A Manual on FOREST SURVEYING

7th Edition

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CHAPTER 1: HORIZONTAL MEASUREMENTS

1.1 INTRODUCTION

Surveying is all about measurements, and these skills are very important for those working in forestry and natural resources. While it involves a great deal of math, it is applied math, with clear formulas available to use for most procedures. This manual will focus on topics that are relevant to skills needed by professionals in the forestry and natural resources fields.

Definition of Surveying

The definition of surveying is: ***The Art of measuring distances and angles on or near the surface of the earth***. It really does focus on measuring two variables- distance and angles. There are many different ways to measure both variables with different instruments. Many of these will be mentioned in this manual.

There are two main areas of surveying:
PLANE Surveying - assumes the earth to be a flat plane (works when measuring distances less than 2-3 miles in length). The math involved is much simpler with this area of surveying and will be the focus on this manual.

GEODETIC Surveying - takes into consideration the curvature of the earth (for measuring long distances over 2-3 miles). This area of surveying focuses on mapping large areas of the earth's surface, like is done by the US Geologic Survey agency.

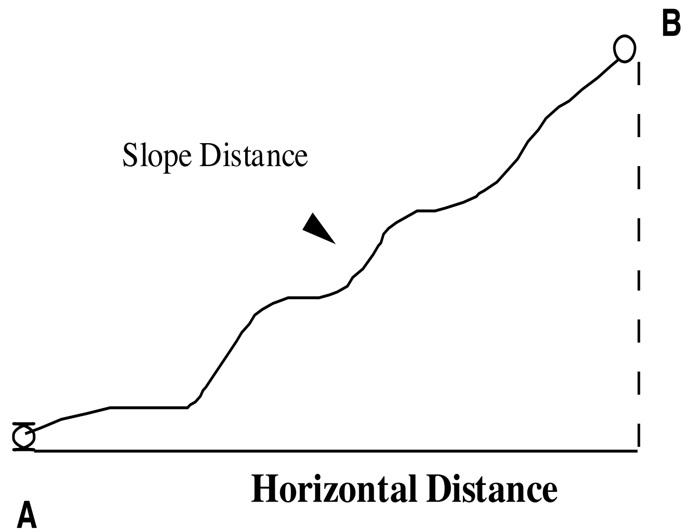
Focusing on measuring distances, there are several techniques and tools that can be used to measure distances on the ground, all of which will be covered in this manual. These include:

- Pacing (average ratio of error = 1/50-1/100 – see Section 1.5)
- Taping
    - Cloth (1/300)
    - Fiberglass (1/500)
    - Steel (1/1000-1/10,000)
- Stadia (1/300)
- EDM/Electronic/Laser Devices (1/100,000 and up)

This chapter will focus on the first two techniques, pacing and taping. Others will be covered in later chapters.

Before detailing the two techniques, it is important to understand the concept of measuring horizontal distances.

Horizontal Distance: Distance between two points on the same horizontal, straight plane, not taking into account any slope or ground angle.



<u>All</u> distances measured and recorded in the field should be <u>HORIZONTAL,</u> no matter which method or tool is used. There are several different techniques for converting slope distance to horizontal distance that will be covered.

It is also important to know the following <u>linear units of measurement</u> used in forest mensuration, and their conversion from one unit to another. Area units of measurement are covered in later chapters. These units and conversions should be entered into the field book (last page) for later reference.

Gunter's Chain = 66 feet
Gunter's Link = 0.66 feet = 7.92 in.
Engineer's Chain = 100 feet
Engineer's Link = 1 foot = 12 inches
1 Gunter's Chain = 100 links = 66 feet
80 Chains = 1 mile = 5280 feet = 63360 inches
1 foot = 12 inches
1 pole = 1 rod = 25 links = 16.5 feet

The conversion formulas for chains, links, and feet are as follows:

Chains X 100 = Links
Links ÷ 100 = Chains
Chains X 66 = Feet
Feet ÷ 66 = Chains
Links X 0.66 = Feet
Feet ÷ 0.66 = Links

Anytime the word chain is used in this manual, it refers to a Gunter's chain. Engineer's chains are more commonly used in surveying, but Gunter's chains are still common in forestry work.

1.2 ACCURACY AND PRECISION

It is important in surveying to understand the difference between accuracy and precision. Accuracy is the absolute nearness to truth; freedom from mistakes. No method of measuring distances is perfectly accurate. There is error involved in every measurement. Certain tasks done in surveying require different levels of accuracy, and the method used in a task should match the required level of accuracy. Many times, the higher the level of accuracy desired, the more time and money it takes to achieve it. It is more desirable to match the required level of accuracy with the method used. Also, it defeats the purpose if a low accuracy method is used to measure angles and a high accuracy method is used for distances. The level of accuracy should match for both types of measurements.

Precision on the other hand is the relative nearness to truth; closeness between several measurements; degree of fineness in reading. Again, the more precision that is needed will usually require an instrument and method that produces more accuracy, and takes more time and money to obtain. It should only be as precise as what is needed to produce required results.

A related issue to precision is Significant Figures. This refers to the number of decimals or precision level for measurements. This is usually determined by the type of instrument or method used for measurements. Examples of this include:

- Hand compass- 1 degree
- Transit- 15 minutes
- Theodolite- 1 second
- Pacing- 1 foot
- Stadia- 1 foot
- Steel taping- 0.01 foot

It is important to know how many significant figures are required for measurements on each task. If two significant figures are required, then each measurement should show two decimals, even if the second decimal is a zero. For example, 12.3**0** should not be recorded as 12.3.

1.3 ERRORS IN SURVEYING

There will be error in all measurements in surveying. It is a matter of how much is allowable on a consistent basis. While much of this is instrument-based, it is also found commonly by the people using the instruments. It is useful to be aware of the sources of error as well as the common categories. Each method has an allowable Ratio of Error and these will be covered below. Much error can be eliminated by awareness and by double checking all measurements.
Sources of Error

Instrumental - check equipment often
Personal - no clue, unaware, spaced out
Natural (weather, local attraction, etc.)

Categories of Error

Mistake - blunder - use checks
Discrepancy - measure twice
Systematic - builds & continues until conditions change. Usually easier to correct
Accidental - once, no pattern, hard to detect

With this information provided as a foundation for measurements, the remainder of this chapter will focus on measuring distances, and more specifically horizontal distances, using pacing or taping as the methods.

1.4 PACING DISTANCES

Pacing is a time-honored forestry practice where horizontal distances are measured by walking at a natural pace through the woods. It involves knowing the length of your stride, since everyone will be different. It is the least accurate method of obtaining horizontal distance, but it is often accurate enough for the forestry job being done. It is important to always match the accuracy desired for a job with the method used to obtain measurements.

Pacing accuracy can be affected by many factors - time of day, weather, fatigue, mental alertness, obstacles on the ground, and steepness of the ground. Therefore, pace size should be checked **often** in different situations to know how to adjust it for changing conditions. The most important changes are for slope of ground and brush. Pace size tends to be <u>smaller</u> going up or down a hill or through thick brush than on flat ground.

Things to remember when pacing to increase accuracy and consistency:

- Do NOT pace next to someone else. People will find themselves adjusting their paces to match the other person.
- Do NOT concentrate on the size of the pace. Focus on counting the paces and just walk a natural stride.
- Stretch out and loosen up legs prior to pacing for accuracy. Otherwise, people tend to take smaller steps than normal until muscles loosen up.

PROCEDURES IN LEARNING THE SIZE OF YOUR PACE

1) Realize that **one pace = 2 steps**. Starting with the left foot, then one pace would be counted every time the <u>right</u> <u>foot</u> hits the ground.

2) First on flat ground, count paces between 2 points at least **10 chains** apart, walking with a <u>natural</u> stride. Again, <u>DO NOT try to take measured steps</u>. Concentrate on counting paces, not taking steps. This known distance should be walked several times with an average number of paces calculated. If a line is more than 2-3 paces different from the other tries, throw it out.
   Example: You walk a 10-chain line 5 times with the following results -
   135, 134,134, 136, 141 paces.

   Throw the 141 out since it is more than 2-3 paces different from the others and average the other 4 together -

$$\frac{(135+134+134+136)}{4} = 134.75 \textit{ paces} \text{ in 10 chains}$$

3) Calculate <u>**feet/pace**</u> (the number of feet walked in one pace on flat ground). Use the following formula -

$$\boxed{\frac{\textbf{\# feet traveled}}{\textbf{Avg. \# paces walked}}}$$

For the 10 chain line just paced, the solution would be:

$$10 \text{ ch. X } 66 \text{ feet/chain} = \frac{660 \text{ feet}}{134.75 \text{ paces}} = \mathbf{4.898\ ft./pace}$$

* carry answers out *three decimal places*.

4) Calculate **<u>paces/chain</u>** (the number of paces walked in one chain or 66 feet). There are <u>two formulas</u> that can be used to calculate paces/chain. They are as follows:

(1) $$\frac{\textbf{Avg. \# paces walked}}{\textbf{\# chains traveled}}$$

For the 10-chain line just paced, the solution would be:

$$\frac{134.75 \text{ paces}}{10 \text{ ch.}} = 13.47 \text{ paces/chain} = \mathbf{13.5^{*}\ paces/chain}$$

The other formula that can be used is:

(2) $$\frac{\textbf{66 feet}}{\textbf{feet per pace}}$$

For the 10-chain line just paced, the solution would be:

$$\frac{66}{4.898} = 13.47 \text{ paces/chain} = \mathbf{13.5^{*}\ paces/chain}$$

* Round this answer off to the *nearest 1/2 (0.5) pace*. That is the normal accuracy in pacing.

5) Repeat steps 2-4 on hills of varying slope angles and brush amount to see how size of pace changes. Most people should know their **feet/pace** for flat ground, moderately steep ground (10-40% slope), and very steep ground (50-80% slope). Most paces will probably be smaller on a hill than on flat ground; therefore, the **paces/chain** will be a larger number. In fact, the feet/pace and paces/chain will probably be slightly different walking up the hill compared to walking down the hill.

When showing pacing distances on a map or in notes, **<u>ALWAYS</u>** convert paces to units like feet, chains, etc. <u>Never</u> record only paces in notes, since everyone's pace is different. Also, remember that paces must be adjusted for the slope angle or amount of brush of the ground, so that **ALL** distances calculated from paces are <u>HORIZONTAL</u>.

Once the PACE Size is known on flat as well as sloped terrain, the next step is to be able to calculate the Horizontal Distance (HD) between two points. The **formula** for <u>calculating HD by pacing</u> is as follows:

Horizontal Distance in Feet = Feet/Pace X Average # Paces

For the calculated distance to be Horizontal, the Feet per Pace must be for the appropriate slope. If the slope of the ground is moderate, the Moderate Slope Feet per Pace must be used.

As an example, a person paces between 2 known points (A & B). They have a pace size of **5.200 feet/pace** and they walk **89 paces** between points A & B.

Therefore, the Distance paced between A & B would be calculated to be:

Horizontal Distance = **5.200** feet per pace **X 89** paces = **462.80 = 463 feet***
*round pacing distances to the nearest foot.

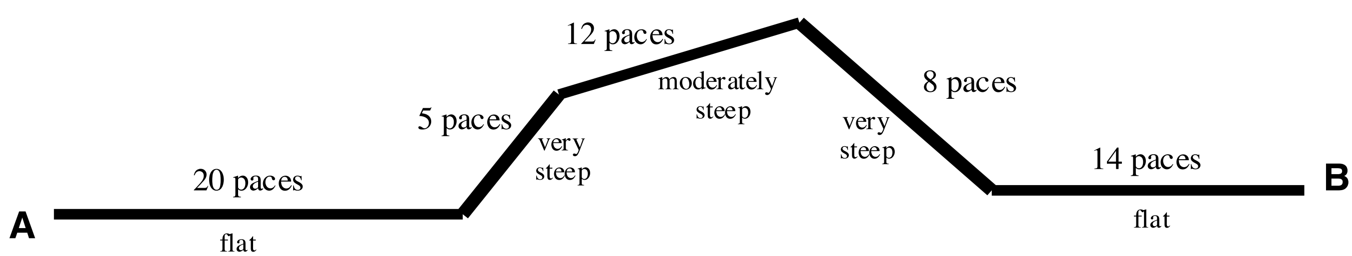
There are basically 2 ways you can use PACING to determine HD.

1) Determine an Unknown Distance between two points, as done in the example above.
2) Measure out a SET Known Distance from one point to locate the other point.

1) Pacing between two set points on the ground to determine the unknown horizontal distance between them.

In this situation the paces between two points are counted and multiplied by the person's feet/pace, as done in the above example. If the distance covers both flat and steep ground, however, the paces must be counted separately for each general slope, because the feet/pace is different between flat, moderately steep, and very steep ground.

For Example, assume the total Horizontal Distance between points A & B is needed, but the ground changes grade several times between the two points, as illustrated below:



To get the total HD between A & B, the HD of each segment must be calculated separately and then added together. This is illustrated below:

The person's feet/pace on different terrain is:

Flat Ground: **5.2 feet/pace** X (20+14) =	176.8 feet
Moderately Steep Ground: **4.9 feet/pace** X (12) =	58.8 feet
Very Steep Ground: **4.5 feet/pace** X (5+8) =	58.5 feet
	294.10' Total HD

2) Pacing a predetermined distance from a starting point and establishing the ending point.

If the ground is all the same slope for the entire distance, simply take the distance and convert it to paces. Example:
A person wants to walk 12 chains, all on flat ground. Assume the feet/pace = **4.900 feet on flat ground**. The easiest way to calculate paces is as follows:

Calculate your PACES/CHAIN, as done in step 4 on page 5.

$$\frac{66}{4.900} = 13.5\, paces\ /\ chain$$

Calculate the total paces needed by multiplying the number of chains by the paces per chain.

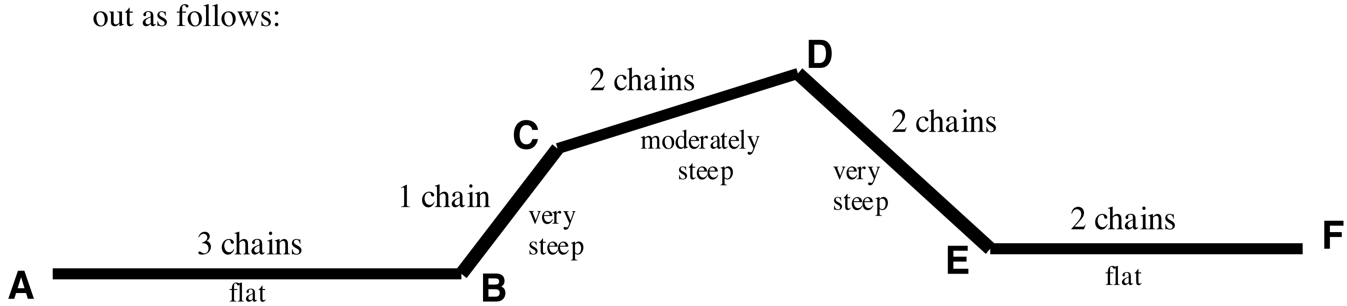
12 chains X 13.5 paces/chain = **162 paces**

This number of paces is figured on the flat ground pace only. If the ground being covered is varied in slope, simply counting that number of paces will not be very accurate.

The easiest way to get around this is to count the distance off in **Chains,** adjusting each chain to the steepness of the slope. To do this, the person must know their paces/chain at different slopes, just as done above. For the following Example, assume the following:

Flat Ground: 13.5 paces/chain
Moderately Steep Ground: 15 paces/chain
Very Steep Ground: 17 paces/chain

The person walks a 10-chain line starting at point A on ground that changes grade and is laid out as follows:



For the first 3 chains, the person would count **13.5 paces** off for every chain (A to B). As it gets steep, they would then count **17 paces** for every chain (B to C). Then, the next 2 chains would be measured by counting **15 paces** for each chain (C to D). The next 2 chains would be measured by counting **17 paces** for each chain (D to E). The final 2 chains are on flat ground, so the person would count **13.5 paces** for each chain (E to F). This way, the person has adjusted each segment to horizontal distance as they went, so when arriving at F, they have measured 10 chains horizontal distance.

Finally, in the discussion on PACING, it is important to know the **RATIO OF ERROR** in measuring distances to ensure that the allowable error has not been exceeded.

For pacing, the average acceptable Ratio of Error is **1/50 - 1/100.**
This means there is 1 foot of error for every 50 (or 100) feet paced. One foot error in every chain would be a Ratio of Error of 1/66, which would be acceptable. The larger the denominator in the Ratio of Error, the better the job.

1.5 CALCULATING RATIO OF ERROR FOR DISTANCES

Once the paced distance has been calculated, the True or Actual distance needs to be known in order to calculate the Ratio of Error. A steel tape or an Electronic Distance Measuring device (EDM) is normally used to determine the actual distance of a line to compare with the paced distance.

For this example, the same paced distance as on page 7 will be used where a person walked 89 paces using a feet per pace of 5.200 feet. The paced distance was calculated to be **462.80 feet**. The actual distance is then measured with a steel tape and found to be **465.32 feet**.

The formula for Ratio of Error is in the form of a proportion:

$$\boxed{\dfrac{\textbf{Error}}{\textbf{Actual HD}} = \dfrac{\textbf{1}}{\textbf{X}}}$$

To calculate the amount of Error, the difference between the paced distance and the actual distance is calculated. For the above example, the Error would be:

  465.32 feet
- 462.80 feet
  2.52 feet error

This 2.52 feet of error was accumulated over a distance of 465.32 feet, so the Ratio of Error is shown as follows:

$$\frac{\text{2.52 feet error}}{\text{465.32 feet (actual distance)}}$$

But the Ratio of Error should be in a form that can be directly compare with other paced lines. To do this, a proportion (two equal ratios) is set up to change the above ratio so one (1) is the numerator. This is shown below:

$\dfrac{2.52}{465.32} = \dfrac{1}{X}$ Use Algebra to solve for the unknown (X) by cross multiplying.

$$2.52\ (X) = 465.32\ (1)$$

$$X = \frac{465.32}{2.52} = \mathbf{184.65}$$

The correct format for this **Ratio of Error** is $\dfrac{\mathbf{1}}{\mathbf{184.65}}$

A GOOD JOB !

In conclusion, PACING is used a great deal in Forestry as a way to measure linear distances on the ground, so it is important to learn how to do it right, and then practice often to stay good at it. The important thing in pacing is consistency. Employers like this.

There are several practice problems at the end of Chapter 1, with the answers in Appendix A.

1.6 TAPING DISTANCES

When horizontal distances must be measured accurately in the field, pacing should not be used. Instead, measuring tapes are used. There are many different types of tapes used in forestry (steel, cloth, nylon, fiberglass, etc.), but most are either Engineer's tapes (multiples of 100 feet) or Gunter's chains (multiples of 66 feet).

Steel tapes are the most accurate tapes that can be used. Even then, they tend to stretch a bit in hot weather and shrink in cold weather. Most steel tapes are designed to be an accurate length somewhere around 68 degrees F. They also require more care, needing to be oiled regularly, especially in wet weather, so they do not rust. While they are durable when pulled, if they have a kink in them, they can snap like a dry noodle if pulled on. It is important to always make sure there are no kinks in the tape before pulling tight.

When taping with any kind of tape, there are two positions: Head Chainperson (HC) and Rear Chainperson (RC). The Head Chainperson always has the 0 end of the tape and always goes first when taping from one point to another. The Rear Chainperson always has the end of the tape. For a 100' tape, that would be the 100' mark. The Rear Chainperson always brings up the rear when taping from point to point.

Steel tapes that do not have the feet broken down by 10ths of a foot every foot can have a trailer at the end of the tape. There can be a trailer at both ends or only at the 0 end. A trailer is a one foot segment that shows the 10ths of a foot for more precise measurements.

Taping Procedures:
- HC unwinds tape and goes ahead
- RC lines up HC
- Pull tape tight, close to ground, but not on it
- RC holds end mark over point, HC pulls tape tight, RC yells "MARK" when end mark is over point & no sag in tape
- HC sets new point at zero mark
- Repeat process to check accuracy

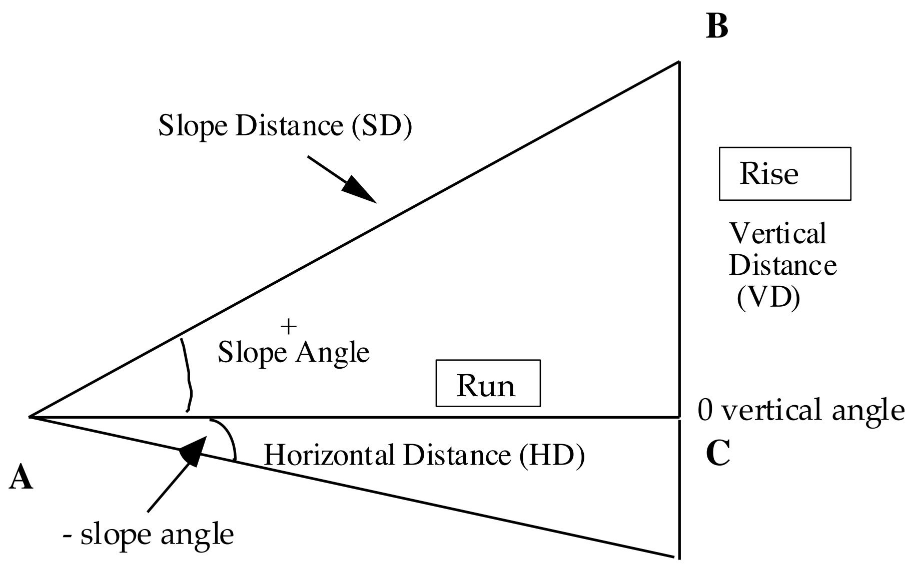
Important considerations then taping:
- keep tape in straight line (1.41' off center - 0.01' error)
- keep tape level (1.41' high on one end - 0.01' error)
- keep sag out of tape (8" sag in middle - 0.01' error)
- don't pull tape too tight (10-15 lbs. more pressure than needed - 0.01' error)
- temperature must be considered (15 degrees above or below 68 degrees - 0.01' error)

– Sag creates curved shape known as Catenary
– Try to pull hard enough to minimize sag
– 20lbs of tension average for 100’ tape
– Overpulling tape reduces error by balancing sag error with tension error (30 lbs)
– Normal Tension - point where lengthening of tape by over-pulling equals shortening by sag

1.7 CONVERTING SLOPE TO HORIZONTAL DISTANCES

SLOPE ANGLES

Before covering the procedures of using a 100/200’ Engineer’s tape, it is important to cover slope measurements and the use of a Clinometer to measure the slope of the ground to adjust the slope distance to horizontal distance, because as in pacing, all distances should be expressed as Horizontal. This is illustrated with the Slope Triangle:



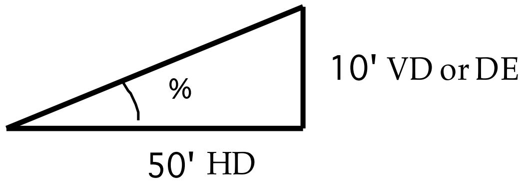
The **Slope Angle** is termed a **Vertical Angle** and can be measured in 3 different scales. They can be measured with more powerful and accurate equipment, like a transit or theodolite, or with hand instruments like a clinometer. With Vertical Angles, a horizontal line is 0^o. A line above the horizontal (up hill) will have a positive (+) vertical angle and a line below the horizontal (down hill) will have a negative (-) vertical angle. The 3 scales used to measure Vertical Angles are:

1) **Percent Slope**: This represents the amount of vertical rise for a set amount of horizontal distance. It is calculated with the formula:

$$\frac{\text{Rise}}{\text{Run}} \times 100 = \frac{\text{VD}}{\text{HD}}$$

where Rise is the amount of Vertical Distance (VD) between 2 points, which is also known as the Difference in Elevation. Run is amount of Horizontal Distance (HD) between the same

two points. It is important that both the rise and run are measured in the Same Units of Measurement (Feet, Chains, etc.).
Example:



10 feet Rise = 0.20 X 100 = **20% Slope**
50 feet Run

Another way to look at Percent Slope is that it is the Rise per 100 feet of Run. A 20% slope means that the Vertical Rise in Elevation is 20 feet for every 100 feet of Horizontal distance. Percent slope can be read directly with a Clinometer or Abney Level. Percent Slope is used to lay out road and trail grades, as well as side slopes of roads.

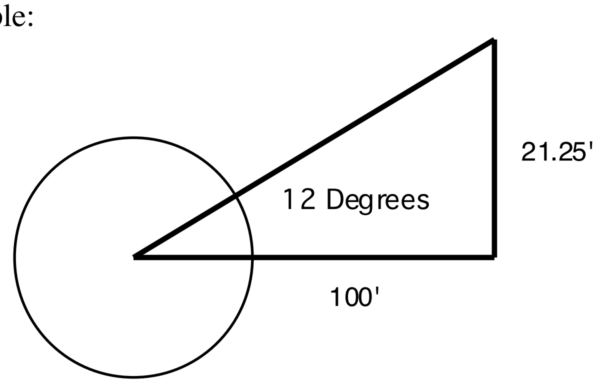
2) **Degrees**: This represents the angle created by dividing a circle into 360 equal parts, each one equaling one degree. Degrees are also read directly with the Clinometer or Abney Level. This unit is necessary to use trigonometry formulas to solve for unknown angles or sides in a triangle.

The formula to convert from degrees to percent involves using the trigonometry Tangent Formula:

Tangent (Degree Slope) = Percent Slope as a Decimal.

$$= \frac{\mathbf{VD}}{\mathbf{HD}} = \frac{\text{opposite side}}{\text{adjacent side}}$$

The tangent of the degree slope can be looked up in a trigonometry table or found using a calculator with trigonometry functions, and it is equal to the percent slope as a decimal.
Example:



Tangent (12) = 0.2125
= 21.25 %

Degrees are used extensively as the main scale for vertical angles in most surveying applications.

