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The development of personal computer software coupled to an analytical stereoplotter allows major gains in efficiency and accuracy in a number of forestry related subjects. This thesis describes the operation of a system developed by Carto Instruments.

This thesis demonstrates how area estimates might be made in a systematic way within 5% of true values by accounting for topographic displacement, non-horizontal flight, and imprecise determination of scale, factors that conventionally result in errors of more than 25%. Ground distances were accurate within 3% at 300 feet on 1:31000 scale black and white prints. At a similar scale, tree heights ranging from 40 to 100 feet could be consistently estimated within 10% of true height.

When applied to mapping the location of snags, key features of riparian zones, and changes in canopy openings, the system proved satisfactory on various film media and scales. Historical analysis of aerial

photographs was demonstrated by adjusting to common scale and measuring rates of vegetation change over four decades toward canopy closure. The same approach has application for other historical analysis where aerial photographs are available.

The application of the system to terrestrial photogrammetry was demonstrated using 35 mm transparencies to measure tree taper within an accuracy of 2 inches.

In summary, merging of software written for a personal computer has finally made the benefits of analytical stereoplotting economically available to a host of forestry-related topics and provides an opportunity for numerous applications including, as demonstrated, a more accurate digitizing of data to be included in any geographic information system.

Photogrammetric Uses of a New-generation Analytical Stereoplotter in Forestry

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Introduction

The initial conception of this thesis was to study the possibilities of using aerial photography to measure changes in small openings over periods of time in naturally disturbed areas of forests (patch dynamics). During the initial research, a relatively new technology in photogrammetry became more economically available. This in turn led to an expansion of this thesis from its original narrow focus to an overall look at the problems encountered through use of conventional photogrammetric methods, the use of this new technology, and its potential for application in several other aspects of forestry.

This thesis is comprised of a series of studies and literature reviews of the problems associated with conventional methods of measurement from aerial photography, research and development of a PC-based analytical stereoplotter (the Carto AP190), and research and analysis of the use of the PC-based analytical stereoplotter for forestry applications.

Several applications are presented including the initial patch dynamics study, forest vegetation mapping, and a section on terrestrial photogrammetery.

Errors in Direct Measurements from Aerial Photography

Aerial photography provides one of the most important and least utilized sources of data for land management decisions. The most significant reason for this under-utilization has been the inability to economically obtain high-precision measurements from aerial photography.

The use of aerial photography in forestry is certainly not small. Field foresters use aerial photography almost daily in their work. The extent of use however and the actual data collected have been limited and often incorrect.

Measurements taken directly from aerial photographs raise the question of accuracy as primarily influenced by a) topographic displacement, b) displacement due to tip/tilt and, c) photo measurement errors. The resulting displacement of objects by tip/tilt and/or topography can result in distortion of distance, area, and direction measurements to the extent that accurate measurements reflecting true conditions are not always possible using conventional methods.

Displacement of an object in a photograph occurs relative to one of three points: a) the nadir, b) the principal point, and c) the isocenter. The nadir is a point where a plumb line from the camera lens intersects the photograph. Topographic displacement is radial from this point. For the purposes of this thesis, all reference to displacement and/or distortion will be in regards to the nadir unless otherwise specified.

The principal point is the point on the photograph that corresponds to the geometric intersection of the fiducial points. Lens distortion is radial from the principal point. However, with modern high-precision camera lenses this error is minimal and can be ignored for forestry purposes.

The isocenter is a point on the photograph that is halfway between the nadir and the principal point. Displacement errors due to tip/tilt are radial from the isocenter and tend to be somewhat compensating over the entire photograph (Avery, 1968) but can be of some concern when single areas are considered.

Topographic displacement is potentially the most serious problem in areas of varying elevation. Because topographic displacement can result in the shift of image position on the photograph, the question arises as to whether this shift results in a significant error in area measurements. If a shift of the entire area occurs equally there is no problem. But, if the shift also occurs within the area, (an unequal shift in points on the photo), as is more likely due to elevation differences within the area, significant error in area measurement may be a legitimate concern.

If the areas of interest are less than a few acres in size absolute errors may not appear to be much of a problem. For example, many ecological studies in forest areas make use of habitat sites that consist of small forest openings or patches (this will be discussed in greater detail in a later section). Small absolute errors in area measurements may not appear to be of great enough concern to warrant consideration of topographic and tip/tilt displacement. However, this could be serious when the differences are considered as a percentage of the area.

Using the topographic displacement formulas:

$$d = \frac{r(\pm \Delta h)}{H} \qquad \text{or} \qquad d = \frac{r\pm(h)}{H}$$

where:

d = Photo displacement at the same scale as the datum in inches or millimeters.

r = Radial distance on the photo from the nadir to the displaced point in inches or millimeters.

h = Difference in elevation between the object and the nadir of the photograph in feet or meters.

H = Flying height above the datum in feet or meters.

$\pm \Delta h$ = The difference in elevation between the base of the object and the top of the object.

Paine (1981) has shown area measurement biases of as much as 30 per cent due to topographic displacement. However, these errors were calculated for sites that were large in area, over 90 acres, and had large values for h, and r, and small values for H. In areas less than a few acres in size, the change in elevation within the sites is generally small and the radial distance is usually kept small by using photos that restrict the study sites to the effective area of the photograph. Reducing the values of these two variables will reduce topographic displacement. In addition, the use of a 12-inch focal length or longer lens will reduce topographic displacement as compared to more commonly used shorter focal length lenses. However, because of the small size of the area, even minimal errors could become large in proportion to the total area. To examine this, a sample calculation of topographic displacement on a small patch area follows.

To test the effects of reducing r and h on area measurements of a small patch opening, a study area was chosen on black and white, 1:7000 project scale, paper print photography. The photography was taken with a 12-inch focal length lens. The photography is of an area in the McDonald-Dunn research forest properties, administered by the Oregon State University School of Forestry, Corvallis, Oregon.

The study site is an oval-shaped forest patch of about 0.8 acres in size with an average slope of 26 percent (radial from the nadir) and an average elevation of 1104 feet. The ground measured distance of the long radius of the oval is 300.0 feet. The ground measured distance of the short radius is 121.4 feet. The elevation difference from the lower edge (point A) and the upper edge (point B) is 32 feet. Points A and B are radial to the nadir. For purposes of an example, the site was simulated as a true oval and the area was calculated from the standard formula for the area of an oval. Four successive photographs in the flight line were used to calculate absolute errors due to topographic and tilt displacement at different photo locations in relation to the nadir as follows:

Photo #	Location of the study site
246-2-3	Photo edge (outside of the effective area)
246-2-4	Mid point between the nadir and the effective area edge
246-2-5	Very close to the nadir
246-2-6	Effective area edge

Because photo locations are lineal distances along a straight line through the nadir, there should be no topographic displacement at right angles to this line. If areas are confined to the effective area and close to the nadir, values for radial distance are reduced and the overall displacement values reduced as well. Conversely, if areas are located away from the nadir, overall displacement will increase.

Additional information for the four photos follows: (Measurements were taken directly from aerial photographs using a micrometer. Elevation above nadir was obtained from an analytical stereoplotter).

Photo Number	H above nadir	Point A h	Point A r	Point B h	Point B r	h B-A	r A-B
246-2-3	6688′	+268′	3.98"	+300′	4.35"	32′	0.37"
246-2-4	6593′	+173′	1.58"	+205′	1.95"	32′	0.37"
246-2-5	6368′	- 52′	0.62"	- 20′	0.31"	-32′	0.31"
246-2-6	6653′	+233′	3.02	+265′	2.70"	32′	0.32"

The results of the four examples are summarized in Table 1.

Table 1. Results of topographic displacement on a study site at four different photo locations. The ground measured area is 34867.35 square feet (0.8 acres).

Photo Number	Displacement (A & B) Photo	Displacement (A & B) Ground	Calculated Area Square feet	% Error
246-2-3	0.035"	19.5′	38168.9	+9.5
246-2-4	0.019"	10.4′	36609.6	+5.0
246-2-5	0.004"	2.1′	34517.4	-1.0
246-2-6	0.002"	1.1′	35049.6	+0.5

In the case of photo 246-2-6, the area is located at the far edge of the effective area of the photo and a larger value for the percent error might be expected. However, in this case, the area is situated so that the higher elevation is nearer the nadir. This offsets the overall displacement of the area by displacing the nearer edge more than the far edge because of h and the reduction in r for the higher elevation point.

