# ACCURACY OF COMMUNITY-BASED SPATIAL DATA COLLECTION IN A GIS

by

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# Accuracy of Community-Based Spatial Data Collection in a GIS

**Abstract**

Training high school students to conduct field mapping and data collection of wildlife habitat on public lands produces important data for local government geographic information systems and introduces students to the field of geography. However, the positional accuracy of the spatial data is important for use in a GIS, as inaccurate data can lead to erroneous results and legal issues. A field mapping manual was created which attempted to provide the methodology for accurate spatial data collection. The data collected by the students were assessed for positional accuracy, and the data were evaluated for potential use in a geographic information system. Although the collected spatial data have an rms error of 16.1 meters and do not meet the accepted standards, they still provide new and useful information for the local municipal GIS. Recommendations for improving the quality of the data include a revision of the field mapping manual, more precise tools, and an increased involvement of the students in the maintenance of the GIS database.

## 1. Introduction

Oregon's Statewide Planning Goal Number 5 requires each municipality to inventory the location, quality, and quantity of, among other things, its open spaces, natural areas, and wildlife habitats (LCDC 1995). The development of geographic information systems and more powerful microcomputers provide the ideal place to store and manipulate these data. However, while these inventories provide a wealth of information, they are often prohibitively expensive to carry out, with data collection being attributed to 80% of GIS costs (Thapa and Burtch 1991).

One method that has been used in the past for geographic inventories is to train high school students to conduct field research (Stamp 1931; Baack 1995). In addition to collecting useful data, field mapping also introduces students to the field of geography.

However, previous geographic inventories have generally been primarily interested in collecting attribute data and only secondarily interested in the collection and accuracy of spatial or positional data. The purpose of this research is to address the potential of high school students conducting geographic inventories which are positionally accurate, the use of these data in a municipal GIS, possibilities for improving the spatial accuracy of future data collections in the future, and the educational benefits of the project.

## 2. Background

Spatial data quality is comprised of five basic components: lineage, positional accuracy, attribute accuracy, logical consistency, and completeness (NIST 1992). All five of these components should be attained for data to be useful in a geographic information system. Lineage, logical consistency, and completeness refer to a description of the data and the methodology of their collection. The recording of this information starts with data collection, but relies mostly upon the GIS technician when converting the data to digital form. The accuracy of attribute and positional data recorded in the field is entirely dependent upon the collection methods, the tools, and the skill of the people in the field.

Data for use in a geographic information system can be collected in several ways. Thapa and Burtch (1991) divide data collection into primary and secondary methods. Primary data collection methods include direct field observation, aerial photography, and satellite image interpretation, while secondary methods are those which collect data from previously classified information such as a hard copy map. In terms of data quality, primary collection methods are considered better as they are more up to date and their accuracy is easier to assess. Secondary methods add more uncertainty because of the age of the hard copy maps, the unknown methods of production, different scales and datum, and the errors inherent in converting to a digital format. Secondary methods of data collection do have one main advantage over primary data collection in that they are much more economical.

One of the issues that should be emphasized when using a geographic information system is that no data are error free. Data collected using the primary methods contain personal errors, instrumental errors, and environmental errors (Thapa and Bossler 1992). Personal errors are caused by the imperfection of the observer, instrumental errors are the direct result of the quality of the instrument, and environmental errors are caused by variations in the environment. These errors can be combined into the general term "source error" or those errors introduced in data collection (Beard 1989). These errors combine to reduce the completeness, attribute, and positional accuracy of the spatial data. Thapa and Bossler (1992) classify source error as being either gross, systematic, or random. Gross errors, or blunders, are caused by the carelessness of the observer and result in useless data. Systematic errors are due to environmental effects and instrumental imperfections, while random errors are due to both the imperfection of the instrument and the observer.

When data are collected by primary methods, they must be assessed for the positional accuracy component of data quality. Robinson, et al. (1995) define positional accuracy as a measure of how close a recorded measure comes to its true value. This accuracy can be measured by comparing the location of specific points in the data to the location of the same points collected using methods of higher accuracy. This test must be completed according to the accepted standards, such as the ASPRS Accuracy Standards for Large-scale Maps (ASPRS 1990) or the U.S. National Map Accuracy Standards (Bureau of the Budget 1947). Both of these standards provide accuracy requirements based upon the scale of the map, although the ASPRS standards relate accuracy to ground measurement, while the U.S. National Map Accuracy Standards relate accuracy to map measurement.

The Spatial Data Transfer Standard specifies using the ASPRS Accuracy Standards for Large-scale Maps to determine positional accuracy. This standard defines accuracy in terms of a root mean square (rms) error, which is the square root of the average of the squared discrepancies between the true location of a point and its recorded position.

$$\text{rms} = \sqrt{(D^2 / n)}$$

where:

$D^2$ = the sum of the squared discrepancies

n = total number of points checked

A minimum of twenty well defined points should be checked using methods of higher accuracy. These higher accuracy points should then be compared to the ground coordinates of the original field work to determine the horizontal accuracy. At a scale of 1:4800, the accepted rms error is 4.0 feet on the ground for a first order map, and 8.0 and 12.0 feet on the ground for second and third order maps (ASPRS 1990).

Another important accuracy issue is that of topological accuracy. Topology refers to the geometric relationship between objects. For data collection to be topologically accurate, all points must fall on the appropriate ground feature as recorded on the basemap. A point is not topologically accurate if it is marked on the basemap as being in grassland for example, but falls in the mixed forest on the ground. A point may be geometrically accurate and topologically incorrect, or geometrically inaccurate and topologically correct. As shown in figure 1, there are four relationships between geometric and topological accuracy, with high geometric accuracy and topologically correct being considered best, and low geometric accuracy and topologically incorrect being the worst. Depending on the type of study, topological accuracy can be more important than geometric accuracy due to the fuzziness of vegetation boundaries. Points on the basemap which are found to be topologically inaccurate need to be moved to insure correct topology.

Many issues need to be considered when assessing the accuracy of spatial data. The type of data collection is important as is the type of errors associated with that methodology. A methodology needs to be determined for assessing error, and both geometric and topological error should be assessed. Using primary data collection methods and the ASPRS Accuracy Standards for Large-scale Maps, this paper discusses the positional accuracy of spatial data collected in this project and the use of these data in a municipal GIS.

## 3. Project Design

This research is a portion of the pilot year of the Green Community Data (GCD) project. Green Community Data is a consortium of Oregon State University professors and students, and community researchers working with a local high school field biology

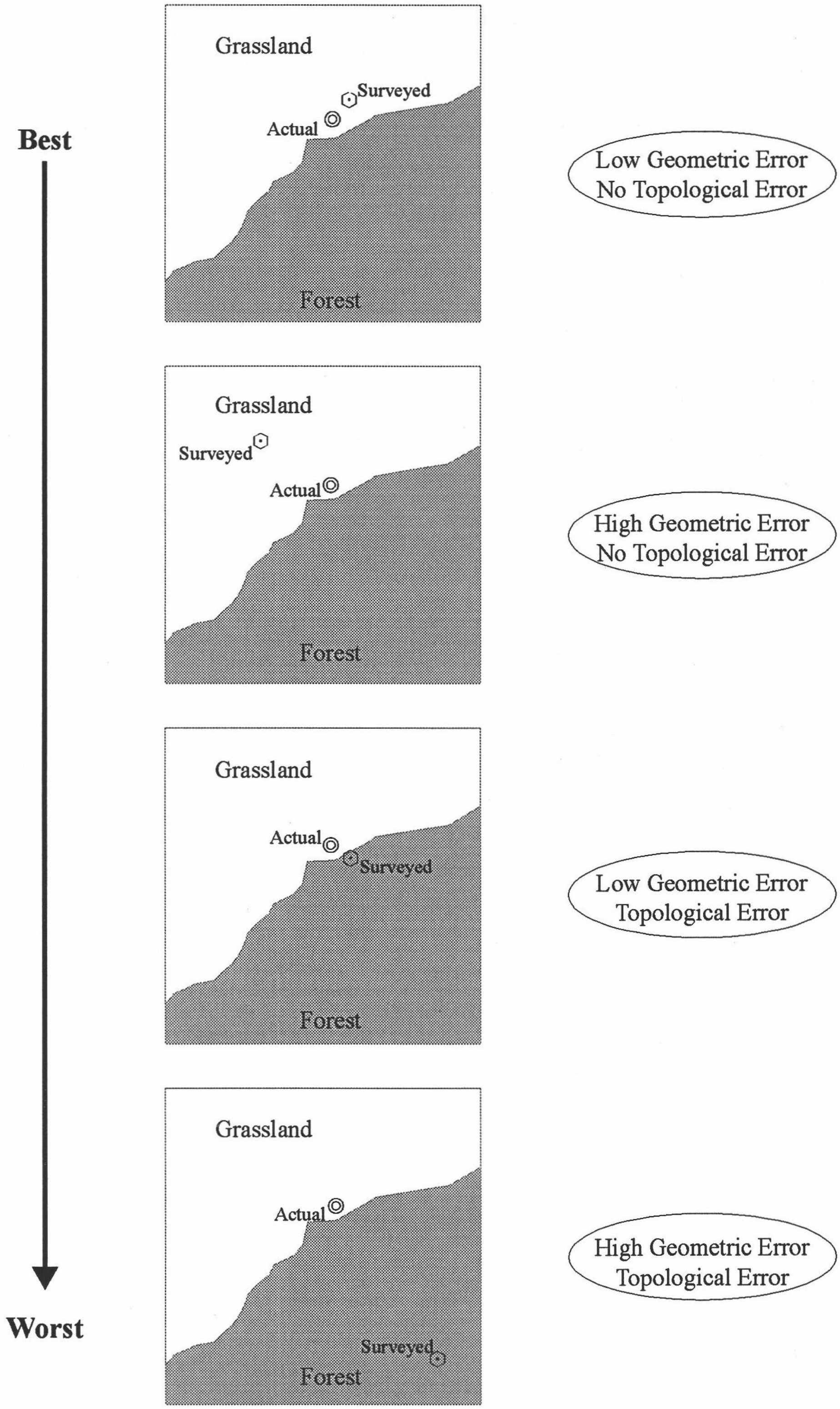



**Figure 1.** *Both geometric and topological error need to be considered when collecting data for a GIS. For a study such as Green Community Data, topological accuracy may be considered to be more important due to the inherent fuzziness in vegetation boundaries.*

class to collect biological data to be used for local community decision making. Students develop their own projects, choose a study site from a list, and decide which questions they want to answer. Data are then collected in the field and positionally referenced. The final step is to produce a product which answers their questions as well as to present findings and make recommendations to the County Parks Department. In addition to collecting data to satisfy Statewide Planning Goal Number 5, this project introduces the students to the field of geography, a discipline not taught in the local high school curriculum.

The initial study site for the Green Community Data project is Open Space Park, a ninety-five acre park which has been newly acquired by Benton County, Oregon. The park provides the ideal study site for this project as it is close to the high school, almost no data have been collected in it, and it contains a variety of vegetation types and slopes which could possibly affect spatial data accuracy (figure 2).