3) **Topographic**: This Unit is similar to Percent, but instead of being equal to the Vertical rise

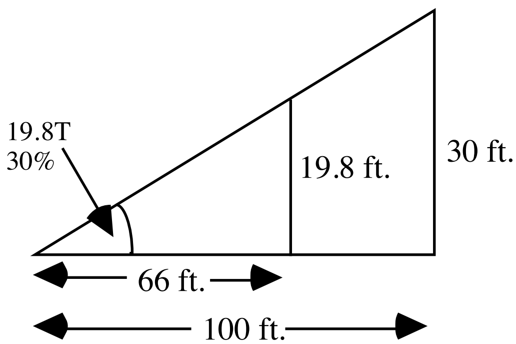
per 100 feet of Horizontal Distance, Topo Angle is equal to the **Vertical Rise (in feet) per 66 feet of Horizontal Distance**. It is designed to use with Gunter's Chains, which is used extensively in Forest Measurements. This unit is used for measuring vertical angles when using the two-chain topographic tape and when measuring tree heights (see Section 4.4). Converting from Percent Slope to Topo Slope is as easy as setting up a proportion and solving for the unknown:

$$\frac{\textbf{Percent}}{\textbf{100}} = \frac{\textbf{Topo}}{\textbf{66}}$$

As an Example:

$30\% = \frac{30}{100} = \frac{X}{66}$, $\quad 100\,(X) = 30\,(66)$, $\quad X = \frac{1980}{100} = \mathbf{19.8\ Topo}$

This means that the same slope that measures a **30% vertical angle is equal to a 19.8 Topo Slope**. In other words, the ground rises (or falls) between the two points 30 feet vertically for every 100 feet horizontally, or 19.8 feet vertically for every 66 feet horizontally. It is simply two different ways to say the same thing. This can be illustrated by viewing two overlapping triangles that have the same vertical angle:

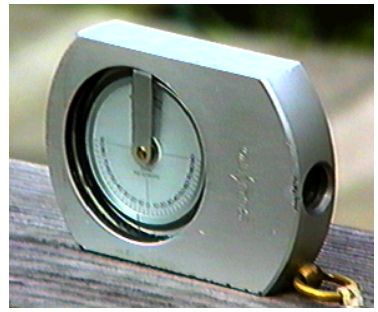


Topo slope is used mostly in Forest Measurements because of the common use of Gunter's chains instead of engineer's chains. Therefore, it makes more sense to measure angles with a scale based on the same unit of measurement.

As a review then, the steps to use with a calculator to convert from one vertical unit of measurement to another are as follows:

If given measurement in percent form:	**%÷100 inv. tan. = decimal degrees**
	%÷100 X 66 = topo
If given measurement in degree form:	**decimal degrees tan. = % slope as decimal**
	% slope as decimal X 66 = topo
If given measurement in topo form:	**topo÷66 = % slope as decimal**
	% slope as decimal inv. tan. = decimal degrees

USE OF THE CLINOMETER



This instrument involves reading the correct scale while sighting at eye level on someone at the other end of the tape. This measures the slope angle or vertical angle between the two points. With the clinometer, a person looks into the viewfinder to read the scales. There are two sets of scales in every clinometer. Clinometers can be purchased with any 2 of the 3 types of scales detailed above. For the third scale, there is a conversion table on the back of the clinometer that converts from one of the included scales to the one that isn't included.

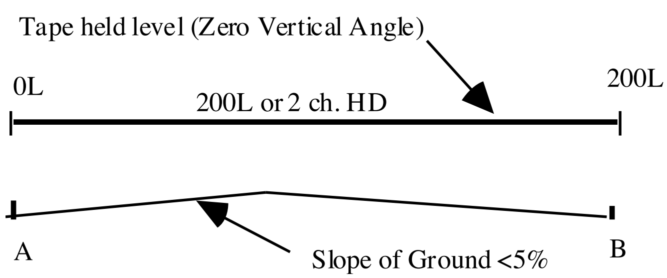
It takes a little getting used to when looking into the **Clinometer**. Either look at the scales with one eye, and the tree or person or whatever with your other eye or look inside at the scales and outside at the object with the same eye, while keeping the other eye closed. By doing so, the cross hair appears to extend outside the instrument by optical illusion, allowing the slope angle to be measured to eye level on the other person. This seems to be the most common technique.

When using a clinometer to read Slope Angles while taping, it should be aimed up or down the hill at the taping partner. In order to ensure a slope angle that is the same as the actual slope of the ground, <u>take the slope reading</u> <u>at eye level on the other person</u>. To locate this point, stand on flat ground close together and hold the instrument up to the eye. <u>Hold the clinometer on a zero Vertical Angle</u> and <u>see where the line intersects the other person</u>. This point on the other person is the eye level point.

SLOPE TO HORIZONTAL DISTANCE CONVERSION

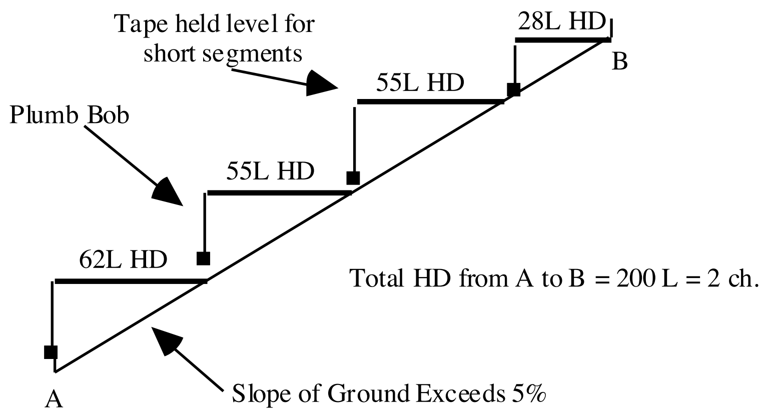
There are **<u>three basic taping methods that can be used to measure HD on the ground</u>**. The three methods are illustrated below:

1) **<u>Hold the tape level</u>** (zero vertical angle) for its entire length. This works if the slope is less than approximately 5%. This involves measuring HD directly one tape length at a time. This is known as a <u>Direct Method</u>. This is illustrated below:



2) **<u>Break Chain</u>**. A procedure where the slope exceeds 5%, but the tape is held level in short segments (as much as the slope will allow), in essence measuring HD directly,

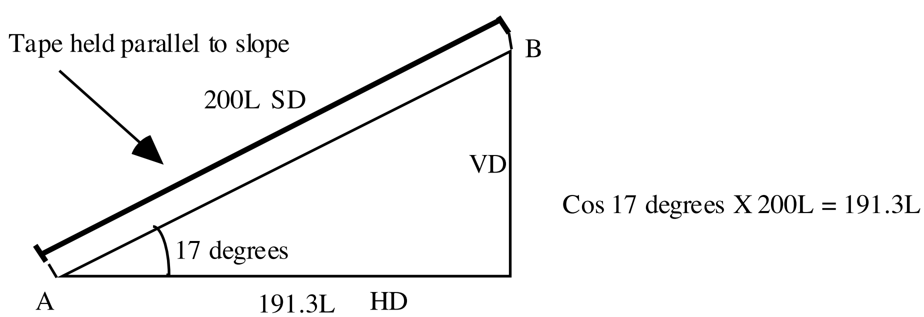
but in short segments. The segment lengths are then summed to get the total HD. This is also known as a **Direct Method**. It tends to be a slow process with many opportunities to make mistakes and it is more time consuming. This is illustrated below:



3) **Hold the tape along the slope**, measuring Slope Distance, and calculate the HD using trigonometry. This is termed an Indirect method of measuring HD. This method is quicker and more accurate than breaking chain. The formula for converting SD to HD using trig is as follows:

HD = Cosine (vertical angle in degrees) X SD

The Vertical Angle (Slope Angle) must be in degrees before using the Cosine function. This is illustrated below:



If you pull 2 ch. along slope, it will be less than 2 ch. HD

If the Vertical Angle is read in percent, the percent angle must be converted to degrees before using the Cosine formula shown above. The complete formula for doing this in your calculator is as follows:

HD = (% as decimal) (Inverse Tangent) Cosine X SD

This is the only way to get HD by holding the tape along the slope (measuring SD) unless you have an electronic instrument. With a calculator that has the trig functions, it is a quick and easy way to measure HD indirectly, and is very accurate.

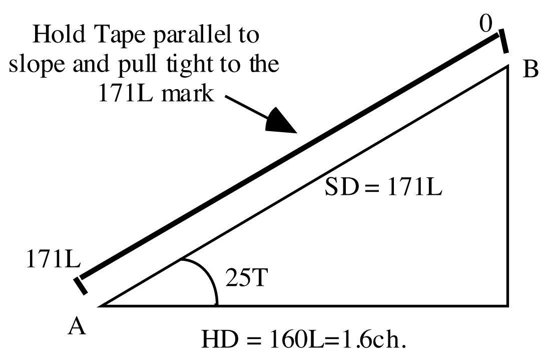
Another situation that can occur in the field where the indirect method can be used is if a Specific or Set Horizontal Distance on the ground needs to be measured, and the ground is too steep to hold the tape level. **The SD needed for a specific slope angle to give a specific HD must be measured**. It is the same formula as above, only turned around to solve for the SD given a specific HD. The formula is as follows:

$$\mathbf{SD} = \frac{\mathbf{HD}}{\mathbf{Cos.\ (degree\ slope)}}$$

As an *example*, a line 1.6 chains long (HD) needs to be measured on a steep slope. This can be done by breaking chain (technique #2 above), which is slow and tedious, or the SD needed to give 1.6 chains HD can be measured directly along the slope, as long as the vertical angle is measured. Then the problem becomes what SD is needed on this slope to measure 1.6 chains (160 L) HD? If the vertical angle is read in topo or percent form, it must be converted to decimal degrees before solving the above trig formula. If we read a +25 topo angle on this slope, the SD needed to measure off 160L of HD would be:

$$\mathbf{SD} = \frac{\mathbf{160}}{\mathbf{cos(25/66\ inv.\ tan.)}} = \mathbf{171.09\ L}$$

This is illustrated below:



To measure off 1.6 ch. (160L) HD on a 25T slope, you would need to measure off 171L along the slope (SD).

1.8 PRACTICE PROBLEMS IN HORIZONTAL MEASUREMENTS

Following are some problems involving computations in pacing and taping. Answers and Solutions can be found in Appendix A.

1) A person counted an average of 95.5 paces walking from Point A to B on level ground. The person's average number of paces for a 5-chain line is 54.5. Determine the following:
   a) Feet/Pace
   b) Pacing Distance from A to B in feet and chains
   c) If the actual distance between A and B is determined to be 581 feet, what is the Ratio of Error for this person's pacing?
   d) Does this pacing have an acceptable Ratio of Error?

2) Convert a 24.93% slope angle to Topo Slope Angle. Then convert a 21 Topo Slope Angle to Percent Slope.

3) A person walked 220 paces between Points A and B. The person has 5.26 feet/pace. The actual distance between Points A and B is 1175 feet. What is the Paces/Chain for this person? What is the Pacing distance between Points A and B? What is the Pacing Ratio of Error? Is it acceptable?

4) A person walks an 8-chain line 5 times and gets the following number of paces each time: 96, 94, 95, 96, 97. What is the average feet/pace and paces/chain?

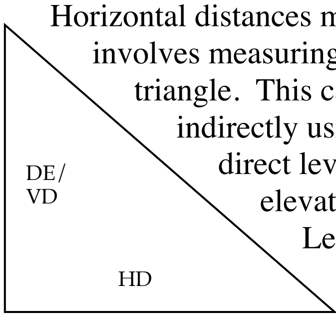
5) A person's pace changes on slopes as follows:
   Level Ground - 4.8 feet/pace, Moderately Steep Ground - 4.4 feet/pace
   Very Steep Ground - 3.9 feet/pace
   The person walks between Points A and B and counts paces for each slope category:
   Level Ground - 45 paces, Moderately Steep Ground - 61 paces
   Very Steep Ground - 32 paces

   What is the total horizontal distance between Points A and B?

CHAPTER 2: LEVELING

2.1 INTRODUCTION TO LEVELING

Leveling involves measuring the vertical distance or elevation change between two points. Horizontal distances measure the distance or length of the HD side of the triangle. Leveling involves measuring the vertical distance (VD) or difference in Elevation (DE) side of the triangle. This can be done directly using different instruments or can be done indirectly using a vertical angle and the slope distance measurement. Two types of direct leveling will be covered here- Differential Leveling which measures the elevation (vertical distance) difference between two points, and Profile Leveling, which measures the elevation of a series of points which allows the development of an elevation profile. Both of these methods along with indirect leveling will be covered in this manual.



A third type of direct leveling is Barometric. Here, the difference in elevation is measured using a barometer, which measures air pressure. Air pressure decreases as elevation increases. Barometers are designed to convert air pressure to elevation. You simply read the elevation at one point, then the other, and subtract the two numbers to get the difference in elevation. GPS units also measure elevation and can be used for barometric leveling.

LEVELING TERMS

Datum - level surface used for reference (usually sea level)
Benchmark (BM) - point of known elevation. Sometimes these are assumed elevations, but usually when the term BM is used, it is brass cap installed by the USGS that has an actual elevation stamped on the top.
Vertical Control - tying into a point of known elevation.
Zenith - Vertical Angle where 0 degrees is straight up, 90 degrees is ahead of you, etc.

LEVELING INSTRUMENTS

Hand Levels
- Hand level
- Clinometer
- Abney Level

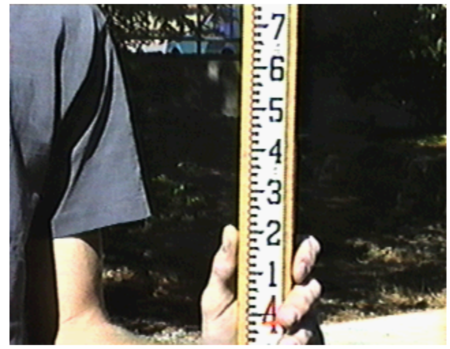
The clinometer is the most common hand instrument used in forestry for reading vertical angles and leveling.

Tripod Levels
- Dumpy
- Wye
- Auto Level
- Level Transit

A common tripod instrument for leveling is an auto level. It only reads 0-degree vertical angles and is used to read the level rod to get differences in elevation between points.

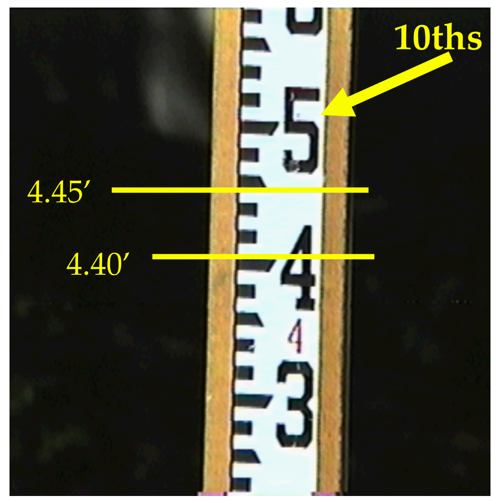
Level Rods

- Philadelphia rod (wooden)
- Fiberglass telescoping rod



USING A LEVEL ROD

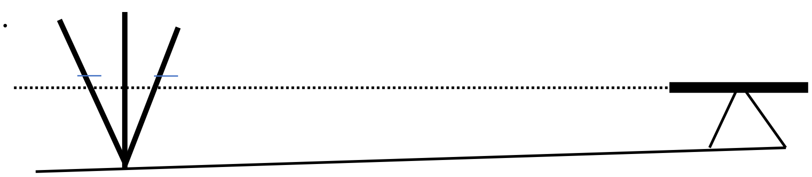
A level rod is nothing more than a vertical stick that has distances marked on it, like a ruler. The most common level rods in the US have distances in feet down to hundredths of a foot. It is important to learn how to read the rod correctly when looking at it through the scope of an auto level type instrument, from a distance.



In reading the level rod, the large red numbers are the feet. The smaller red numbers found along the rod between the larger black numbers are also the feet. They are there because when the instrument person looks at the rod through a high-powered auto level scope, it is hard to know which foot mark to read.

The black numbers are the tenths of a foot. The black rectangles between the black tenths are then used to read the hundredths of a foot. The bottom edge of each rectangle is an odd hundredth and the top edge is an even hundredth.

To make sure you have the level rod as level as possible when the reading is taken, a hand level can be used by holding it next to the rod when the reading is taken, making sure the hand level shows the rod is as vertical as possible. If there is no hand level available, there is a process called rocking the rod that can be used. To ensure a plumb rod reading, ROCK the ROD forward and backward at each set-up. The most plumb reading by the instrument person will be the LOWEST Reading while rocking the rod.



CHECKING ACCURACY OF THE LEVEL INSTRUMENT

There are different methods of checking the accuracy of a level instrument. This manual will cover one of the easier methods that can be done quickly in the field. The accuracy of the level instrument, especially an auto level instrument, should be checked regularly if the instrument has not been used for a while, after using it continuously for a period of time, or certainly if the

instrument is jostled or dropped in the field. This process is called the **Two-Peg Method**.
Set Level halfway between two points approx. 200' apart and take rod reading at both points. Get difference between the two readings (correct diff.). This will be a1 and b1.
Set level right next to rod at one of the points and take the two rod readings again (a2 and b2). Compare the second rod reading to the far rod with the formula below (b2). The difference is the error in the horizontal cross hair, which can then be adjusted to correct the error.

If Horizontal Cross hair of Level is in adjustment, **b2 = (b1 - a1)+a2**. The difference between this calculation and the actual b2 read in the field is the Error. It can be adjusted with a screwdriver to adjust the horizontal cross hair up or down until the rod reading matches the b2 calculated with the formula. Following is an example:

a1= 3.22'
b1= 3.87'
a2= 5.79'
b2= (3.87-3.22)+5.79 = 6.44

If the rod reading for b2 is 6.46', that then indicates 0.02' of error in the auto level (6.46-6.44). The instrument person would then adjust the auto level horizontal cross hair until the b2 rod reading (second rod reading to the far rod) equals 6.44. Then the instrument is in adjustment.

2.2 DIRECT LEVELING- DIFFERENTIAL

This is the method used to determine the difference in elevation between two points. This is often used to carry an elevation from a benchmark (point of known elevation) to the start of a project point or line. In order to do differential leveling, a starting elevation for the ground must be used, either the actual elevation or an assumed elevation. If the difference in elevation is the main thing needed, an assumed beginning elevation works fine.

For differential leveling, there are two main field positions- the instrument person (usually also the note keeper) and the rod person. The rod person starts out setting the rod on the ground at the benchmark or beginning point. It is important that the rod person make sure the rod is held as level as possible (either use a rod level or do the rocking the rod process).

The instrument person then sets up the auto level as far ahead as possible so there is a clear shot from the instrument to the rod and then ahead in the direction of the end point. It does not matter where the instrument is set up as long as the line of sight is clear, and the level is solid in the ground. It is important that the instrument not move between the shot back to the beginning point and ahead to the next point. With an auto level, these distances can be hundreds of feet apart with the magnification on the scope. A reading down to the hundredth of a foot needs to be taken. If using a hand level, the distances between the instrument and the rod will be less than 50'.

The rod reading back to the beginning point is called the Backsight (BS). It is also called a + sight since the backsight rod reading is always added to the beginning elevation to calculate the Height of Instrument (HI). Once this reading is taken, the rod person moves ahead of the instrument person about the same amount of distance, which might be the ending point, but could be an intermediate point between the beginning and end points. The instrument person then turns the auto level around without moving the instrument and shoots the rod. This is called the Foresight (FS). This is also called the – sight since it is always subtracted from the HI to get the elevation of the ground where the rod is located now. This process can be repeated as much as possible with the instrument person and rod person leapfrogging around each other until the end point is reached.

DIFFERENTIAL LEVELING NOTEKEEPING

It is very important to take consistent notes in the field to produce accurate and precise results. There are different formats that can be used for leveling. A very common one will be illustrated in this manual. Following is an example set of notes where the leveling team is leveling between BM1 and BM2. BM1 is given an assumed elevation of 1000’. There are two turning points (TP) where the rod is set up on a random point between the two benchmarks. The readings taken in the field will be the BS and FS. The HI and subsequent elevations are then calculated and put in the notebook. To begin, the first BS is added to the BM1 assumed elevation to get the first HI. Then the first FS is subtracted from the HI to get the TP1 elevation. This process is then repeated. The instrument moves ahead, so a new HI needs to be calculated. That requires a BS to be added to the TP 1 elevation to get the new HI. Then the rod moves ahead and that produces a new FS to subtract from the second HI to get the TP2 elevation. Then the instrument moves ahead approximately halfway between TP2 and the end point (BM2) and takes a third BS reading to TP2. That is added to the TP2 elevation to obtain the last HI. The rod then moves ahead to BM2 where the last FS is taken and subtracted from this last HI. That then gives the elevation of BM2 which is the end point in this exercise. There is no need to mark the locations of the TPs in the field, but they will be shown in their approximate location on the sketch in the field notes.

The next step is critical to the leveling process. This is the math check. It is very easy to make mistakes in the math doing this process. The math check will catch these mistakes. It will not catch any errors reading the rod or if the instrument is out of adjustment. This is where checking the auto level before starting with the two-peg method and taking each rod reading twice in the field before moving on will eliminate those instrumental or personal errors.

To do the math check, total the BS and total the FS. There should always be the same number of BS and FS. Then subtract the total BS from the total FS. The difference should then match the difference between the beginning elevation and the ending elevation. If not, there is an error in the math in calculating the HI and elevations. Always make the calculations in the field and do not wait until getting back to the office. That way, if there are errors and the level loop needs to be repeated, it does not require another trip out to the location.

Station	BS(+)	HI	FS (-)	Elevation	Distance (ft)
BM1				1,000.00	
	3.15	1,003.15	2.61		250.00
TP 1				1,000.54	
	7.55	1,008.09	4.21		150.00
TP 2				1,003.88	
	6.03	1,009.91	3.36		300.00
BM2				1,006.55	
	16.73		10.18		
	16.73 - 10.18 =	6.55		MATH	
				CHECK	
	1006.55 - 1000.00 = 6.55				
	difference between BS & FS totals should equal				
	difference between beginning and ending elevation				

One of the only ways to check the accuracy of leveling in the field is to do a level loop. Using the example above, the leveling would go back to BM1 from BM2. This is termed “closing the loop”. Obviously, if the beginning elevation at BM1 was 1000’, then the leveling loop should produce a BM 1 elevation of 1000’ when it comes back from BM2. Any difference between the beginning and ending elevation of BM1 is the error in the loop. If the assumption is that the error was accumulated equally throughout the loop (systematic error), then the process to remove the error is straightforward using a proportional method which is illustrated in the example below.

Besides calculating the amount of error in a level loop, the allowable error must be calculated as well. If the amount of error in the loop exceeds the allowable error, the level loop must be redone. If the amount of error is less than the allowable error, then the error can be proportionately removed as shown below.

Example:
Allowable Error for Low Precision Leveling
$C = (+/-0.40\sqrt{M})$; C = Allowable Error; M = Miles of distance in level loop.
If M= 800/5280= 0.15 miles, then C = 0.155’. So the maximum allowable error in this level loop is just over 15 hundredths of a foot. The actual error needs to be less than this or the loop has to be redone. In the example below, the actual error is 0.21’, so it exceeds the allowable amount for a low precision level loop. It needs to be redone in the field. For this example, the error will be removed proportionately to show the process and math involved.

To do this, distances between the instrument and each BM and turning point needs to be at least estimated. This can be done easily by pacing the distances while leveling.

Adjusting Allowable Error out of Level Loop:

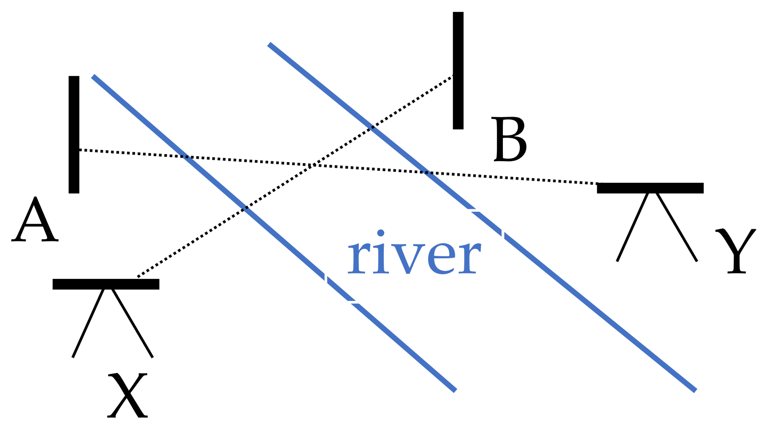
Station	Elevation	Distance	Adjustment	Adjusted Elevation
BMA	1000.00			
		250		
TP1	1005.63		$\frac{250}{800}$ (0.21) = 0.07'	1005.63 - 0.07 = **1005.56'**
		300		
TP2	1008.92		$\frac{550}{800}$ (0.21) = 0.14'	1008.92 - 0.14 = **1008.78'**
		250		
BMA	1000.21		$\frac{800}{800}$ (0.21) = 0.21'	1000.21 - 0.21 = **1000.00'**
	Error = 0.21'	**Total = 800'**		

RECIPROCAL LEVELING

When leveling, it is important to make an effort to keep the distances between each BS-FS at an instrument set-up as close to equal as possible. Sometimes this is not possible due to some obstacle along the path of the level loop. In these cases, reciprocal leveling should be employed.

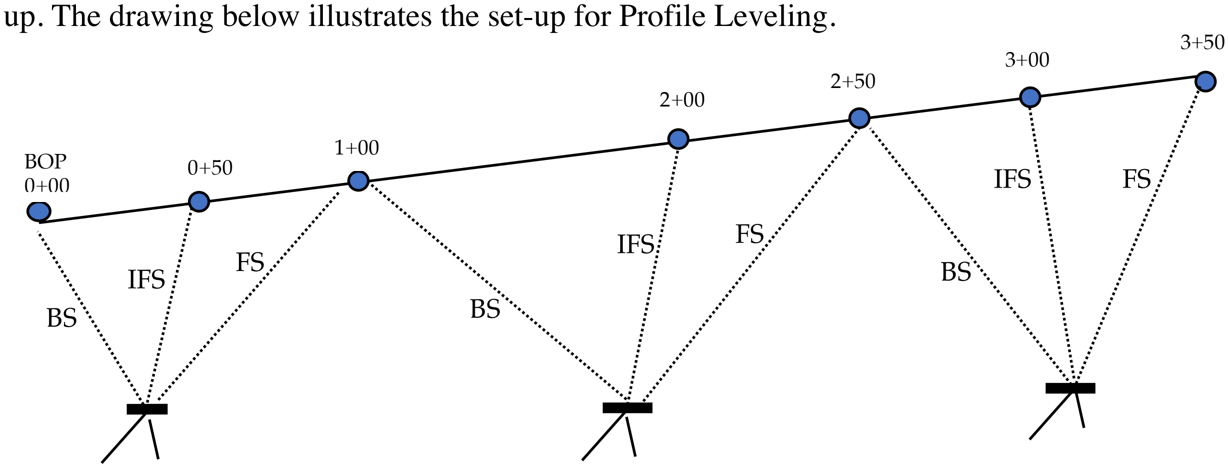
If an obstacle of some kind requires an unequal BS & FS distance, do the following:

- to determine the difference in elevation between points A & B requires two instrument set-ups (X & Y).
- Rod readings on A & B are taken at both X & Y.
- The two differences in elevation are averaged.



2.3 PROFILE LEVELING

Profile Leveling is determining the elevation of points spread out in a line at set intervals, and is another direct leveling technique. It is used to draw up a side view profile showing the lay of the land. Profile leveling differs from differential leveling in that it is possible and actually probable that the instrument person can view multiple points in a level line from the same position. There is still only one BS (shooting the rod back to the beginning point with a known or assumed elevation) and one FS (last shot ahead prior to moving the instrument). But there can then be multiple points in between the BS and FS that need a rod reading. These are all termed Intermediate FS or IFS. The number of IFS's depends on how far you can see from each HI set-up. The drawing below illustrates the set-up for Profile Leveling.



