for one point measured in requirement 2. The elevations of the other four corners you measured in requirement 2 are then determined. We have already seen what levels are, and generally how they work; we will now use one.

If you used a leveling rod when you took measurements for requirement 2, and if you are using the same rod for this leveling requirement, you already know how to use it. Otherwise, take a close look at the leveling rod. It probably has more than one section and may have a movable target for reading the scale at great distances.

Examine the scale on the leveling rod you are using. There are many different types of scales, and you might ask your merit badge counselor to help you understand the scale on the particular rod you are using. If you are using a digital level, the leveling rod will have a series of bar codes.

To measure the elevation difference between two points, set up the level approximately halfway between them. If you cannot see both points from your observation point (view obstructed by a tree, for example), move to one side. The level should still be set up at a point approximately equidistant from the two points that you want to measure. That way, if the level is slightly out of adjustment, so that the line of sight (past the horizontal crosshair) is not quite level, the error is virtually canceled because the sight distances are approximately equal.

On long sights, equidistant sights also cancel the effect of the Earth's curvature. Your merit badge counselor will

If you are using a digital level, once the level is pointed at the leveling rod, it will read the bar code on the level line and record the data automatically. Your merit badge counselor will show you how to keep good notes for leveling.

show you how to remove your level from its case, secure it to the tripod, level it, adjust the bubble-level or check the vertical compensator, and focus the telescope on the crosshairs and the object.

Have the person in charge of the leveling rod hold it vertically over the starting point, which has an assumed elevation of 100 feet. To hold the rod truly vertical, a device called a *rod level* might be necessary. A rod level is held against the rod or is attached permanently to it. If the person in charge of the rod will be hundreds of feet away, the two of you might not be able to communicate. Two-way radios or mobile telephones are helpful. If you do not have either one of these, your merit badge counselor will show you and your crew how to signal to each other. Remember that you can see your rod helper through the telescope much more clearly than that person can see you.

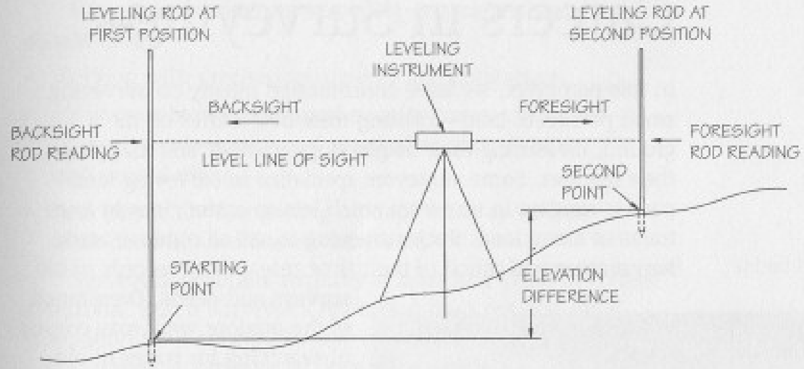
Rotate the level to face the leveling rod, which is positioned at the first point. This sight is called the *backsight*. Focus the telescope ocular on the crosshairs, and then adjust the object focus on the leveling rod. Read the leveling rod's scale where the telescope's horizontal crosshair appears on the scale. Record the reading or have your recorder do it.

The person in charge of the leveling rod should then move to the second point and hold the rod vertical. Rotate the level to face the leveling rod. This sight is called the *foresight*. Read the rod and record the reading. If you have the luxury of two leveling rods and two rod helpers, then you can save time by leapfrogging the rods and the level between two points; your counselor will show you how.