## 4. Methodology

### 4.1 Student Data Collection

As the students have no background in any geographic techniques, a field mapping manual was developed for this project (Appendix A). The manual and several classroom lectures introduced the students to map interpretation and spatial data collection in the field. To do this, the concepts of location, distance and direction were discussed using the USGS 1:24000 Corvallis Quad (1987). The State Plane Coordinate System was discussed to understand the concept of location, and students located

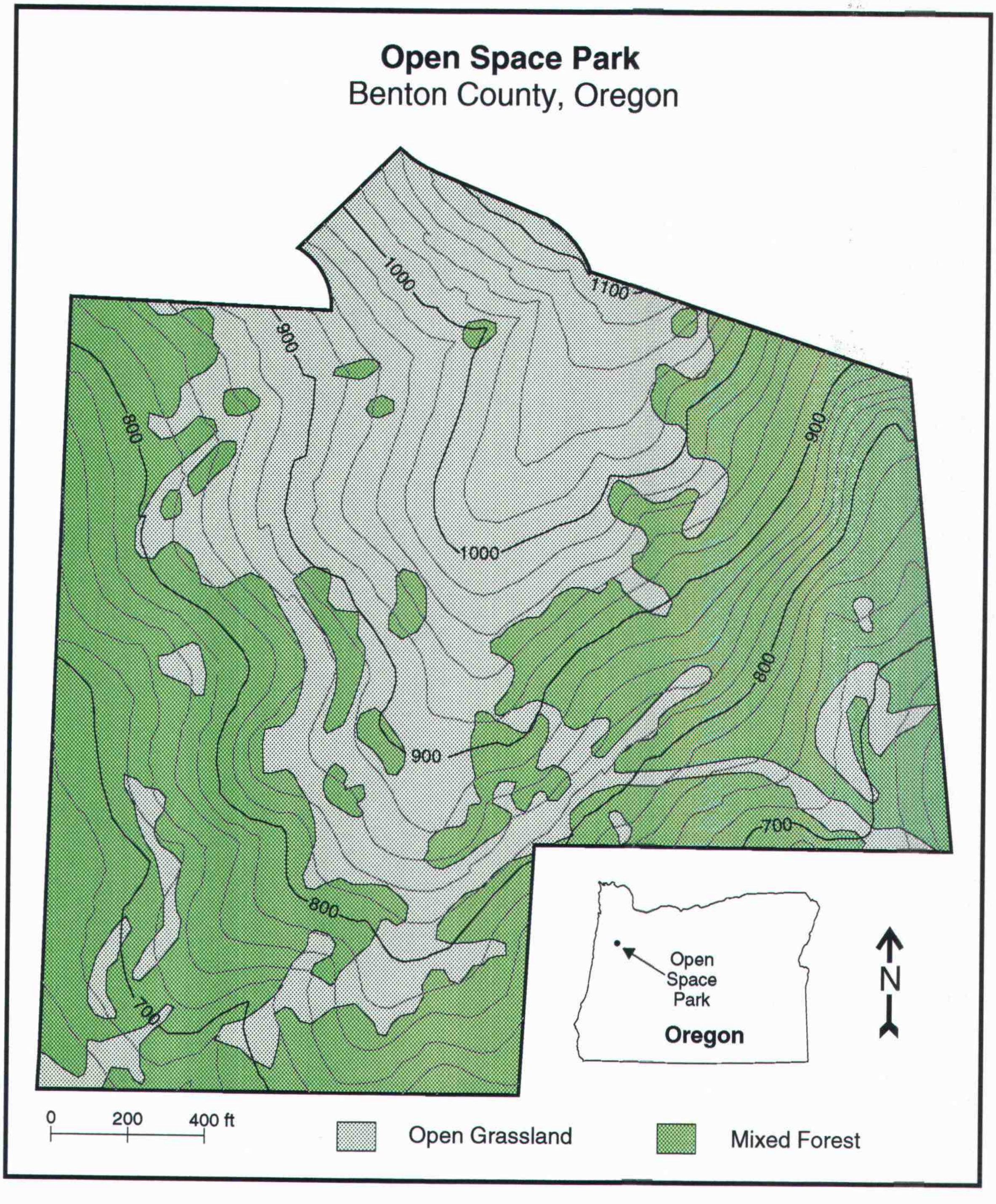



**Figure 2.** *Open Space Park, the preliminary study site for Green Community Data.*

buildings on the Quad in order to determine their State Plane Coordinates. Distances were measured on the Quad and converted to ground distance using both the representative fraction and bar scales. To determine direction on the Quad, students used the north arrow and the magnetic declination displayed on the map. Finally, the idea of a benchmark was introduced as "a point which could be easily located on both the basemap and in the field". The benchmark provided the students with a starting point for their data collection, and was used as a reference to tie their data to the State Plane Coordinate System.

The concepts learned in the classroom were then transferred to the field where students located points once again using the ideas of location, distance, and direction, recording their data on basemaps and data sheets specifically designed for the project. As in the classroom, the locations of objects were recorded in the State Plane Coordinate System, starting from a benchmark clearly marked on the basemap. Distances from the benchmark were measured using the length of a stride, and direction was measured with a compass and the magnetic declination taken from the USGS quad.

The students created a regular grid of points 125 feet apart in a section of the park, and recorded this information on their basemap. Starting from the benchmark, the students then located and flagged the study points in the field using the methodology presented in class. Once the points were located in the field, their coordinates were calculated using the distance and direction traveled from the benchmark, and the known 1927 State Plane Coordinates of the benchmark.

## 4.2 Higher Order Data Collection

The higher order independent data used to determine the accuracy of the student data were collected using a post-processed differential global positioning system. One hundred-sixty readings were recorded at the location of each study point using a Trimble Basic+ GPS receiver. These readings were post-processed using base station files from the Portland United States Forest Service Community GPS Base Station and averaged to get one point with a horizontal accuracy of ±2 meters (Trimble 1992; USFS 1997). The GPS points were then transformed from the Universal Transverse Mercator system (Zone 10) to the 1927 State Plane Coordinate system (Oregon, North Zone) for a comparison with the student data. Although the error involved with the GPS method is large, it is still accurate enough to determine the accuracy of the student data. Both sets of data were then compared both visually and numerically to determine the X, Y, and linear error of each point, as well as the X, Y, and linear rms error for the entire group of points (Appendix B).

An independent field check of this methodology used the horizontal third order United States Coast and Geodetic Survey, Bald Hill triangulation point (QE 2057). This point was chosen because it has approximately the same elevation (758.00 feet NAVD 88) and coordinates (1,261,602.60E, 340,732.96N, Oregon, North Zone) as Open Space Park. This field check resulted in an error of 3.71 feet or 1.1 meters. Although not statistically valid, it does confirm the expected error from the Trimble Manual.

## 5. Results

Using the ASPRS Accuracy Standards for Large-scale Maps, the data gathered were analyzed for positional and topological accuracy. The data were analyzed to determine the positional error and the error as it relates to distance from the benchmark. Topological error was analyzed to determine the number of points which fell in different categories on the basemap and in the field. From the analysis of the data and the positional and topological error they contain, possible uses for the data will be discussed.

ASPRS requires that large-scale maps be tested for positional accuracy in order for maps to carry the map standard statement. The accuracy is determined by an rms error in both the X and Y directions measured from a minimum of 20 check points in the area covered by the map. As shown in figure 3, the positional accuracy of the 36 points checked from the Green Community Data project is very low for large-scale maps. The rms error in the X direction is 20.8 feet or 6.3 meters ($\sqrt{15565.87 / 36}$), while the accuracy in the Y direction is 49.4 feet or 14.8 meters ($\sqrt{87811.49 / 36}$). This results in a linear rms error of 53.6 feet or 16.1 meters.

When the data are examined from the perspective of the distance of the point from the benchmark, there is a trend toward the accuracy decreasing the farther the point is from the benchmark. This trend, however, is not statistically significant as only 16% of the variation of geometric error can be explained by the simple linear regression on distance ($R^2 = .1618$). Additionally there is moderate evidence that the error is not zero at the benchmark as would be expected, with a 95% confidence interval of error between 5.49 and 44.50 feet at the benchmark (2-sided p-value = .0136 for a test that the intercept is zero in the simple linear regression).

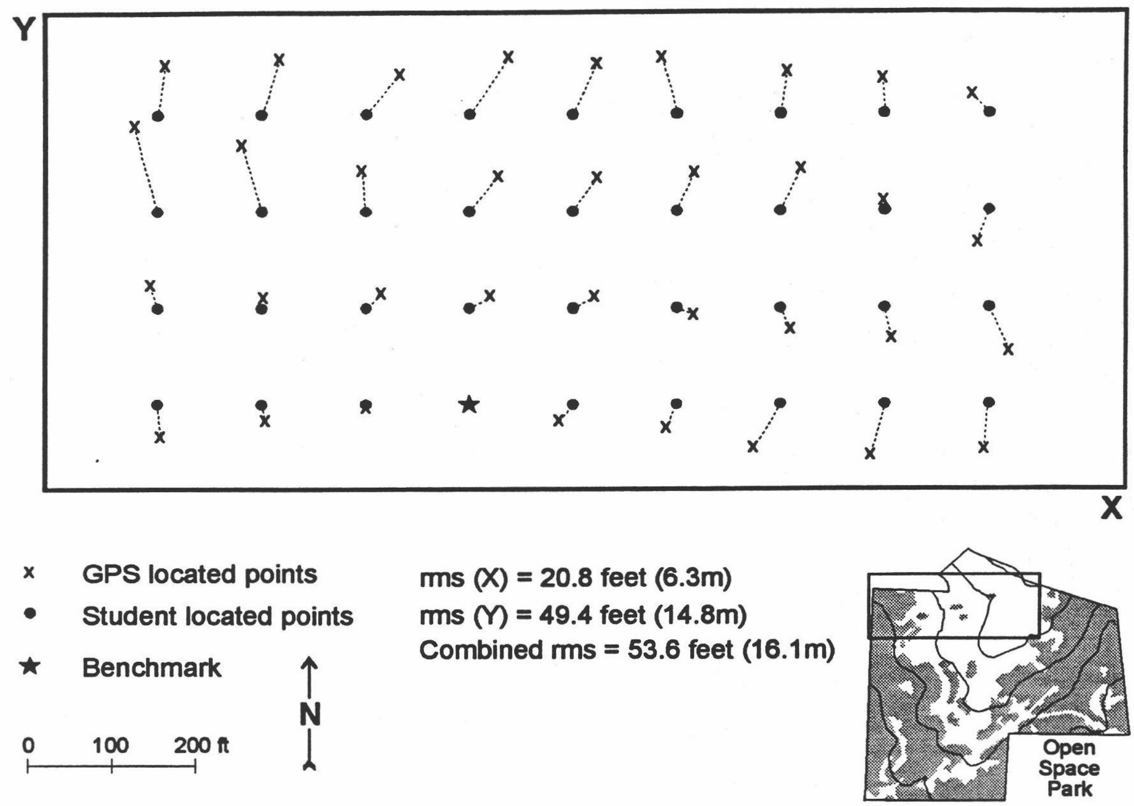



**Figure 3.** *The spatial data collected in the Green Community Data Project have an rms error larger than that permitted by the ASPRS Accuracy Standards for Large-scale Maps.*

Topologically, 4 points (11%) contained error and were misclassified on the basemap. As shown in figure 4, two of these points have high geometric error and two have low geometric error. Considering the concept of topological error was not discussed in the manual, this level of error is quite low. To correct this error, these points would need to be moved on the basemap or in the field in order to make the data topologically correct.

The errors found in the Green Community Data project are a combination of gross and random errors. The limitations of the instruments are great--the human stride for distance and a $15.00 compass for direction. Additionally, the students have had limited

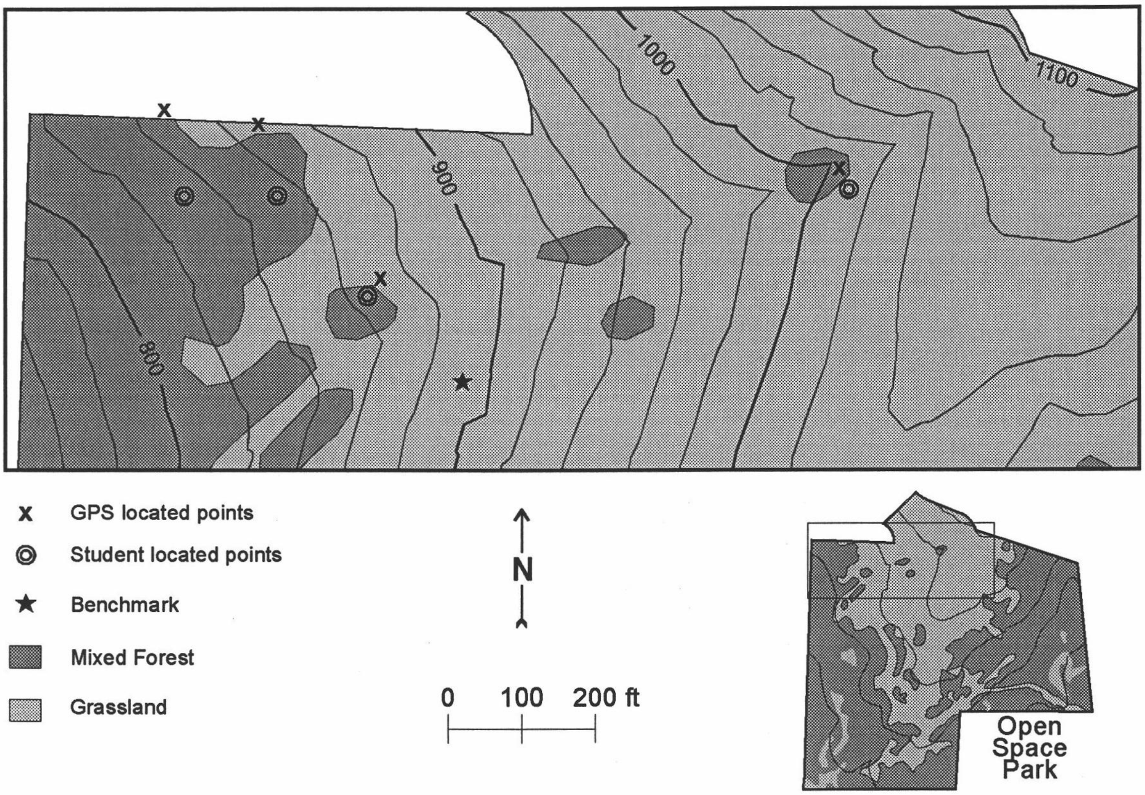



**Figure 4.** *The data collected from Green Community Data have approximately 11% topological error.*

training in spatial data gathering. It is difficult to assess which percentage of the errors are due to random factors. The data have an equal frequency of positive and negative errors in both the X and Y directions, but large errors occur as often as small errors. However, the error does not accumulate in the sequential linear order of data collection away from the benchmark (figure 5). Only 14% of the variation of geometric error can be explained by the simple linear regression on sequential linear order away from the benchmark ($R^2 = .1449$). As with the distance regression, there is convincing evidence that the error is not zero at the benchmark as would be expected, with a 95% confidence interval of error between 9.66 and 46.32 feet at the benchmark (2-sided p-value = .0038 for a test that the intercept is zero in the simple linear regression).