The notes for Profile Leveling are slightly different from differential leveling. Now there is an IFS column. Again, the BS is still added to the previous elevation to get the HI, and the last FS ahead is then subtracted from the HI to get the elevation for the last station before the instrument is moved ahead and the process is repeated. It is important that each IFS is subtracted from the same HI where the reading was taken to get the elevations of the intermediate points on the ground.

The math check is still done as before, adding up the BS and the FS (not the IFSs), getting the difference between the two totals, and comparing that difference to the difference in elevation from the beginning point to the last point on that page. They should match or there was a mistake made on the math. The IFSs are not used at all for the math check.

Below is an example set of Profile Leveling notes (not intended to match the drawing above):

Station	BS(+)	HI	IFS(-)	FS(-)	Elevation
0+00					1000.00
	3.12	1003.12	2.05		
0+50					1001.07
				1.73	
1+00					1001.39
	4.69	1006.08	3.39		
1+50					1002.69
			2.55		
2+00					1003.53
				1.11	
2+50					1004.97
	5.54	1010.51		4.18	
3+00					1006.33
	13.35			7.02	-1000
					6.33
	13.35-7.02=	6.33			
		math check			

PROFILE PLOTTING

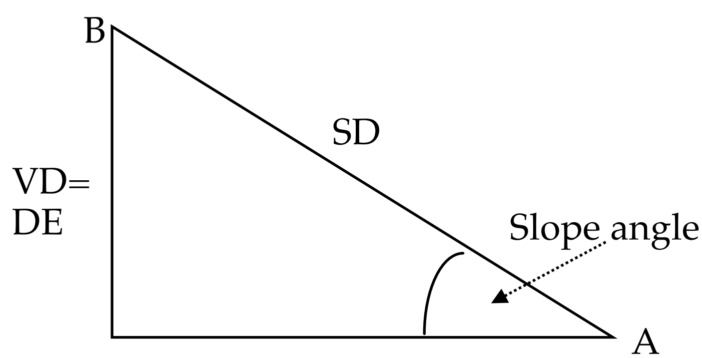
Profile leveling is usually done to calculate the grade of the ground between points, usually at a set interval. This is usually presented as a percent grade using the same formula from Section 1.7 above, Rise/Run = VD/HD= Percent slope as a decimal. These calculations can then be used in designing a road and determining the amount of cut and fill needed to produce a desired grade, or the depth to dig at each point to create a set grade for a drainage ditch or pipe, so water will flow easily downhill.

2.4 INDIRECT LEVELING

Indirect Leveling uses the same process as indirect measurement of HD from SD. The slope distance is measured on the ground with a tape, and a vertical angle is read with a clinometer. Instead of then calculating the HD side of the triangle, the VD or DE side is calculated. This requires a different trigonometric formula. The formula is: **VD = Sin (degree slope) X SD.**

Example problem:
Using the Sine function on the calculator:
If the SD= 49.55' and the Slope Angle is 28%;

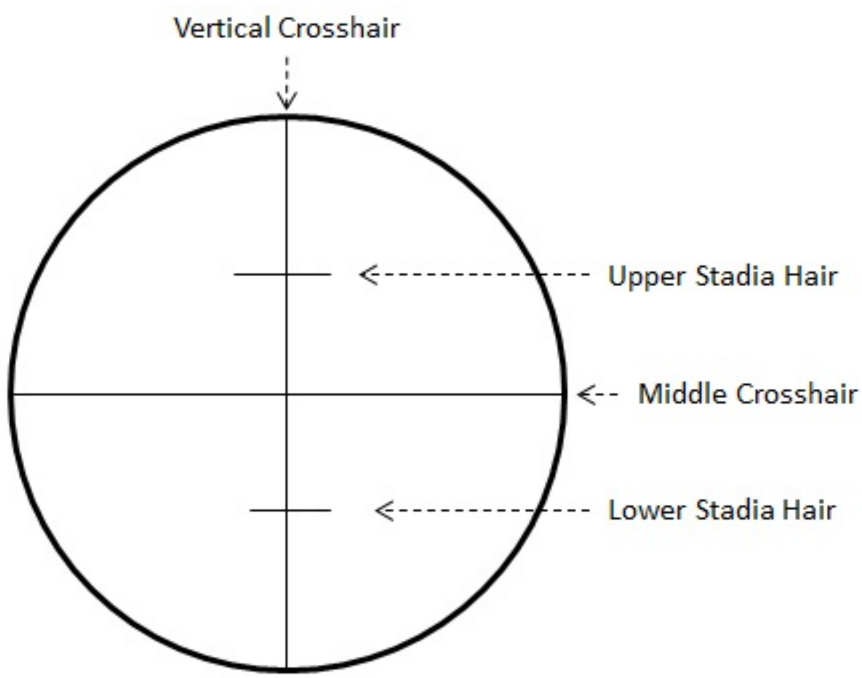
0.28 inv tan = 15.64 degrees
Sin (15.64 degrees) = 0.2696
0.2696 X 49.55' = 13.36' VD/DE
If A= 125' Elevation, then
B= 125 + 13.36 = 138.36 elevation



2.5 STADIA

A level rod can also be used with an auto level, transit, or theodolite to measure distances. The average ratio of error for Stadia distances is about 1/300. This is more accurate than pacing but less accurate than taping, but is a quick and easy way to get approximate distances while using tripod instruments with scopes and a level rod.

Almost all scope instruments have Stadia hairs built into the cross hairs in the scope. They usually appear as a short cross hair above and below the center cross hair. This is illustrated below:



The Stadia hairs are almost always calibrated at a ratio of 100. This means that the difference between rod readings taken on the upper and lower stadia hairs multiplied by 100 will provide a slope distance in the same scale as the level rod. If using an auto level, since readings are always taken at a 0 degree vertical angle, the distances can be considered to be horizontal.

As an example,
Upper stadia hair rod reading = 6.88’
Lower stadia hair rod reading = 4.49’
Distance = 6.88 – 4.49 = 2.39 X 100 = 239’

2.6 PRACTICE PROBLEMS IN LEVELING

1. BM1= 500.00’
   BS= 5.21’ HI= ? FS=3.19’
   BS=7.36’ HI= ? FS= 4.28’
   BM2= ?

2. Calculate the allowable error for the following level loop:
   $C = (+/- 0.40\sqrt{M})$
   BM1= 600.00’ BM1 to TP1= 350’
   TP1= 603.44’ TP1 to TP2= 420’
   TP2= 609.11’ TP2 tp BM1= 380’
   BM1= 600.17’
   Is the level loop an acceptable accuracy?
   Corrected elevations for TP1 and TP2?

3. Profile Leveling: complete the notes and calculate the elevation of each point.
   0+00 = 45.63’
   BS=3.58’ IFS=2.99’
   0+60= ?
   FS- 2.83’
   1+10= ?
   BS= 4.22’ IFS= 3.98’
   1+60= ?
   IFS= 2.78’
   2+10= ?
   FS= 3.16’
   2+85= ?
   What is the % grade between station 2+10 and 2+85?

4. SD between points A and B is measured at 98.34’. Slope Angle = +22%.
   Calculate the VD.
   If the elevation of Point A = 32.44’, what is the elevation of Point B?

CHAPTER 3: ANGULAR MEASUREMENTS

3.1 MEASURING DIRECTION

As mentioned in Section 1.1, a critical skill to have in Forestry is the ability to accurately find your way in the woods utilizing a compass, map, and aerial photographs. Techniques for measuring **Distances** in the field (pacing and taping) have been covered. The other measurement needed to accurately locate yourself and complete field maps is **Angles.** An angle is defined as the space (usually measured in degrees) between two intersecting lines or surfaces at or close to the point where they meet. Here, angles will be read using directions with either a hand compass or staff compass. The use of these instruments will be discussed in detail in this chapter.

It is important to learn the different scales used to measure direction on a compass and how to work with those scales. To accomplish this, the following topics will be covered:

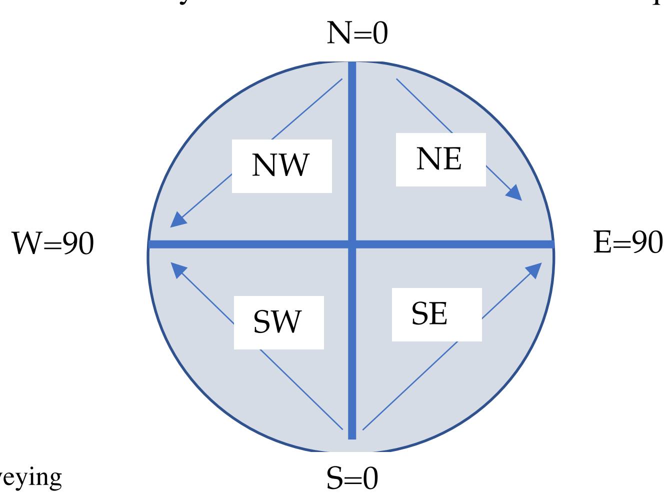
- Bearings
- Azimuths
- Converting from one scale to the other
- Magnetic Declination
- Local Attraction

To measure Direction, Horizontal Angles are used. Vertical Angles (Slope Angles) were covered in the previous chapter, which were used to convert Slope Distance to Horizontal Distance. Horizontal Angles will be used to measure Direction.

Instead of having three different units of measurement with vertical angles, horizontal angles in this country are measured in **DEGREES.** Compasses show Direction in two different scales - Bearings and Azimuths. Most hand compasses have either one or the other of the scales. Staff compasses often have both scales on the dial. Both will be covered here. First, BEARINGS will be discussed.

BEARINGS

A circle is broken down into <u>360 degrees</u>. The only difference between Bearings and Azimuths is the way that 360 degree circle is divided. With bearings, it is divided into <u>Four 90 degree quadrants</u>, each identified by the Directions on both ends of the quadrant.



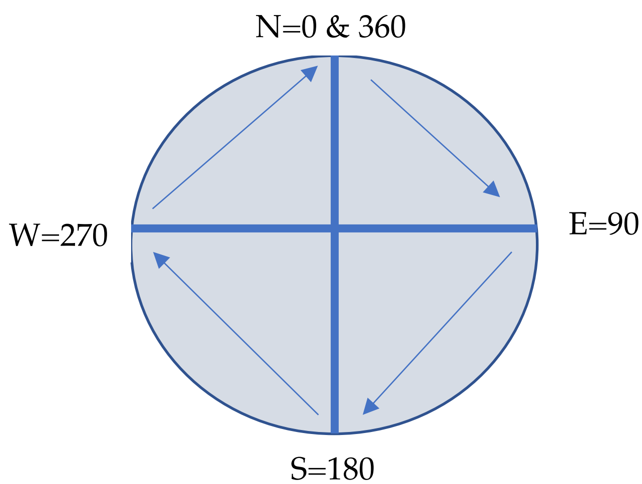
ALL BEARINGS have the following characteristics:

- They are read FROM North or South TOWARD East or West.
- They cannot exceed 90 Degrees, **EVER**!
- The Bearing ANGLE is ALWAYS Measured from the North or South Meridian, never from the East or West Meridian.
- They are written with the N or S direction first, then the angle from the N or S Meridian (in degrees), then the E or W direction (i.e.. N 48^{o} W).
- The North and South Meridians are equal to 0 degrees, and the East and West Meridians are equal to 90 degrees.

This means there are 4 quadrants, each going from 0-90 degrees. This is why it is necessary to include the N-S and E-W directions with the Bearing. Therefore, directions can be read in either a clockwise and counterclockwise direction from North or South.

AZIMUTHS

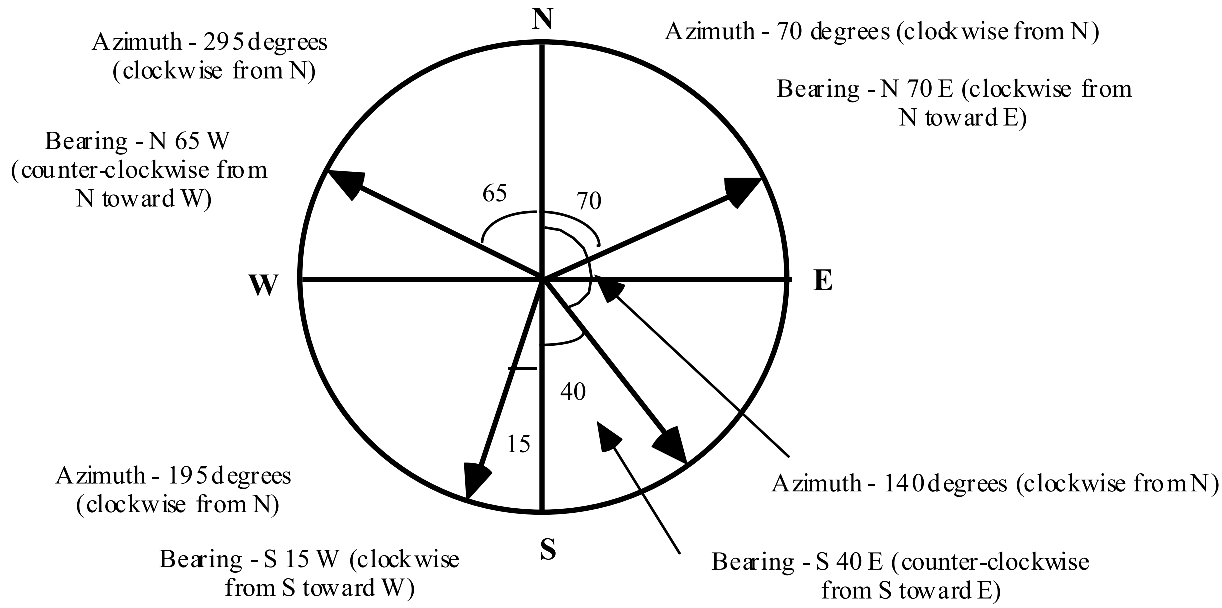
Unlike bearings, azimuths do not divide the 360-degree circle into quadrants. Azimuth directions are read from 0-360 degrees in only one direction - clockwise and from only one Meridian - North. The following diagram illustrates the Azimuth Circle:



There can never be two different azimuths with the same numeric angle, as with bearings. Therefore, no Quadrant or Meridian letters need to be shown with Azimuths as with bearings (i.e. 275^{o}).

CONVERTING BETWEEN BEARINGS AND AZIMUTHS

Regardless of the type of compass scale used, it is important to be able to easily and quickly convert from one to the other. It is just a matter of learning a few rules of thumb and understanding the relationship between the quadrants and the angles. In the following diagram, imagine the person with your compass standing in the middle of the circle (where cross meets) looking to the outside, reading the bearing or azimuth. The following diagram shows an example illustrating the relationship between bearings and azimuths:



The formulas for converting from bearings to azimuths change according to the quadrant the direction falls within. The formulas are as follows:

<u>Conversion from AZIMUTHS to BEARINGS in NE Quadrant</u>
Bearing = Azimuth

<u>Conversion from BEARINGS to AZIMUTHS in NE Quadrant</u>
Azimuth = Bearing

<u>Conversion from AZIMUTHS to BEARINGS in SE Quadrant</u>
Bearing = 180^{o} - Azimuth

<u>Conversion from BEARINGS to AZIMUTHS in SE Quadrant</u>
Azimuth = 180^{o} - Bearing

<u>Conversion from AZIMUTHS to BEARINGS in SW Quadrant</u>
Bearing = Azimuth - 180^{o}

<u>Conversion from BEARINGS to AZIMUTHS in SW Quadrant</u>
Azimuth = 180^{o} + Bearing

<u>Conversion from AZIMUTHS to BEARINGS in NW Quadrant</u>
Bearing = 360^{o} - Azimuth

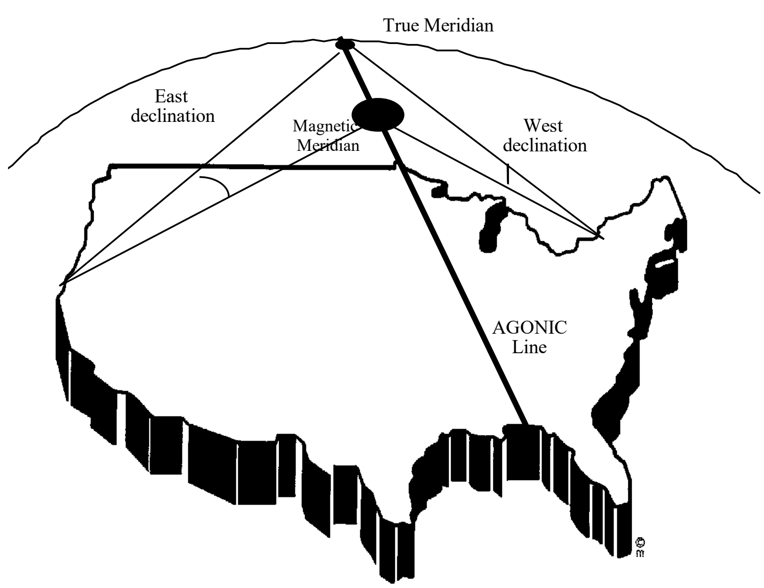
<u>Conversion from BEARINGS to AZIMUTHS in NW Quadrant</u>
Azimuth = 360^{o} - Bearing

MAGNETIC DECLINATION

If a compass always read the correct direction of a line, regardless of where the person is on the earth's surface, it would be fairly simple. Unfortunately, that is not the case. There is something called Magnetic Declination to contend with. Basically, it is defined as **the angle formed between the TRUE MERIDIAN and the MAGNETIC MERIDIAN**. In other words, the magnetic needle on the compass does not point to the True Geographic North Pole (True Meridian) in the Northern Hemisphere. Instead, it points toward the spot where the magnetic forces come to the surface. Currently, that is approximately 1000 miles South of the True North Pole, in the Hudson Bay area (Magnetic Meridian). The other issue is that this magnetic meridian is not stable. It continually moves small amounts in different directions. So it is not very accurate to reference magnetic directions that cannot be re-established unless you know the declination at that place at that time. Also, the angle formed from the true to the magnetic (declination) will change as position on the surface changes (especially longitude position).

The declination in NY is termed West Declination and in Oregon and California East Declination. That is because the compass needle is pulled to the WEST of True North in NY, but in Oregon and California, it is pulled to the EAST of True North. Most hand compasses can have the proper declination angle set on it so that the compass will automatically compensate for the declination and show a True reading, not a magnetic one.

Since the declination is east declination on the West Coast and west declination on the East Coast, somewhere in between it switches from east to west declination. At that location the declination is ZERO. It is a line that can be drawn through the True Meridian and Magnetic Meridian and continued down through the US where the compass needle would be pulled to the Magnetic Meridian, but because the True Meridian is right in line with it, there is No declination. This is called the **AGONIC LINE**. Currently, it runs through Tennessee, Alabama, and part of Florida. Declination is not an issue there - THIS YEAR! Following is a diagram which illustrates the concepts of Magnetic Declination:



It is important to be able to convert magnetic bearings or azimuths to true bearings or azimuths because there are compasses that can't compensate for declination, so all readings are magnetic directions. A conversion is necessary if true directions are needed before the traverse can be run. Listed below are the Rules of Thumb formulas that can be used to convert back and forth with either bearings or azimuths. Only conversion with **EAST** Declination is covered since that is what is experienced in the western US. For West Declination, the rules are reversed.

CONVERTING TRUE BEARINGS TO MAGNETIC BEARINGS

NE Quadrant - East Declination: **SUBTRACT** declination
SE Quadrant - East Declination: **ADD** declination
SW Quadrant - East Declination: **SUBTRACT** declination
NW Quadrant - East Declination: **ADD** declination

CONVERTING MAGNETIC BEARINGS TO TRUE BEARINGS

NE Quadrant - East Declination: **ADD** declination
SE Quadrant - East Declination: **SUBTRACT** declination
SW Quadrant - East Declination: **ADD** declination
NW Quadrant - East Declination: **SUBTRACT** declination

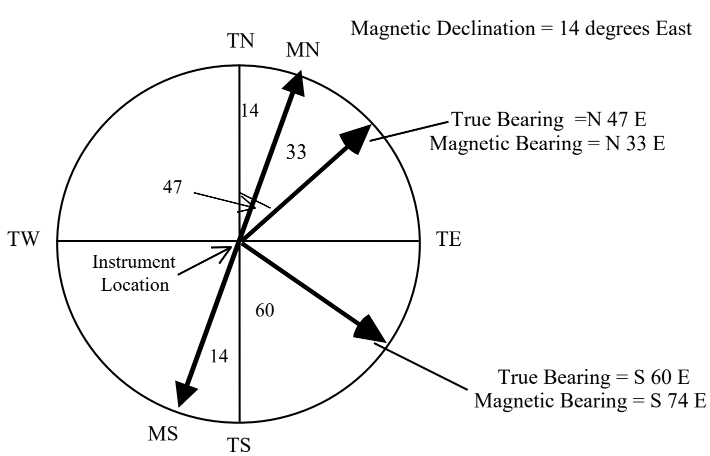
CONVERTING TRUE AZIMUTHS TO MAGNETIC AZIMUTHS

SUBTRACT declination in ALL Quadrants

CONVERTING MAGNETIC AZIMUTHS TO TRUE AZIMUTHS

ADD declination in ALL Quadrants

In converting directions for declination, it is more efficient to learn the reasoning behind the conversion instead of just memorizing the Rules of Thumb, which can be easily confused. Understanding is best achieved by drawing the direction circle and visually calculating whether to add or subtract the declination. This is illustrated in the following diagram:



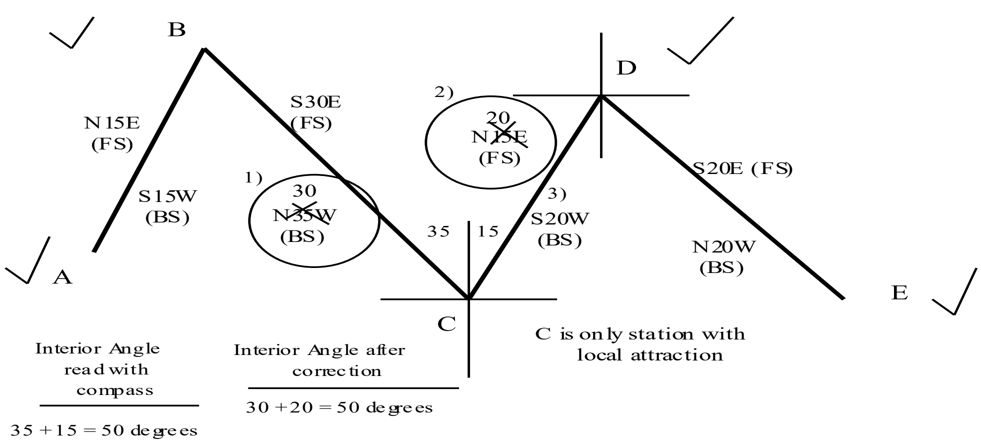
As the above diagram shows, **a true bearing angle is always measured from the True Meridian**, and a **magnetic bearing angle is always measured from the Magnetic Meridian**. If a circle is drawn with the true and magnetic meridians in the correct position, it is simply a matter of measuring the angle from the appropriate meridian to the LINE in question. With EAST Declination, the Magnetic North Meridian (MN) is always placed to the East of the True North Meridian (TN). Then the magnetic meridian is extended straight through into the SW Quadrant. So the Magnetic South Meridian (MS) is to the West of the True South Meridian (TS). This will hold true as long as there is East declination in the area. With azimuths, it is even easier, because there is no South Meridian, since all azimuths are read from the North Meridian clockwise. With Azimuths, the Rule of Thumb is almost easier to use.

LOCAL ATTRACTION

As mentioned previously in this section, local attraction will pull the magnetic needle away from the magnetic North Meridian and give erroneous readings (bearings or azimuths). The amount of error depends upon the proximity of the source of attraction to the compass and the strength of the source. Usually, the amount of error will build from point to point as the compass gets closer to it, and then decline as it moves away from it. If the error remains fairly constant at every station, it is a good bet the source of attraction is on <u>the</u> <u>instrument</u> <u>person</u>! Take rings or jewelry off, remove pens, etc. from pockets until the source of the problem is located.

If the source is not on the instrument person, but is somewhere near the points, and there is nothing that can be done about it, the correct directions can be calculated mathematically after returning to the office. The key to correcting a traverse for local attraction is to keep the <u>Angle</u> at each point the same. In order to do this, there must be at least one line in the traverse that is correct (i.e. where the FS and BS both match within the acceptable range). That line can be anywhere in the traverse, but it is easier if it is on one end of the traverse. Again, remember that <u>local attraction cannot be found unless a BS is taken at every point</u>.

Following is an example of how to correct a short open traverse for local attraction:



1) Change incorrect BS at C to match correct FS taken at B = Change 35 to 30 degrees

2) Change incorrect FS at C by same amount as BS at C was changed in step 1 to keep interior angle the same = Change 15 to 20 degrees

3) Corrected FS at C matches BS taken at D, which means D is Free of Local Attraction

By noticing that the FS and BS of the first line (AB) match, it indicates there is **NO local attraction at either Point A or B**. Since the FS and BS of the second line (BC) do NOT match and it is known that Point B is okay, then it is determined that **C must be the Point that is affected by Local Attraction**. Therefore, the BS taken from Point C back to B is wrong, and the FS taken from Point C to D is wrong. They are the ones circled above. Since the BS read at C is N35^{o}W and the FS to Point D is N15^{o}E, the angle formed at Point C by the two lines is 35+15 = 50^{o}. It is assumed that <u>the compass needle is pulled off the same amount at Point C no matter which direction the compass is facing</u>, so the angle of 50^{o} is correct. The two lines coming into Point C must then be shifted one way or the other to compensate for the local attraction.

To know how much shifting to do, look at the difference between the good FS from Point B to C and the bad BS from Point C back to B. It is 5^{o}. <u>The Local Attraction at</u> <u>Point C is therefore 5^{o}</u>. But which way should the lines be shifted by 5^{o}? If it is assumed the FS from B to C is correct, then adjust the BS from C to B to match the FS. Therefore, the correct BS should be N30^{o}W, not 35^{o}. That means the line from C to B is moved 5^{o} closer in towards the North line. In order to maintain the 50^{o} angle at Point C, the CD line must be moved 5^{o} further away from the North line, which increases the bearing by 5^{o}, from N15^{o}E to N20^{o}E. So the corrected FS from C to D is N20^{o}E. Since the corrected FS now matches the BS taken at D, the BS from D to C is correct and D has no local attraction. All the local attraction has therefore been eliminated out of the traverse. If more than one point has local attraction, continue correcting the BS, then the FS of each succeeding line until the next BS finally matches the corrected FS.

As a summary, therefore, the following rules of thumb should be used to correct local attraction out of a traverse once all the FS and BS have been taken:

1. Local Attraction cannot be detected without taking BS readings at each station or turning point.
2. There MUST be two consecutive stations or one set of FS and BS readings that MATCH within acceptable amounts in the traverse before local attraction can be corrected out.
3. The first INCORRECT BS reading must be <u>changed to MATCH the corresponding correct FS</u> in the same set of readings.
4. The next FS reading taken at the same station where the local attraction was found must be <u>changed by the same amount</u> as the previous BS was changed (step 3).
5. The FS must be changed so that the <u>corrected interior angle</u> formed at the local attraction station <u>matches the interior angle calculated from the original readings</u> (refer to diagram on previous page).
6. Change the next BS to match the corrected FS and continue the process around the traverse until the next BS matches the last corrected FS within the acceptable amount of discrepancy.