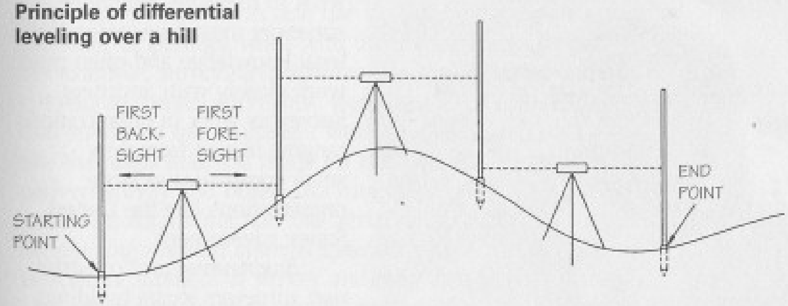
For requirement 5, an elevation of 100 feet is assumed for the backsighted point. The elevation of the leveling instrument is 100 feet plus the backsight rod reading. The elevation of the foresighted point is the elevation of the leveling instrument minus the foresight rod reading. Thus the second point's elevation is 100 feet (the assumed elevation of the first point), plus the backsight rod reading, minus the foresight rod reading. This method is called *differential leveling* because you use the difference between rod readings to determine the elevation difference between two points.

If the two points being measured are on a steep slope or are separated by a hill, you might need to measure one or more intermediate points in stair-step fashion on the slope or over the hill, as in the diagram shown here.

Principle of differential leveling



Principle of differential leveling over a hill



Move the leveling instrument to a point between the second and third points for which you are finding elevations. Measure the elevation difference between the second and third points, just as you measured the elevation difference between the first and second points. Continue in that way around the lot until you have made a complete circuit back to the starting point. Verify that you measured the starting point's elevation to be very close to 100 feet. If it is not 100 feet, there is an error, which you must find. If that happens, your merit badge counselor can show you how to locate the error without repeating all of your measurements.

Careers in Surveying

In this pamphlet, we have concentrated mostly on surveying small parcels of land—locating their boundaries on the ground, measuring their height (topography), and mapping their features. Some surveyors specialize in surveying land parcels ranging in size from small lots to entire cities to huge tracts of forest land. Such surveying is not all outdoor work; surveyors spend much of their time researching records of old surveys and deeds. Even much of the outdoor work may consist of searching for traces of old surveyor's monuments. To know what to measure, *boundary surveyors* must have extensive legal knowledge and often must work closely with attorneys. Surveyors work in organizations ranging in size from very small companies to large organizations like the United States government.

Engineering and construction surveyors locate buildings and other structures on the land and ensure that they are built in the right shape. *Geodetic surveyors* specialize in the detailed shape of Earth and in the precise measurement of widely separated points, so that the local surveys can be connected to each other. *Hydrographic surveyors* measure rivers, lakes, ship channels, and ocean bottoms. *Mine and tunnel surveyors* make sure that tunnel crews boring toward each other from opposite ends, possibly many miles apart and deep underground, actually meet in the middle. *Route surveyors* lay out highways, railroads, and pipelines over long distances, sometimes under difficult terrain and weather conditions.

If you are considering surveying as a career, you should enjoy:

- Working with precise instruments and computers.
- All of your high school mathematics courses and take as much mathematics and physical science as your high school offers.
- Both physically demanding outdoor work as well as work done in an office environment.

Surveying generally requires at least four years of college education. But, a surveyor's education does not end upon graduation from college. To stay current in new instruments and methods, a surveyor is always learning.

Other career fields related to surveying also might be considered. These areas also use surveying instruments and methods, or perhaps work with the measurement of land. For example, *surveying draftsmen* use sophisticated computer systems to convey surveyors' work into the detailed maps that surveyors use to present work to clients (somewhat like the maps that you made for this badge). *Cartographers* convert survey and other data into maps of all sizes and scales. *Photogrammetrists* use aerial photography for mapping. *Graphic information systems specialists* collect and process enormous amounts of survey and map data to coordinate landownership, taxation, roads, and utilities. Some *attorneys* work closely with surveyors on land and water rights. *Title insurance specialists* use surveyors' data and other information as a basis for insuring their clients' land. *Optical tooling* is a very precise and specialized form of surveying that engineers use to align large machinery like rolling mills, large structures like ships, and large scientific instruments. Other engineers design and build mechanical, optical, and electronic instruments for surveying and related fields, and develop computer hardware and software for automating data collection and processing, and for drawing maps.