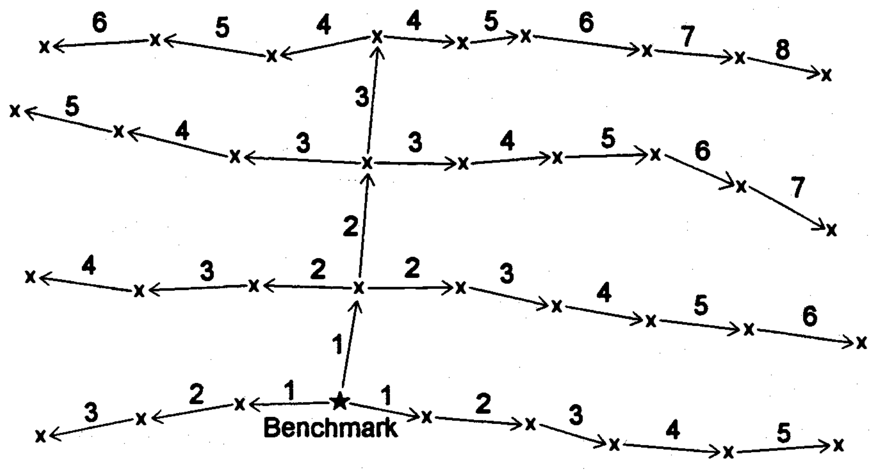



**Figure 5.** *Statistically, positional error does not appear to be cumulative when measured on the sequential linear order upon which the data were collected.*

The error cannot be explained simply by distance from the benchmark or the sequential linear order of data collection due to a number of confounding variables. The steep terrain and varying slope contributed to the error as did the different vegetation types. Also, due to the precision of the instruments, an imprecise distance measurement could be characterized as either a blunder, the carelessness of the observer in striding or reading a compass azimuth, or as a random error due to the general imprecision of the compass or of striding as an instrument.

The data collected in Green Community Data do not meet the standards of the ASPRS Accuracy Standards for Large-scale Maps. Green Community Data has an rms error ten times that of the accepted first order standard for a map at a scale of 1:4800. These standards, however, are designed for mapping features such as roads and buildings which have distinct boundaries. Vegetation zones are fuzzy in that they do not have distinct boundaries. Instead, vegetation has a gradual change and indistinct, or fuzzy boundaries. Because of this, these data are better than they originally seem and they may be useful in a municipal geographic information system.

Although the positional accuracy of the data are not of the highest accuracy, they are still useful considering the cost of acquisition and when compared to other available technologies (figure 6). While other technologies are available which produce data with a higher spatial accuracy, most are too expensive or time consuming. The Green Community Data project is able to provide data which are positionally more accurate than the Thematic Mapper or SPOT multisensor data, and much more accurate than unprocessed GPS. The other, more accurate data collection methods, such as a Total Station or a post-processed GPS, are not available to this project due to their cost and the necessary training.

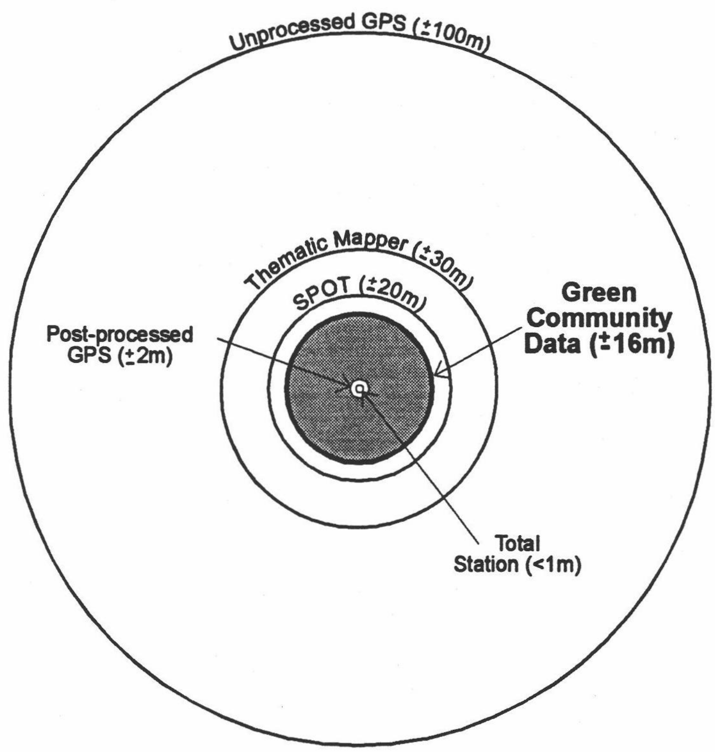



**Figure 6.** *Most technologies which are available for collecting spatial data have a larger positional error than Green Community Data.*

## 6. Discussion

### 6.1 GIS Use

All spatial data contain a certain amount of error, and data therefore must attain a minimum level of accuracy to be useful to a particular GIS application. Data quality can be defined as 'fitness for use', and a particular data set may be entirely suitable for one application, but not fit for a different process (Chrisman 1991). The final judgment on the quality threshold or level of accuracy in a data set must be made by the GIS user, provided he or she has access to a quality report. Without a data quality report, spatial data have no use in a geographic information system as the GIS technician will have no confidence in the results of analysis. Even low quality data have some use provided they are accompanied by a quality report. It is possible to misuse both low and high quality data which may lead to poor results or data with a higher level of error.

A geographic information system is a computerized hardware and software system designed to collect, manage, manipulate, analyze, and display spatially referenced data (Olson 1990). The quality as well as the use of spatial data is very important to the results produced from the system. Barbara Buttenfield (1993) states: "Information on data quality is important for effective use of GIS data. It impacts the credibility of data representations and the confidence that is attached to data interpretations. It impacts the reliability of interpretations and thus decision-making based on GIS modeling and data exploration (1)." The quality of GIS data impacts every level of GIS use from analysis to decision making, and the quality of the data directly impacts the validity of the decision influenced by the GIS (Stanislawski et al. 1996).

One of the benefits of geographic information systems is that they provide increased access to spatial data. This increased access gives users, both trained and untrained, the ability to quickly manipulate these data without thinking about possible drawbacks. This misinterpretation and misapplication of data is called use error (Beard 1989). Use error can be revealed in several ways, and failure to consider it reduces the benefits obtained from the use of a GIS. One of the major types of misuse is to assume that the quality of GIS data is very high. This is easy to do because GIS precision far exceeds the precision of the data used in the system. Due to the high precision of the GIS, the inaccuracies of the data may not be fully understood by the user (Goodchild and Gopal 1989). To prevent use error, a data quality report should be provided to trained GIS users along with the data (Beard and Mackaness 1993). By considering the level of error in a data set, even low quality data may be of some use.

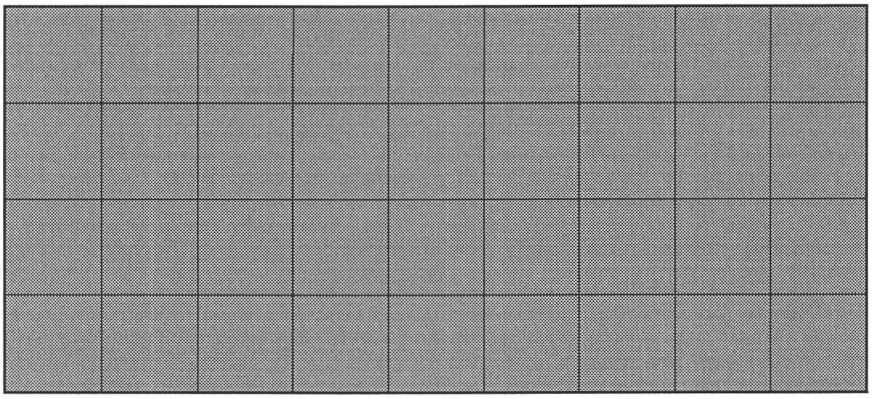
Although the data gathered in the Green Community Data project do not attain the accuracy standards set forth under the ASPRS Accuracy Standards for Large-scale Maps, they can still be useful in a GIS if their accuracy is considered. Due to the inherent fuzziness in vegetation boundaries, it is possible to use these data for a variety of GIS functions, as well as for baseline data where the community previously had none. Because of this, these data are suitable for the preliminary analysis of vegetation studies.

As there is no information currently collected for Open Space Park, these data may be used to help determine how the open space is going to be developed. Park managers and municipal GIS personnel will need to determine where the different vegetation zones are, what types of plant and animal habitat are within each zone, where to develop trails, and where to build a parking lot and other structural features. Many of these questions can be answered with the data collected in the Green Community Data project.

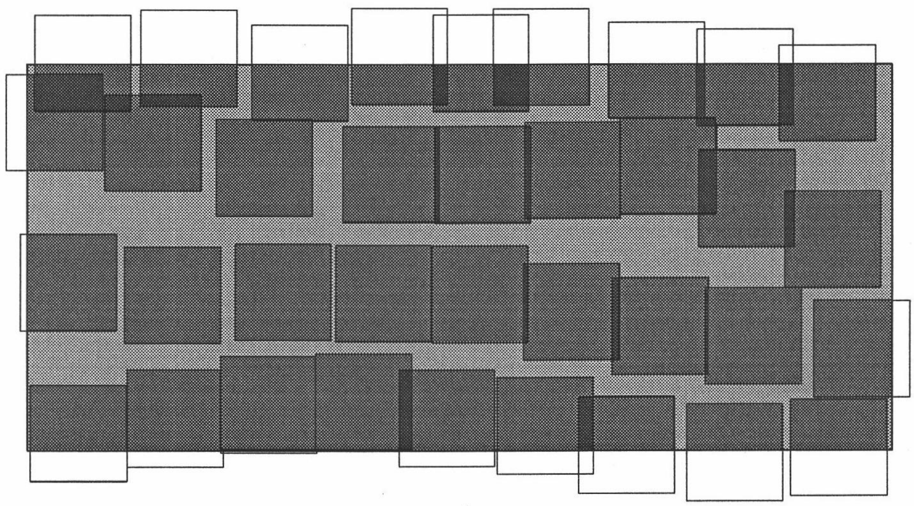
To answer some of these questions, the data will need to be converted from point features to polygon features using a point to polygon interpolation method. Data points spaced 125 feet apart can be converted to regular polygons which are 125 feet square and which have attribute data attached to each polygon. Polygon borders can be dissolved for those adjacent polygons which have the same attributes. This process can be repeated from the same set of data points to develop polygon coverages for each type of data collected at the study point such as different plant habitat and animal habitat.

One problem with developing polygon coverages from the study points determined in this project is the amount of positional error associated with each data point. As shown in figure 7 and table 1, there is a large difference between polygon interpolation methods, as well as between the student located points and the GPS located points. A regular point to polygon interpolation of the student located points results in a regular series of 36 polygons each 15,625 square feet in area and all within the study boundary. Due to the irregularity of the points, the same point to polygon interpolation on the GPS data leaves 23.4% of the study area unsampled. This lack of complete coverage will result in reduced confidence when analyzing the polygon data.