3.2 PRACTICE PROBLEMS IN MEASURING DIRECTION

1) Convert the following bearings to azimuths:

N 24^{o} W
N 72^{o} E
S 62^{o} W
S 17^{o} E

2) Convert the following azimuths to bearings:

100^{o}
280^{o}
23^{o}
182^{o}

3) If you run a line in the field using a compass that does not have a way to compensate for magnetic declination, and the direction read is N 47^{o} W, what is the true bearing of the line if the magnetic declination of the area is 17^{o} W? What is the true azimuth?

4) Using a compass with the declination compensated for, you read a true azimuth of 246^{o}. The next day, you come out to rerun the line, but have a compass with no declination scale on it. What magnetic azimuth do you set on your compass to retrace this line? If you mistakenly brought out a bearing compass, what magnetic bearing do you set on your compass to retrace the line? (assume a magnetic declination of 10^{o} W).

5) The magnetic bearing of a line AB in 1920 was S 89^{o} E and the declination was 5^{o} W. In 1985 the declination was 9^{o} W. Calculate the following:

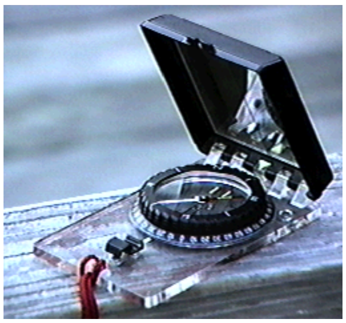
a) Magnetic Bearing of Line AB in 1985 = _________________

b) True Bearing of Line AB in 1985 = _____________________

3.3 HAND AND STAFF COMPASS

This section will cover the parts of the hand and staff compasses and how to use both types to get bearings or azimuth directions of lines or to set in a specific direction to follow on the ground. The process for setting the declination on the compass will also be covered.

HAND COMPASS



One of the most accurate and durable types of hand compass is the Silva Ranger Mirror Hand Compass. The sighting mirror allows the compass to be held at eye level so both the correct direction and the point can be lined up at the same time.

The Silva Ranger, like most hand compasses, come with either a bearing scale or an azimuth scale. Some come with both scales on the dial. The bearing scale is called a Quadrant compass, and the azimuth scale is termed a 360^{o} compass.

The **main parts of the hand compass** include :

1. Base Plate (made of clear plastic), which has a metric ruler scale on one side and an English ruler scale on the other side. There is an Index Pointer at the mirror end of the base plate, which is used to mark the direction set on the dial.

2. Safety Cord with Declination Screw Driver attached.

3. Compass Dial which turns to set any direction on the scale. The Declination Adjusting Screw is on the edge of the dial in the NE Quadrant. The Declination scale is on the bottom of the dial. By placing the screw driver in the adjusting screw, the declination can be set into the compass. Notice that one side of the declination scale reads E. Decl. (East Declination) and the other is W. Decl. (West Declination). When the adjusting screw is turned, the wide double arrow on the bottom of the dial moves. The center mark at the BOTTOM of the broad double arrow should match the declination mark on the declination scale. Each mark represents 2^{o} of declination. The magnetic needle should always be lined up in the middle of this double arrow to read the correct direction. Be sure the **red end of the needle (N end) is at the top of the arrow**. The outside of the dial is where the bearing or azimuth scale is located. Each mark on the dial is equal to 2 degrees. Therefore, the reading accuracy is to the nearest 1 degree when the needle falls halfway between two marks on the scale.

4. Magnetic Needle - the Red end of the needle always points toward Magnetic North. To get the correct direction off the dial at the index pointer, always line up the North end of the needle in the top of the broad double orienting arrow on the bottom of the compass dial.

5. Sighting Mirror and Cover with a sighting line etched down the middle of the mirror. The most accurate direction readings are obtained by reading the direction off the dial from the sighting line, instead of the index pointer on the base plate. This way you can keep your

sighting point in view and see the reading on the dial at the same time. The plastic clip at the top of the sighting mirror is also your sight, used to pinpoint the spot ahead that you want the direction of or that you are heading toward.

There are basically two different ways to use the compass. The first involves heading toward a given point on the ground and wanting to know the bearing or azimuth of that line. The other involves heading in a specific direction and wanting the compass to indicate which way to walk. The steps involved in using the compass both of these ways are detailed below.

Determining the Direction of a Given Line on the Ground

Standing on the given line, hold the compass at eye level and adjust the sighting mirror so a point on the given line can be viewed through the plastic sight, and the compass dial in the mirror can be seen at the same time. **Be sure to hold compass base plate level.**

Turn the compass dial until the red end of the needle (North end) can be seen and centered in the top of the broad arrow on the bottom of the dial. Adjust the mirror so the tip of the needle can be seen in the mirror and is even with the center of the broad arrow.

Now recheck to make sure you are sighting right on line in the direction you want to head. If your line of sight is correct and the needle is centered in the arrow, then follow the black sighting line in the mirror down to where it intersects the direction scale on the compass dial. Read the correct bearing or azimuth from the sighting line. Remember, the scale is measured in 2-degree increments, so the direction can be determined down to the nearest 1 degree (odd degrees in between the marks and even degrees on a mark).

Repeat this process at least twice to check the reading and make sure the same reading is obtained at least twice. This is the direction that should be recorded.

Determining the Correct Route to Travel to Follow a Given Direction

1. You want to travel at a specific direction from a given starting point. Standing on the given point, turn the dial around until the given direction is lined up on the index pointer at the top of the dial. If using a bearing compass, be sure to have the dial turned to the correct quadrant.

2. Holding the compass at eye level, with the sighting mirror adjusted so you can see the dial in the mirror, make sure the black sighting line is on the given direction.

3. Holding the compass in place, so you can see the dial in the mirror and through the sight, turn your body completely around until the red end of the needle lines up in the very center of the broad arrow. Check to be sure the black sighting line is still on the correct direction and the needle is lined up, then look through the sight and pick out an object ahead that you can walk toward. As soon as you get to that object, you need to repeat the process and pick out another object ahead to walk towards. In this way, you stay on line.

Learn to be consistent with the compass. By using it properly, an average ratio of error of **1/50 to 1/200** can be obtained. Refer to the owner's manual of the compass for more detailed information.

STAFF COMPASS

For the most part, staff compasses are more accurate than hand compasses. Their scales read to the nearest 1-degree, instead of 2 degrees on the hand compass. They have a level bubble on the base plate that is used to ensure a level reading. They also have a string sight that folds down on both sides of the dial which allows for accurate sights ahead.

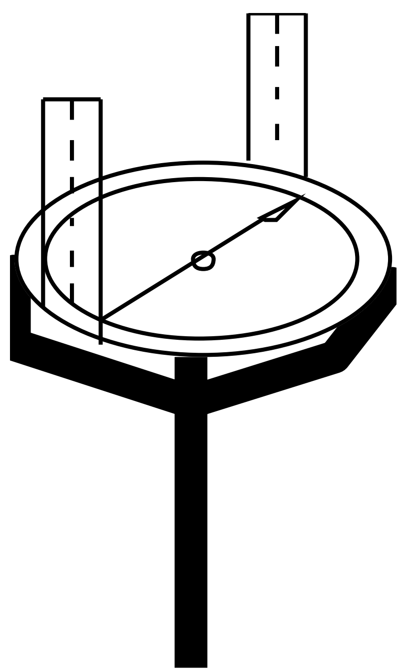
They are termed 'staff' compasses because the compass fits onto a wooden Jacob staff which is pushed into the ground, giving the opportunity to get the compass right on top of the point. Other features of the staff compass include:

- a Needle Lock Screw which allows the needle to be locked down so it does not pop off the jewel it sits on when transporting it from spot to spot. With the hand compass, the needle usually sits in a liquid-filled vacuum. With the staff compass, the needle sits on a pointed jewel so it has free movement when not locked down. If the needle does come off the jewel, the top of the dial can be unscrewed and the needle put back on the jewel. The North end of the needle usually has an arrow etched in it, but not always. The South end of the needle, however, does always have a counterweight wire wrapped around it to balance the needle on the jewel.
- Some staff compasses have declination screws for adjusting magnetic declination and some do not. If it does not have one, only magnetic directions can be read with the compass. The declination screw will be found in different spots on the compass depending on the type of staff compass.
- The other odd feature of the staff compass is that the East direction is on the left side of North, instead of on the right side as it seems it should be. The reason for this is because the entire compass is turned to line up the direction instead of turning just the dial as done with the hand compass. This can ignored, however, and the bearing or azimuth can be read directly as the scale shows it (where North Arrow points to scale).
- The base plate is square and has ruled inches and centimeters on it for use with maps.
- The dial usually has a bearing scale on it. Some models have both azimuth and bearing scales on the dial.
- There is a metal adapter that screws into the bottom of the base plate which then fits onto the top of the Jacob's staff. It has a ball joint in it which allows the compass to be maneuvered until it is level. Most are made out of brass and can be easily stripped, so be careful with the adapter.

As far as using the staff compass, it is easy to get accurate directions with it if you know how to use the hand compass. Following are the basic procedures used in getting a bearing reading off the compass:

- Carry the staff compass in its leather case, along with the metal adapter. When you arrive at the point where the reading is to be made, drive the staff solidly into the ground next to the point on your line. Angle the staff slightly so the top of the staff is directly over the point.
- Take the compass out of the leather case, screw in the metal adapter, and place the compass firmly on top of the staff. Make sure it is not loose on the staff, and that the screw on the adapter is tight. Now level the compass by watching the level bubble, making sure the center of the compass is directly over the point.
- Unscrew the Needle Lock Screw which releases the needle. Use the needle lock screw to slow the swing of the needle down so it can be accurately read.
- Lift the sights up into position and turn the compass around until the sight with the string down the center is facing the direction you want to go. Look through the narrow slit on the other sight, find the point ahead, and put the string right on it. Being careful not to bump or move the compass, look directly down over the compass dial and read the bearing or azimuth direction where the North end of the needle is located. Also be sure the level bubble is still centered. Now repeat the process to double-check your reading. If you do not get the same reading, do it a third time. One thing to watch for is settling of the staff in the ground between the time you set up the compass and then read the direction. This can create errors.
- Once the reading has been obtained, lock the needle down, lower the sights back on top of the dial, pull the compass off the staff, and replace it in the leather case. Now pull the staff out of the ground and you are ready to move on to the next point.

By following these simple procedures, the staff compass will provide accurate readings and a traverse ratio of error between **1/300 and 1/500**. Directions can be read to the nearest **0.5 degree** (30 minutes) when the needle falls halfway between the degree marks on the scale.



3.4 CLOSED TRAVERSES

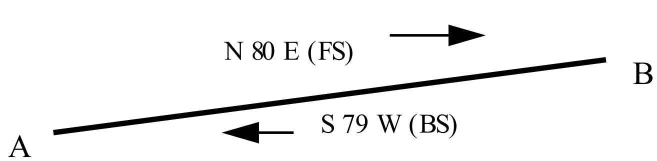
This section will introduce the definition of a closed traverse and show how to calculate the interior angles from bearing and azimuth directions and determine the angular error of closure for the traverse from the interior angles. Correcting the directions of lines for local attraction will also be covered. Further discussion involving the drafting of a traverse to scale and measuring the ratio of error for the traverse will occur in Section 2.1.

A **Closed Traverse** can be defined as a succession of straight lines of different directions connecting a succession of established points along a specific route that always end up where they started, forming a multi-sided closed figure. In Forest Mensuration, they are mostly used to lay out the boundaries of timber stands in the field so they can be mapped and then cruised. From the traverse directions and distances, not only can a map of the traverse be drawn to scale, but the area inside the traverse can be calculated.

There are many types of traverses, depending on what kind of instruments and equipment are used to measure the directions and distances of the lines. When compasses are used to measure all the directions, it is termed a **Bearing/Azimuth Traverse.**

The first step in completing a traverse is to run the edges of the stand with a compass, measuring the bearing or azimuth and distance of each line (every time direction is changed, a new line is started). The accuracy of the instruments used should match the accuracy of the measuring methods, so if a hand compass is used for directions, pacing should be used to get distances, since they have a similar level of accuracy. With a staff compass traverse, a cloth or steel tape would be used to measure distances.

When using a compass on a traverse, directions of each line should be read twice as a check. The first reading ahead from the beginning point is termed the **FORESIGHT.** As a check, the direction back to the beginning point is read from the foresight point. This is termed the **BACKSIGHT.** It should be exactly 180^{o} different from the foresight to be correct. Some leeway is given on the difference between the foresight and backsight. Acceptable difference is usually the amount of each mark on the scale. With the hand compass, that would be 2 degrees. With the staff compass, 1 degree. If the difference between the foresight (FS) and backsight (BS) exceeds this amount, the FS should be read a second time and the error located. Both the FS and BS readings are usually recorded in the notes. The following diagram illustrates the FS and BS concept:



	FS	BS
A		
	N 80 E	S 79 W
B		

Notice that with bearings, the BS should be the same degrees, but in the opposite quadrant. Since in this example there was a difference of only one-degree, it is an acceptable reading. If the FS and BS do not match after several tries, and the compass seems to be in proper condition, then there is probably **Local Attraction**, which means there is some metal or iron material nearby that is pulling the magnetic needle away from Magnetic North. This could be anything from a nearby car to power lines to a metal cap on a pen in the instrument person's pocket. The only way to determine whether there is local attraction is to take the FS and BS for each line. After discussing the calculation of interior angles, a method for correcting traverses with local attraction will be covered.

INTERIOR ANGLES

Directions can be determined for a straight line. They are measured in degrees based from the North or South Meridian as bearings or azimuths. Where two lines join, it is termed a point of intersection. The area between the two intersecting lines is termed an **ANGLE**. It is also measured in degrees. In a closed traverse, there will be two angles that can be measured at each point. The one on the inside of the traverse is termed the **Interior Angle**. The one on the outside of the traverse is termed the **Exterior Angle**.

The directions of the traverse lines (bearings or azimuths) are used to calculate the interior angles at each point. In higher level surveys with high-powered instruments like theodolites, angles at points are read with the instrument and directions of lines between points are calculated from the angles. With hand and staff compasses, directions of lines are read with the instrument, so angles at the intersecting points must be calculated. Once the interior angles are calculated, they are summed to compare with the total that would be obtained if there was no angular error.

It is important to be able to calculate the interior angles from the bearings or azimuths so the angular error of closure can be determined. The formula for calculating the Correct Sum of the Interior Angles is as follows:

$$\textbf{Total of All Interior Angles} = (N-2) \times 180^{o},$$

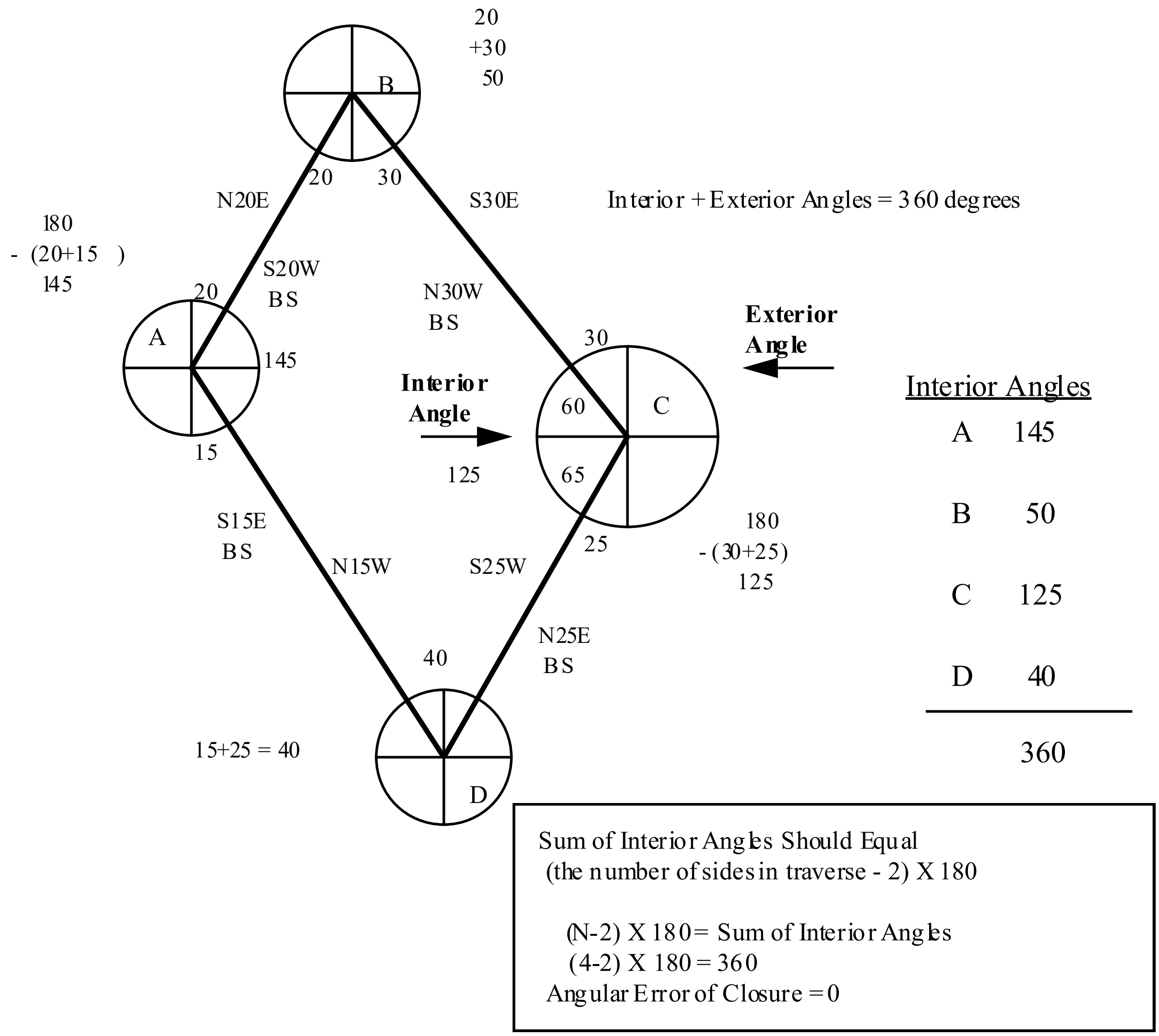
where **N = the number of sides in the traverse**.

This formula gives the actual, correct sum of the interior angles. This is the first step in determining whether the traverse is acceptable. The amount of acceptable error depends on the type of instrument used. For a hand compass traverse, it is usually 2 degrees. For a staff compass, it is usually 1 degree. If the angular error of closure exceeds this amount, it must be rerun. If it is equal to or less than this amount, the next step is to draft the traverse to scale, which will be covered in Section 2.1. This is where the error from the linear distances measured in the field will be determined and adjusted.

The **Angular Error of Closure** is then calculated for any closed traverse by comparing the correct sum of the interior angles using the above formula to the actual sum of the interior angles. This can be shown with the following formula:

$$\begin{aligned}\textbf{Angular Error of Closure} = \; & \textbf{Correct Sum of Int. Angles} \\ & - \underline{\textbf{Actual Sum of Int. Angles}}\end{aligned}$$

Following is an example traverse that will illustrate these concepts and show how to calculate the interior angles of a closed traverse and then determine the angular error of closure:

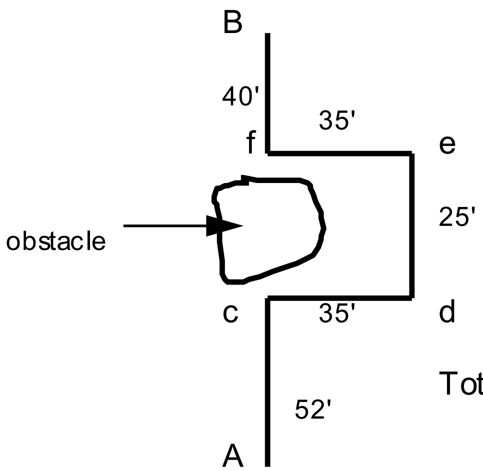


OFFSETS

Often, when traversing in the forest, obstacles are encountered when running a straight compass line. It is important to stay on that line as closely as possible. Sometimes, if the obstacle is small brush or saplings, it can be cut out of the way. But if cutting vegetation is not desirable, or if the vegetation is too large, or the obstacle is a boulder, building, or more permanent structure, then it must be bypassed, while staying on the same bearing and line. To accomplish this, the OFFSET method is a common technique employed.

Using a staff or hand compass, the easiest and most common way of applying the offset method is to turn a 90-degree angle at a point in front of the obstacle, go far enough out to get past the obstacle, turn another 90-degree angle back to the original bearing, travel far enough to get past the obstacle, turn another 90-degree angle to head back to the original line, measuring the exact distance traveled at the other end of the offset. At this point, turn one last 90-degree angle back to the original bearing, and you are back on line ready to continue on the original bearing.

On the final map, offsets are not usually shown, but definitely in the field notes. The offset distance is not important, as long as it is the same on both ends. The distances measured on the lines at the original bearing are added together to get the total distance of that line. The following diagram illustrates the offset principle:



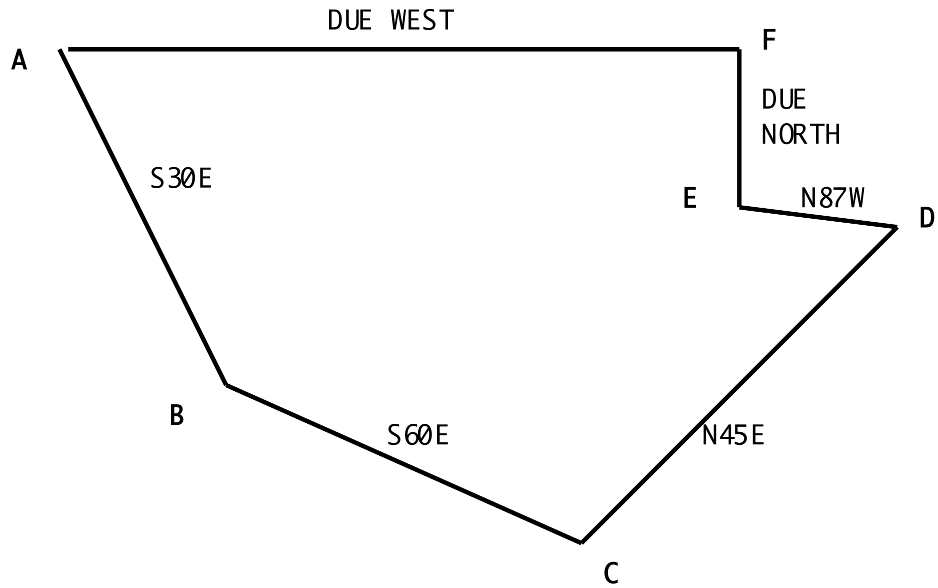
Right Angle Offset Method

Angles at c,d, e, & f are all 90 degrees

Total Distance of Line AB = 52' + 25' + 40' = 117'

3.5 PRACTICE PROBLEMS IN TRAVERSING

Answer the 1st two questions using the closed traverse below:



1) Calculate the Magnetic Bearings of the lines above if the declination is 16^0E.

2) Calculate the Interior Angles for Points A, B, C, D, E, F from the bearings.

3) Calculate the angular error of closure using the formula (N-2) X 180.

4) The correct FS bearing of Line AB is **N41^{o}E**. Calculate the correct FS and BS bearings for Lines BC and CD by correcting for Local Attraction.

Sta	Initial FS	Initial BS	Correct FS	Correct BS
AB	N41^{o}E	S38^{o}W		
BC	N22^{o}W	S17^{o}E		
CD	S31^{o}W	N30^{o}E		

CHAPTER 4: BASIC MAPPING SKILLS

4.1 MAPPING CLOSED TRAVERSES

Many times, lower accuracy traverses can be mapped to scale using a protractor and ruler. This involves using distances of lines in a traverse as well as directions. By plotting a traverse to scale, you can easily calculate the Linear Error of Closure and Ratio of Error of the traverse. The next step is to calculate the other errors. This can only be done by either drafting the traverse to scale or running a series of trigonometric calculations called Latitudes and Departures, covered in Chapter 5.

USE OF PROTRACTOR AND RULER TO DRAFT TRAVERSE

The best kind of protractor to use is a small 360^{o} round plastic one. It allows bearings or azimuths in any quadrant to be measured without moving it around. But any protractor (or even a hand compass) can be used to lay off directions for a scaled traverse. The protractor should be divided into single degree marks. The main thing to remember in using a protractor is to <u>keep it lined up to True North</u> as you draft in each line. This is best done by referencing the first traverse line to a True North line drawn in through the beginning point. After that, the protractor can be referenced to the preceding line. This will be detailed further below as the steps involved in drafting a traverse are covered.

Considering rulers, the **Engineer's Scale Ruler** is most commonly used in scientific measurements because it works with decimals instead of fractions. Regardless of the traverse scale, the **50 scale** is usually the most accurate to use to plot distances. This method will be detailed in this section. The 50 scale divides an inch into 50 equal parts, which is 0.02 inches. The numbers on the 50 scale refer to those parts of an inch. <u>The 2 on the scale means that mark is 20 marks from the 0 mark, which would be 20 X .02 = 0.4 inches in length</u>. The Engineer's Scale Ruler divides inches into <u>decimal parts</u>, not fractions. Decimals are more precise than fractions, and works directly in calculators.

If the distances measured with the ruler are to the nearest 0.10 (one tenth) of an inch, then the 10 scale on the ruler should be used, where each mark is equal to 0.10 inch. **If the distances measured with the ruler are to the nearest 0.01 (one hundredth) of an inch, then the 50 scale should be used**. By estimating in between each mark on the 50 scale, the lengths are being measured to the nearest 0.01 inch.