For this example, the slope was 26 percent. However, in the Pacific Northwest, it is not uncommon for forested areas to have slopes in excess of 60 percent or more. In the above example, assuming a 60 percent slope and assuming that the change in elevation would not cause a change in radial distance, calculations were again made for area displacement. In fact, the change in elevation would cause an increase in r and any errors reported here would be underestimated. The results are summarized in Table 2.

Table 2. Results of topographic displacement on a study site at four different photo locations. The slope has been increased to a 60%.

Photo Number	Displacement (A & B) Photo	Ground	Calculated Area Square Feet	% Error
246-2-3	0.062"	34.6′	40828.1	17.1
246-2-4	0.031"	17.0′	37737.3	8.2
246-2-5	0.006"	3.2′	34339.8	1.5
246-2-6	0.018"	10.0′	36541.8	4.8

In the case of photo 246-2-5, the change in elevation has little effect on the area calculation because the value of r remains small. In the case of 246-2-6, the increase in h resulted in a change in direction of the displacement of point B. This resulted in enough of an increase in overall displacement as to appear significant. For these examples, any significance would depend upon the accuracy expected of the measurements.

The problem of photo measurement error can probably be linked in most cases to an improper assumption of photo scale. A common mistake is to assume photo project scale and individual photo or point scale as one and the same. This would actually be true only by coincidence of the nadir elevation being equal to the project assumed average elevation. In fact, this would be extremely rare.

By combining the photo measurement errors of an assumed photo point scale with tip/tilt and topographic displacement, additional errors from the first example are shown as follows.

Using the same photos and the same areas from the first example, the photo scale is assumed to be 1:7000 project scale instead of the true photo point scale as calculated. The results of photo measurement errors are summarized in table 3.

In each case, the larger error of the short radius is due to its distance being radial to the nadir and shows the additional error attributed to displacement.

Table 3. Results of photo measurement errors using an incorrectly assumed project scale on a study site at four different photo locations. The ground measured distance for the long radius is 300.0 ft. the short radius is 121.4 ft.

Photo Number	Calculated Long Radius	% Error	Calculated Short Radius	% Error
246-2-3	340.3′	13.4	175.0′	44.2
246-2-4	340.3′	13.4	165.3′	36.1
246-2-5	330.6′	10.2	155.6′	28.2
246-2-6	320.8′	6.9	165.3′	36.1

Generally, forest areas are not simple geometric shapes nor do they have smooth, easily defined boundaries as in the above theoretical example. Because of this, precise measurements, especially area calculations, are not a matter of simple mathematics.

Traditional area measurements on aerial photography have been done in the office using dot count, planimeter, apportionment, and transect methods. These are useful methods but not without problems beyond the fact that they do not take topographic displacement into account. The accuracy and precision of dot counts and transects are dependent upon dot or line intensity as a variable for area calculations. For large areas this is a limited concern. However, for small area measurements and estimation of small changes in area, even small errors in measurements may become large relative to the size of the area. Planimeters are based upon the formula method of area measurement but are tedious and expensive (Avery, 1978) and the apportionment method is not suited to the measurement of a few small areas (Paine, 1981).

Forest Measurements with a Computer Digitizing Tablet. Accuracy of the Hewlett Packard 9830A for Computer Digitizing of Aerial Photography

One alternative method for area measurements is computer tablet digitizing. The software is relatively inexpensive and the method is a little less labor intensive than planimeters (Tracing areas using a digitizing cursor seems to be less tedious than using the planimeter). The resolution of the digitizing boards (0.100 mm) appears to be high enough to significantly reduce the standard error of sampling measurements to acceptable levels. Thus a greater precision may be expected from the digitizing boards as opposed to more conventional methods of dot counts and transects.

The next objective was to test the feasibility of using a computerized digital tablet and accompanying software to calculate area measurements from aerial photography on small forest areas with accuracy and precision.

The digitizing software for this study was developed by the U.S. Department of Agriculture. The program was designed for determining average yarding distances (AYD) and was developed for the Hewlett Packard (HP) 9830A desk top calculator/plotter/digitizer system (Twito and Mann, 1979).

The Hewlett Packard system utilizes a subprogram for calculating the area of timber harvest units within the AYD program. The system is composed of the HP 86b computer and the HP 911a graphics tablet. The digitizer uses an electromagnetic field to simulate a cartesian coordinate system. Resolution of the tablet is rounded to 0.100 mm.

Three replicate tests of area measurements of patches on different photos (same nominal-scale) with different relationships of the patch to the nadir were conducted. Two different patches were used. Because errors will be proportionally the same at all scales, it was not critical to test various scales of photography. Instead, the patches were examined at the larger scales of 1:7000 and 1:4000 to provide more distinct boundaries.

For each patch, two photographs of similar scale were used. The first photograph had the patch confined to the effective area at or near the nadir of the photograph to minimize displacement. The second photo had the same patch located outside of the effective area at or near the edges of the photo to maximize displacement effects. Separate patch photo scale reciprocals were calculated from ground measurements and area measurements were averaged over five replications using the Hewlett Packard digitizing tablet with corresponding computer and software described earlier.

The results of this preliminary study are summarized in Table 4. The largest standard error noted of mean area value was 0.94%.

To further test the differences within a patch, a standard paired t-test was run on each of the three trials. The results are summarized in Table 5. In all three trials, no significant differences were found even at the 50% level ($P < 0.50$).

Table 4. Summary of three tests to determine the differences in area measurements of the same unit on different photographs as a result of displacement on aerial photographs. SE percent is for a test of repeatability of measurements on each photo (n = 5). The first test in each pair is within the effective area and the second is outside the effective area.

Patch No.	Photo No.	Project PSR	Patch PSR	Mean Area Square Feet	SE Percent
1	246-2-5	1:7000	6530	42266.41 ±175.42	0.42
1	246-2-4	1:7000	6530	42398.14 ±101.59	0.24
1	267-4-8	1:4000	3760	45517.72 ±158.58	0.35
1	267-3-7	1:4000	3525	45569.65 ± 55.90	0.12
2	246-2-4	1:7000	6820	11257.10 ±106.18	0.94
2	246-2-5	1:7000	6945	11321.15 ± 75.98	0.67

The results indicate that displacement may not introduce error in making area measurements of small areas on aerial photography using a computerized digitizing tablet. However, this does not mean that displacement should be ignored. The degree of displacement is highly variable and should be evaluated, not ignored.

Table 5. Standard t-test for significant differences between mean area measurements of the same unit on different photographs in each of three separate trials.

Patch NO.	Project PSR	t 0.05,8	Significant
1	1:4000	0.30884	NS
1	1:7000	0.64983	NS
2	1:7000	0.49056	NS

Although the previous tests showed that it may be possible for displacement to not be a significant concern, the tests did not address the accuracy to which the area was measured. For example, the range in area measurements of patch number 4 between project PSRs of 1:7000 and 1:4000 was 3303.24 sq. ft. or 7.8%. These area measurements have been tested and the differences found were not significant. However, topographic displacement has not been taken into account. Table 6 summarizes the errors caused by topographic displacement.

In this example, camera focal length was 8.25 in. This is important to note because of the relationship it plays in the displacement formula.

Table 6. Summary of errors due to topographic displacement and tip/tilt in area measurements on aerial photographs using a computerized digitizing tablet. Camera focal length is 8.25 in. Ground measured area = 34867.35 sq. ft. The first test in each pair is within the effective area and the second is outside the effective area.

Patch No.	Photo No.	Project PSR	Patch PSR	Mean Area (n=5) Square Feet	Percent Error
1	246-2-5	1:7000	6530	42266.41	17.5
1	246-2-4	1:7000	6530	42398.14	17.8
1	267-4-8	1:4000	3760	45517.72	23.4
1	267-3-7	1:4000	3525	45569.65	23.5

Because of the relationship of the variables in the displacement formula,

$$d= \frac{r(\pm \Delta h)}{H} \quad \text{and} \quad H= f\ (PSR)$$

several options are available for reducing topographic displacement in making area measurements. Most notably is to increase H (increase camera focal length or aircraft flying height) which results in an increased value for H and a decrease in the value for r. On the other hand, larger scales can be used as long as the study areas are located at or near the nadir, (reducing the value of r), are not sufficiently large areas, (causing an increase in the difference in displacement between points), or do not have changes in elevation within to a large degree, (increasing h).