Regular and Thiessen Polygon Interpolation from Student Points



Regular Polygon Interpolation from GPS Points



Thiessen Polygon Interpolation from GPS Points

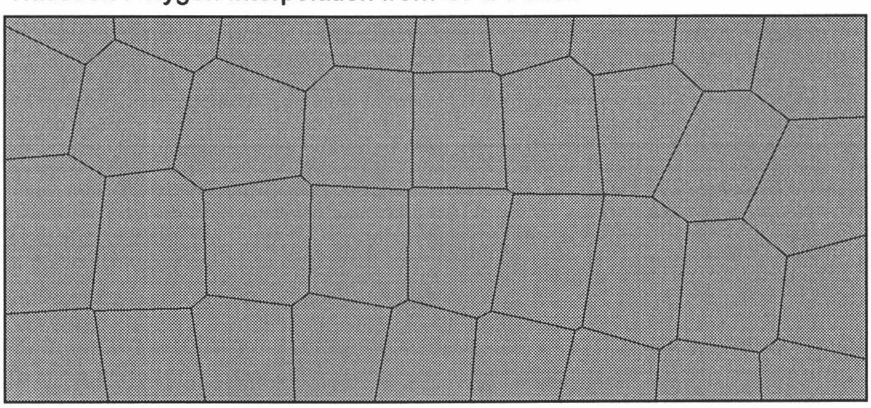


**Figure 7.** *Different types of point to polygon interpolation methods create different results when performed on the student points and the GPS points.*

| Type | # Polygons | Polygon Size | Unsampled | Outside | Overlap |
|---|---|---|---|---|---|
| Student-Regular | 36 | 15,625 feet$^2$ | 0 feet$^2$ | 0 feet$^2$ | 0 feet$^2$ |
| GPS-Regular | 36 | 15,625 feet$^2$ | 131,719 feet$^2$ | 105,085 feet$^2$ | 22,077 feet$^2$ |
| Student-Thiessen | 36 | 15,625 feet$^2$ | 0 feet$^2$ | 0 feet$^2$ | 0 feet$^2$ |
| GPS-Thiessen | 36 | 5,536 feet$^2$ | 0 feet$^2$ | 0 feet$^2$ | 0 feet$^2$ |
| | | to 24,209 feet$^2$ | | | |
| | | | | | |
| Total area of study site = 562,500 feet$^2$ | | | | | |

**Table 1.** *The results of polygon interpolation on the student data and the GPS data provide a varying level of confidence.*

A Thiessen point to polygon interpolation provides better results. This method creates polygons so that any point within a particular polygon is closer to the original data point of that polygon than to the original point of any other polygon. A Thiessen point to polygon interpolation on a regular grid still results in a regular series of 36 polygons each 15,625 square feet in area. The same interpolation on the GPS located points creates a series of irregular polygons which vary in size. The Thiessen polygon interpolation method has the advantage that each polygon is entirely within the study area and there is no overlap of polygons. If the GIS technician were to perform a regular polygon conversion on the data provided by the students, he or she would get the same result as a Thiessen polygon interpolation and also know that the data correspond fairly well to a Thiessen polygon interpolation of the GPS points. This would result in a higher level of confidence for wildlife habitat coverage creation, especially when considering the fuzziness of the boundaries.

Another common use of a geographic information system which these data could be used for is a buffer operation. In this instance a distance buffer would generate a circular polygon of a specified radius around one or more of the collected data points.

This operation could be used to create safety zones around sensitive vegetation when determining where to build new trails. As with the point to polygon interpolation, the error associated with the data can reduce the confidence of the results (figure 8).

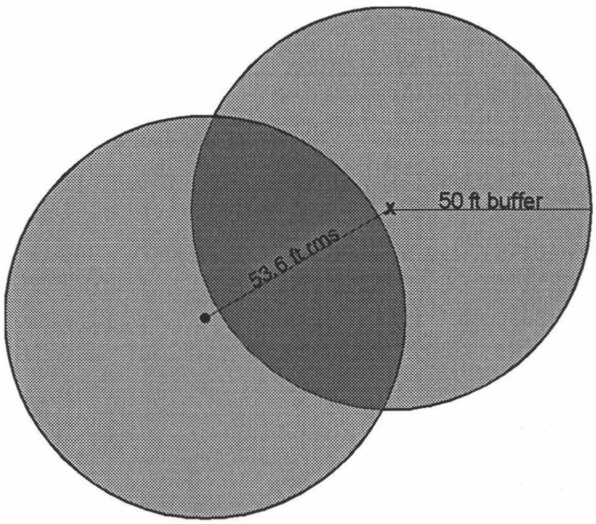



**Figure 8.** *A fifty foot buffer on two points 53.6 feet apart (the rms error of Green Community Data) results in only a 35% overlap of the two buffers.*

Due to a lack of accuracy, any decisions based upon the data gathered in this project will lack confidence. These data do, however, provide new data to the community where there were none before. If the GIS technician considers the data accuracy as presented in the data quality report, these data cold be used for simple GIS analyses such as buffering, point to polygon interpolation, and polygon overlay. These data have the potential to be a tool for first-line decision making in the county parks departments, as they represent a general overview of the area. Additionally, these data could be used to help determine areas which would need a more in-depth, professional study, as well as a basis for temporal studies on a smaller scale.

Geographic information system data and maps made from a GIS which are disseminated to the public provide the potential for legal issues. When the data quality is relatively low, such as the data collected in this project, the chance of legal problems increases. Legal problems arise for a municipality when an individual makes an incorrect decision due to inaccurate data provided by the municipal GIS. Protection comes from a legal disclaimer which alerts users to potential errors in the data. This disclaimer should contain the source and nature of the data, when the data were compiled, appropriate uses of the data, and should be visible to the user (Antenucci et al. 1991). Legal issues are minimized in the situation of Green Community Data because the data are collected on public land and will be used only for municipal decision making. Private individuals will not be making decisions which would adversely affect them based upon these data. However, all data should still contain a legal disclaimer to protect the municipality from any misuse of the data.

Data quality is dependent upon the particular use of the GIS. Even if data quality is high, inappropriate products may still result due to misuse of the data. User error can be reduced by providing a data quality report which specifically lists the accuracy of the data. Low accuracy data such as that gathered in Green Community Data may still be of some use in basic decision making, but their misuse could be harmful at the local governmental level.

## 6.2 Educational Benefits

Three key educational themes are currently in the national secondary curriculum spotlight. A renewed interest in geography instruction has been part of the national agenda for the last fifteen years since U.S. students did poorly on a geographic place name test. Geography also provides the ability for students to analyze data and think analytically, and provides students with increased access to the use of information technology, such as a geographic information system. The Green Community Data project has been specifically designed to provide educational benefits in all three of these areas.

In a school system with no specific geographic education, the Green Community Data project hopes to attain some of the goals set forth in the National Geography Standards (Geographic Education Standards Project 1994). The overriding goal of these standards is to teach geography from a spatial and ecological perspective. At the twelfth grade level, the specific goals include the ability to formulate and answer geographic questions, the ability to systematically locate and gather geographic data from a variety of primary and secondary sources including spatial data sampling in the field, and the ability to select and design appropriate forms of maps to organize geographic information.

Although the students involved in the Green Community Data project are enrolled in a field biology class, they are still using geographic skills and concepts. Students design their own projects to answer specific questions, some of which involve spatial problems. To answer these questions, students gathered information from air photos, by interviewing the former landowner, and by collecting and spatially locating biological data in the field. Once all the data have been gathered, students will produce maps as a part of their final project which will include a presentation to the County Parks Department. Also, by designing a research problem and gathering data from which to draw conclusions, students move away from the trend of rote memorization and instead learn to think analytically.

Although the Geography Education Standards Project does not require the use of geographic information systems to satisfy the geography goals, it is hoped that the use of GIS will become incorporated into the goals as the technology becomes available. Similarly, the National Center for Geographic Information and Analysis (NCGIA) hopes that geographic information systems will be used in many secondary schools. Three different levels of GIS education in secondary schools as set forth by the NCGIA are an introduction to GIS and its uses, the use of GIS as a tool to support existing learning objectives, and courses where GIS is the main focus (Palladino 1992). However, for these education goals to become reality access to the technology needs to become more available, and written materials which will help teachers incorporate GIS into the classroom need to be developed. The first of these two needs is now within the grasp of many schools as the price of hardware and software has drastically decreased. Written GIS materials, however, are not currently available.

While Green Community Data does not currently use a geographic information system as part of the project, it is in an ideal situation to do so given access to the technology. The GIS could be used in the NCGIA second level of implementation as a tool to support existing learning objectives. Since the Green Community Data project gathers spatially referenced data, a GIS such as ArcView would be the ideal place to store, retrieve, and conduct simple analysis of the data. Instructors, however, are apprehensive about including this technology into the classroom without supporting materials.

It is not necessary to have a geography class in order to incorporate geographic education or geographic information systems. As shown by the Green Community Data project, many of the goals are easily included in other classes such as biology or environmental studies. Additionally, the use of a geographic information system in this project, provided there were written materials for the instructor, would introduce a new skill to the students, increase access to information technology, and provide the ideal place to store, retrieve, and analyze spatial data.

## 6.3 Improving Data Accuracy

At this time the Green Community Data Project does not produce information which is of sufficiently high positional accuracy to yield high confidence when used for decision making in a municipal geographic information system. The data collected by the students provide new information where there were previously little or no data, and the positional error can be ignored to a certain extent when used in a GIS due to the fuzzy nature of vegetation boundaries. There are, however, ways of improving the quality of the data collected in the future so that decisions based upon the data could hold more confidence.

Generally, one of the main reasons for the lack of data quality is the precision of the tools and methods used in data collection (Buttenfield 1993). This is also true in the case of Green Community Data, which is a community-based project with no funding for quality tools. In this project, distance was measured using strides and direction was measured using inexpensive compasses. With a minimal expenditure, more precise tools could be used. Field tapes for measuring distances and higher quality compasses for measuring direction would drastically increase the overall positional accuracy of the data.

The methodology used for this project has also been changed to increase the positional accuracy of the collected data. The methods described in the manual for the students were entirely new to the whole class, and therefore caused a certain amount of frustration. Too much background information was presented which did not directly pertain to the field biology class and not enough information was presented regarding exact methods of designing a sampling strategy. While this encouraged students to think through every step of the field work, the extra time spent in the classroom reduced the enthusiasm for the project which led to sloppy work in the field. Because of the problems encountered this year, the field manual has been revised to include a step-by-step methodology for designing and implementing a field collection strategy.

A final way to increase the accuracy of the data will be through the use of a geographic information system. By providing a GIS such as ArcView to the students, they will be able to understand the entire process of answering geographic questions from data collection, to data analysis, to displaying their results. This will increase the students' understanding of the importance of each step, as well as the importance of positional error. Additionally, close student participation throughout the entire process will create more of a community-based geographic information system. Students would gain insight into how the entire GIS process works and the usefulness of the collected data. Students would also have some input as to what type of data they are collecting and possible uses for the data in a geographic information system and for the local government. By combining the technology of a GIS with a greater interest in the final product, students may take an increased interest in the results of their work, thus increasing the accuracy of the data.

Because the error in the data collected in this project is so large, there will be little confidence in the conclusions drawn from the data when used in a municipal geographic information system. With minor adjustments, it is possible that the project will produce more accurate data in the future. By increasing the precision of the tools used and revising the methodology presented to the students, accuracy should increase drastically. Another important way to increase accuracy is by increasing student participation in the entire process of using a geographic information system. This would provide students with the understanding of the entire process of answering geographic questions as well as allow them to have some input as to what data are collected and how they are used. This increased involvement with GIS would allow students to take a greater interest in their work, thus increasing the accuracy of the data.

## 7. Conclusion

Green Community Data is a project designed for high school students to collect spatially referenced biological data for decision making purposes. By designing a project, collecting and analyzing data, and producing results, students satisfy many of the geography goals set forth by Geography Education Standards Project. The data collected in this study confirms what would be expected in any geographic study: that the first law of geography continues to hold--all things are related, but nearer things are more similar than those far apart. Due to the rms errors as large as 50 feet in the positional accuracy of the collected data, the information produces little confidence when used in a municipal GIS. These data are, however, useful, especially when compared to the accuracy and cost of alternate technologies. This error may be reduced in the future by providing access to more precise instruments and through the classroom use of geographic information systems, which are the key to the future of Green Community Data. A GIS can store and manipulate the collected data as well as provide students with access to informational technology. If access to a GIS is available with supporting written materials for the instructors, students will build their own GIS databases for classroom use and add to the information each year as new sites are studied.