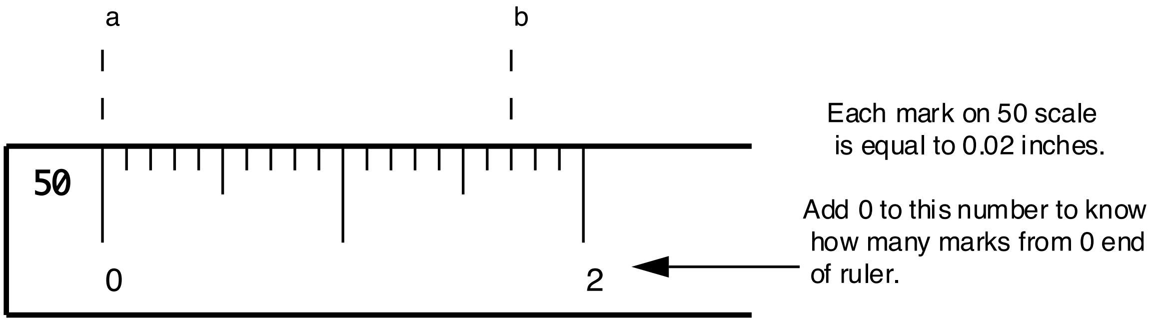
When <u>measuring an existing line</u> on a drawing or map, lay the ruler down and count the marks on the 50 scale from the beginning to the end of the line. If it is 185.5 (halfway between the 185 and 186 mark), then divide the 185.5 by 50 to get inches of length (this is because there are 50 marks per inch on the 50 scale). This equals 3.71 inches. Then convert it to ground distance with a proportion formula (covered in Section 2.2). The formula for converting 50 scale marks to inches is as follows:

Length of Line in INCHES = (# of 50 scale marks) ÷ 50

To lay off a line of a set distance, first calculate the distance on the map in decimal inches. Conversion of ground to map distance and vice versa is covered in Section 2.2.2. Then take the decimal inches and multiply by 50. This gives the number of marks on the 50 scale to lay off with your ruler. Using the above example, for a line that is 3.71 inches in length, 3.71 multiplied by 50 gives you 185.5 marks. Simply count those marks off on the ruler. The formula for converting Inches to 50 scale marks is as follows:

(# of 50 scale marks) = (Length of line in Inches) X 50

Following is a diagram which illustrates the **50 scale ruler** concepts:



Distance from a to b in inches = 17 marks X .02 " per mark = 0.34 "

or

Distance = 17 marks / 50 = 0.34 inches

Procedures for Drafting a Traverse with a Protractor and Ruler

1. Get notes with bearings and distances for all lines in the closed traverse. Then convert the ground distances (in feet or chains) to map distances in decimal inches using procedures outlined further down in Section 4.2.

2. Using a piece of graph paper or drafting paper, determine approximately where the starting point (usually Pt. A) should be placed so the entire map will fit on the paper with the desired scale. Put a dot on the paper and label it Pt. A.

3. Maps can be drawn oriented to Magnetic North, but are usually oriented to True North. True North is always toward the top of the page. If not using graph paper, lightly draw a straight line through Pt. A representing True North.

4. Take the protractor and lay it down so the reference line in the center of the protractor is on Pt. A and the circle scale is aligned to the True North line (the zero degree mark on the protractor). Now mark off the first bearing (or azimuth) for Line AB. Remember, **the ZERO mark on the Protractor must be aligned N-S on the paper**.

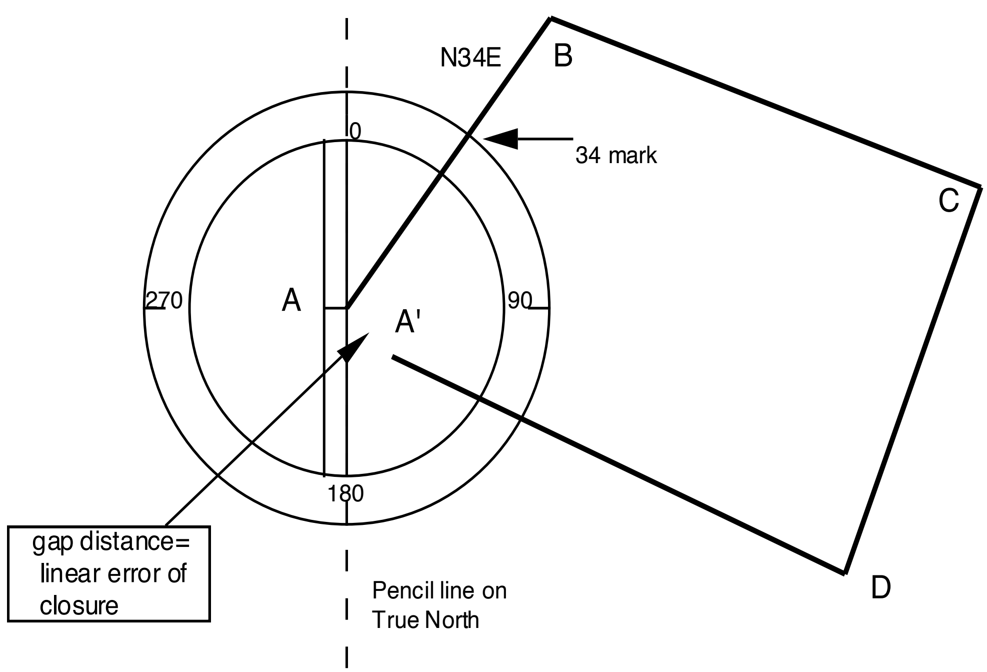
5. Assume the bearing of Line AB is N34^{o}E. With the protractor correctly oriented to True North at Pt. A, find the 34^{o} mark toward the East and put a small, light mark with a pencil at that mark. Now draw a line from Pt. A through the pencil mark. Remember, **ALWAYS measure the bearing angle from the N-S line, not the E-W line**.

6. Now lay the ruler down along the drawn line with the zero end at Pt. A. Measure off the correct distance with the 50 scale using the procedures outlined above. Put a dot at that point and label it B. The first line of the Traverse has been drafted.

7. For the next Line (BC), repeat the above steps. The only difference is how the protractor is aligned. The easiest way is to orient the protractor to the backsight of the line just drawn (AB). This would be S34^{o}W (same bearing angle, opposite quadrant). Now the protractor has been quickly oriented to North and is ready to measure off the next bearing (Line BC). If using graph paper, the protractor is oriented to North at each turning point because the lines on the graph paper are all lined to North (straight up and down on the paper). Then measure the distance of the line with the 50 scale of your ruler, put a dot, and Pt. C has been plotted. Repeat these steps to completely draft the traverse.

8. When the last line has been drafted, it <u>should</u> come back exactly to Pt. A since it is a closed traverse. Actually, that would be the case if there was no error. Usually, with a compass, there will be no appreciable angular error. If there is some, it can be eliminated from the traverse before drafting it to scale by adding or subtracting an equal portion of the error to each point. But there is still distance or linear error to consider, as well as any plotting error in drafting the traverse. So in most cases there will be a gap at the end when the last line back to Pt. A is drawn. Make sure the last line is drawn at the bearing listed in the notes, and the distance is measured as listed in the notes. <u>Do</u> <u>Not</u> just draw a line from the last point back to the beginning point. That is incorrect.

9. With the Traverse drafted, and a gap at the end between where the traverse should end and where it actually ends, calculate the ***Linear Error of Closure*** (distance error) and the ***Ratio of Error*** (determines if the traverse has an acceptable amount of error or not). That will be done next. First is a diagram to illustrate the steps just covered:



FORMAL MAP DEVELOPMENT

Drafting traverses to scale, calculating error of closure and the area inside the traverse has already been discussed. When this is all done for a formal map in a report, there are other items that should be included on and around the map to inform the reader and make it look professional. Following is a typical format for stand type maps. Placement of these items is usually not critical as long as it looks neat and balanced. **Most formal maps should be done in black ink on clear Mylar, usually 8.5" X 11" sheets**.

Border - Solid black ink line drawn around the map 0.5" in from edge of paper.

Title Block - Located in the lower left or right corner of map. All information in the block should be centered with a border drawn around it (thinner than the overall border) and should contain the following information:

TITLE of Map (ex: Stand Type Map of Portion of CR Lands)- All CAPS.
LOCATION (Specific Area, Town, County, State, and Legal land description).
CREW NAMES & CREW NUMBER (**be sure to specify WHO drew map**)
DATE(S) Traverse was run in the field.
COURSE Traverse was drawn for (ex: FOR 54 - Natural Resource Measurements)

***Be sure title block is proportionally smaller in size than the traverse**

Scale - Located in the opposite corner from title block. Must have an Equivalent Scale included. Can also include Graphic Scale, but is usually not required.

Stand Area - In Square Chains and Acres, below the scale.

Linear Error of Closure & Ratio of Error - Put below Acreage.

North Arrow - In upper right hand corner of Map. North is always toward the TOP of the map as you are looking at it on the paper. Label it TN for True North. Include the Magnetic Declination line on the arrow and mark it MN.

Legend - Located above the title block. This shows the list of symbols included on the map and their meaning. Use standard USGS symbols. This should include roads, trails, streams, swamps, and man-made structures, cruise lines, stand type boundaries, plot centers, etc. Points or Plots should be numbered. All relevant physical features should be included on the map.

Stand Classification Codes - As listed above in Section 2.6.1. They should be part of the Legend. The stand types should be Color Coded on the map, with the colors shown in the legend.

Bearings & Distances of Traverse Lines - Locate on lines on outside of traverse so they can be read from the bottom or the right side of the page, or they can be listed above the scale and area information if there is not enough room to put them on the traverse lines. If listed, be sure to label the 'FS bearing' column and the 'Distance in Feet or Chains' column. Also be sure to label turning points or hubs with letters.

4.2 CLOSED TRAVERSE COMPUTATIONS

Once a closed traverse is drafted on paper to scale, there are several computations that can be done to measure accuracy as well as the area inside the traverse. While there are mathematical and electronic ways to perform this work, it is important to learn the foundation of how traverse computations are done by hand to fully understand all of the components of the process.

CALCULATING LINEAR ERROR OF CLOSURE & RATIO OF ERROR

To calculate the **Linear Error of Closure** (also known as the Gap Distance), the gap from where the last line ends and the first Point begins (usually termed A' and A, respectively) is measured using the 50 scale in inches and then converted to ground distance in either feet or chains using the traverse scale (see Section 2.3). This distance is the Linear Error of Closure. It usually represents the distance error in the traverse. At least some of the error, however, is probably due to the plotting with the protractor and ruler. This is one of the drawbacks to plotting a traverse using this technique.

In order to determine if this error is an acceptable amount, the Ratio of Error for the Traverse needs to be calculated. To do this, set up a proportion just as done back in Chapter 1.

$$\textbf{Ratio of Error} = \frac{\textbf{Linear Error of Closure}}{\textbf{Traverse Perimeter}} = \frac{\textbf{1}}{\textbf{X}},$$

where the **Traverse Perimeter** is the Sum of the Distances of ALL traverse lines. As with all Ratio of Errors, X is calculated by cross multiplying and dividing. This converts the Ratio to a 1/X form that allows comparison with other Ratio of Errors. The Linear Error of Closure and the Traverse Perimeter MUST be in the same units, and they must be GROUND Distance, not map distance.

Below is an example showing the calculation of a ratio of error. Assume a traverse was drafted to scale and a gap distance of 26 feet was measured with an engineer's ruler. The Traverse Perimeter is equal to 1895 feet. The Ratio of Error for this traverse is :

$$\frac{26}{1895} = \frac{1}{X}, \text{ so } 26(X) = 1895, \text{ so } X = \frac{1895}{26} = 72.88 \text{ ft.}$$

The Ratio of Error is therefore $\frac{1}{72.9}$. This means there was 1' error for every 72.9' traversed. This is marginally acceptable for a hand compass-pacing traverse, but is unacceptable for a staff compass-taping traverse.

Notice that the Ratio of Error is **Unitless**. This means that any unit of measurement can be applied to it, as long as the numerator (1) and the denominator (72.9 in the above example) are both in the same units. Therefore, the above Ratio of Error can also mean there was 1 chain error for every 72.9 chains measured in the traverse.

Always calculate the ratio of error for every traverse. If the error exceeds the allowable amount for the equipment being used, then it must be done over until the Ratio of Error is found to be acceptable.

MEASURING AREA INSIDE CLOSED TRAVERSES

Before discussing the methods of determining traverse areas, the common units of measurement for areas and the conversions between them will be covered. In measuring distances in Section 1.2, only Length (1 dimension) was considered. With areas, both Length and Width (2 dimensions) must be considered. This gives **Square Measurements**.

The Most Common AREA Units are as follows:

1 Acre = 43,560 Square Feet = 10 Square Chains

1 Square Mile = 640 Acres = 6400 Square Chains

The conversion formulas for acres, square chains, and square feet are as follows:

Acres X 43,560 = Square Feet

Square Feet ÷ 43,560 = Acres

Acres X 10 = Square Chains

Square Chains ÷ 10 = Acres

Measuring areas with feet, chains, or any other length unit of measurement, the word SQUARE must be added before it. With Acres, it is already an area measurement and is only an area measurement, so it doesn't need the Square in front of it.

There are many ways of calculating the area of a traverse. One technique is to use the Traverse Map drawn to scale to calculate the area. This can be done three different ways - Geometric Shapes, Dot Grid, and Planimeter.

USING GEOMETRIC SHAPES TO MEASURE AREAS

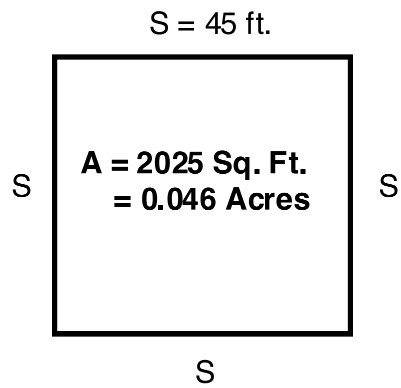
All closed traverses are no more than a Polygon. For example, if a traverse has 3 sides, it is a triangle. This fact makes it easy to use geometric formulas to calculate the areas inside the figures. Here, the focus will be squares, rectangles, and triangles. Any traverse can be divided into one or more of these shapes. The areas can then be calculated for each shape and then added together to get the total area of the traverse. These formulas will always calculate square feet or square chains. Then the square feet or square chains can be converted to acres using the above conversions. The formulas will never give Acres directly, because linear measurements (feet or chains) are being used in the formulas. GROUND Distances should always be used in the formulas, NOT Map Distances, or the map area will be calculated in square inches.

First, **Squares** will be covered. A square is a four sided figure where all four sides are of equal length. The area formula for a square is:

Area = S X S
where S is the
length of any side

If S = 45 feet, then
A = 45 X 45 = 2025 Sq. Ft.

$$\frac{2025}{43560} = 0.046 \text{ Acres}$$

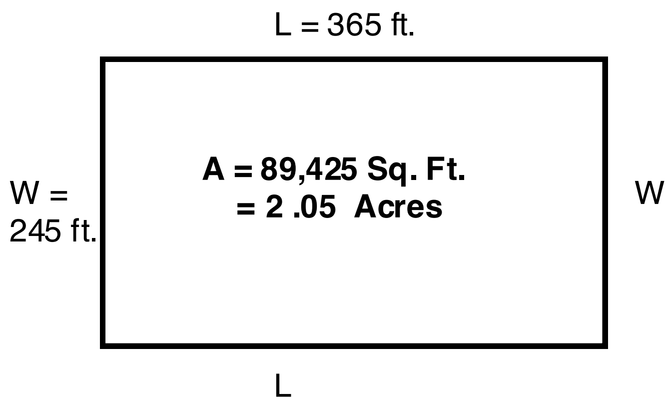


Next is **<u>Rectangles</u>**. A rectangle is also a four-sided figure, but <u>only the parallel opposite sides are equal to each other in length</u>. The area formula for a rectangle is:

Area = L X W
where L & W are the
lengths of the pairs of sides.

If L=365 ft. & W=245 ft.
then A = 365 X 245 =
89,425 Sq. Ft.

$$\frac{89{,}425}{43560} = 2.05 \text{ Acres}$$



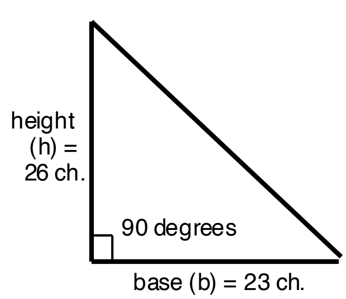
As can be seen, the lengths of the sides are measured in feet, and the areas are in square feet. In order to calculate acreage, square feet must be calculated first and then converted to acres. If the lengths of the sides were measured in chains, the area would have come out in square chains, and then the conversion to acres would be to divide by 10. This will be illustrated in the next example.

Finally, there are **<u>Triangles</u>**. It is a three-sided figure where <u>the sides can be equal or different lengths</u>. For most purposes, there are two types of Triangles to consider:

Right Triangles: <u>one of the three angles in the triangle is exactly 90°</u>. This is the easiest type of triangle to deal with, but the least likely to find in the field setting. The formula for calculating the area of a right triangle is:

$$\mathbf{A = \frac{b \times h}{2}}$$

$$A = \frac{26 \times 23}{2}$$
= 299 Sq. Ch.
= 29.9 Acres

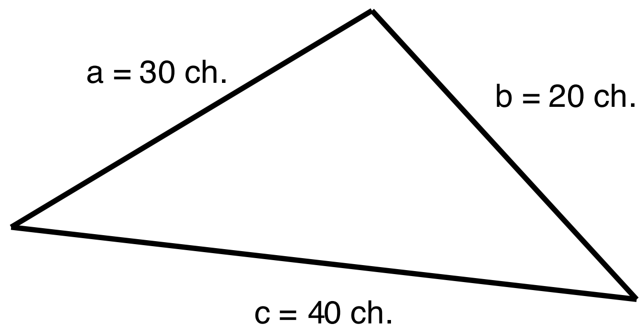


Notice that the formula is basically 1/2 of the rectangle formula, because a right triangle is 1/2 of a rectangle. Note that to convert **Square Chains to Acres**, just move the decimal over one place to the left (divide by 10).

Next is the **Oblique Triangle:** a triangle where <u>none of the three angles equal 90^{o}</u>. The Area of <u>ANY</u> Triangle can be calculated with this formula, even a right triangle, but it is more complicated than the right triangle formula. The formula for calculating the Area of an Oblique Triangle is called <u>Heron's Formula</u> or the "S" Formula:

$$\mathbf{S = \frac{a + b + c}{2}}$$

$$\mathbf{A = \sqrt{S\ (S\text{-}a)\ (S\text{-}b)\ (S\text{-}c)}}$$



$$S = \frac{30+20+40}{2} = \frac{90}{2} = 45 \text{ Ch.}$$

$$A = \sqrt{45\ (45\text{-}30)\ (45\text{-}20)\ (45\text{-}40)}$$

$$= \sqrt{45\ (15)\ (25)\ (5)} \qquad = 290.47 \text{ Square Chains} = 29.05 \text{ Acres}$$

With a calculator, the formula only takes a few minutes, and as mentioned before, can be used on any traverse. Notice that the length of the sides is in chains, so the area came out in Square Chains. If the sides were in feet, the area would have come out in Square Feet. Then the conversion to acres would have involved dividing the square feet by 43,560.

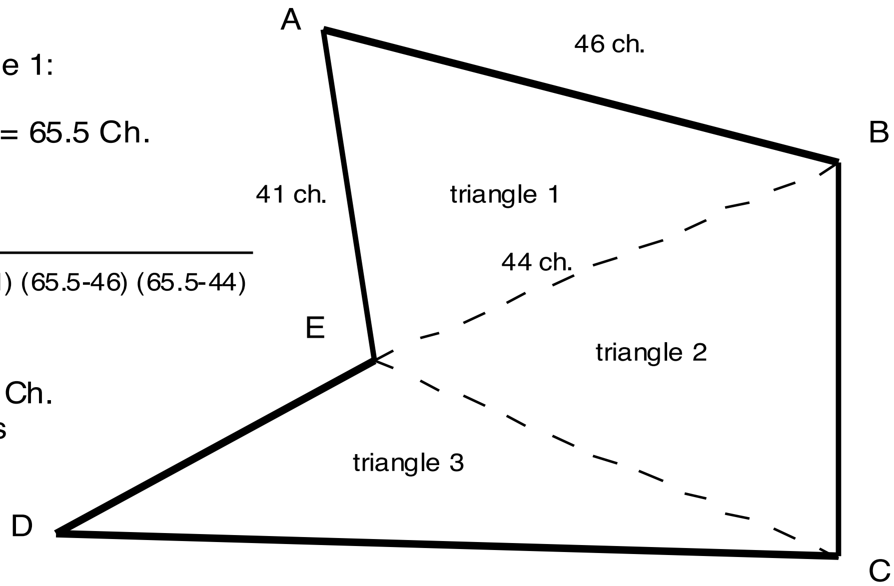
In order to use geometric shapes to calculate the area of a traverse, it must be drawn to scale as outlined in Section 2.1. Then <u>the interior lines can be drawn in and measured with a ruler</u> to use in the geometric shape formulas. Below is an example of a <u>5 sided traverse</u> which is <u>divided into 3 triangles</u>. Any traverse with straight lines can be divided into triangles. Drawn to scale, measure the length of all three sides of each triangle and plug them into the "S" Formula to calculate the area (the lengths must be Ground Distance, not Map Distance). The area of all 3 triangles must be calculated separately and then added together to get the area of the entire traverse. Usually, square feet or square chains will be obtained for all triangles, and then the total converted to Acres. In the example below, the area of only the first triangle is calculated to show how it is done:

Area of Triangle 1:

$$S = \frac{41+46+44}{2} = 65.5 \text{ Ch.}$$

$$A = \sqrt{65.5\,(65.5-41)\,(65.5-46)\,(65.5-44)}$$

A= 820.24 Sq. Ch.
= 82.02 Acres



The outside lines were measured in the Field. The dashed lines were measured with a ruler after the traverse had been drafted to scale.

If triangle 2 has an area of 76 acres and triangle 3 has an area of 43 acres, then the total area of the traverse is = 201.02 Acres.

MEASURING AREAS WITH DOT GRID

Dot Grids are a quick and easy tool for calculating areas of small maps and traverses. If the area to measure is much larger than the dot grid itself, it is probably better to use the geometric shape method or a planimeter.

A Dot Grid is a piece of plastic with a certain number of dots/square inch on it. The standard USFS dot grid has 64 dots per square inch. This can be used to calculate the area of traverses drawn to scale or areas drawn off on the topographic quad map or aerial photos.

In using a dot grid, <u>randomly lay the grid down on the area to measure</u> so that it completely covers the area. Holding the grid firmly down (or taping it to the map or photo), count all the dots that fall within the area's boundaries. <u>For dots that fall on the line</u> (borderline dots), <u>count every other one</u>. **Count the total dots at least 2-3 times and take an average** (each count should be within a few dots of the other counts). Before using the average number of dots inside the area to be measured, calculate the Acres per dot for the map scale being used and the particular dot grid being used. The ACRES/DOT is calculated with the following formula:

$$\textbf{Acres/Dot} = \frac{(\mathbf{PSR})^2}{(\mathbf{43560})(\mathbf{144})(\mathbf{GI})} \;,$$

where **<u>PSR is the Photo Scale Reciprocal</u>**. This is the denominator of the RF scale. As an example, if the RF scale is 1:800, the PSR would be 800.

where **<u>GI is the Grid Intensity</u>** or the number of dots/sq. in. on the dot grid used, which is usually **64**.

The 43,560 and the 144 are constants in the formula, and simply convert the square inches measured from the grid to square feet and then acres, so the answer comes out in ACRES represented by each dot. Notice that with dot grids, **the Area is calculated in ACRES directly**, instead of square feet or square chains.

Once the Acres per Dot is calculated, it will always be the same for that map scale and that dot grid intensity. Then the formula for calculating AREA is as follows:

Area in Acres = (Acres/Dot) X (Average # Counted Dots)

As an Example, assume the following:

Average Number of Dots counted inside area boundary lines: **432**
Scale of Traverse drawing: **1/12,000**
Grid Intensity for Dot Grid used: **64 dots/sq. in.**

$$\text{Acres/Dot} = \frac{(12{,}000)^2}{(43560)(144)(64)} = \frac{144{,}000{,}000}{401{,}448{,}960} = 0.3587$$

This means that each dot on this grid at this map scale (1:12000) represents 0.3587 acres. Now using the above area formula, we can calculate the area in acres.

AREA = (0.3587) X (432) = 154.96 acres = **155 Acres in Traverse**.

Be careful to count the dots accurately by checking the total at least 2-3 times. This then provides a quick and easy way to calculate acreage directly if the area being measured is small enough to fit inside the dot grid.

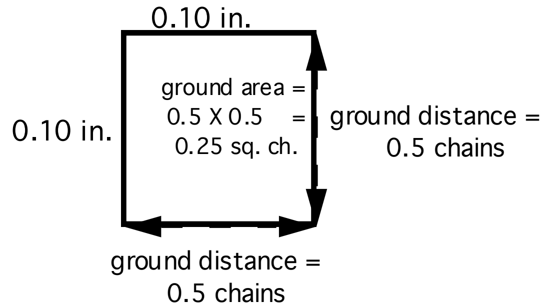
A related method of calculating area when **using graph paper** is to <u>count the number of small squares within the traverse</u>, and multiply by the square chains per square using the scale of the traverse. As an example, assume a traverse scale of 1" = 5 chains. Since each small square on the graph paper is 0.10 inches by 0.10 inches, each square would represent 0.10 of 5 chains, or 0.50 chains on each side. The area of a square is L X L, so the area of each small square would be:

0.50 X 0.50 = 0.25 square chains.

If 249 small squares are counted within the traverse, the traverse area would be:
249 X .25 sq. ch. per square = 62.25 sq. ch. = 6.2 acres.

This is illustrated in the following diagram:

one small square on 10 lines per inch graph paper



Scale: 1" = 5 chains

so each small square on the graph paper would represent 0.25 sq. ch. at this scale.

So the formula for calculating the area of a traverse using the <u>small squares</u> within the traverse on the graph paper is as follows:

AREA = (Equivalent Scale ÷ 10)^2 X (# small squares in traverse)

If in the above example 634 small squares were counted within the traverse, the area would be:

Area = (0.25 sq. ch. per square) X (634 squares) = 158.5 square chains = 15.9 acres

Note that the area calculated using this method will be in Square Chains or Square Feet, not Acres. In the above example, the area came out in square chains because the equivalent scale was in chains.

4.3 PRACTICE PROBLEMS IN TRAVERSE COMPUTATIONS

1) A 5 sided traverse is run in the field with the following distances: 14.3 ch, 26.5 ch, 31.7 ch, 29.8 ch, and 33.4 ch. After drafting it to scale with a protractor and ruler, a gap of 0.23" is measured between point A and A' with a scale of 1" = 10 chains.

    a) What is the Linear Error of Closure for this traverse?

    b) What is the Ratio of Error for this Traverse?

2) A three sided traverse has sides with lengths of 61.2 ch, 38.9 ch, and 45.1 ch. What is the area of the traverse in square chains and acres?

4.4 TOPOGRAPHIC MAP READING

Topographic maps help to detail both topographic and cultural features important to the mensurationist. Changes in elevation, magnetic declination, the location of drainages and roads, etc. can be determined from these maps once information provided in the legend is understood. Some of this information is self-explanatory and will not be covered here.

MAP SYMBOLS

Included in the fold up metric quadrangle topographic map is a legend showing all the symbols included on all USGS topographic maps. In the older English measurement maps that lay flat, the symbols are not shown, but can be obtained from most surveying books. They are mostly self-explanatory. Notice that the symbols are grouped by <u>color symbols</u> as follows:

Blue - Water
Green - Vegetation
Black - Man-made features (buildings, boundaries, campgrounds, power lines, roads, trails, railroads, etc.)
Red - Highways, Fences, Rectangular System of Survey Boundaries
Brown - Contours to read elevations and slopes

MAP SCALES

There are <u>three different ways scales can be shown on a map</u>. All do the same thing - show the relationship between **Map Distance** and **Ground Distance.** These three scale types are:

Representative Fraction (RF) Scale
Equivalent or Written Scale
Graphic Scale

The **<u>Representative</u> <u>Fraction</u> (RF) scale** is the most common and is found on every USGS Topo Map. It is simply <u>a ratio which compares map distance to ground distance</u>, where BOTH parts of the ratio are in the SAME UNITS.