Accuracy of the digitizing tablet was further tested by using 1:18000, high-resolution, color infra-red diapositives of an area of the Elk River. The focal length of the photography was 12.0 in. This had the effect of both increasing H while decreasing r on the photo in the displacement formula. Three areas were chosen at the center and three areas at the edges of the effective area of the photography. Table 7 shows the area calculations for these areas. Measurements were again made using the HP digitizing tablet and software. Actual area and area PSR were obtained using an analytical stereoplotter. Ground control was obtained from USGS 7 1/2 minute quadrangle sheets.

The results suggest that the influence of displacement on area measurements of small areas can be small when the variables in the equation are established to minimize displacement. In fact, with small areas, the problem of actual photo measurement errors, as opposed to displacement, may prove to be the more significant and should be looked at in future studies. In either case, the problem can be divided into two parts; a) obtaining reliable ground measurements and subsequent PSRs to minimize potential additive errors and b) assuring the operator is well trained in using the digitizing tablet.

Table 7. Errors in area calculations for six small areas when tip, tilt, and topographic displacement are not accounted for. Data are from 1:18000 scale CIR transparencies of an inland area of the Elk River, Southwest Oregon.

Area #	Area PSR	Photo Position	Dot Count Area sq ft	Actual Area sq ft	Percent
1	20330	Center	50229	46765	7.4
2	20402	Center	14453	14010	3.2
3	20440	Center	21760	20497	6.2
4	20344	Edge	35926	32876	9.2
5	19988	Edge	13872	13453	3.1
6	19926	Edge	34465	35916	4.2

Although areas of such small size historically have not been of great importance in forestry, they are now receiving a considerable amount of attention, especially from the integrated disciplines of fisheries, wildlife, and plant ecology. For this reason, a section on analytical photogrammetry of small areas is included in this thesis (Patch Analysis).

In general forestry practices, areas are much larger than a few acres and errors in photo measurements are generally more significant. For example, the use of aerial photography to determine unit areas for timber sales is often done by assuming an average elevation for a stand from USGS quadrangle sheets and then calculating areas by use of a polar planimeter or more likely by using the dot count method. However, as stated earlier, in areas of steep terrain, such as the Pacific Northwest, measurement errors can be as high as 30% when tip, tilt, and topographic displacement are not accounted for (Paine, 1981).

Table 8 shows area calculations for four clearcuts with tip, tilt, and topographic displacement not accounted for. Photography was 1:18000, high-resolution, color infra-red diapositives of the Butler Bar area of the Elk River in Southwest Oregon. Actual area and area PSR were obtained from an analytical stereoplotter. Ground control was obtained from a USGS 7 1/2 minute quadrangle sheet. Clearcuts were chosen to provide distinct area boundaries. Average elevation of each area was determined from 7 1/2 minute USGS quadrangle sheets and areas determined by dot count method. Dot intensity was 400 dots to the square inch.

Table 8. Errors in area calculations for four clearcuts when tip, tilt, and topographic displacement are not accounted for. Data are from 1:18000 CIR transparencies of the Butler Bar area of the Elk River, Southwest Oregon.

Area #	Area PSR	Average Slope	Dot Count Area sq ft	Actual Area sq ft	Percent Error
1	18691	37.8	1455639	1659015	12.3
2	19010	35.4	1028929	1350329	23.8
3	19461	50.3	1130931	1375026	17.8
4	19650	39.3	1447959	1954281	25.9

Area 1 was closest to the nadir of the photograph and had the least amount of displacement associated with it. Area 4 was the farthest from the nadir and subsequently had the greatest amount of displacement of the four areas. This is reflected in the percentage error in area measurement between the four areas.

Errors this large could have serious implications in forestry operations. Timber sold on the cruise (other than 3P) will have volume errors of at least the percentage error in area measurement. Forestry supplies such as seedlings for regeneration, herbicides, and fertilizers, purchased on a per acre basis, will likewise be in error. Additionally, other disciplines utilizing forest area measurements will have similar errors associated, for example, riparian zone analyses, wildlife habitat determinations, and even recreation use studies.

In addition to area calculations, aerial photography provides a significant data base for linear measurements in x,y and x,y,z directions. However, as has been shown, the probability for error is high using the conventional methods. This is not to say that conventional methods should be cast aside. On the contrary, conventional methods are important and have their place, especially in field use. Rather, this thesis points out a) that conventional field methods should be coupled with an understanding of the importance of displacement, and b) that conventional methods should not be employed in the office where a higher order of accuracy may be required and/or obtainable.

Present day technology has rapidly advanced to the point that data from aerial photography is in high demand. This is especially true in the case of the newer extensive data base systems and geographic information systems. Data are required to be both accurately and quickly obtained.

The next step in progression for this type of data acquisition is the use of an analytical stereoplotter. The analytical stereoplotter provides a means for making these measurements accurately and quickly. This thesis will examine the use of analytical stereoplotters as an important tool in many aspects of forestry and will focus primarily on the use of a new generation PC-based analytical stereoplotter, the Carto AP190.

Analytical Stereoplotters

A stereoplotting instrument is defined as any instrument that permits an operator to define the shape of an object by observation of the stereoscopic model formed by a single stereoscopic pair of photographs (Merrit, 1958). The main function is the formation of a three-dimensional model of the ground at a known scale which can be measured by the operator (Moffitt and Mikhail, 1980).

Stereoplotting instruments fall into two basic categories; analog stereoplotters and analytical stereoplotters. In each case, the end results are the solutions to the geometrical relationships of the terrain and the photography, the differences being in the way the solutions are determined.

The geometric relationship of the photographs is established by the process of orientation of the stereomodel. Orientation of the stereomodel occurs in three steps: 1.interior orientation, 2. relative or exterior orientation, and 3. absolute orientation.

Interior orientation establishes the positioning of the photos on the photo carrier and locates the principle point using the fiducial coordinates. This is a mathematical reconstruction of the interior geometry of the camera used. Interior orientation allows the positioning of the principle point of the photograph to exactly coincide with the perspective center of the projector (Lyon, 1959).

Relative orientation is the mathematical reconstruction of the positioning of the camera(s) relative to each other at the moment of exposure. The reconstruction occurs by solution to the five independent mechanical motions of the photographs (elements of relative orientation) including tip (pitch,omega) and tilt (roll,kappa) of the first photograph and tip, tilt , and rotation (swing, phi) of the second photograph (Lyon, 1959). Relative orientation additionally establishes camera separation of the exposures. A least squares fit is used to obtain refined photo coordinates and y parallax is removed at control points in the stereomodel.

Finally, absolute orientation translates the photo (model) coordinates into an object (ground) coordinate system from existing ground survey data or existing map data (i.e. USGS Quadrangle sheets) correlated to photo control points. This process establishes the correct scale and position of the stereomodel with reference to the existing control (Lyon, 1959).

The analog stereoplotter is a stereocomparator which requires the optical stereomodel to be reconstructed by physical (non-mathematical) means. This requires a simulation of a direct projection of bundles of light rays using mechanical rods, lineals, or a combination of both. Stereo fusion of the model is accomplished by the operator (Wolf, 1983; Cimerman and Tomasegovic, 1970).

The analog plotter consists of (a) a projection device, (b) a means for observing the images of the stereomodel, and (c) a means of measuring coordinates and/or plotting the model (Born et al., 1980).

The projection device is used in the reconstruction of the light ray bundles, in effect, reconstructing the image at the moment of exposure from a stereo pair of photographs.

Observation of the stereomodel is necessary for any quantitative and/or qualitative analysis. Observation can be accomplished by direct observation, use of a telescopic device through a restitution camera, or direct observation with magnification by binoculars. Quantification of data is accomplished through the use of a measuring device, usually a floating mark, and manual movement of the mark in x and y directions. X- Parallax measurement permits calculation of elevation data. A more thorough discussion of analog stereoplotters, including recent plotters in use, may be found in Born et al.(1980).

The development of the analytical stereoplotter has its roots as far back as the 13th century. Thompson and Grunner (1980) compiled a thorough documentary of the history of photogrammetry from which the following timeline was established (Figure 1) with reference to those events that most correspond to the development of the analytical stereoplotter.

The analytical stereoplotter has been in production use since the early 1960's. At the time, its advantages over the analog plotters were well known, but the prohibitive costs of the instruments, and the supporting computer hardware, relegated the plotter to the role of an interesting invention but not very practical. However, advances in mechanical and computer technology have dramatically reduced costs and pushed the analytical plotter to the forefront of what many are calling a new dawn in photogrammetry.