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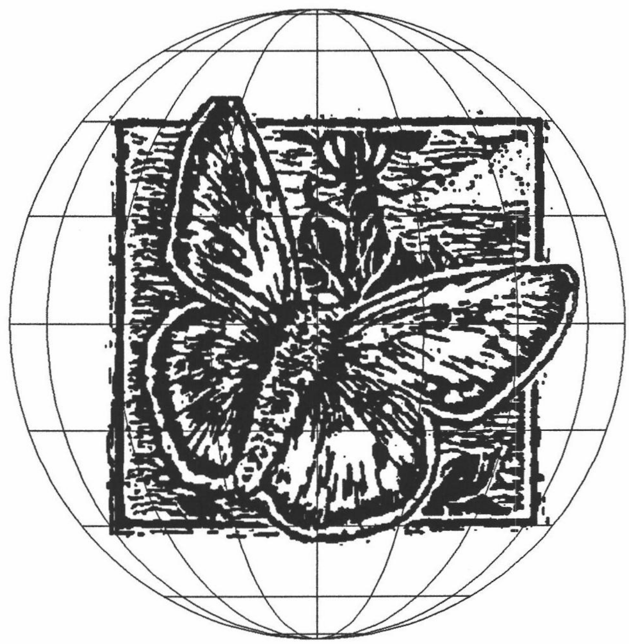
# Appendix A

# Green Community Data Cartography Manual

# Green Community Data



# Cartography Manual

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## INTRODUCTION

Green Community Data is a program designed to introduce high school students to new skills, foster an appreciation for the environment, and provide scientific data to local governmental offices. Students work as teams to inventory plant and animal habitat in local open spaces. The Green Community Data project is not only interested in knowing what types of wildlife habitat are in the community, but also where the habitat is located. Because of this, field mapping is an important part of the program.

This manual is intended to provide the necessary background in the concepts of field mapping so that students can accurately record spatial data in the field and use these data to create an accurate map of their study site. The manual is divided into three sections which will provide the necessary information to interpret maps, record data in the field, and create a final map. The first section discusses concepts and terms related to map interpretation. This material includes concepts such as distance and scale, direction, and location, ideas which all cartographers must be familiar with in order to perform accurate field mapping. The second section is a step-by-step methodology for field mapping. This section builds on the ideas covered in the first part and introduces the students to the skills needed to go into the field and record spatial data. In the third and final section, the principles of map production are presented so that students will be able to produce a map which follows accepted cartographic standards and graphically displays the collected information in an understandable manner.

This manual presents the necessary skills to conduct the field mapping portion of the Green Community Data project. It provides a way to accurately record the location of the collected data. Location is important in that it allows local governmental departments to use the collected data to make decisions and it allows further inventories to be conducted in the same areas in the future to assess any change.

**PART I**--Map Interpretation.

| | |
|---|---|
| goal: | To gain map interpretation skills of distance, direction, and location |
| supplies: | USGS 7.5 minute Corvallis quadrangle<br>Protractor<br>Straight edge |

A map is a symbolic representation of the Earth's surface and provides a vast amount of information in a spatial, or visual, manner. Cartographers use symbols to represent objects and simplify things such as lines in order to make maps easier to read. This section will discuss how to determine location, distance, and direction from a map. Just about every map shows these items, however, the United States Geological Survey (USGS) produces a very accurate map series which covers almost the entire United States. These maps cover 1/8° by 1/8° (7.5' by 7.5') of the Earth's surface and are used by geographers, cartographers, and many other people who do work in the field. The 7.5' Quad will be used as an example for the concepts discussed in this section.

Location is shown in many different ways by cartographers and geographers and is very important for recording spatial data. There are many forms of recording location on maps, three of which are discussed here: Latitude/Longitude, the State Plane Coordinate System, and Township and Range. Latitude/Longitude is a world-wide form of recording location which takes into account the curvature of the earth. The State Plane Coordinate System is a square grid system used only in the United States for recording location in smaller areas. Township and Range is a general location system used in the United States and is the basis for most property surveys. All three systems are useful for recording location, but for different purposes. Location can be determined starting from a benchmark, a point of known location which can be found on both a map and in the field.

The Earth's graticule, or latitude and longitude grid, is a system used for recording location on a world-wide basis. As shown in Figure 1, latitude, or parallels, run east-west, are measured starting at the Equator (0° latitude), and extend to the North and South Poles (90° latitude). Lines of latitude run parallel to each other and get progressively smaller as they circle the globe near the pole. Longitude, or meridians, run north-south, are measured starting at the Prime Meridian (0° longitude), and extend east and west to the International Date Line (180° longitude) in the middle of the Pacific Ocean. Lines of longitude get closer to each other as they near the poles where they converge, but each line of longitude is the same length.

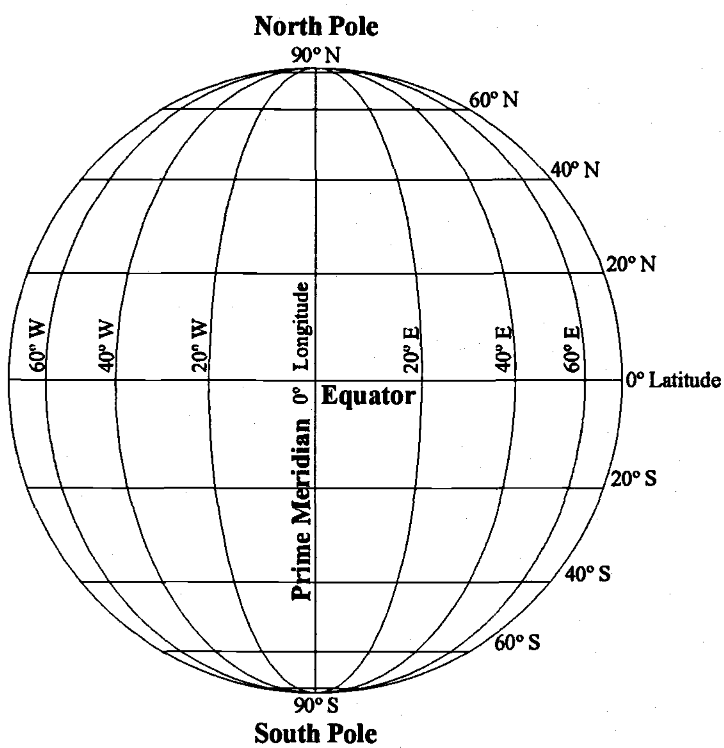



**Figure 1.** *The Earth's Graticule is made up of lines of latitude and longitude. Lines of latitude run east-west, are parallel to each other, and get smaller as they near the poles. Lines of longitude run north-south, converge as they near the poles, and are all the same length.*

For greater accuracy, each degree of latitude or longitude can be divided into 60 minutes (60'), and each minute can be divided into 60 seconds (60"). When recording location, lines of latitude are measured first, north or south of the equator, but no larger than 90°, and then longitude is measured east or west of the Prime Meridian, but not exceeding 180°. All USGS quads have latitude and longitude marked with blue tics on the side of the maps. Using latitude and longitude, the location of the intersection of Highland Drive and Crescent Valley Drive is 44° 16' 35" N, 123° 16' 35"W (Figure 2).

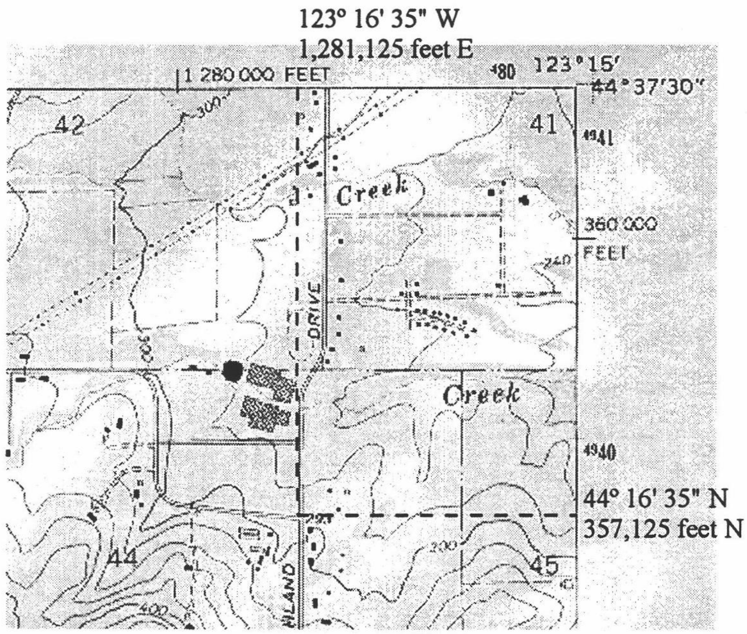



**Figure 2.** *The USGS 7.5' Corvallis Quad shows many types of location systems including the State Plane Coordinate System and Latitude/Longitude.*

Another system used for recording location is the State Plane Coordinate System, which is used by many property surveyors and county mappers. Unlike latitude and longitude, State Plane is a square grid system. Each state has its own grid, and to reduce errors caused by the curvature of the earth, most states are divided into two or more sections called zones. For states such as Oregon which are elongated east-west, there is a north zone and a south zone (Figure 3), while most states which are elongated north-south have an east zone and a west zone. Each zone has an origin point, called a false origin, which is located south and west of the zone. Location is measured in feet east (called an easting) and north (northing) from the false origin and is stated as: easting, northing, state, and zone. As with latitude and longitude, State Plane coordinates are shown with black tics on the edge of every USGS 7.5' quad. The location of the intersection of Highland Drive and Crescent Valley Drive is 1,281,125 feet east, 357,125 feet north, Oregon, north zone.

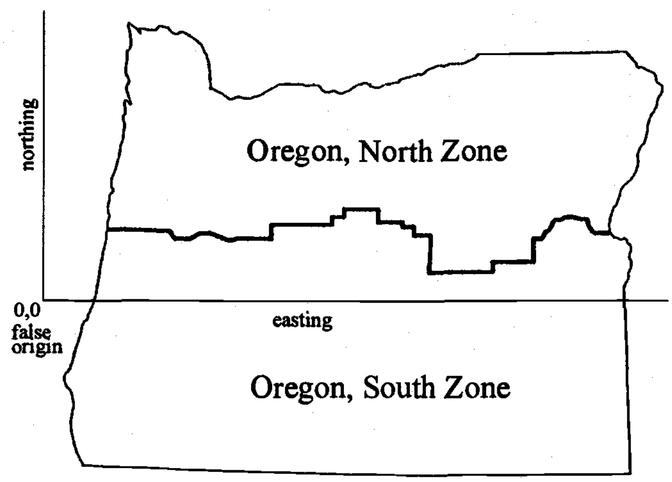



**Figure 3.** *States such as Oregon which are elongated east-west are divided into a north zone and south zone in the State Plane Coordinate System, a square grid system which measures the number of feet east and north of a false origin. As the State Plane Coordinate System is most often used by county mappers and surveyors, zone boundaries follow county boundaries so that a county does not fall within two different zones.*

A third location system used in the United States is Township and Range. This system uses a grid of lines spaced six miles apart, forming six mile by six mile squares called Townships. The origin of the grid system is a north-south principal meridian and an east-west baseline. The rows formed by this grid are also called townships, while the columns are called ranges. As shown in Figure 4, the townships are numbered in sequence north and south of the baseline and the ranges are numbered sequentially east-west of the principal meridian. Each Township is divided into 36 one square mile Sections, which can be further subdivided into quarter sections or smaller. Location on the Township and Range system is recorded from the smallest area working out: Section, Township, Range, and Principal Meridian. Using this system, the location of Highland Drive and Crescent Valley Drive is the SE quarter of the NW quarter of Section 14, Township 11S, Range 5W, Willamette Meridian.