Most USGS English measurement maps have a RF scale of **1:24,000.** The scale can also be shown as a fraction - **1/24,000**.

This means that **<u>1 unit on the map is equal to 24,000 of the same units on the ground</u>**. This way the scale can be converted to any units. The RF scale is the type used most often to convert map distance to ground distance or vice versa. The process for doing this is listed below:

1) **<u>To convert a GROUND Distance to a MAP Distance</u>**, set up a PROPORTION using the RF scale, comparing it to the distance measured on the ground that is to be converted (remember, a proportion is nothing more than 2 equal ratios). Assume a Ground Distance of 300 feet. The objective is to convert the 300 feet of ground distance to Inches on the map. This is illustrated below:

$$\frac{\textbf{\textit{Map Dist.}}}{\textbf{\textit{Ground Dist.}}} = \frac{\mathbf{1}}{\mathbf{24{,}000}} = \frac{\boldsymbol{X}}{\mathbf{300}\ \textbf{\textit{feet}}}$$

The problem with this proportion is that the denominators are NOT in the same units, and they MUST BE before solving for the Unknown X. Therefore, the 24,000 must be changed to feet, or the 300 feet must be changed to the same units as the 24,000. But what unit is the 24,000? Since the map distances are almost always measured in INCHES, and the units are the same for both parts of a RF scale, <u>we can assume the 24,000 is in INCHES</u>. It is therefore easier to change the 24,000 Inches to feet and then insert that number into the proportion. This is shown below:

$$\frac{\mathbf{24{,}000}\ \textbf{\textit{inches}}}{\mathbf{12}\ \textbf{\textit{inches per foot}}} = \mathbf{2000}\ \textbf{\textit{feet}}$$

This means that **1" on the map equals 2000 feet on the ground**. With Inches in the Numerator and Feet in the Denominator (note that both numerators MUST be in the SAME units, and both denominators MUST be in the SAME units), the unknown X can be solved:

$$\frac{\mathbf{1}\ \textbf{\textit{inch}}}{\mathbf{2000}\ \textbf{\textit{feet}}} = \frac{\textbf{\textit{X inches}}}{\mathbf{300}\ \textbf{\textit{feet}}}$$

Cross multiplying to solve for X, we get: 300 (1) = 2000 (X), so

$$\boldsymbol{X} = \frac{\mathbf{300}}{\mathbf{2000}} = \mathbf{0.15}\ \textbf{\textit{inch}}$$

This means that a line on the ground that is 300 feet in length is equal to 0.15 inch on the map at a RF scale of 1:24,000. To scale this line off on the map using the 50 scale on the engineer's ruler, follow the formula in Section 2.1.1:

50 Scale Marks on Ruler for Line on Map = 0.15 X 50 = 7.5 = 8

To mark this distance off on the map, we would measure off 8 marks on the 50 scale, which is about as accurate as you will be able to get for this short a line. So <u>the formula for converting Ground Distance in feet to Map Distance in inches using a RF Scale of 1:24,000</u> is as follows (the ground and map distances can be in any units)(notice that **the First RATIO is always the map SCALE**, converted to whatever equivalent ground distance unit is being used):

Ground to Map Conversion Formula using a map scale of 1:24,000

$$\boxed{\frac{\textbf{1 inch on map}}{\textbf{2000 ft. on ground}} = \frac{\textbf{X inches on map}}{\textbf{Measured ft. on ground}}}$$

To convert a RF scale (unitless) to an equivalent scale (best for converting ground distance to map distance), it means converting the ground distance portion of the RF scale (denominator) from INCHES to whatever unit is being used on the ground (usually feet or chains).

2) **To convert a MAP Distance to a GROUND Distance**, again set up a PROPORTION using the RF scale, comparing it to the distance measured on the map that is to be converted. Assume the map has a RF scale of 1:10,000 and a line on the map is measured to be 4.23 inches in length. The length of the line is to be calculated in chains on the ground.

First, assume the 1 and the 10,000 in the RF scale are in inches. Convert the 10,000 inches in the RF to chains. This is done by using the conversions in Section 1.2:

$$\frac{\mathbf{10{,}000}\ \textit{inches}}{\mathbf{12}\ \textit{inches per foot}} = \frac{\mathbf{833.33}\ \textit{feet}}{\mathbf{66}\ \textit{feet per chain}} = \mathbf{12.63}\ \textit{chains}$$

Again, this means that **1" on the map equals 12.63 chains on the ground**. Now set up the proportion to solve for the unknown Ground Distance.

$$\frac{\mathbf{1}\ \textit{inch on map}}{\mathbf{12.63}\ \textit{chains on ground}} = \frac{\mathbf{4.23}\ \textit{inches on map}}{\textit{X chains on ground}}$$

This means if 1" equals 12.63 chains on the ground (RF scale), then 4.23 inches on the map will equal X chains on the ground. This is simply two equal ratios where the units are the same in the numerators and the same in the denominators. Now cross multiply and solve for X.

$$(1)\ (X) = (12.63)\ (4.23) = 53.42 \text{ chains}$$

So the line on the map is 53.42 chains in length on the ground. The formula, then, for converting Map Distance in inches to Ground Distance in chains using a RF scale of 1:10,000 is as follows (same for any scale and any units):

Map to Ground Conversion Formula using a map scale of 1:10,000

$$\frac{\textbf{1 inch on MAP}}{\textbf{12.63 chains on Ground}} = \frac{\textbf{Measured Inches on MAP}}{\textbf{X chains on Ground}}$$

Always insert the given information into the proportion and solve for the unknown length. Realize that the first ratio (the equivalent scale) will be different if the scale is different. As long as 3 of the 4 numbers in the proportion are known, the one unknown can be solved for using basic algebra.

The **Equivalent or Written scale** simply indicates how many feet, chains, meters, etc. are equal to 1 inch (or centimeter) on the map. The RF scale is usually shown in the middle bottom portion of the map as a ratio. The equivalent form of the scale is not given on the USGS maps because it can be shown in many ways, and is easier to just calculate using the RF scale. The equivalent scale in feet for the USGS map would be:

Equivalent Scale **1" = 2000 feet: This is the same scale as the RF 1:24,000**

Notice that in changing an equivalent scale to a RF scale, it involves just converting the ground distance portion of the equivalent scale (2000 feet in above example) back to INCHES. Here, the feet are multiplied by 12 to obtain inches.

In using an equivalent scale to convert map distance to ground distance or vice versa, a proportion is still set up as done in steps 1 and 2 above, but now the denominator is shown in units which match that of ground distances. If it is not the same unit as the ground distance, simply convert it to the same unit using the conversions in Section 1.2. The process is then identical to the one used for RF scale conversions just covered.

The **Graphic scale** is a drawn scale looking like a ruler line where you can lay a string, ruler, stick etc. on the scale and then on the map to get quick, easy map-ground conversions. It is not as accurate as using the RF scale, but in some cases, it is adequate. On the USGS map, it is shown below the RF scale. It allows quick conversion to kilometers, miles, feet, or meters for ground distance. It is almost like an automatic conversion table, but should not be used when accurate results are necessary.

Usually, only one of the scale types is shown on a drafted map. Normally, the Equivalent scale is the easiest to put on the map and makes it easy to set up a proportion for checking map to ground distances.

Concerning the calculation of AREA on maps, the procedures is detailed in Section 4.2. Be sure to convert map distance to ground distance BEFORE inserting the numbers into the area formulas, because areas represent two dimensions, so the conversions from map inches to ground feet or chains are different with areas than with linear distances. It is easier to deal with ground distances, and then the area formulas can be used directly with no other conversions. Square feet or square chains will be directly calculated as an answer, which can then be converted to acres.

CONTOURS

The most important part of a topo map is that it shows elevation changes of the ground (also known as Relief) to give a sense of what the slope of the ground is like at any point on the map. A contour is defined as a **line of equal elevation drawn on a map**. There are other ways to show elevation on a topo map, but contours are the most common.

The first step is to know what the contour interval is and realize that elevation changes shown by contours represent VERTICAL Distance, which was explained in Chapter 1. The contour interval on the English measurement USGS maps is 40 feet, which means the vertical distance (elevation change) between each contour line is 40 feet. Every 5th contour line is darker and is called an **Index Contour**. Only the Index Contours have the Elevation marked at intervals along the line. To calculate the elevation of the other contour lines involves knowing the contour interval and deciding whether the elevation is increasing or decreasing by looking at the lay of the land and the next index contour.

Contours have the following characteristics:

1) Every contour closes on itself, either on or off the map.
2) Contours never cross each other except in the case of an overhanging cliff.
3) Contours cannot ever split or branch.
4) Equally spaced contours represents a uniform slope. The closer the contours are together, the steeper the slope.
5) At streams, contours cross them at right angles after forming a U upstream. This can be used to determine which way a stream is flowing.
6) The depression between two summits is called a saddle.

Contours can also be used to calculate **average percent slope** between two points on the map. Since contours measure Vertical Distance (VD) and Horizontal Distance (HD) can be measured with a ruler using the scale conversion proportion, the following rise/run formula can be used to quickly calculate percent slope.

$$\frac{\mathbf{VD}}{\mathbf{HD}} = \mathbf{\%\ slope}$$

(Both VD and HD must be in the same units, and HD must be converted to ground distance)

So as an example, a line is measured on the map and the ground distance is calculated to be **242 feet in length (HD)** using the proportion formula listed above, and the contours are used to determine that the elevation at the beginning of the line is **1735 feet** and the elevation at the end of the line is **1753 feet**. The difference in elevation (VD) is 1753 - 1735 = **18 feet**. The percent slope is therefore:

$$\frac{18}{242} = 0.07438 \times 100 = 7.438\ \%$$

Finally, the black BM symbols on the map marked with a X and with a number below are termed **Benchmarks.** These are brass cap markers set by the USGS with the correct elevation above sea level stamped on it. The number printed next to each BM on the map represents the ground elevation at that location.

4.5 ORIENTEERING

This section details how to use a map and/or aerial photo with a hand compass to lay off specific directions and distances to travel on the ground between known points, using the map as a guide to stay on track and not get off line. This process is termed **Orienteering**. There are clubs around the world that do this for competition and fun. It is a very popular sport in many areas.

LAYING OFF A BEARING ON A MAP

Often, field technicians are asked to follow a certain bearing from a given point on a map, or to pinpoint a ground location on the map, which is the usual procedure when orienteering. The following procedures can be used with your Silva Ranger Hand Compass to accomplish either objective:

1) Set the given bearing you want to plot on the map into the compass dial, following the procedures detailed in Section 3.3.

2) Lay the compass on the map so that either side of the base plate intersects either the starting point on the map or the known point on the map being used as a triangulation point.

3) Leaving the given bearing on the dial and keeping the edge of the compass plate on the given map point, TURN the entire compass on the map until the compass meridian lines (red or black lines running N-S on the bottom of the compass dial) are parallel with the meridian lines on the map. The thin, black grid lines on the topo quad map that form 1000-meter squares can be used as the True North Meridian lines. Also be sure that the North-orienting arrow on the bottom of the base plate is pointing to the North and not the South.

4) Draw a line on the map along the edge of the compass, intersecting the given point on the map. A bearing has now been laid off on the map using the compass. If trying to locate a position on the map, this must be done a second time using another point on the ground that can be located on the map. <u>The point where the two lines drawn on the map intersect is the location of the compass person on the ground</u>.

DETERMINING THE BEARING OF A GIVEN LINE ON A MAP

When wanting to know the best direction to take from one given point on the map to another, a line can be drawn on the map and the bearing of the line determined using a hand compass. The procedures are as follows:

1) Lay the edge of the compass base plate along the line in question on the map. Be sure there is a North Meridian line on the map showing through the compass dial. Also <u>be sure the end of the compass by the mirror cover is facing in the forward direction</u>. Otherwise, the backsight direction will be measured.
2) Turn the compass dial around until <u>the compass meridian lines on the bottom of the compass dial are parallel with the North Meridian lines</u> on the map AND <u>the North orienting arrow on the bottom of the dial is pointing to the North</u>.

3) Pick the compass up and <u>read the bearing off the dial</u> where it intersects the marker at the North end of the base plate. That is the bearing you need to set into your compass at the beginning point to follow the line on the map. That is all there is to it!

FINDING YOUR WAY IN THE WOODS USING A MAP & COMPASS

Knowing how to read bearings from a map and apply them on the ground is an important part of orienteering, but not the whole story. Technicians must also be able to follow the contours and physical features on the map to know they are staying on track and to help them pinpoint specific spots on the map when they are reached on the ground.

The contours are very helpful in following locations into drainages, over ridges, down steep slopes or sudden changes in slope, or reaching summits. Always check the surrounding topography while traveling along and make sure it matches closely to the contours viewed on the map.

Whether using aerial photos or maps, physical features like road intersections, edges of fields, large trees standing alone (on photos), boundary corners, streams, etc. can be used to help locate specific points on the ground. As an example, a point on an aerial photo needs to be located on the ground, but it is right in the middle of a dense stand. Find the nearest specific point on the photo that can be accurately located on the ground. Then using the procedures outlined above, determine the bearing and distance from that point to the desired location. Then ride or walk to the known point, set the bearing into the compass, and head in that direction for the measured distance. Make sure to remain on line by checking the bearing every couple of chains. Use the physical features on the photo or map to constantly check the ground location. This will help ensure that the accuracy of the work will be acceptable.

4.6 COORDINATE SYSTEMS ON MAPS

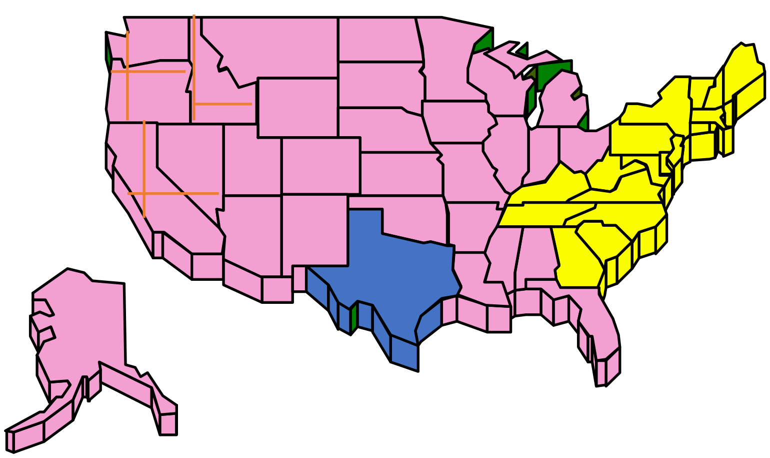
There are multiple coordinate systems used on maps to help people define a specific point on the earth's surface. Some coordinate systems cover the entire earth and some only portions of the earth. This manual will look at two different coordinate systems that cover all or most of the earth and are used around the world. There are then two other coordinate systems that are specific to the United States that will be covered. Most of the USGS quad maps that cover all of the US have all four coordinate systems on them and it is important to be able to locate points on the surface of the earth using all of the systems. These four coordinate systems include:

- The Rectangular System of Survey- one of the most common systems that covers almost three-quarters of the US
- Latitude and Longitude- world-wide
- State Plane Coordinates- US
- UTM (Universal Transverse Mercator)- covers all of the earth except the two pole areas

RECTANGULAR SYSTEM OF SURVEY

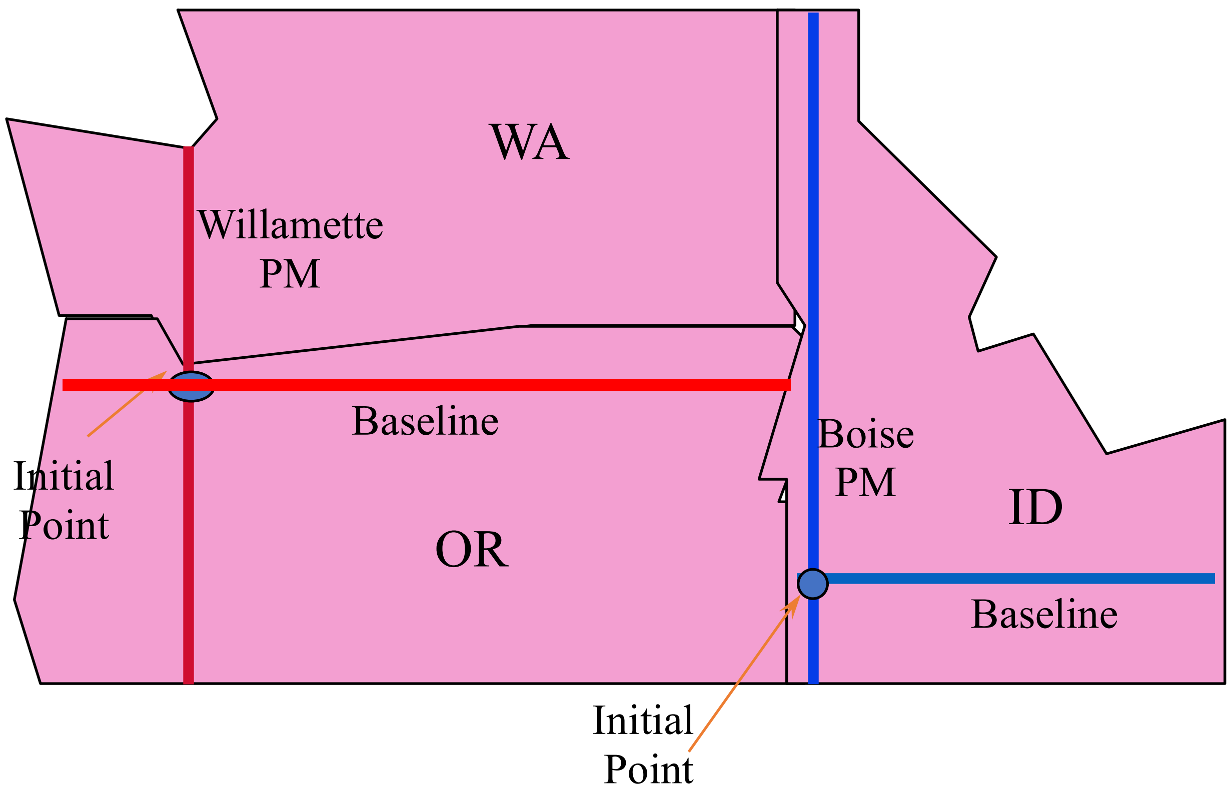
The Rectangular System of Survey was developed in 1785 by Thomas Jefferson in response to the rapid growth of the new country as people pushed west from the original 13 colonies. By the time it was developed, the land in the 13 original colonies and a few other new states had already been surveyed under the old English survey system, Metes and Bounds, shown in yellow in the map below. Survey boundaries in this system were haphazard and based on local landmarks near or on boundary lines, like trees, streams, boulders, etc. This made it very difficult to accurately find corners and boundary lines over time. Due to the inaccuracy, Thomas Jefferson, himself a surveyor, developed a grid system that got away from local landmarks as corners and instead used stakes, posts, and later metal rods as corners in a well-defined grid system. The reddish states in the map below are all surveyed under the rectangular system. Land parcels are all identified by their location based on the Rectangular System.

There is one state that does not fall under either survey system- Texas. It was surveyed before becoming a state using the old Spanish survey system called VARA. This survey system was similar to Metes and Bounds, but used a Vara as the unit of measurement, which was approximated at 33.33 inches. Again, a very inaccurate system, but one that is still in place today.



The Rectangular System covers about 72% of the US and is based on a system of 35 Initial Points that were established by astronomical observation, most covering one of two states. Due to the extreme effect of the curvature of the earth in Alaska, 5 initial points were required to keep the error in each grid to a manageable amount.

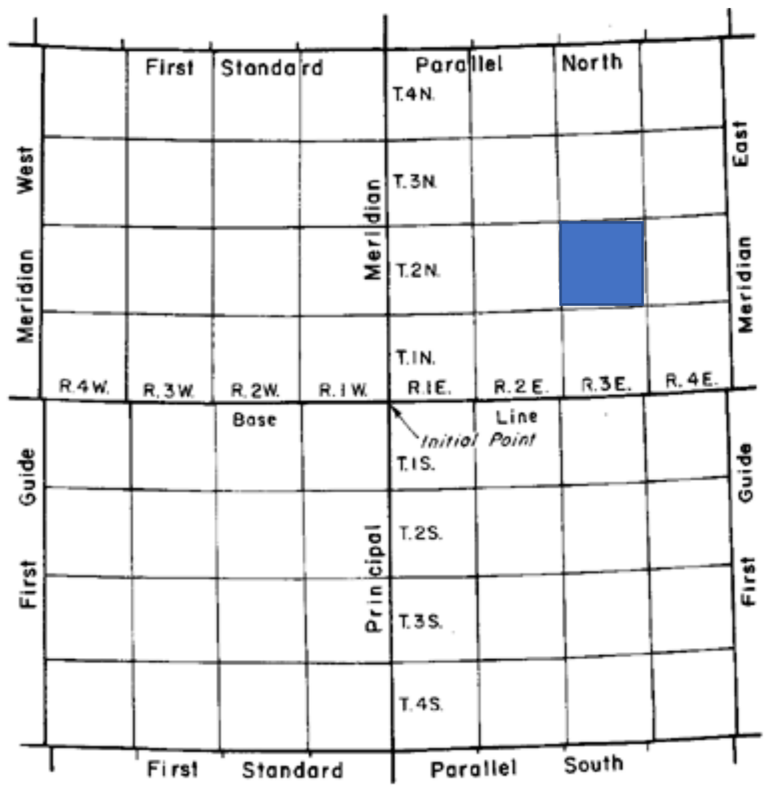
A grid was then developed with a True North-South line running through each Intital Point called a PRINCIPAL MERIDIAN (PM) & True East-West line running through each initial point called a BASELINE (permanent corners set every 1/2 mile on both lines). The first Initial Point is in Ohio and they were surveyed in as they moved west. Focusing on the Pacific Northwest, there is one Initial Point covering both Washington and Oregon, and one Initial Point covering Idaho. This can be shown on the map below:



Each Initial Point is a permanent marker (brass cap, cement monument, etc.) and has a unique number or name. The first Initial Points were numbered, but then they switched to names. The letters after each Initial Point name stands for Principal Meridian. On the map above, the Boise PM is the Initial Point that represents the grid for the state of Idaho. The Willamette PM covers both Oregon and Washington. That Initial Point is close to Portland.

The size of each Initial Point grid is based on the latitude of the grid. Grids could not be too big due to error caused by convergence of longitude lines as they approach North Pole. That is why there are five Initial Points in Alaska. The grids needed to be smaller due to the extreme amount of convergence of longitude lines at those far north latitudes.

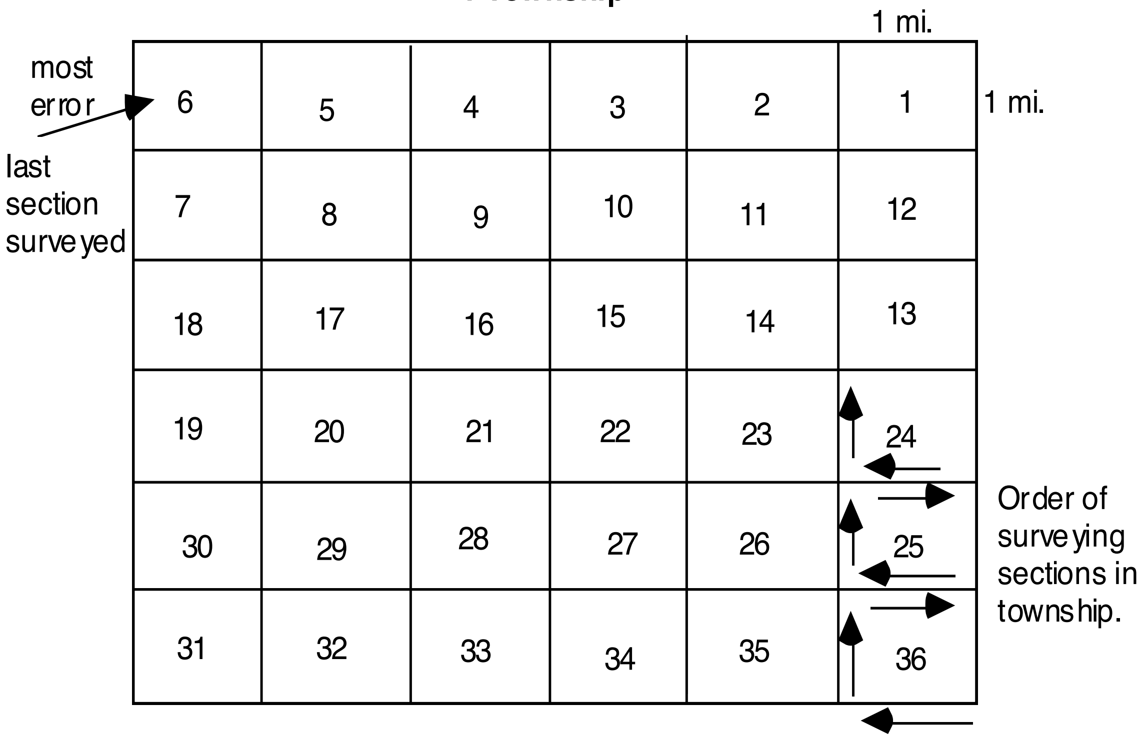
Once the Baseline and Principal Meridian lines were surveyed in to form the X and Y axis for the grid, then the next set of lines could be surveyed in, again putting permanent markers in the ground every half mile going east and west from the Principal Meridian, called the Standard Parallel lines, following lines of latitude, and then north and south from the Baseline, called Guide Meridians, following lines of longitude. These were true east/west, north/south lines. In the 1800s, this required using a transit and shooting the angle from the North Star or the Sun to calculate true directions. The Standard Parallel and Guide Meridian lines were spread out 24 miles apart, creating a square grid around the Initial Point of boxes 24 miles by 24 miles, again with permanent corners every half mile. Note of the drawing below that the Guide Meridians were offset after they hit the next Standard Parallel line going north. This was due to convergence again, as lines of longitude curve over long distances where they all meet at the North Pole.



These 24-mile square blocks were termed a Tract of Land and then became the basis for the next level of subdivision in the Rectangular System. Within each Tract of Land, blocks of 6 miles by 6 miles were surveyed in, again surveying the east-west lines across each Tract of Land first, then the north-south lines, moving from south to north. By the time they reached the next Standard Parallel line to the north, there would be error due to convergence, so the north set of 6 mile blocks were not actually 6 mile squares. This produced another set of corners on each Standard Parallel, so it was important to note whether the corner referred to the land to the south or to the north. Each 6 mile block was then termed a Township. The row of Townships running east and wet were termed a Tier, and the row of Townships running north and south were termed a Range. The Townships in each Initial Point grid were numbered based on the number of Townships north or south from the Baseline and east and west from the Principal Meridian, as viewed on the diagram above. The Township that is shaded out in the diagram above would then have the designation of <u>Tier 2 North, or T2N, Range 3 East, or R3E</u>. That is because it is 2 Tiers to the North of the Baseline and 3 Ranges east of the Principal Meridian, so each Township in the grid has a unique Tier and Range number combination.