The analytical stereoplotter encompasses a photogrammetric plotting system that mathematically solves the relationship (orientation) between photographic image coordinates of points measured in a two-dimensional photographic reference system and the ground coordinates of points in the three-dimensional world (Friedman et al., 1980).

The analytical plotter is an active device, as opposed to an image space plotter or analog plotter, where computer intervention is required to determine the relative positions of the photographs in an oriented stereomodel and to drive the photographs to their position in real time (Konecny, 1980).

Figure 1. Timeline for the development of the analytical stereoplotter (Thompson and Grunner, 1980).

Date	Event	Inventor
1492	Principles of aerodynamics and optical projection	DaVinci
1525	1st true perspective drawing device	Durer
1600	Stereoscopy defined mathematically First hand-drawn stereopair published	Keppler Chimeniti
1726	First topographic maps constructed from drawings	Kapeller
1759	Geometric fundamentals of photogrammetry defined	Lambert
1800	First zonal lens developed	Fresner
1810	First variable diaphram	Bausch
1837	First tangible photographs taken	Daguerre
1844	First multi-element lens	Petzval
1858	First aerial photographs	Tournachon
1864	Photogrammetry becomes an official survey tool in France	Laussedat
1892	Floating dot principle	Stolze
1893	Overlapping photographic principles Forerunner to radial line triangulation	Adams
1897	Theory of double projection	Scheimpflug
1901	First prototype stereo comparator	Pulfrich
1907	First prototype stereoplotter	Thompson
1921	First universal analog plotter	Hugershoff
1937	Geometry of relative orientation	Finsterwalder
1958	First prototype analytical stereoplotter	Helava
1980's	First modern microcomputers	(various)

In contrast, analog stereoplotters rely on mechanical and/or optical elements to establish absolute orientation. Interior and relative orientation are established by hand and absolute orientation is achieved by the use of space rods or optical projection.

The analytical stereoplotter has several key advantages over the analog plotter. Because analytical plotters rely on a minimum of mechanical and optical components, measurement precision can be obtained at a higher level. The most precise analog plotters can obtain measurements to ± 20 microns at best while it is not unreasonable to expect measurements to within ± 2 microns with the best analytical plotters (Friedman et al., 1980). However, as previously pointed out, operator error may negate this as a valid advantage.

The analog plotter is limited in the types of photography it can accept relative to the capability of the plotter to achieve interior orientation including camera focal length, film format, lens distortion, and film shrinkage. The analytical plotter mathematically calculates the interior orientation relative to the geometry of the specific camera used and applies necessary corrections in real time (Friedman et al., 1980). It should be noted that the types of photography that analytical plotters will accept is not the same for all plotters but is a function of the physical design of the plotters.

In addition to photo format, there are several other key differences between available analytical stereoplotters. Reutebuch (1987b) has summarized these (Appendix 1).

Additional advantages of the analytical plotter correspond to the application of computer technology to the system. This includes 1) data storage and retrieval, 2) archival capability for model orientation, 3) potential for integration with existing software for data handling (i.e. data base systems and geographic information systems), 4) options for micro or mini-computer interfacing, and 5) possibilities for customized usage design through software development.

Until recently, the analytical stereoplotter was at a disadvantage due to the high costs of the instruments ($100,000.00 +). However, recent developments in analytical stereoplotting systems have led to a significant breakthrough in photogrammetry, most notably, the integration of high-precision analytical stereoplotters with personal computing systems. Photogrammetric precision is now possible at levels that were previously unobtainable at reasonable costs. In addition, computer software developments allow for digital data from photographs (x,y, and z coordinates) to be directly input into a number of CAD (Computer Aided

Drafting) and geographic information systems (GIS) using the analytical stereoplotter to emulate a direct data capture device such as a digital cursor or mouse.

Carto AP190 Analytical Stereoplotter

After a thorough investigation of available analytical stereoplotters, Oregon State University College of Forestry purchased a Carto AP 190 analytical stereoplotter system (hence referred to as the AP190) in September of 1987. The AP190 is the result of a four year intensive research effort by the Royal Norwegian Council for Scientific and Industrial Research to provide analytical photogrammetry capable of interfacing with a personal computer at a minimal cost.

Because the AP190 system is constantly changing, all references to the system apply to the instrument installed at Oregon State University as of 1987 (instrument No. 8). Some deviations may occur between that reported in this thesis and the current status of other AP190 instruments installed at later dates.

In order to reduce production and design costs of the analytical plotter, some sacrifice of its inherent advantages over the analog plotter were necessary (Carson, 1985). The first of these involved relaxing the high standards of precision imposed on the instrument itself (± 1 - 2 microns). This precision far exceeded the capability of the operator and could therefore be relaxed without any significant overall loss of precision.

The second factor in cost reduction was the elimination of the requirement for the more expensive mini-computer and its replacement by the desk top personal computer (PC). This is not so much a sacrifice but rather the result of advancing micro-computer technology.

The AP190 system consists of 5 component parts.

A. The AP190 stereoplotter - The stereoplotter itself consists of 5 sub-component parts; a) The SB190 mirror stereoscope, b) The SB189 light table, c) The MS190 mechanical guidance system, d) The ES190 encoding system, and e) The IS190 electrical interface (Figure 2 a-e).

a. The SB190 is a high quality mirror stereoscope with variable intensity control of a floating measurement dot. The stereoscope is equipped with binocular magnification in a range of 1x, 2x, 4x, 6x, and 8x. Exterior illumination for paper prints is from a top-mounted fluorescent light source.

b. The SB189 light table is a variable intensity fluorescent light source for diapositives and backlighting for paper prints. It additionally serves as a support for the glass plate photo carriers.

c. The MS190 is a rigid structure that guides the movement of the left and right photo carriers. Repeatability of the MS190 determines the accuracy of the

AP190.

d. The ES190 measurement system consists of a set of x and y step motor-driven linear encoders which are computer driven to remove x and y parallax by control of the glass photo carriers. A parallax control wheel regulates the z component of the measurement system by allowing manual positioning of the right photo carrier, in relation to the left photo carrier , in the x direction to simulate vertical movement of the floating dot.

e. The IS190 is a microprocessor based computer that acts as the interface between the AP190 and the host computer. Electronic signals from the ES190 encoders are registered and translated by the IS190 via the RS232 lines. Host computer input to the AP190 is registered and translated in the same manner.

B. IBM or IBM compatible personal computer - The computer controls the system including the AP190 and the additional peripheral equipment to be discussed. The computer minimum specifications are a 10Mb hard drive with a 360k floppy drive, 8087 math co-processor, 1 RS232 serial port, and a monochrome monitor.

C. Standard dot-matrix printer - Used for hard-copy display of screen graphics and printed output of data and text.

D. Pen Plotter - The College of Forestry uses the Hewlett Packard 7475A 6-pen plotter. The plotter is used to output digital coordinates from the AP190 to paper or transparencies at user-determined scale for presentation and/or analysis.

E. Digitizing tablet - The digitizing tablet is used for absolute orientation of the stereo model to ground control points. The College of Forestry is using the GTCO 1724L digitizing tablet. Ground control is calculated as state plane, Universal Trans Mercatur (UTM), or latitude/longitude coordinates from USGS quadrangle sheets, orthophotos, or other map or survey control.

In addition, the College of Forestry has integrated the AP190 to a Textronic 4109 color computer display terminal with a peripheral Textronic 4695 seven-color graphics printer for polygon display and editing as well as full-color map production of digitized data.