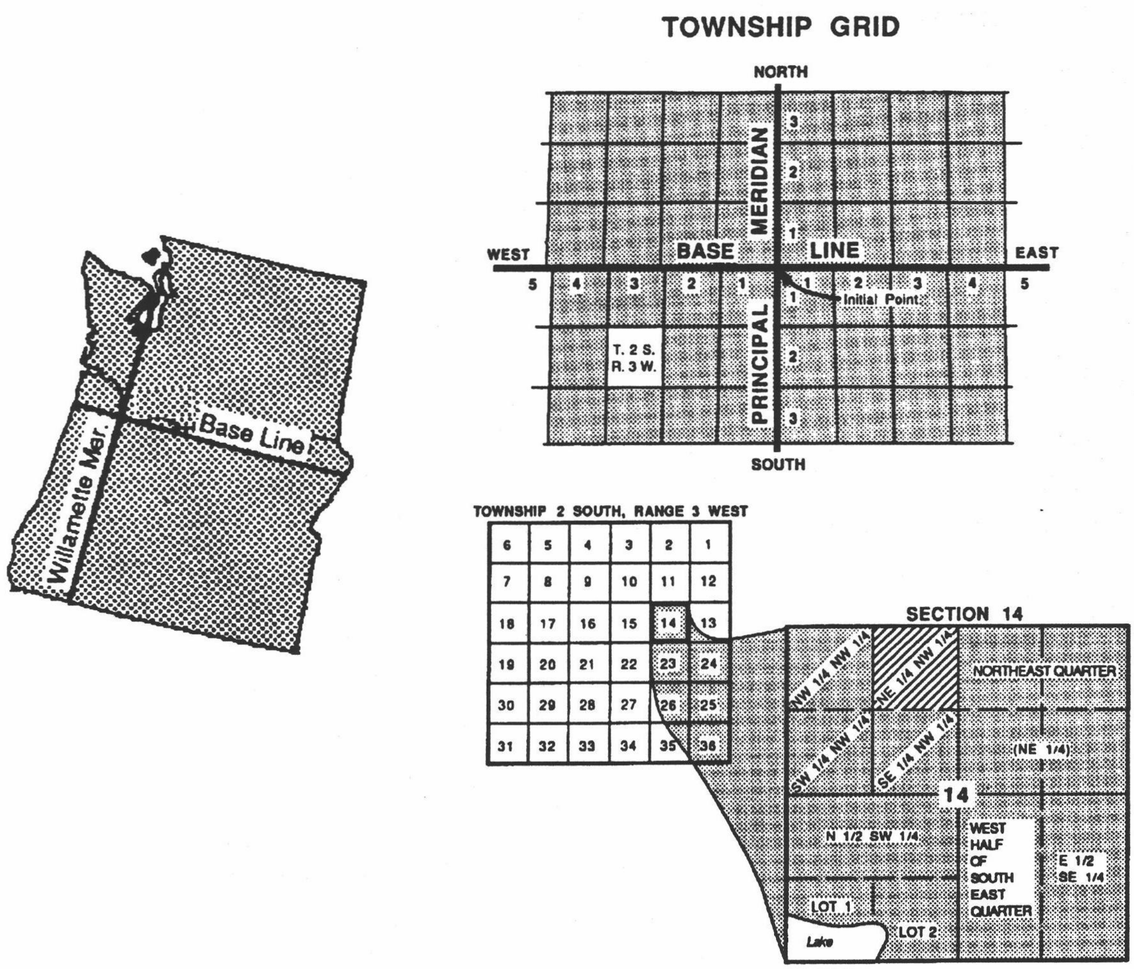



**Figure 4.** *The Township and Range system starts from a principal meridian and baseline, and is divided into townships, ranges, sections, and further subdivisions.*

Distance is shown on a map by scale, which is the ratio of the distance between two points on a map, and the same two points on the Earth's surface. Scale is commonly represented on a map in three ways: bar scale, written scale, or representative fraction (RF). The bar scale and verbal scale are fairly common, but the RF is the type of scale used most often by geographers, and the most confusing to some people (see Figure 5). The most important thing to remember with the RF is that the unit of measurement used on the left side of the fraction is the same unit used on the right side of the fraction. A scale of 1:125,000 states that 1 inch on the map is equal to 125,000 inches on the Earth (or 1 centimeter on the map equals 125,000 centimeters on the Earth). To find the number of miles on Earth for one inch on a map using a representative fraction, divide the right side of the RF by the number of inches in a mile, 63,360. A scale of 1:125,000 also states that 1 inch on the map equals approximately 2 miles on the Earth (125,000/63,360).


Bar Scale

**One inch equals approximately two miles** — Written Scale

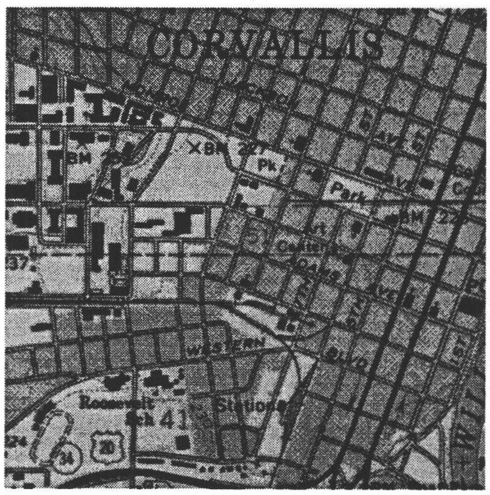
**1:125,000** — Representative Fraction (RF)

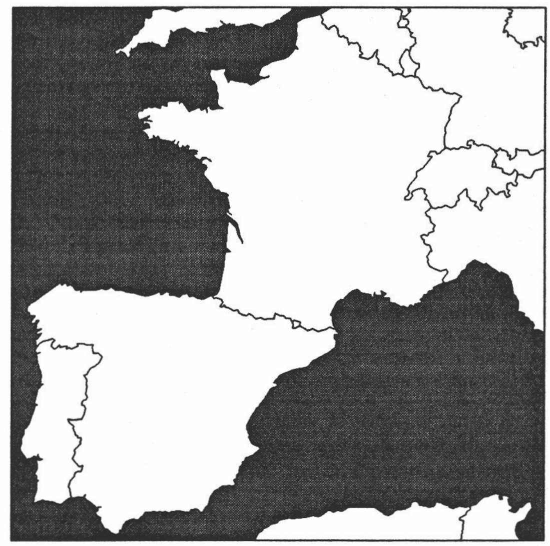
1 inch on the map = 125,000 inches on the ground
1 inch on the map = 10,416.67 feet on the ground (125,000/12)
1 inch on the map = 1.93 miles on the ground (125,000/63,360)

**Figure 5.** *Three types of scales are commonly used on maps: bar scale, written scale, and representative fraction (RF).*

Maps are commonly called either Large Scale or Small Scale. A large scale map shows a small area of the earth's surface in great detail. For example, the 7.5' USGS Corvallis Quad (1:24,000) shows all of the streets and some of the buildings of Corvallis-

-this is a large scale map. A small scale map shows a large area of the earth's surface in less detail. Any world map is small scale (1:24,000,000), as it shows large cities as dots--less detail (figure 6). Choosing the scale for any mapping project is important because it helps define the size of the map, space constraints, and the level of detail to be shown.



Large Scale
1:24,000

Small Scale
1:24,000,000

**Figure 6.** *Large scale maps such as this section of the 1:24000 USGS Quad showing downtown Corvallis, Oregon show a small portion of the Earth's surface in great detail with streets and building clearly visible. Small scale maps such as this 1:24,000,000 map of a part of Europe show a large portion of the Earth's surface with little detail.*

Direction is measured on maps and in the field using the 360° of a circle. The direction between two points is called an azimuth with north at 0° (or 360°), east 90°, south 180°, and west 270°. Maps indicate direction with a north arrow and as shown in Figure 7, some maps show more than one type of north. The USGS 7.5' Quads show three types of north: grid north, true north, and magnetic north. Grid north shows north if the earth were on a flat north-south oriented grid system such as the State Plane

Coordinate System. True north shows the direction along the meridian of longitude in the center of the mapped area. The third type of north is magnetic north, which is the direction a compass needle points in the middle of the area encompassed by the map. The earth's magnetic field is not centered directly over the north pole, and the magnetic north pole is constantly moving. Magnetic north shows the magnetic declination, or number of degrees a compass needle points away from true north, which is an important thing to know when mapping in the field.

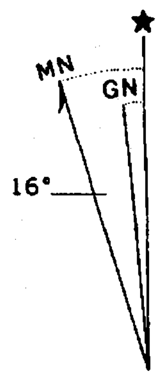



**Figure 7.** *USGS Quads have a north arrow which shows true north, grid north, and magnetic declination--the number of degrees and direction that a compass reads away from true north due to changes in the Earth's magnetic field.*

It is important to understand the concepts of distance and scale, direction and magnetic north, and location and the State Plane Coordinate System in order to perform accurate field mapping. Not only will these ideas be encountered in the field, but they will also be used when creating a final map of the study site. The questions on the following page are intended to provide a brief introduction to interpreting a USGS 7.5' Quad.

**Use the USGS 7.5' Corvallis Quad to answer the following questions:**

1) Use the black tic marks to determine the State Plane location of the Benton County Courthouse.

2) What is the scale (RF) of the 7.5' Quad?

3) How many miles are there in one inch on this map?

4) Is this a large or small scale map?

5) How many inches on a 1:1200 map is 500 feet on the ground?

6) What is the magnetic declination of this map (number of degrees and direction)?

7) Why is this important?

**PART II** - Field Mapping

| | |
|---|---|
| goal: | Measuring and mapping location, distance, and direction in the field |
| supplies: | Base map<br>Compass<br>Data sheet<br>Flag markers<br>Ruler<br>Tape measure |

Field mapping consists of measuring location, distance, and direction in the study site, and recording this information on a base map and data sheets so that it can later be used to create a map. This section will discuss one way to record this information. In the field, direction will be recorded with a compass, distance will be recorded with striding, and location will be recorded using bench marks, the State Plane Coordinate System, and a basemap. The method used here involves an open traverse, which is a series of distances and directions which make up a line, to locate a series of study points forming a regular grid. All of this information will be measured in the field and recorded using base maps and data sheets.

Location is measured from a benchmark which is a point of known location that can be found both on a base map and in the field. As shown in Figure 8, prepare the basemap prior to going to the field, by creating a regular grid of points, starting from the benchmark. It is best to have the benchmark be one of the points in the middle of the grid and to create the grid in a north-south, east-west direction. The distance between each point needs to be determined based upon the size of the study site and the level of detail needed for data collection.

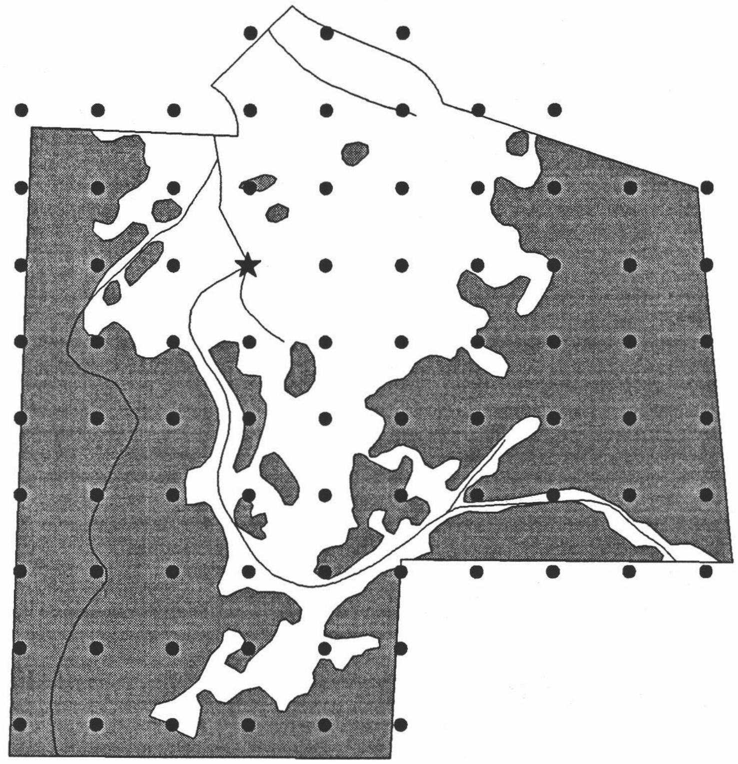


**Figure 8.** *This regular grid starts from the benchmark and each point is 250 feet away from the previous point.*

When the grid has been created on the basemap, determine the State Plane Coordinates of each point starting with the benchmark and using the distance between each point in the grid. As shown in figure 9, those points to the east of the benchmark have the grid distance added to the easting, but the northing remains the same. Those points to the south of the benchmark have the grid distance subtracted from the northing, but the easting remains constant.