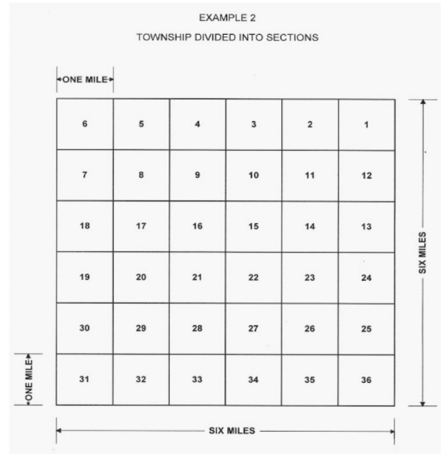
Once the grid of Townships was established, again with permanent corners every half mile around the outside of the Township, each Township was then subdivided into 36 one mile by one-mile sections. This was always done starting in the southeast corner of each Township and surveying to the west a mile, then heading north for a mile. Then back east a mile to tie into the east boundary of the Township to check for error. Then they went back to the west a mile, then north again for a mile and repeated the process until they reached the north boundary of the Township. Again, due to convergence, the northwest corner of the northern most section did not match the southwest corner of the section in the Township just north of that one. The diagram below illustrates the process of surveying sections within a Township, which always pushed the majority of error into the northwest section of the Township.

1 Township



After Section 1 is layed out, surveyors go back to SE corner of Section 35 and repeat process up to Section 2.

Once the 36 sections are surveyed in the Township (corners every half mile), they can be numbered. The numbering of sections in a Township may appear strange, but it allows a person to walk in order from Section 1 to Section 36. Section 1 is always in the NE corner of the Township and Section 36 is always in the SE corner of the Township. Every Township uses the same numbering system. However, due to error from not following proper procedure, it is possible that some of the northern sections can be either much smaller than 1 square mile or much larger. There are some Townships where there is no Section 1 due to running the north-south line from Section 36 into the east Township line before it reaches the north Township line. Interestingly, once the original survey was completed (most in the 1800s), they became official and final, and no corrections could be made.

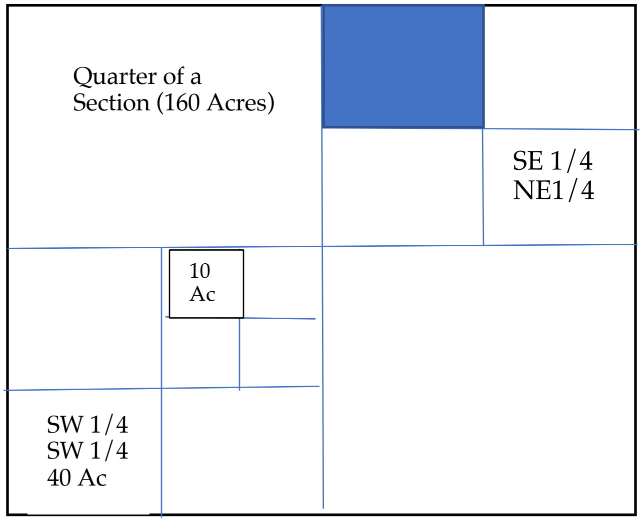


The corners put in at the half mile point along each section line were termed Quarter corners, because if you connect the opposite Quarter Corners of the four section lines, it divides the section into four quarters. The corners at the four corners of each section are termed Section Corners. All of these original corners were either stakes, rocks, or posts. At some point in the late 1800s and early 1900s, the federal government starting using brass caps where the section number, tier and range could be stamped on the top of the cap. Today, most of the replacement caps are made of aluminum, since they are lighter.

Original Rock Corner & new Brass Cap

There is also a process that was developed to make it easier to locate corners that were removed or lost, especially in forested areas. These are called Bearing Trees. Trees close to each corner would have the bark removed and the section number stamped onto the wood in the direction of the corner. A bearing and distance from the Bearing Tree to the corner was measured and recorded in the notes. More recently, Bearing Tree markers are attached to the tree with the bearing and distance to the corner marked on the tag. These have been very helpful in relocating lost corners.

All parcels of land are able to be described using this system, down to a very small size. These are called Legal Land Descriptions. Here, a parcel down to 10 acres in size will be illustrated in the diagram below:



<u>Division of Section 22</u> (640 Acres)
Assume this section is in Tier 4 South, Range 3 East in the Willamette Principal Meridian

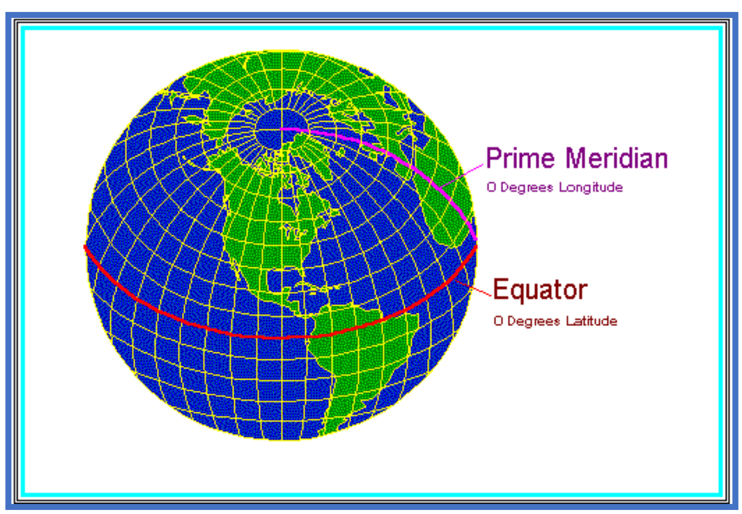
Legal Land Descriptions start with smallest unit & works out to the largest unit (PM). To locate parcel of land on a map, read land description backwards.

Example:
Shaded parcel (40 acres)
NW ¼, NE ¼, Section 22, T 4S, R3E, WPM

In this system, federal Cadastral Surveyors only surveyed down to Quarter Corners - further subdivision was done by private surveyors unless the land was owned by the Federal Government.

LATITUDE AND LONGITUDE

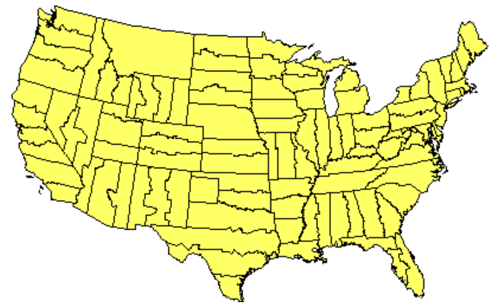
Two coordinates determine the position on the surface of earth's ellipsoid: Latitude (north or south of the equator) and longitude (east or west of the standard meridian at Greenwich, England. Latitude and longitude are measured in degrees, minutes (60' in 1°) and seconds (60" in 1"). The mean minute of latitude defines one nautical mile = 1,852m. The Equator is 0 degrees Latitude, and the Prime Meridian (running north and south through Greenwich, England) is 0 degrees Longitude. The lines of Longitude all converge at the North and South Poles. The North Pole is 90 degrees N Latitude, and the South Pole is 90 degrees S Latitude. The 45 degree N Latitude line (halfway between the Equator and the North Pole) is located close the Salem, OR. Since a sphere has 360 degrees, the Earth is divided into 360 longitudes. The meridian opposite the Prime Meridian (on the other side of the Earth) is the 180° longitude and is known as the *antimeridian*. The Prime Meridian is set as 0° longitude and it divides the Earth into the Eastern and the Western Hemispheres. All the other longitudes are measured and named after the angle they make with respect to the



center of the Earth from the intersection of the Meridian and the Equator. Every point on the earth's surface can be identified with a N-S Latitude and an E-W Longitude (X,Y Coordinates).

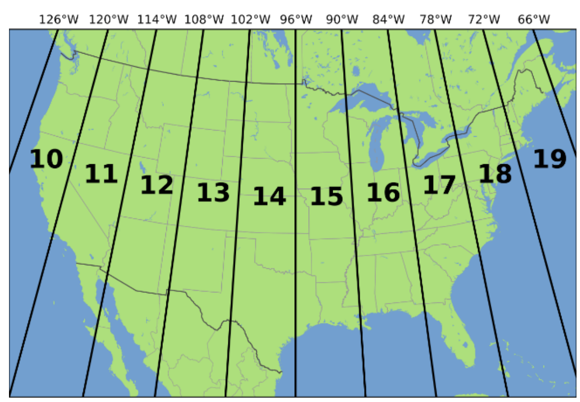
STATE PLANE COORDINATES

In the US, each state has a coordinate system grid that was developed in feet that again allows points on the earth's surface in those states to be located accurately with a X, Y coordinate. The X coordinate is termed the East coordinate, and the Y coordinate is termed the North coordinate. The coordinate zones in the State Plane system are designed to produce positive numbers.



State plane systems were developed in order to provide local reference systems that were tied to a national datum. Some smaller states use a single state plane zone. Larger states are divided into several zones. State plane zone boundaries often follow county boundaries. The x (E), y (N) coordinates are measured in FEET on USGS topo maps in intervals of 10,000 feet. In Oregon, there is a North Zone and a South Zone.

UNIVERSAL TRANSVERSE MERCATOR COORDINATE SYSTEM



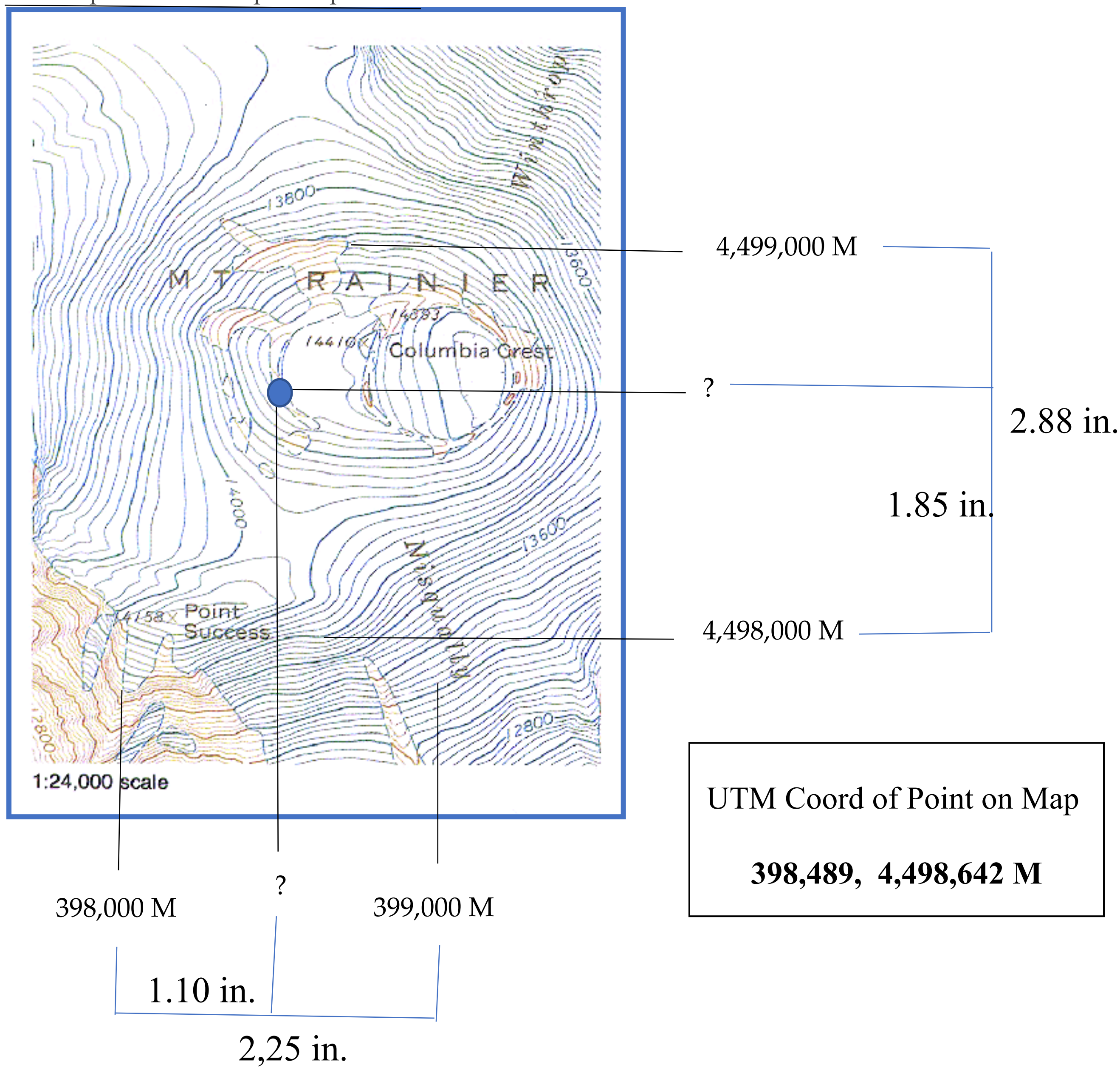
The Universal Transverse Mercator Grid (UTM) was developed by the military in World War II. The UTM system divides the Earth into 60 zones, each 6° of longitude in width. Zone 1 covers longitude 180° to 174° W; zone numbering increases eastward to zone 60, which covers longitude 174°E to 180°. The Polar Regions south of 80°S and north of 84°N are excluded.

UTM coordinates are measured in METERS (x, y) on topo maps. Marks on edge of the USGS topo maps are in intervals of 1000 meters. Western Oregon is in Zone 10, and Eastern Oregon in Zone 11.

4.7 MEASURING COORDINATES ON A MAP USING INTERPOLATION

It is often necessary to determine the coordinates of a point on the ground from a map. For the Rectangular System, a Legal Land Description is determined from the map using the process above. If given a Legal Land Description from a deed, for instance, the parcel can be located on a map by reading the Legal Land Description backwards. The Sections and Townships are shown on USGS topo quad maps as lines in red.

For the other coordinate systems, the x, y coordinates are usually shown on the edges of the map. In order to accurately measure the coordinates of a point inside the map, the process of interpolation is used. Here, a ruler is needed to measure map distances from the known coordinates on the edge of the map and use a proportion to calculate the coordinates of the desired point in the map. The process is illustrated below:



<u>X coordinate</u>

$$\frac{X}{1000} = \frac{1.10}{2.25}$$

X = 488.89 M

UTM X Coord = 398000 + 488.89

= **398,489 M**

<u>Y coordinate</u>

$$\frac{Y}{1000} = \frac{1.85}{2.88}$$

Y = 642.36 M

UTM X Coord = 4498000 + 642.36

= **4,498,642 M**

4.8 PRACTICE PROBLEMS IN TOPOGRAPHIC MAPS

1. Using a map with a scale of 1:16,000, you count 834 dots inside a traverse using a dot grid with a GI of 64 dots/square inch. What is the area of the traverse in acres?

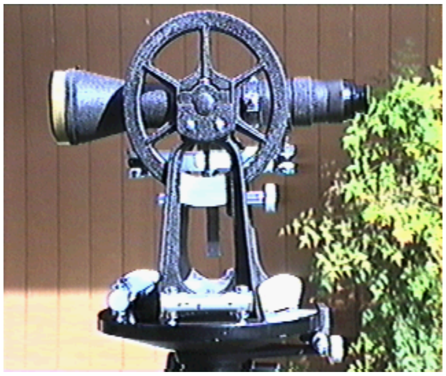
2. Using a map with a scale of 1:16,000, how many feet ground distance are equal to 1 inch on the map? How many chains?

3. A line is measured on the map with the 50 scale ruler and 112 marks are counted. The map scale is 1:15,840. How long is the line in ground distance (feet and chains)?

CHAPTER 5: HIGH LEVEL TRAVERSING

5.1 TRANSIT AND THEODOLITE

High level surveys usually involve the use of a transit or theodolite for turning angles (and measuring distances with an EDM). To match the accuracy level or Ratio of Error with the angle instrument, distances should be measured at a similar level of accuracy, which usually means either steel tapes or EDM.



Transits have been around for hundreds of years and usually read angles down to at least the nearest 15 to 30 minutes. They are able to measure both vertical angles and horizontal angles. The scope is able to rotate 360 degrees vertically which allows back sights and deflection angles to be read accurately.

The scales used to measure angles are called verniers. Many transits also have a compass built in to allow reference points and beginning assumed bearings to be read. They also have two sets of knobs for both the vertical and horizontal verniers. One is a clamp screw that releases the Vernier scale for large movement. The other is a tangent screw that allows for small, fine movement of the Vernier once the clamp screw is tightened. That way the cross hairs in the scope can easily be put on the exact point. These instruments also have 4 leveling screws and level bubbles to ensure proper leveling of the instrument every time it is set up.

Most high level surveys are now done using a theodolite since the price difference with transits has diminished over recent years, and theodolites have more accuracy and versatility. Most theodolites read horizontal angles down to the nearest 1 second and have an EDM built in to measure distances with a prism. So the rest of the information regarding high level traversing will assume the use of a theodolite.

A theodolite can be defined as a precision optical instrument for measuring angles between designated visible points in the horizontal and vertical planes. The traditional use has been for land surveying, but they are also used extensively for building and infrastructure construction, and some specialized applications such as meteorology and rocket launching. Most theodolites do not have a built-in compass.

Other uses of a theodolite include:

- Boundary Line Traversing - horizontal & vertical angles, directions, distances
- Prolonging Straight Lines
- Determining Unknown & Inaccessible distances of lines (triangulation)
- Measuring Angles by repetition
- Measuring Intersection of lines

SETTING UP A THEODOLITE AND READING ANGLES

Steps for setting up a theodolite in the field include:

- Set tripod so head is level
- Set tripod legs firmly in ground
- Put Plumb bob on hook & set just above tack in stake (loosen level screws to move spindle). Modern theodolites now have an optical plummet which allows the centering of the instrument over a set point while on the tripod.
- Most Theodolites have three leveling screws. Level the instrument, first getting bullseye bubble centered with optical plummet near the point. Then turn instrument so that the leveling bubble above the screen is between two of the three leveling screws. Turn the leveling screws either both in or both out at the same time. The bubble will move in the direction of the left thumb. Then turn the instrument to line up with two other leveling screws and repeat until level bubble is centered in all the directions.
- Loosen the horizontal clamp screw and locate the previous point using the Collimator above the scope. Then using the scope, find the point and put the center cross hair close to the tack on top of the stake.
- Tighten the horizontal clamp screw when the cross hair is close to the point and then use the horizontal tangent screw to put the cross hair right on the point. Both the horizontal and vertical clamp screws should be tight.
- Set the horizontal angle to zero degrees.
- Once the cross hair is on the previous point, and the horizontal scale is set to 0^{o}, the horizontal clamp screw can be loosened which will then turn the angle in the instrument. The type of angle being used will dictate the way the instrument is turned to the point ahead.
- Again, once the cross hair is close to the point ahead, the horizontal clamp screw is tightened, and the horizontal tangent screw is then used to get the cross hair exactly on the top of the tack in the stake of the point ahead. Then the vertical clamp screw can be tightened. Both the vertical and horizontal angles can then be read.
- On most theodolites, angles are given digitally, so the instrument person can read the horizontal and vertical angles directly once the cross hair is put right on the point.

5.2 TRAVERSING WITH THEODOLITES

Traverses run using a theodolite and steel tape or EDM for distances produce a high level of accuracy and precision. This requires computations and map production using higher level processes than explained in Chapter 4, which focuses on reading bearings or azimuths for obtaining angles at each station. With a theodolite (or transit), angles are read directly at each station and can be read down to minutes and seconds (described below). This process will be described along with a common computation method which involves mathematics, latitudes and departures. These types of traverses are now computed with maps drawn using computers and plotters. For the purpose on this manual, the hand process for accomplishing this is detailed to provide a basic foundational understanding of how these results are obtained.

TURNING ANGLES WITH A THEODOLITE

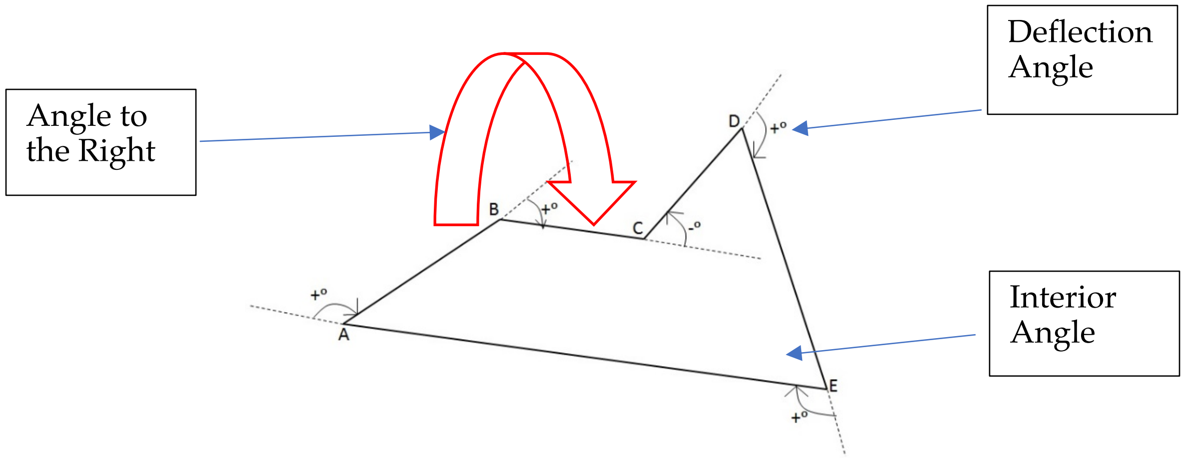
There are basically three different types of angles that can be read with a transit or theodolite at each traverse station. The same type of angle should be read at every station in a particular traverse to prevent confusion. It is common to calculate one or both of the other type of angles in a traverse to provide mathematical checks, which helps to prevent mistakes and personal errors.

Interior Angles
This is where the instrument person lines up the cross hairs in the theodolite scope on the previous point and then turns the angle inside the traverse to the point ahead, recording the interior angle directly. The math on these can be easily checked for a closed traverse by using the formula (N-2)180 degrees, where N= number of sides in the traverse.

Deflection Angles
These are common angles to turn in an open or closed traverse. They require using an instrument with a scope that is able to flip vertically to point 180 degrees from the back line. Here, the instrument person lines up on the previous point. The scope is flipped so it points 180 degrees from the previous line. The angle is then turned either left or right to the point ahead. A left deflection angle is considered a -, and a right deflection angle is considered a +. Summing all the right deflection angles and subtracting it from the sum of the left deflection angles produces a difference that should equal 360 degrees. The difference between the actual total and 360 degrees is the angular error of closure.

Angles to the Right
Here, the instrument person lines up on the previous point and then turns an angle to the right (always to the right) to the point ahead. This is the least common method for reading angles, since it could equal the interior angle but not always.

Below if a diagram illustrating all three types of angles in a traverse.



MEASURING ANGLES DOWN TO SECONDS

Since degrees, minutes, and seconds (DMS) are based on a scale of 60, whereas calculators are based on the 10 scale, it is challenging working with degree calculations. This section will show a way to convert degrees, minutes, and seconds (DMS) into decimal degrees (DD) so they can then be plugged into a calculator. Calculators with DMS buttons will do this conversion automatically. Without that function on the calculator, this method works best.

There are 60 minutes in each degree. There are 60 seconds in each minute. There are 360 degrees in a full circle.

Adding angles by hand -

$$\begin{array}{r} 55^{o}\ 33'\ 20'' \\ +\ \underline{35^{o}\ 44'\ 40''} \\ 90^{o}\ 77'\ 60'' = 90^{o}\ 78' = 91^{o}\ 18' \end{array}$$

Subtracting Angles by hand -

$$\begin{array}{rcr} 135^{o}\ 14'\ 20'' & \text{becomes} & 134^{o}\ 73'\ 80'' \\ -\ \underline{24^{o}\ 35'\ 40''} & & -\ \underline{24^{o}\ 35'\ 40''} \\ & & 110^{o}\ 38'\ 40'' \end{array}$$

A calculator is required to convert decimal degrees to DMS and back. Some calculators have a DMS function that allows the automatic conversion back and forth. If the calculator being used does not have that function, the conversion has to be done by hand using the following steps with a calculator:

Convert 32 degrees, 15 minutes, 43 seconds to decimal degrees.
Starting with the seconds, divide them by 60 to obtain the decimal minutes.
43/60 = 0.72 minutes
Add the decimal minutes to the whole number minutes
15+0.72 = 15.72 minutes
Divide the decimal minutes by 60 and add to degrees to obtain the decimal degrees.
15.72/60 = 0.26 + 32 degrees = 32.26 degrees
This is the number that needs to be used in the calculator when using the trig formulas for

converting slope distance to horizontal distance or when doing any calculating of an angle in the calculator.

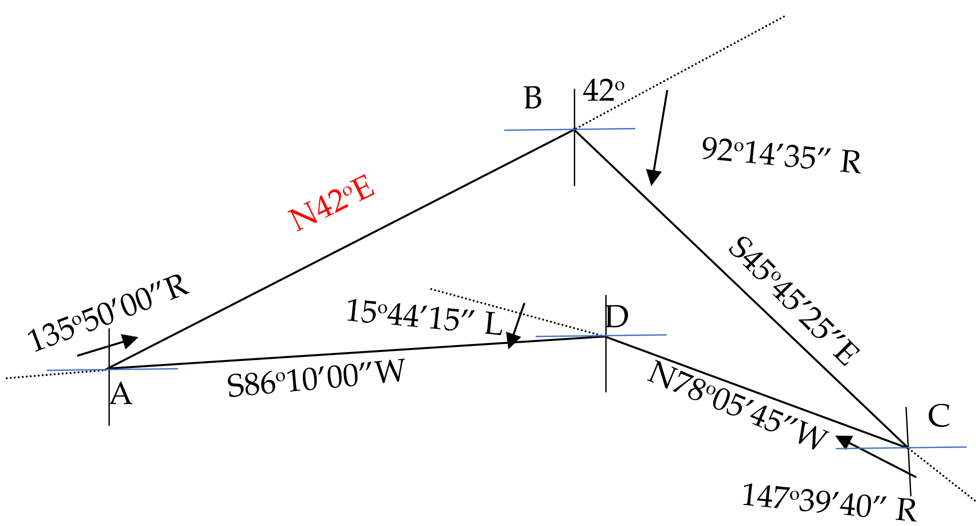
To convert an angle in Decimal degrees back to Degrees, minutes, and seconds, the steps are reversed:
28.3766 degrees = what in degrees, minutes, seconds?
Take the decimal part of the angle (0.3766) and multiply by 60 to convert to decimal minutes.
0.3766 X 60 = 22.60 minutes.
Take the decimal part of the minutes and multiply by 60 to get the seconds.
0.60 X 60 = 36 seconds
The converted angle is 28 degrees, 22 minutes, 36 seconds.