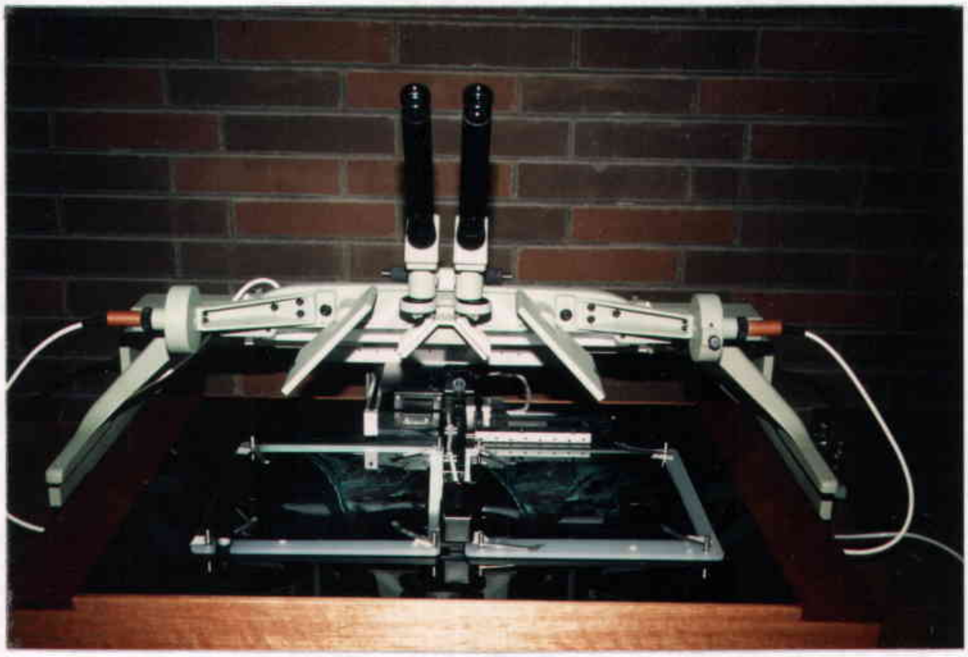


Figure 2a. The AP190 Analytical Stereoplotter

Figure 2b. The SB190 mirror stereoscope

Figure 2c. The SB189 variable intensity light system

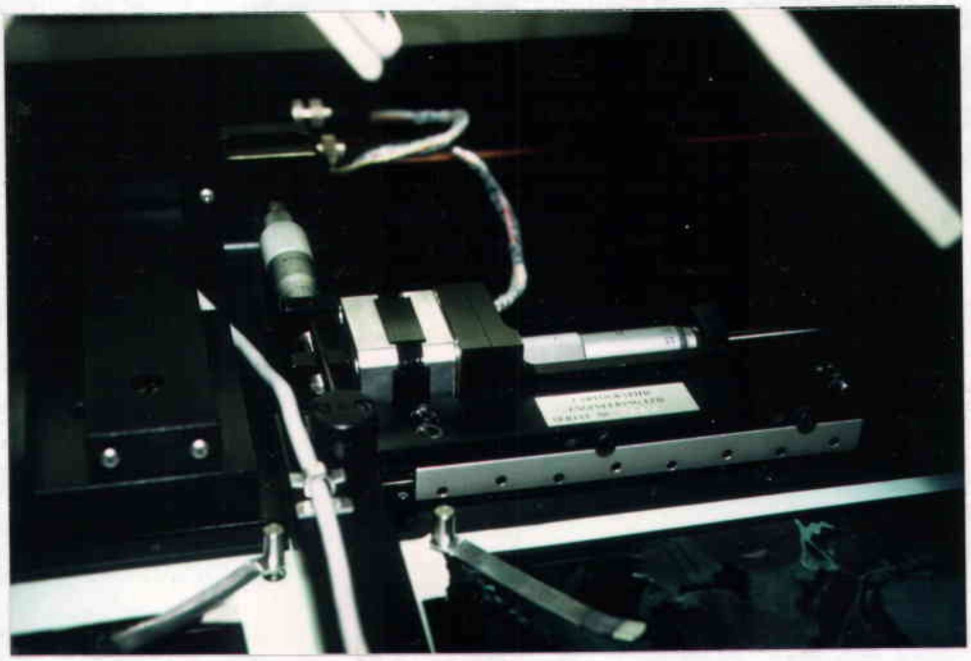


Figure 2d. The MS190 mechanical guidance system

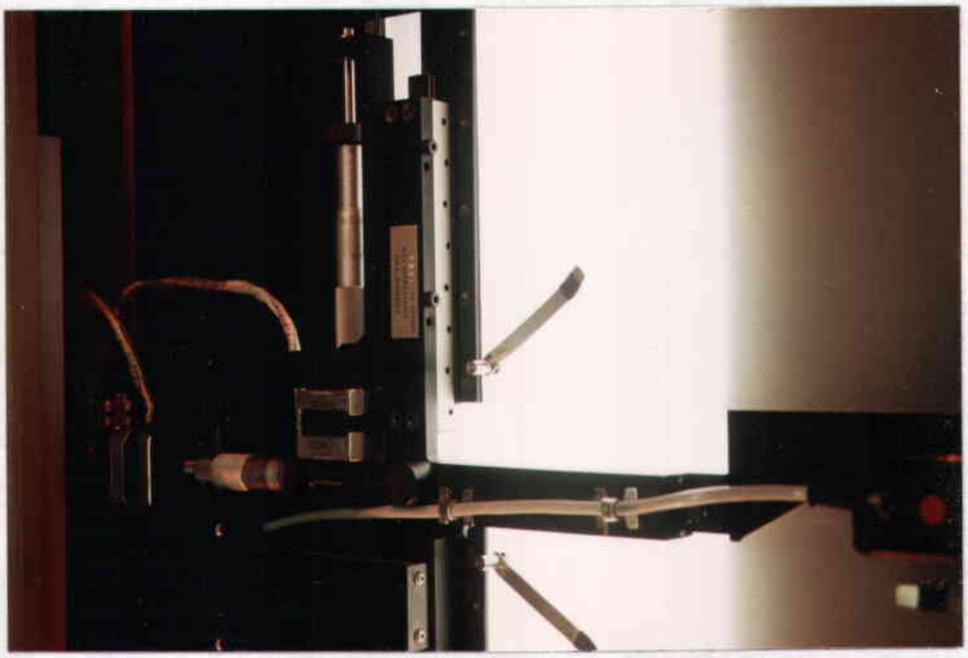


Figure 2e. The ES190 measurement system

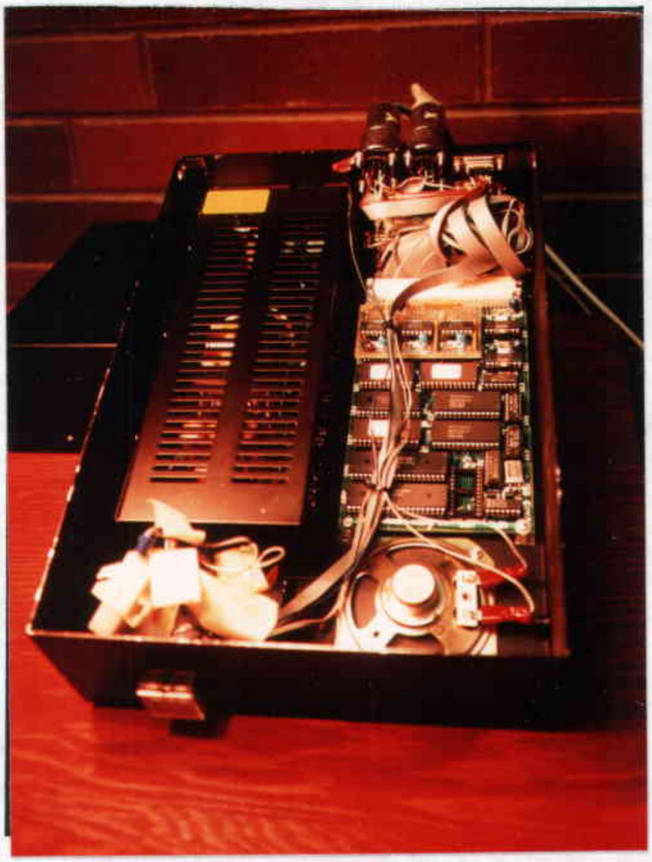


Figure 2f. The IS190 microprocessor

In addition to mapping capabilities, the collection and storage of x, y, and z coordinates and the subsequent transformation to object scale provide the capability to be used by any number of resource personnel for land management decisions.

The next section of this thesis will concentrate on the accuracy and precision of the AP190 and will address the types of accuracy that may be expected in forestry applications of the instrument.

Accuracy of the Carto AP190 Analytical Stereoplotter

For most forest planning activities involving aerial photography, measurement precision of ten feet at the object scale is adequate (Reutebuch, 1987a). This corresponds to a photo distance of about 254 microns for 1:12000 scale photography.

Measurement precision with the analytical stereoplotter may be identified through four potential sources for measurement error : 1) actual error in the mechanics of the instrument, 2) photographic distortion as a function of the photographic medium used (differential stretch and shrinkage), 3) model transfer from photo to ground (map) coordinates (absolute orientation), and 4) measurement error as a function of the individual operator. The four sources of error have been quantified and are discussed with respect to the Carto AP190 analytical stereoplotter.