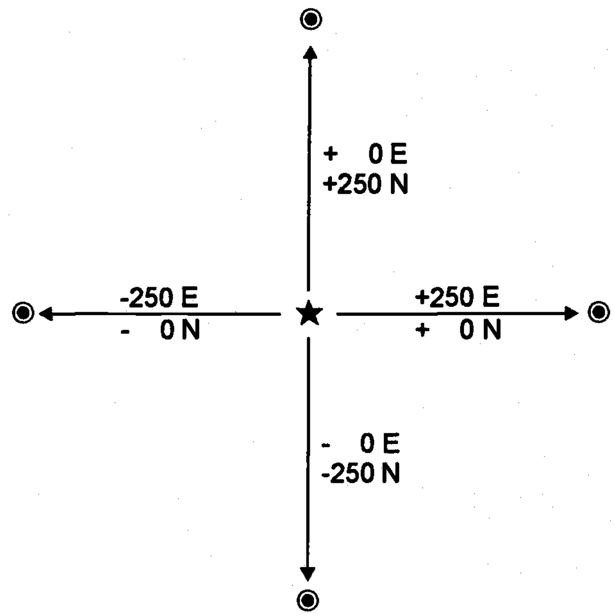



**Figure 9.** *The State Plane Coordinates can be determined for each point on a north-south, east-west grid by adding or subtracting the grid distance from the known coordinates of the benchmark.*

Distance is measured in the field by recorded the number of strides between two objects. A stride is two steps and can produce accurate results if measured carefully. To determine the length of a stride, measure out 100 feet with a tape measure, and walk at a normal, relaxed pace from end to end. Start with your right foot and count every time your left foot lands on the ground. Divide 100 by the number of strides you took to determine the length of each stride. Do this process at least four times and average the results. If any one of these tests is off by 5%, discard that test and do another one. Use the table below (Figure 10) to determine stride length. Alternatively, to record distance with a higher accuracy, it is possible to bring the tape measure into the field to use instead of striding.

| # of Feet | # of Strides | Stride Length (feet) | | |
|---|---|---|---|---|
| 100 | | | | |
| 100 | | | average stride | |
| 100 | | | | feet |
| 100 | | | | inches |

**Figure 10.** *Determine the number of strides for 100 feet at least four times to get the average length of one stride.*

The best way to record direction in the field is with a compass. A compass, which measures north based upon the Earth's magnetic field, is made up of several different parts: the magnetic needle, which points to magnetic north, the dial, which displays the 360° of a circle, and the direction arrow which is used as an aid for sighting objects and reading direction. Just as on a map, direction between two objects in the field is measured in degrees, called an azimuth (Figure 11).

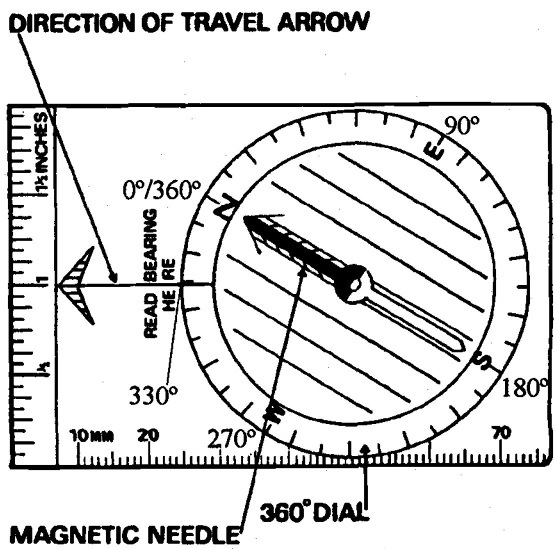



**Figure 11.** *A compass is made up of several different parts including the magnetic needle, direction arrow, and dial. The dial measures the degrees of a circle and can be used to determine the azimuth between two objects. This example shows an azimuth of approximately 330°.*

**Finding a certain azimuth with a compass:**

1) Hold compass level and steady and rotate dial until azimuth reading to be determined is on the direction arrow.

2) Rotate entire body until the red end of the magnetic needle is inside the red orienting arrow on the base of the dial and pointing toward 'N', the direction arrow should still read the azimuth to be determined.

3) Rotate body to adjust for magnetic declination (if the magnetic declination is 20° east, rotate your body 20° west).

4) The direction arrow is now pointing toward the azimuth to be determined.

A good way to measure direction with a compass is to work in pairs. The first person in the pair stands at the benchmark with the compass. The second person strides off the distance in the approximate direction to the next point. Once the second person has reached the approximate location of the point, the first person, using the compass, directs the second person either left or right until the two team members create a line in the correct azimuth between the two points. The first person then strides off the appropriate distance walking toward the second person. This method eliminates the need to walk and keep the compass pointed in correct direction at the same time, and reduces the risk of striding in the wrong direction.

**Putting it all together:**

1) Find the benchmark in the field, mark on basemap as point #1.

2) Find the azimuth (as determined earlier) with a compass from point 1 to point 2.

3) Stride off the distance (as determined earlier) to point #2.

4) Mark the study point with a labeled marker flag.

5) Repeat process to the other study points in the field.

Once these areas have been found in the field, the appropriate environmental data can be collected. At the end of the field work each team will have several types of cartographic data consisting of a rough basemap and associated field mapping data sheets. Part III of this manual will discuss how to turn this rough information into a final map which follows cartographic standards and will be useful for governmental offices.

Name:______________________ length of stride:_______ft site:___________

Map Scale:________________ or 1 inch =_____________ft date:___________

| starting point | ending point | azimuth | strides | feet | notes |
|---|---|---|---|---|---|
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**Figure 12.** *Field mapping data sheet.*

**PART III** - Map Design

goal: To create a final map from data collected in field
supplies: Data collected in the field
Straight edge
Protractor
11" by 17" paper
Colored pencils

In order to create maps which clearly convey the information you wish to present, it is important to follow a few cartographic concepts. The first thing to keep in mind when creating a map is your audience--who will be using the map. In this case it will be several different groups with varying map reading abilities: community officials, local mapping and GIS offices, and the general public. In addition to knowing your audience, it is also important to understand the amount of information you want to convey. Too much information can clutter up a map and make it difficult to read, just as a lack of information does not tell the reader everything he or she needs to know. At a minimum, different habitat locations, in-depth study points, and cultural features such as buildings and paths should be shown.

Once the data have been collected and the map reading capability of the audience assessed, it is time to create the map. When doing this, it is important to include the five following items in the map (Figure 13).

1) Every map should have a title which clearly conveys the information contained in the map. It is best not to include the word "Map" in the title, as anyone looking at the map will be able to tell that it is a map.

2) Every map should also contain a north arrow, which will allow the reader to orient himself or herself to the real world.

3) A legend should also be included. The legend should contain an explanation of

each symbol found on the map. Remember that a map is a symbolic representation of the earth's surface, and every map reader may not know what all of your symbols mean. It is not always necessary to put the word "Legend" or "Key" at the top of your legend.

4) Another important item which should appear on a map is the scale. As there will probably be several different types of people using the map, it may be worth putting two different types of scale on the map.

5) The name of the person who made the map and the date the map was created are the last things which should appear on every map. The name tells the map reader who made the map, so he or she knows who to go to for more information. The date explains how recent the information on the map is.

In addition to the items mentioned above, there are other things which may appear on the map. A border, or neat line, looks nice on a map and helps draw the reader's attention in toward the map. An inset map which shows a larger area at a smaller scale also helps to give the map reader an area of reference and can be used to show how to get to the study area from the closest major road. Another useful piece of information which would be helpful for future scientific studies, would be to provide coordinates of certain landmarks such as the boundary corners of the study area and the in-depth study points. This will allow future people to find the same location and see how things have changed over time.

Creating a map of the study site involves converting the data collected in the field to the proper map scale. When making a map, distance can be measured on the map with a ruler and direction measured with a protractor. It is a good idea to make a draft map on a piece of graph paper so that the general layout and design of the map can be determined prior to working on the finished product. Be creative and include the five cartographic components to create a map which is pleasing to look at and which provides accurate data for government departments.

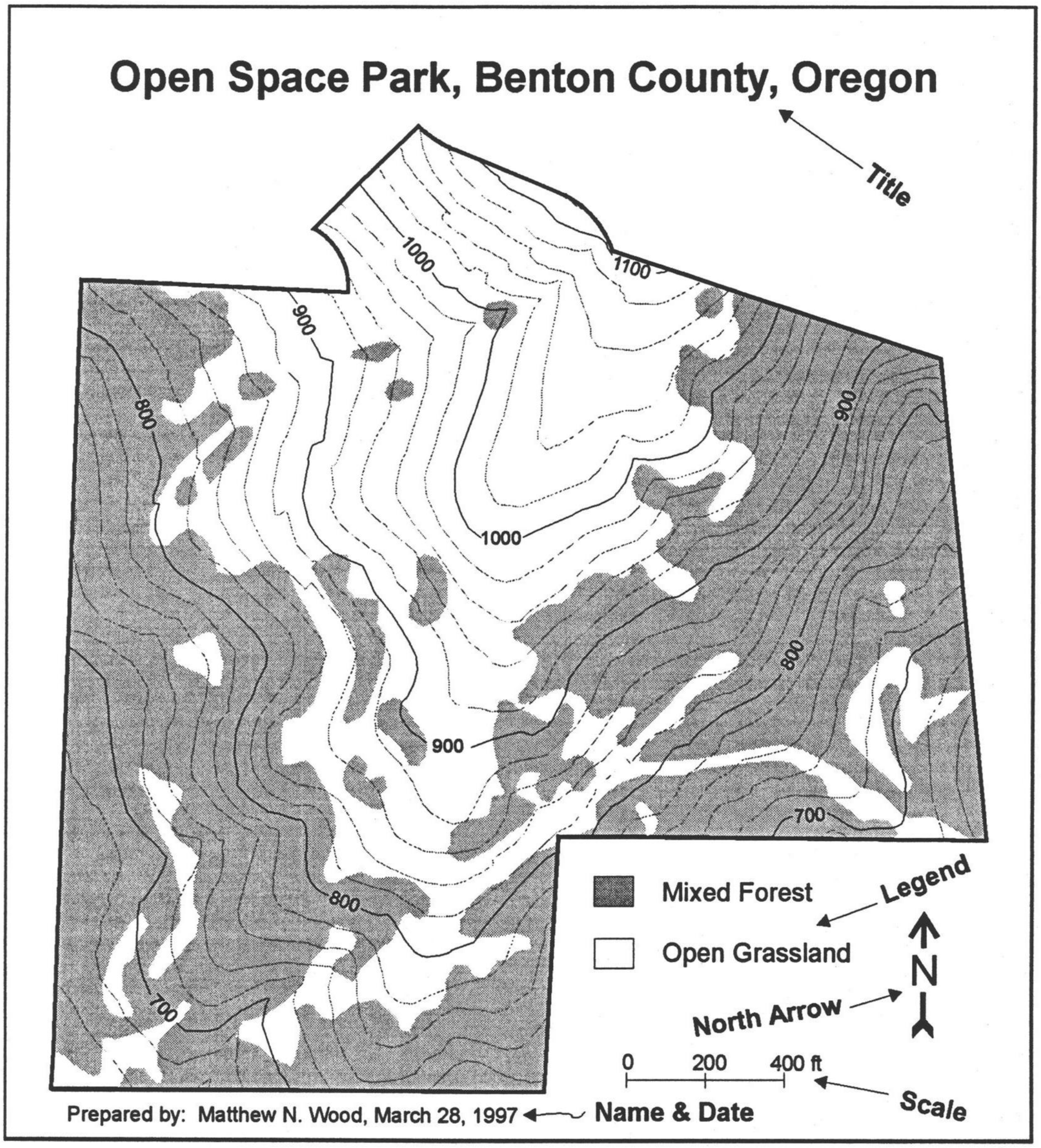



**Figure 13.** *All maps should include a title, scale, north arrow, legend, name of creator and date created.*

## Glossary

**Azimuth:** The direction of a line, between 0° and 360° defined by the angle from true north.

**Benchmark:** A point of known location which can be found on both a map and in the field.

**Declination:** Magnetic Declination is the difference between true north and magnetic north.

**Graticule:** The grid on the earth's surface which is formed by lines of Latitude and Longitude.

**Large Scale:** A term for map scale in which a small area of the earth's surface is shown in great detail.

**Latitude:** The measure of location north or south of the equator.

**Longitude:** The measure of location east or west of the Prime Meridian.

**Map:** A scaled, symbolic representation of all or a portion of the earth's surface.

**Meridian:** A line that connects all points having the same longitude.

**Parallel:** A line that connects all points having the same latitude, parallels run east-west and get smaller as they approach the poles.

**Range:** Six mile wide north-south zone in the Township and Range location system.

**RF:** Representative Fraction, map scale expressed as a ratio or fraction.

**Scale:** The ratio of the distance between two points on a map and the distance between the same two points on the earth's surface, commonly expressed as a bar scale, representative fraction, or written scale.