CALCULATING BEARINGS/AZIMUTHS FROM ANGLES

The calculations to balance a traverse and distribute the error involves using bearing directions and a process called Latitudes and Departures. This process will be covered in the following section. Since the use of theodolites to run a traverse in the field involves reading angles at each traverse point, and most theodolites do not have a compass built in, a beginning bearing is needed for the first line of the traverse. This can be obtained by astronomical observations which produces the true, accurate direction of a line, or it can be assumed (as accurate as a compass can provide). This is usually good enough for most surveys, especially if the traverse points can be tied to a known, permanent point in the field.

With a bearing on the beginning line of the traverse, the remaining bearings then need to be calculated using the angles read with the theodolite. Since these angles are read down to seconds, it will involve using the skills learned in the previous section to add and subtract angles in DMS.

An example problem will illustrate the process of calculating bearings from deflection angles (starting bearing in red provided by hand compass):



- First, add up the R Deflection angles and subtract from the L deflection angle. This total should be 360°. It is, so the angular error of closure = 0°.
- Draw a cross at each station to see where the lines fall on compass circle.
- At Point B, add 42° to deflection angle 92°14’35” and subtract from 180° to get bearing of line BC (use 179°59’60” when subtracting angles from 180°).
- This should equal a bearing of S45°45’25”E for line BC.
- Next, use that bearing angle at Point C and subtract from the deflection angle at C which is 101°54’15”. Since this is more than 90°, that indicates the bearing is in the NW quadrant going from C to D, so subtract 90° to find out how far into the NW quadrant it goes. This is 11°54’15”. To get the bearing from C to D, subtract that angle from 90° to get the bearing angle from N.
- This calculates a bearing of N78°05’45”W for line CD.
- At Point D, add this bearing angle to the deflection angle. Since this total is over 90°, it indicates that the line DA is in the SW quadrant by 3°50’. This angle needs to be subtracted from 90° to obtain the bearing angle from the S line. This would then be S86°10’00”W.
- As a check, at Point A, add the deflection angle to the bearing angle to see if it calculates the bearing for line AB to be N42°E, which it should since the angular error of closure is 0°. Adding the 135°50’ R deflection angle to the 86°10’ bearing angle and subtracting from 180° gives a bearing angle of 42° in the NE quadrant, which is the beginning bearing. The math checks out.

MEASURING DISTANCES IN A HIGH LEVEL TRAVERSE

Most theodolites contain an electronic distance measuring device that is built in and is termed an EDM. These instruments are typically called a <u>Total Station</u>. It produces a laser beam of light that travels to a prism on the other end of a line. The prism is a piece of glass that is designed to bounce the beam of light and return it at the exact angle it came into the prism. The EDM then measures the amount of time it takes for the beam of light to hit the prism and bounce back to the instrument. This is then converted to a distance and displayed on the theodolite screen. This is the most accurate method of measuring distances and can exceed a ratio of error of 1:1,000,000. Distances of 2-3 miles can be read with an EDM and prism. These long distances require an array of many prisms connected together to help capture the light beam.

Most Total Stations will take the Vertical Angle and the VD measured with the EDM and convert it in the theodolite to HD. So, vertical angle, % slope, VD, SD, and HD can all be obtained on the theodolite screen.

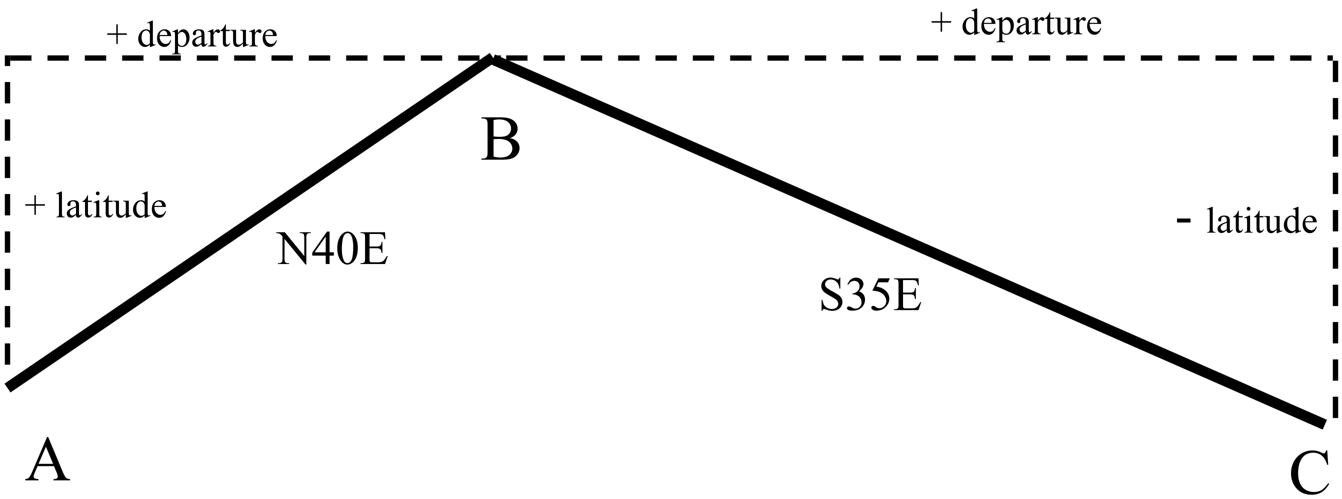
5.3 HIGH LEVEL TRAVERSE COMPUTATIONS

Traverse computations for high level traverses is usually done by computer. The following process is a common method in surveying and provides a foundational understanding of how these computations are done to produce accurate results for the data taken in a theodolite-taping or EDM survey. This method is termed Latitudes and Departures, which is detailed below.

LATITUDES AND DEPARTURES

- Calculate Interior Angles and check Angular Error of Closure using the (N-2)*180 Rule or use Deflection Angles and compare total of left – right angles to 360^o for Angular Error of Closure.
- If Angular Error of Closure is acceptable, distribute error evenly among all stations.
- Calculate Bearings from corrected interior angles (or deflection angles).
- Calculate Latitudes and Departures using Bearings and Horizontal Distances of each line in the traverse.

- **Latitude** of a Line - Distance of the line extended in a north or south direction (N is +, S is -).
- **Departure** of a Line - Distance of the line extended in an east or west direction (E is +, W is -).



- LATITUDE = Cosine (bearing angle) X Horiz. Distance (N bearing is +, S bearing is -)
- DEPARTURE = Sine (bearing angle) X Horiz. Distance (E bearing is +, W bearing is -)
- LINE AB = N 40^o E, 374 Feet
- **Lat** = Cos 40^o X 374 = 0.76604 X 374 = + 286.50062
  (Lat is + because direction is North) (Carry out to 5 decimals)
- **Dep** = Sin 40^o X 374 = 0.64279 X 374 = + 240.40257
  (Dep is + because direction is East)

- Sum up Lats & Deps (North Lats are +, South Lats are -, etc.) to get Lat and Dep ERROR.
- Calculate the Linear Error of Closure using the following formula:
- Calculate the Ratio of Error using the following formula:

Linear Error of Closure = $\sqrt{(lat\ error)^2 + (dep\ error)^2}$

Ratio of Error = $\frac{\text{Linear Error of Closure}}{\text{Perimeter Distance}} = \frac{1}{X}$

Following is an example problem that covers all the steps from providing corrected bearings and distances for a traverse to calculating the ratio of error, area, and mapping coordinates for a closed traverse. Note that the bearing angles that are in DMS will need to be converted to DD to use in the trig formulas to calculate the latitudes and departures.

					LATITUDE		DEPARTURE	
Station	**N-S**	**E-W**	**Bearing**	**Distance**	**N(+)**	**S(-)**	**E(+)**	**W(-)**
A								
	N	**E**	40	374	286.50062	0.00000	240.40257	0.00000
B								
	S	**W**	30.5	332.4	0.00000	286.40553	0.00000	168.70575
C								
	S	**W**	89.75	70	0.00000	0.30543	0.00000	69.99933
A								
				776.40	286.50062	286.71096	240.40257	238.70509
					LAT Error =	-0.21034	DEP Error =	1.69748
				LEofC =	1.71		R of Error = 1/	453.91

BALANCING LATITUDES AND DEPARTURES

- If the Ratio of Error is acceptable, then calculate the corrected lats and deps for each line in order to calculate the corrected bearings and distances of each line. This will remove the error out of the traverse.
- Use the Compass Rule to calculate the correction for each Lat and Dep with following formula:

  Lat Correction = $\frac{\text{Horiz. Distance X Lat Error}}{\text{Perimeter}}$

  Dep Correction = $\frac{\text{Horiz. Distance X Dep Error}}{\text{Perimeter}}$
- If Lat Error (or Dep Error) is +, use the corrections to make the N Lats (E deps) smaller and the S lats (W deps) larger.
- If Lat Error (or Dep Error) is -, use the corrections to make the N Lats (E deps) larger and the S lats (W deps) smaller.
- The Sum of the corrected Lats (N-S Lats) and corrected Deps (E-W) should now be 0.

Employing the Compass Rule on the example problem, the Sum of the corrected Lats (N-S Lats) and corrected Deps (E-W) should now be 0.

LAT Correction	DEP Correction	Correct LAT (N)	Correct LAT (S)	Correct DEP (E)	Correct DEP (W)
A					
-0.10132435	0.8176941	286.6019461	0	239.5848719	0
B					
-0.09005405	0.726742	0	286.315479	0	169.432494
C					
-0.01896445	0.1530444	0	0.2864672	0	70.152378
A					
Total.....		286.6019461	286.601946	239.5848719	239.584872
		LAT ERROR =	0.00000	DEP ERROR =	0.000000

CALCULATING CORRECT BEARINGS AND DISTANCES

- If the Sum of the corrected Lats (N-S Lats) and corrected Deps (E-W) should now be 0, then calculate the corrected distances and bearings of each line using the following formulas:

Corrected Distance = $\sqrt{(Correct\ \ Lat)^2 + (Correct\ \ Dep)^2}$

Corrected Bearing = ArcCosine $\dfrac{(\text{Correct Lat})}{(\text{Correct Dist})}$

Check the sign (+/-) of the corrected Lat and Dep to verify the quadrant of the correct bearing.

Distance	Bearing	
A		
373.55	39.8939	NE
B		
332.69	30.6157	SW
C		
70.15	89.7660	SW
A		
776.397553		

These corrected bearings are in decimal degrees, and should then be converted to DMS.

Corrected
TOTAL Perimeter Distance

CALCULATING COORDINATES

Start with an assumed beginning X, Y coordinate for the beginning point,. They should be large enough so all the coordinates will be positive (in NE quadrant). Then the process for calculating the coordinates of each point in the traverse is as follows:

- Add the first corrected Lat to the beginning point Y coordinate to get the Y coordinate for the second point (take into account +/- signs on Lats).
- Add the first corrected Dep to the beginning point X coordinate to get the X coordinate for the second point.
- Continue adding the next corrected Lat to the Y coordinate just calculated to get next Y coordinate (using Deps to get X coordinate). The last coordinate + last Lat (or Dep) will bring you back to the first Y (or X) coordinate, which is a math check that they were correctly calculated.

Use Corrected Deps to calculate X coordinate

Check

	X Coordinate	Y Coordinate	
A	1000	1000	Start with assumed number for 1st coordinate
B	1239.58	1286.60	1st Y Coord. + Corrected LAT for line AB (+286.60195)
C	1070.15	1000.29	2nd Y Coord. + Corrected LAT for line BC (-286.31548)
A	1000.00	1000.00	3rd Y Coord. + Corrected LAT for line CA (-0.286467): should bring you back to original coordinate for Pt. A

CALCULATING TRAVERSE AREA

To calculate the area inside a closed traverse with Lats and Deps, the DOUBLE MERIDIAN DISTANCE (DMD) Method will be used. The process for the DMD Method is:

Calculate the DMD of each line (take +/- signs into account) with the following steps:
- DMD of first line = 1st Corrected DEP
- DMD of second line = 1st DMD+1st Corrected DEP+2nd Corr. DEP
- DMD of third line = 2nd DMD+2nd Corrected DEP+3rd Corr. DEP
- Continue through traverse to last line
- LAST DMD should equal the last Corr. DEP, but with the opposite sign.

For the example problem, the DMDs are calculated to be:

	Correct DEP (E)	Correct DEP (W)	DMD
A			
	239.5848719	0	239.5849
B	0	169.4324939	309.7372
C	0	70.152378	70.1524
A			

Dep (E) is +
Dep (W) is -

1st DMD=1st DEP

2nd DMD=1st DMD+1st DEP+2nd DEP

3rd DMD=2nd DMD+2nd DEP+3rd DEP

Last DMD=last DEP with opposite sign

Next, the Area inside the closed traverse can be calculated using the Corrected Lats and the DMDs for each line (take into account +/- signs). The formula to calculate the Area is:

- DOUBLE AREA = Corr. LAT X DMD (for each line)
- Sum the Double Areas algebraically (N Lats are positive and S Lats are negative)
- Traverse Area = Sum of Double Areas divided by 2
- If the line distances are in feet, the area is in square feet
- The Square Footage divided by 43,560 converts the area into Acres

Correct LAT (N)	Correct LAT (S)	DMD	Double Area
286.6019461	0	239.5849	68665.49054
0	286.3154789	309.7372	-88682.56903
0	0.286467199	70.1524	-20.09635522
			(20,037.17)
		AREA (sq.ft.) =	10,018.59
		Area (acres) =	0.23

Lat (N) is +
Lat (S) is -

Double AREA = LAT X DMD

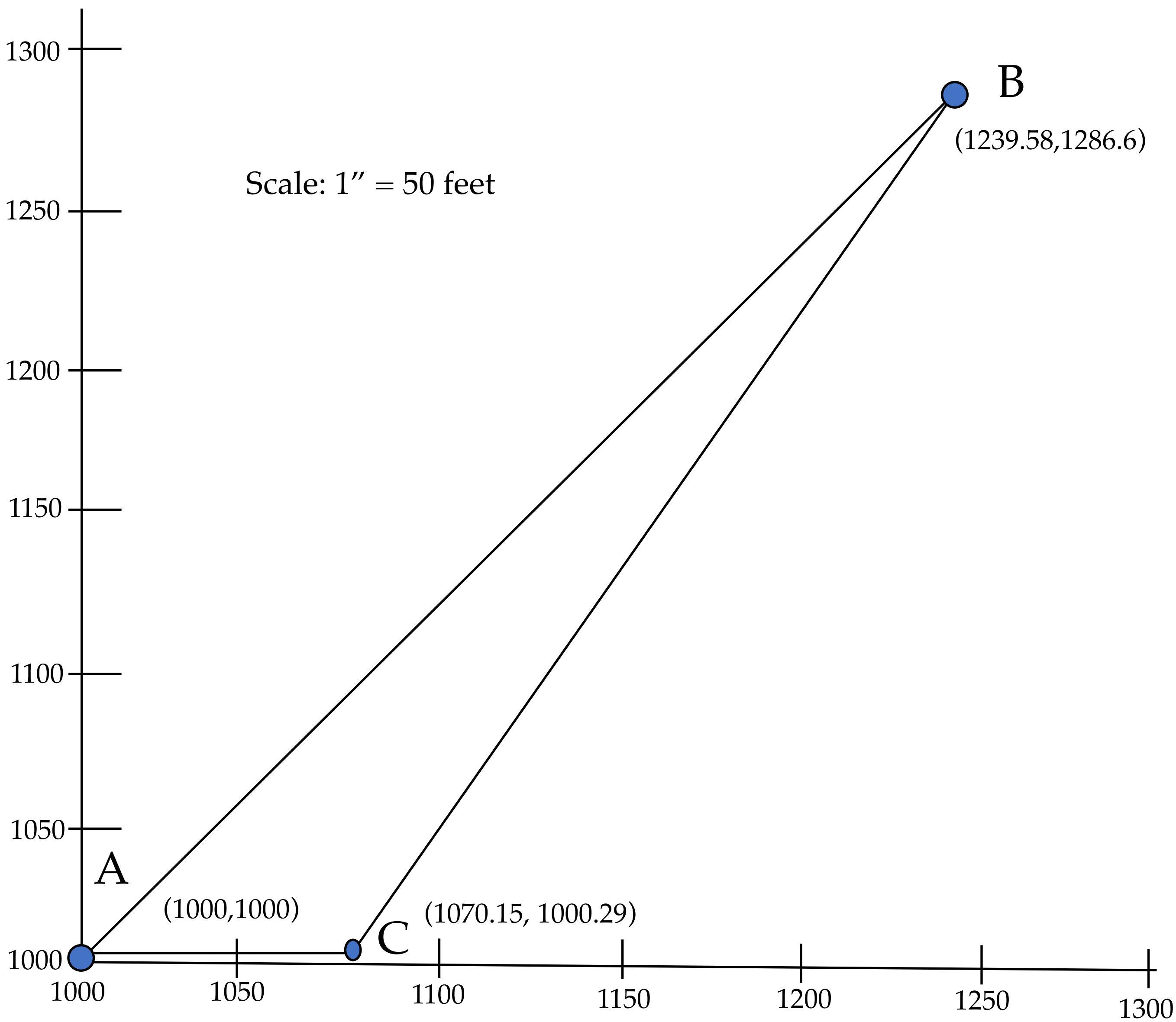
Algebraic sum of Double Areas/2 = AREA in sq.ft.

Area in sq.ft./43,560 = acres

TRAVERSE MAPPING WITH COORDINATES

As mentioned above, high level survey computations and maps are usually now done using computers and plotters. In order to better understand the concepts behind how these results are obtained, the steps involved in plotting a traverse using x, y coordinates will be summarized here. This will produce a much more accurate map than using a protractor and ruler using the bearings and distances of each traverse line.

- Set up X,Y grid on graph paper & label X & Y axis with coordinates on every inch - to scale.
- Plot X, Y coordinates of each point in traverse and label on paper as shown below.
- Measure bearing & distance of each line on paper with protractor & ruler to check plotting accuracy.
- Transfer points from graph paper to formal map paper using light table.
- Connect points with lines and add other information to map.



5.4 PRACTICE PROBLEMS IN HIGH ACCURACY TRAVERSE COMPUTATIONS

1. What is the difference between these two angles in DMS?
   72°28'42" and 34°42'51"

2. Convert 78.6159° to DMS.

3. Convert 38°41'51" to Decimal Degrees (DD).

4. What is the Angular Error of Closure for a Deflection Angle closed traverse with the following Deflection Angles?
   A= 146° L
   B= 138° L
   C= 147° L
   D= 72° R

5. Calculate the bearings of the lines BC and CA from the deflection angles and the Angular Error of Closure:
   a. Line AB= S28°W
   b. Deflection angle at Point B= 132°28'45" L
   c. Deflection angle at Point C= 157°31'10" L
   d. Deflection angle at Point A= 70°00'05" L

6. For the following closed traverse, calculate the following:
   a. Corrected Bearings and Distances
   b. Ratio of Error
   c. X, Y Coordinates if A=500, 500
   d. Area in Acres

	Bearing	Distance (ft)
A		
	N 38°E	368.00
B		
	S29°W	328.44
C		
	N89°38'W	68.25
A		

APPENDIX A: ANSWERS TO PROBLEMS

1.8A ANSWERS TO PRACTICE PROBLEMS IN HORIZONTAL MEASUREMENTS

1) a) Feet per pace = $\frac{(5 \text{ X } 66)}{54.5} = \frac{330'}{54.5} = 6.055$ ft / pace

b) 6.055 ft per pace X 95.5 paces = 578.26 ft.

c)
$$\begin{array}{r} 581.00 \text{ ft.} \\ -\ \underline{578.26} \text{ ft.} \\ 2.74 \text{ ft. error} \end{array} \qquad \frac{2.74' \text{ error}}{581' \text{ corr. dist.}} = \frac{1}{X}, \quad X = 211.8$$

Ratio of Error = $\frac{1}{211.8}$

d) Yes, since the Ratio of Error exceeds 1/50.

2) $\frac{24.93}{100} = \frac{X}{66}$, so X = 16.45 Topo Slope

$\frac{21}{66} = \frac{X}{100}$, so X = 31.82% slope

3) Paces per Chain = 66 ft per chain/5.26 ft per pace = 12.5
= 220 paces walked/(1175'/66) = 12.3 = 12.5

Pacing Distance = 5.26 ft per pace X 220 paces = 1157.2 ft.

$$\text{Ratio of Error} = \begin{array}{r} 1175.0' \\ -\ \underline{1157.2'} \\ 17.8' \text{ error} \end{array} \qquad \frac{17.8}{1175} = \frac{1}{X}, \text{ so } X = 66 \qquad \text{Ratio of Error} = \frac{1}{66}$$

It is Acceptable

4) Average number of paces walked = 95.6
Total Feet walked = 8 chains X 66 = 528'

Feet/Pace = 528'/95.6 paces = 5.52' per pace
Paces/Chain = 95.6 paces/8 chains = 11.95 = 12 or 66/5.52 = 11.95 = 12

5)

45 X 4.8' per pace on level =	216'
61 X 4.4' per pace on moderate =	268.4'
32 X 3.9' per pace on steep =	124.8'
	609.2' total horizontal distance

2.6A ANSWERS TO PRACTICE PROBLEMS IN LEVELING

6. BM1= 500.00'
   BS= 5.21' HI= **505.21** FS=3.19'
   BS=7.36' HI= **509.38** FS= 4.28'
   BM2= **505.10**

7. Calculate the allowable error for the following level loop:
   $C = (+/- 0.40\sqrt{M})$
   BM1= 600.00' BM1 to TP1= 350'
   TP1= 603.44' TP1 to TP2= 420'
   TP2= 609.11' TP2 tp BM1= 380'
   BM1= 600.17'
   Is the level loop an acceptable accuracy? **C = 0.1867'; Error = 0.17'; Accuracy is Acceptable**
   Corrected elevations for TP1 and TP2? **TP1= 603.39'; TP2= 609.00**

8. Profile Leveling: complete the notes and calculate the elevation of each point.
   0+00 = 45.63'
   BS=3.58' IFS=2.99'
   0+60= **46.22**
   FS- 2.83'
   1+10= **46.38**
   BS= 4.22' IFS= 3.98'
   1+60= **46.62**
   IFS= 2.78'
   2+10= **47.82**
   FS= 3.16'
   2+85= **47.44**
   What is the % grade between station 2+10 and 2+85?
   47.82-47.44= 0.38/75= 0.01= -1%

9. SD between points A and B is measured at 98.34'. Slope Angle = +22%.
   Calculate the VD.
   If the elevation of Point A = 32.44', what is the elevation of Point B?

   22%/100= 0.22inv tan= 12.41°
   VD= Sin(12.41°) X 98.34 = 21.13'
   Elev of Point B= 32.44+21.13 = 53.57'

3.2A ANSWERS TO PRACTICE PROBLEMS IN MEASURING DIRECTION

1) $360 - 24 = 336^o$
   $72 = 72^o$
   $180 + 62 = 242^o$
   $180 - 17 = 163^o$

2) $180 - 100 =$ S 80^o E
   $360 - 280 =$ N 80^o W
   $23 =$ N 23^o E
   $182 - 180 =$ S 2^o W

3) True Bearing = N 64^o W
   True Azimuth = 296^o

4) Magnetic Azimuth = 256^o
   Magnetic Bearing = S 76^o W

5) Magnetic Bearing of Line AB in 1985 = S 85^o E
   True Bearing of Line AB in 1985 = N 86^o E

3.5A ANSWERS TO PRACTICE PROBLEMS IN TRAVERSING

1) Interior angles are as follows:

$A = 60^o$
$B = 150^o$
$C = 105^o$
$D = 48^o$
$E = 267^o$
$F = 90^o$

2) Angular Error of Closure = 0^o

$(N-2)\ 180^o = (6-2)\ 180^o = (4)\ 180^o = 720^o$
Sum of Interior angles = 720^o

3)

STA	CORR FS	CORR BS
AB	N 41^o E	S 41^o W
BC	N 19^o W	S 19^o E
CD	S 29^o W	N 30^o E

4.3A ANSWERS TO PRACTICE PROBLEMS IN TRAVERSE COMPUTATIONS

1) a) $\frac{1"}{10 \text{ ch}} = \frac{0.23"}{X}$, so the Linear Error of Closure = **2.3 chains**

b) Perimeter = 135.7 chains, so the Ratio of Error = $\frac{2.3 \text{ ch}}{135.7 \text{ ch}} = \frac{1}{59}$

2) s= 72.6, so Area = 875.79 sq. ch. = **87.58 acres**.

4.8A ANSWERS TO PRACTICE PROBLEMS IN TOPOGRAPHIC MAPS

1) Acres per dot = $\frac{16000^2}{(43560)(144)(64)}$ = 0.638 acres per dot X 834 dots = **531.8 acres**.

2) $\frac{1}{16000} = \frac{1''}{1333.33'}$ because 16000”/12 inches per foot = **1333.33’**

1333.33’/66’ per chain = **20.2 chains**

3) 112 marks X .02” per mark = 2.24” on map.

$\frac{1}{15840} = \frac{1''}{1320'} = \frac{2.24''}{X}$, so X = 2956.8’ = **44.8 chains**

5.4A ANSWERS TO PRACTICE PROBLEMS IN HIGH ACCURACY TRAVERSE COMPUTATIONS

1. What is the difference between these two angles in DMS?
   72°28'42" and 34°42'51"
   37° 45' 51"

2. Convert 78.6159° to DMS.
   0.6159 X 60 = 36.95'; .95 X 60 = 57"
   78° 36' 57"

3. Convert 38°41'51" to Decimal Degrees (DD).
   51/60 = 0.85' + 41 = 41.85'/60 = 0.6975° + 38 = 38.6975°

4. What is the Angular Error of Closure for a Deflection Angle closed traverse with the following Deflection Angles?
   A= 146° L
   B= 138° L
   C= 147° L
   D= 72° R
   Sum of L Deflection Angles = 431°
   Sum of R Deflection Angles = 72o
   Difference = 431-72= 359°
   Difference of Deflection Angles (L-R) should = 360°
   Angular Error of Closure = 1°

5. Bearing of Line BC= **N75°31'15"E**
   Bearing of Line CA= **N81°59'55"W**
   Angular Error of Closure = **0°**

6. For the following closed traverse, calculate the following:
   a. Corrected Bearings and Distances
   b. Ratio of Error
   c. X, Y Coordinates if A=500, 500
   d. Area in Acres

	Bearing	Distance (ft)	**Correct Bearing**	**Correct Dist**
A				
	N 38°E	368.00	**N 38° 12' 02" E**	**367.07'**
B				
	S29°W	328.44	**S 28° 49' 32" W**	**329.44'**
C				
	N89°38'W	68.25	**N 89° 52' 13" W**	**68.17'**
A				

Ratio of Error = 1/232.11
X, Y Coordinates: A= 500, 500 B= 727, 788.47 C= 568.17, 499.85
Area in Acres = 0.23 Acres