Mechanical precision of the AP190

Carson (1985, 1986) has established the accuracy of the optical and mechanical components of the AP190 stereoplotter. In prototype testing, the accuracy of the system, based on the optics of a mirror stereoscope, a precision ball-slide assembly guidance system, and linear encoders, was established at ± 10 microns for x,y parallax measurements and ± 25 microns on the left photo carrier.

In addition, the AP190 has superior optics and an automated parallax adjustment mechanism (2.5 micron increments) that was found to be imperceptible to all users in testing (Carson, 1987). For measurements, the system uses a high-resolution, variable intensity floating dot which is 50 microns in diameter at photo scale and can register parallax differences in 10 micron increments over a range of 25 millimeters in y and 50 millimeters in x.

Because the mechanical components of each instrument are unique, based on manufacturing tolerances, calibration of each instrument is independent. For this particular instrument the mechanical component measurements translate into a calibration of 15 microns. At the photo scale of 1:12,000 this corresponds to an object scale error of about 0.6 foot.

Photographic medium precision

Measurement precision is affected to a small degree by 1) the distortion of the photo material and to a very small extent 2) on the distortion of the camera lens. However, the mathematical fitting of the model corrects for all but a small part of these.

Using paper prints under the best conditions, Reutebuch (1987a) found that measurement accuracy was limited to 20 to 40 microns at photo scale as a function of resolution and degree of distortion in the paper print itself. Lachowski (1986) found this even when an affine transformation (assumes non-uniform shrinkage of the medium in the x and y directions) is applied during interior orientation of the model. Shrink-stretch of the photos is reduced and resolution is increased using positive transparencies. It should be noted that measurement precision is a function of the instrument and is therefore not additive. Thus a precision of 40 microns as a worst case corresponds to an object scale error of about 1.6 feet across the entire photo model at a photo scale of 1:12,000.

Map control precision

The largest source of error in photo measurements with an analytical stereoplotter is usually associated with error in the control data particularly when control is measured from a map (Reutebuch and Shea, 1988).

A general scenario is to obtain control from USGS 7 1/2 minute quadrangle sheets (1:24,000 scale) using road intersections and other well defined points. These are usually mapped to a tolerance of 1/50 inch (508 microns) (Steger, 1986) corresponds to about 40 feet on the ground. This tolerance is spread out over a large area when well spaced control points are used.

The use of well-spaced map digitized control points (up to 20) and transfer to object coordinates by an affine transformation to establish absolute orientation will control stereo model uncertainty to well below 1 percent (Valentine, 1986). Reutebuch and Shea (1988) reported similar precision in field tests.

The accuracy of independent measurements from the USGS quadrangle was also tested in order to examine the ability of different operators to repeat measurements of the same control points. For this test, digitizing was done on a high-resolution GTCO 1724L digitizing pad (0.02mm resolution). Four corners of a 7 1/2 minute quadrangle sheet with known state plane coordinates were marked and ten road intersections located at different positions on the quadrangle sheet were circled. A group of ten persons was chosen to independently digitize the corners and the ten control points. A map showing the points of the road intersections to be digitized was available as a reference for the persons digitizing. The results are shown in table 9. In all cases, errors were well below the acceptable mapping error of 40 feet at 1:24,000 scale.

Operator Error

Operator error is a function of the three previous mentioned sources of error and additionally individual experience. This is not difficult to quantify for the most part, however, this error cannot be generalized to all operators. In this respect, the use of well-trained photogrammetrists cannot be overemphasized. While the AP190 has the advantage of ease of operation for even the untrained technician, the art of photointerpretation and photogrammetry precision still rely on skill and experience.

Table 9. Control point digitizing results. The data are from independent digital measurements of ten control points from a USGS 7 1/2 minute quadrangle sheet. Observations were recorded for each control point by ten persons. All values are in feet (ground scale for a 1:24000 scale 7 1/2 minute quadrangle sheet).

POINT #	MEAN X VALUE	STD DEV	MEAN Y VALUE	STD DEV
101	960488.72	11.83	377704.19	13.49
102	966201.00	8.66	376830.74	15.26
103	983822.27	5.48	377259.34	11.64
104	988465.23	8.37	391503.50	6.52
105	974385.10	0.00	391016.63	8.19
106	961590.97	7.42	394329.52	17.96
107	990948.63	4.47	405409.57	7.17
108	977055.37	13.60	402803.78	5.61
109	959378.85	6.32	399007.09	23.77
110	976885.09	8.06	398784.35	6.93

Given the maximum error of the mechanical system and photography, and a reasonable accuracy error for a trained operator, it would not be unreasonable to expect maximum errors of about 40 microns at photo scale. At 1:12000, this relates to an error in measurement at object scale of about 1.5 feet. Given the dynamics of forested areas, (change in terrain, vegetation, etc. over time), this is well within the limits of accuracy that could be described as adequate.

While the accuracy of the instrument has been previously established under controlled situations, it is important to develop some understanding of the expected accuracies that may be developed under field conditions.

The precision reported by Reutebuch and Shea (1988) was done using well identified stumps in clearcuts on large-scale (1:2000) and medium scale photography (1:12000). However, in traditional use, the forester is generally working with conditions ranging from light to heavy canopy cover. The next section of the thesis addresses the precision of the AP190 under normal field conditions of moderate to heavy forest canopy.

Accuracy of the AP190 in Forest Field Conditions

Most foresters are familiar with what may be called standard resource photography at 1:12000 scale black and white paper prints. In addition, aerial photography is available for all areas of the Pacific Northwest at this time from WAC corporation (Eugene, Oregon) at 1:31000 scale black and white paper prints. Both of these scales were tested for measurement precision in field conditions most encountered by practicing foresters.

In each case, models were controlled by 7 1/2 minute USGS quadrangle maps. For each model, points were identified on the photos and measurements were made for ground distances (x,y) and separate measurements made for tree heights (z). All measurements were made on the photography before going to the field for verification. Field verification was made similar to actual conditions using a Spencer tape and a clinometer. Heights for each tree were measured in conditions that ranged from open grown to heavy canopy.

Data for the tests are summarized in tables 10 and 11. The data suggests that the precision of the AP190 is well within tolerances expected of foresters under field conditions using standard available photography.

It appears that there is very little difference between the two scales of photography. This was because the 1:31000 scale photography was filmed with a mapping lens while the 1:12000 scale photography was not. The mapping lens is a high precision lens with lower lens distortion that produces a higher resolution photograph than the standard lens. This suggests that in many cases, it is not only more economical to use the 1:31000 photography (6.7 times fewer photos to cover the same area) but may be just as precise.

$$(31{,}000)^2 / (12000)^2 = 6.7$$

Table 10. A summary of the field verification of the accuracy of the AP190 on 1:12000 scale black and white paper prints under normal field conditions. Photos used are identified as 41-001-071 AND 07. Photos were taken in 1986 and measurements made in 1989.

1. TREE HEIGHTS (measurements in feet)

POINT NO.	PHOTO MEASURED	FIELD MEASURED	ACTUAL DIFFERENCE	% DIFFERENCE
1	82	90	- 8	- 8.9
2	129	116	+13	+11.2
3	63	75	-12	-16.0
4	126	131	- 5	- 3.8
5	57	64	- 7	-10.9
6	73	77	- 4	- 5.2
7	79	73	+ 6	+ 5.5
8	131	126	+ 5	+ 4.0

mean difference = -1.5 feet
std dev of difference = 8.5 feet

2. GROUND DISTANCES (measurements in feet)

POINT NO.	PHOTO MEASURED	FIELD MEASURED	ACTUAL DIFFERENCE	% DIFFERENCE
1	227	222	+5	+2.3
2	240	246	-6	-2.4
3	434	428	+6	+1.4
4	98	96	+2	+2.1

mean difference = 1.8 feet
std dev of difference = 5.4 feet

Table 11. A summary of the field verification of the accuracy of the AP190 on 1:31000 scale black and white paper prints under normal field conditions. Photos used are identified as 8-31 & 32.