**Small Scale:** A term for map scale in which a large area of the earth's surface is shown in less detail.

**State Plane:** A square grid location system measured in feet, east and north of a false origin.

**Stride:** The distance covered in two steps, used to measure distance in the field.

**Township:** Six mile wide east-west zone in the Township and Range location system. Also, the 36 square mile area formed by the intersection of townships and ranges.

**USGS:** United States Geological Survey, creates accurate map series of the United States.

## Selected Bibliography

The following sources can be consulted for further information on map interpretation, field mapping, and map design.

Campbell, John. 1993. Map Use and Analysis. Dubuque, Iowa: Wm. C. Brown Publishers.

Greenhood, David. 1964. Mapping. Chicago: University of Chicago Press.

Robinson, A. H., et al. 1995. Elements of Cartography. New York: John Wiley & Sons, Inc.

Tyner, Judith. 1992. Introduction to Thematic Cartography. Englewood Cliffs, New Jersey: Prentice Hall.

## Acknowledgments

I thank Dr. A. Jon Kimerling, Department of Geosciences, Oregon State University for his cartographic review, Connie Wiegers, Nature Education Director, Corvallis Environmental Center, and Doug Sackinger of Benton County GIS for supplying the cartographic data used to create the base maps.

**Use the USGS 7.5' Corvallis Quad to answer the following questions:**

1) Use the black tic marks to determine the State Plane location of the Benton County Courthouse.

**1,280,050 feet east, 339,870 feet north, Oregon, north zone**

2) What is the scale (RF) of the 7.5' Quad?

**1:24,000**

3) How many miles are there in one inch on this map?

**.38 miles**

4) Is this a large or small scale map?

**large scale**

5) How many inches on a 1:1200 map is 500 feet on the ground?

**5 inches**

6) What is the magnetic declination of this map (number of degrees and direction)?

**19° east**

7) Why is this important?

**In the field a compass will show north as being 19° east of true north.**

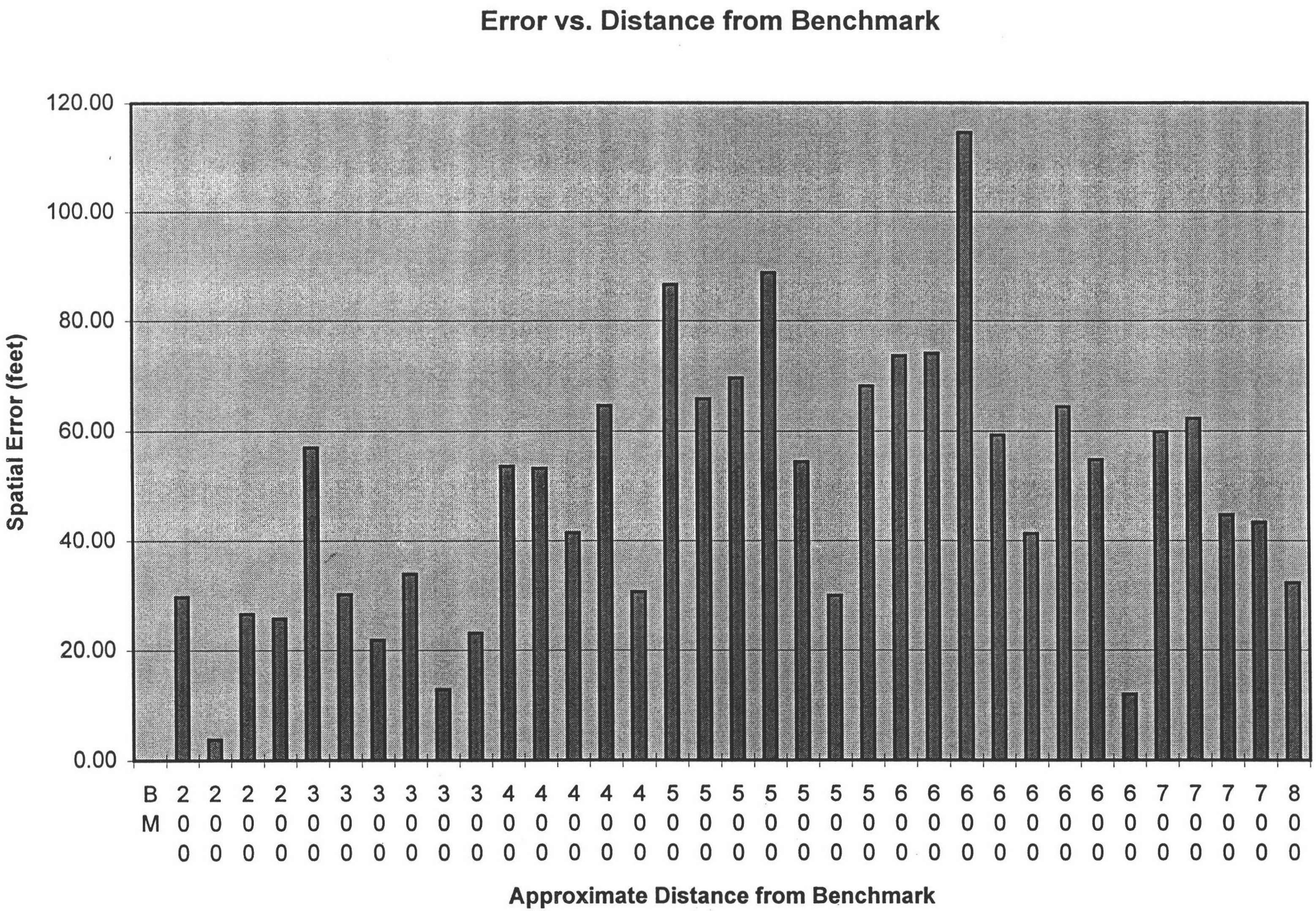
| no. | Point # | GPS Easting | GPS Northing | Student East | Student North | Veg type | East diff | North diff | **Geom error** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | A-1 | 1250999.50 | 343772.78 | 1250990.23 | 343709.00 | Grass | 9.27 | 63.78 | **64.48** |
| 2 | A-2 | 1251136.62 | 343779.45 | 1251115.23 | 343709.00 | Grass | 21.39 | 70.45 | **73.69** |
| 3 | A-3 | 1251281.38 | 343760.32 | 1251240.23 | 343709.00 | Grass | 41.15 | 51.32 | **65.92** |
| 4 | A-4 | 1251411.51 | 343782.10 | 1251365.23 | 343709.00 | Grass | 46.28 | 73.10 | **86.64** |
| 5 | A-5 | 1251517.85 | 343772.90 | 1251490.23 | 343709.00 | Grass | 27.62 | 63.90 | **69.71** |
| 6 | A-6 | 1251596.75 | 343780.86 | 1251615.23 | 343709.00 | Grass | -18.48 | 71.86 | **74.14** |
| 7 | A-7 | 1251747.29 | 343763.25 | 1251740.23 | 343709.00 | Grass | 7.06 | 54.25 | **54.74** |
| 8 | A-8 | 1251862.10 | 343753.68 | 1251865.23 | 343709.00 | Grass | -3.13 | 44.68 | **44.77** |
| 9 | A-9 | 1251968.91 | 343733.44 | 1251990.23 | 343709.00 | Grass | -21.32 | 24.44 | **32.28** |
| 10 | B-1 | 1250962.89 | 343695.34 | 1250990.23 | 343584.00 | Forest | -27.34 | 111.34 | **114.59** |
| 11 | B-2 | 1251090.55 | 343669.46 | 1251115.23 | 343584.00 | Grass | -24.68 | 85.46 | **88.89** |
| 12 | B-3 | 1251235.32 | 343637.35 | 1251240.23 | 343584.00 | Grass | -4.91 | 53.35 | **53.55** |
| 13 | B-4 | 1251400.17 | 343628.81 | 1251365.23 | 343584.00 | Grass | 34.94 | 44.81 | **56.96** |
| 14 | B-5 | 1251519.95 | 343627.99 | 1251490.23 | 343584.00 | Grass | 29.72 | 43.99 | **53.22** |
| 15 | B-6 | 1251637.47 | 343633.57 | 1251615.23 | 343584.00 | Grass | 22.24 | 49.57 | **54.43** |
| 16 | B-7 | 1251762.00 | 343639.00 | 1251740.23 | 343584.00 | Grass | 21.77 | 55.00 | **59.24** |
| 17 | B-8 | 1251864.33 | 343595.97 | 1251865.23 | 343584.00 | Forest | -0.90 | 11.97 | **11.99** |
| 18 | B-9 | 1251976.03 | 343542.93 | 1251990.23 | 343584.00 | Grass | -14.20 | -41.07 | **43.38** |
| 19 | C-1 | 1250981.35 | 343487.72 | 1250990.23 | 343459.00 | Grass | -8.88 | 28.72 | **29.99** |
| 20 | C-2 | 1251116.38 | 343471.80 | 1251115.23 | 343459.00 | Grass | 1.15 | 12.80 | **12.87** |
| 21 | C-3 | 1251259.21 | 343476.16 | 1251240.23 | 343459.00 | Grass | 18.98 | 17.16 | **25.76** |
| 22 | C-4 | 1251390.66 | 343473.97 | 1251365.23 | 343459.00 | Grass | 25.43 | 14.97 | **29.71** |
| 23 | C-5 | 1251516.79 | 343472.91 | 1251490.23 | 343459.00 | Grass | 26.56 | 13.91 | **30.19** |
| 24 | C-6 | 1251636.34 | 343450.10 | 1251615.23 | 343459.00 | Grass | 21.11 | -8.90 | **23.12** |
| 25 | C-7 | 1251751.78 | 343430.70 | 1251740.23 | 343459.00 | Grass | 11.55 | -28.30 | **30.65** |
| 26 | C-8 | 1251873.28 | 343418.53 | 1251865.23 | 343459.00 | Grass | 8.05 | -40.47 | **41.31** |
| 27 | C-9 | 1252013.66 | 343401.41 | 1251990.23 | 343459.00 | Grass | 23.43 | -57.59 | **62.26** |

| no. | Point # | GPS Easting | GPS Northing | Student East | Student North | Veg type | East diff | North diff | **Geom error** | |
|---|---|---|---|---|---|---|---|---|---|---|
| 28 | D-1 | 1250993.97 | 343292.68 | 1250990.23 | 343333.95 | Forest | 3.74 | -41.27 | **41.46** | |
| 29 | D-2 | 1251119.53 | 343312.57 | 1251115.23 | 343333.95 | Forest | 4.30 | -21.38 | **21.85** | |
| 30 | D-3 | 1251241.18 | 343330.37 | 1251240.23 | 343333.95 | Grass | 0.95 | -3.58 | **3.77** | |
| **31** | **D-4** | **1251365.23** | **343333.95** | **1251365.23** | **343333.95** | **Grass** | **0.00** | **0.00** | **0** | Benchmark |
| 32 | D-5 | 1251473.79 | 343312.87 | 1251490.23 | 343333.95 | Grass | -16.44 | -21.08 | **26.59** | |
| 33 | D-6 | 1251602.16 | 343302.59 | 1251615.23 | 343333.95 | Grass | -13.07 | -31.36 | **33.89** | |
| 34 | D-7 | 1251708.04 | 343277.74 | 1251740.23 | 343333.95 | Grass | -32.19 | -56.21 | **64.66** | |
| 35 | D-8 | 1251848.38 | 343267.80 | 1251865.23 | 343333.95 | Grass | -16.85 | -66.15 | **68.21** | |
| 36 | D-9 | 1251983.90 | 343274.40 | 1251990.23 | 343333.95 | Grass | -6.33 | -59.55 | **59.86** | |
| | | | | | | | | sum | 1708.77 | |
| | | | | | | | | mean | 47.47 | |
| | | | | | | | | SD | 25.22 | |
| | | | | | | | | **RMS** | **53.59** | |

| Point # | GPS Easting | GPS Northing | Benchmark E. | Benchmark N. |
|---|---|---|---|---|
| Test | 1261604.77 | 340735.98 | 1261602.60 | 340732.96 |

| East diff | North diff | **Geom error** | |
|---|---|---|---|
| 2.17 | 3.02 | **3.71** | GPS Test |

All coordinates measured in the 1927 State Plane Coordinate System (feet), Oregon, North Zone.
1927 North American Datum (CONUS).
RMS and geometric error shown in feet.


Error vs. Distance from Benchmark
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Spatial Error (feet)
BM 200 200 200 200 300 300 300 300 300 300 400 400 400 400 400 500 500 500 500 500 500 500 600 600 600 600 600 600 600 600 700 700 700 700 800
Approximate Distance from Benchmark

**Error vs. Sequential Linear Order**