1. TREE HEIGHTS (measurements in feet)

POINT NO.	PHOTO MEASURED	FIELD MEASURED	ACTUAL DIFFERENCE	% DIFFERENCE
1	70	68	+ 2	+ 2.9
2	66	80	-14	-17.5
3	39	47	- 8	-17.0
4	100	94	+ 6	+ 6.4
5	62	67	- 5	- 7.5
6	73	64	+ 9	+14.1
7	97	91	+ 6	+ 6.6

mean difference = -0.6 feet
std dev of difference = 8.6 feet

2. GROUND DISTANCES (measurements in feet)

POINT NO.	PHOTO MEASURED	FIELD MEASURED	ACTUAL DIFFERENCE	% DIFFERENCE
1	289	297	- 8	-2.7
2	304	312	- 8	-2.6
3	372	378	- 6	-1.6
4	311	306	+ 5	+1.6

mean difference = -4.3 feet
std dev of difference = 6.2 feet

With the establishment of the precision of the AP190 under field conditions, the rest of this thesis will concentrate on the AP190 for forestry applications. The following sections will concentrate on preliminary testing, some specific applications in production use, and a section focusing on the use of the instrument as a tool for looking at a specific ecological study (Patch Dynamics).

Preliminary Testing of the CARTO AP190 For Forestry Applications

Limited tests of photogrammetric approaches of the AP190 in forestry applications were conducted on the Tongass National Forest, Alaska (Reutebuch, 1987a). Photography was standard 9" x 9" black and white prints, 70 mm color prints, and 35 mm color prints. The scales used varied from 1:3000 to 1:15840. Control for the photography was obtained from USGS 7 1/2 minute quadrangle maps and was bridged from high-altitude photography (1:60000).

Preliminary tests included mapping of timber stands, soils, and vegetation types, preliminary road locations, property boundaries, stream channel debris, and polygon input into a Geographic Information System (GIS). In all cases, the stereoplotter exceeded USDA Forest Service field office requirements including measurement precision, adaptability to forestry field offices, and ease of operation during this testing.

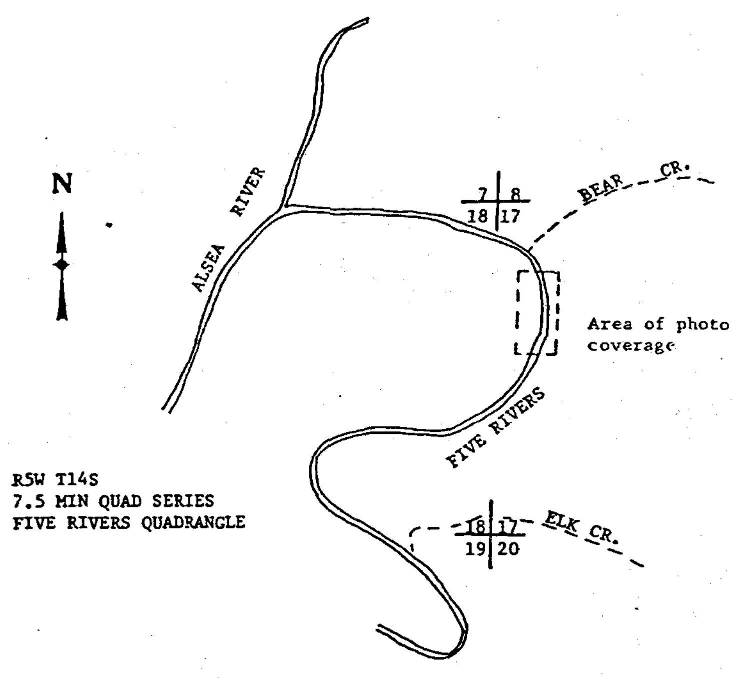
A follow-up study was conducted (Reutebuch and Shea, 1988) to determine the feasibility of bridging ground control to large-scale (1:2000) photography while maintaining adequate precision. Control was first bridged from small-scale (1:32000) black and white prints to 1:12000 black and white prints. Control was then bridged a second time to the 1:2000 black and white prints. It was found that the AP190 had average errors of less than one per cent between ground surveyed distances and photo measured distances.

Overall small-scale mapping is adequate for most projects. However, it is not uncommon for a project to require vegetation mapping at larger scales. For example, many forestry related projects require data for individual trees, (tree height, crown class, crown diameter, etc.), the ability to suborder vegetation classes by a vertical component (height classes), and the ability to manipulate digital data in such a multi-disciplinary way as to simulate GIS applications or actually integrate into an existing Geographic Information System (GIS) beyond simple polygon input.

In order to examine the suitability of the AP190 for this type of work, a pilot study was conducted by the author in the summer of 1987 at the USDA Forest Service Pacific Northwest (PNW) Research Station in Seattle, Washington. In addition, the pilot study served as a basis for training and to determine the relative ease of operation of the instrument. It was felt that in forestry applications of the instrument, ease of operation of this, or any instrument, is an important consideration. This eliminates the need for a single, specialty-trained operator.

Photography chosen for the study was existing 1971 1:20000 color infra-red transparency film. The stereo pair used is identified as photos 116-3 and 116-4. The area chosen for mapping concentrated on a 1/2 mile long section of riparian zone along Five rivers near its junction with the Alsea river. The area is located along the central Oregon coast (Figure 3).

Figure 3. Riparian area covered by 1:20000 CIR aerial photography. The map was reproduced from the 7.5 minute Five Rivers Quadrangle.



Absolute orientation of the stereomodel was established using the USGS 7 1/2 minute Five Rivers Quadrangle sheet. Nine control points were used for both x,y control and elevation control.

An initial classification (feature code) system was established based upon the overall ground features and acreages calculated for the ground feature types (Table 12). The 1/2 mile river segment was divided into reach types and surface characteristics. Ground vegetation was divided into vegetation type classes. Additional classes were set up for agriculture/grass and roads. The road classification includes turnouts and shoulders.

The initial data file contained x,y, and z ground coordinates for all of the digitized points from the stereo model. On its own, this was a valuable data set, but its size made it difficult to work with efficiently. With the use of a standard text editor, the file was divided into ten smaller files based upon feature code classification (attribute codes) and digitized polygons of specific attributes became more easily accessible. This proved to be an efficient, though somewhat primitive, simulation of a GIS. Using this initial approach, data analysis of each classification was accomplished. Overlays of each classification type were generated through a plotting program written for the Carto AP190 and interfaced to a Hewlett Packard 7576A 6-pen plotter.

Table 12. Acreage Data table. The data are from a 1/2 mile segment of the Five rivers area and were photogrammetricly derived from 1:20000 CIR photography using the AP190 analytical stereoplotter. Additional ground features were photointerpreted from the same photography.

ACREAGE TABLE

SOURCE	ACREAGE
A. RIVER	
1. Pools	1.97
2. Riffles without exposed structures	0.39
3. Riffles with woody debris	0.15
4. Riffles with exposed rock	0.41
5. Riffles with exposed vegetation	0.14
6. Unknown reaches	0.67
Total	3.73
B. VEGETATION	
1. Conifer	0.11
2. Hardwood	2.08
3. Conifer/hardwood mix	4.16
4. Brush	4.66
Total	11.01
C. OTHER	
1. Agriculture/grass	0.53
2. Roads	2.11
Total	2.64
Total Acreage =	17.38

Stream reach data were divided into classes based on geomorphic characteristics and vegetation type present. The data are summarized in Table 13. The table includes an unknown reach type classification. These were stream reach types that were concealed by overhanging vegetation and were not identifiable from vertical aerial photography. However, because ground control is established for these areas, ground truthing could easily be done for the unknown areas. Stream reach grade was not recorded at the time of the data collection, but could be obtained by using vertical coordinates at each end of the reach type and the overall reach length.

It should be noted that with stream reach data, interpretation is dependent upon the conditions of the stream at the time of the photography. In this case, the photography was flown in late August and it may be inferred that the stream was approaching its low flow volume and area. Additionally, many of the exposed surface features may be expected to change over time as a function of peak flows and storm events. However, photography at time intervals using identical classifications could provide valuable overlay data on stream reach behavior over long time periods or even as a function of an individual storm event.

Table 13. Stream Reach Data table. The data are from a 1/2 mile segment of the Five rivers area and were photogrammetricly derived from 1:20000 CIR using the AP190 analytical stereoplotter.

STREAM REACH DATA

FEATURE CODE	REACH TYPE	LGTH (ft.)	AVE WIDTH (ft.)	SHAPE	EXPOSED STRUCT.	VEG TYPE	DEBRIS TYPE	ACRES
1101	P	53.5	48.6	S	N	CH	N	0.08
1501	R	102.1	53.5	S	V	CH	N	0.14
1102	P	136.1	51.0	S	N	B	N	0.20
1301	R	92.4	58.3	S	N	B	LW	0.15
1103	P	155.6	43.8	S	N	CH	N	0.17
1601	U	87.5	34.0	S	U	CH	U	0.08
1104	P	452.0	43.7	S	N	CH	N	0.51
1602	U	26.7	58.3	S	U	CH	U	0.05
1105	P	102.1	58.3	S	N	B/H	N	0.15
1603	U	68.1	92.4	S	U	CH	U	0.27
1106	P	432.6	53.5	S	N	B	N	0.59
1604	U	126.4	68.1	C	U	CH	U	0.27
1201	R	223.6	68.1	C	N	CH	N	0.39
1401	R	398.6	53.5	C	R	H	N	0.41
1107	P	238.2	48.6	S	N	B	N	0.27

CODES: REACH TYPE; P = Pool, R = Riffle, U = Unknown

SHAPE; S = Straight, C = Curved

EXPOSED STRUCTURE: N = None, V = Vegetation
R = Rock, U = Unknown

VEG. TYPE; CH = Conifer/Hardwood mix, B = Brush,
H = Hardwood

DEBRIS TYPE; N = None, LW = Large woody pieces

Vegetation type classes were divided into sub-classes based upon stocking class and average height class. The data are summarized in Table 14. In some instances, hardwoods were identified as pure stands by species (ie maple or alder) though it should be noted that this is not usually possible at this scale. All conifer vegetation types were Douglas-fir. Measurement of individual trees was possible in one case (feature code 231). Measurements made at this scale provided the requirement for larger scale mapping of vegetation.

Stand heights of the conifer/hardwood mix include a brush designation (B). Brush heights were not obtained during the data collection, however this could be accomplished if needed in future projects.

A final class was established for location of wildlife trees which includes snags, trees with broken and/or dying tops, and dead brush clumps (Figure 4).

Mapping of wildlife trees proved to be most valuable in terms of identification, map position, and time savings over conventional ground surveying. Field crew mapping and identification would be expected to take a considerably greater amount of time, be less accurate, and possibly result in a larger number of missed trees especially in steep and brushy terrain. Tree heights were not obtained at the time of data collection, but could be obtained in future studies when needed.

Table 14. Vegetation data table. The data are are from a 1/2 mile segment of the Five rivers area and were photogrammetricly derived from 1:20000 CIR using the AP190 analytical stereoplotter. Additional ground features were photointerpreted from the same photography.

VEGETATION DATA

FEATURE CODE	VEG TYPE	NOTES	STAND HEIGHT (ft.)	STOCKING CLASS	STORY STRUCTURE	ACRES
341	H	-	40	H	1	0.71
342	H	-	60	H	1	0.12
343	H	ALDER	45	H	1	1.13
344	H	MAPLE	65	H	1	0.12
231	C	2 TREES	115	L	1	0.03
241	C	-	80	H	1	0.08
541	C/H	-	50,20,B	H	3	0.28
542	C/H	-	80,40,B	H	3	0.17
551	C/H	-	80,40,B	M	3	0.82
511	C/H	-	115,80	H	2	1.42
543	C/H	-	95,80	M	2	0.45
544	C/H	-	70,45,B	M	3	1.02

CODES: VEG TYPE; H = Hardwood, C = Conifer,
C/H = Conifer/Hardwood mix

STOCKING CLASS: H = Heavy, M = Medium, L = Light

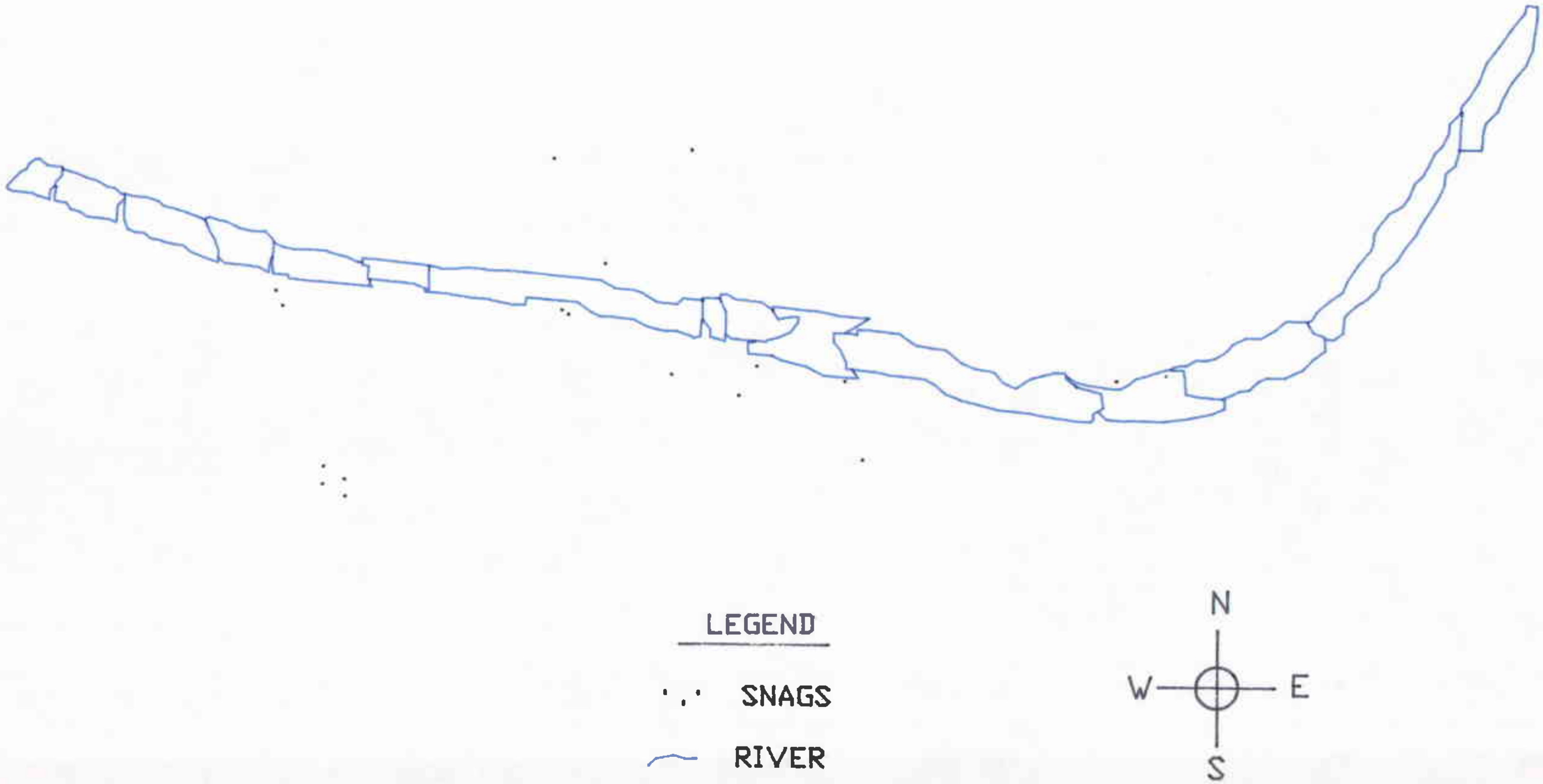
Story structure refers to the number of distinct layers of vegetation in the stand.

Figure 4. Potential Wildlife trees. The data are are from a 1/2 mile segment of the Five rivers area and were photogrammetricly derived from 1:20000 CIR using the AP190 analytical stereoplotter.

Figure 4

FIVE RIVERS TEST PHOTOS PLANIMETRIC MAP

SCALE: 1 In = 300 ft



Finally, combined data were used to produce a planimetric map of the area (Figure 5) based on the absolute orientation of the model (Table 15).

Table 15. Absolute orientation report for the Five rivers preliminary study. Photography is 1:20000 CIR; photos 116-3 and 116-4.

Model (BX,BY,BZ), Object units: 85.754 0.328 -0.854
L-Photo orientations (Omega, Phi, Kappa),gons:
0.233 -0.016 0.000
R-Photo orientations (Omega, Phi, Kappa),gons:
- 0.053 0.259 0.246
Horiz. angle between model x and object x, gons:
95.270
Obj. /model scale, Object units/microns:
67.100
Expected planimetric accuracy, Object units:
42.000
Deviations (x,y,z): 24.35 45.31 10.75

(Gons are international units commonly used in photogrammetry. There are 400 gons in a circle as opposed to 360 degrees).

Ground verification was not done at the time of this study because of the 16-year time period since the photography was flown. However, ground truth accuracy of the plotter has been previously established.

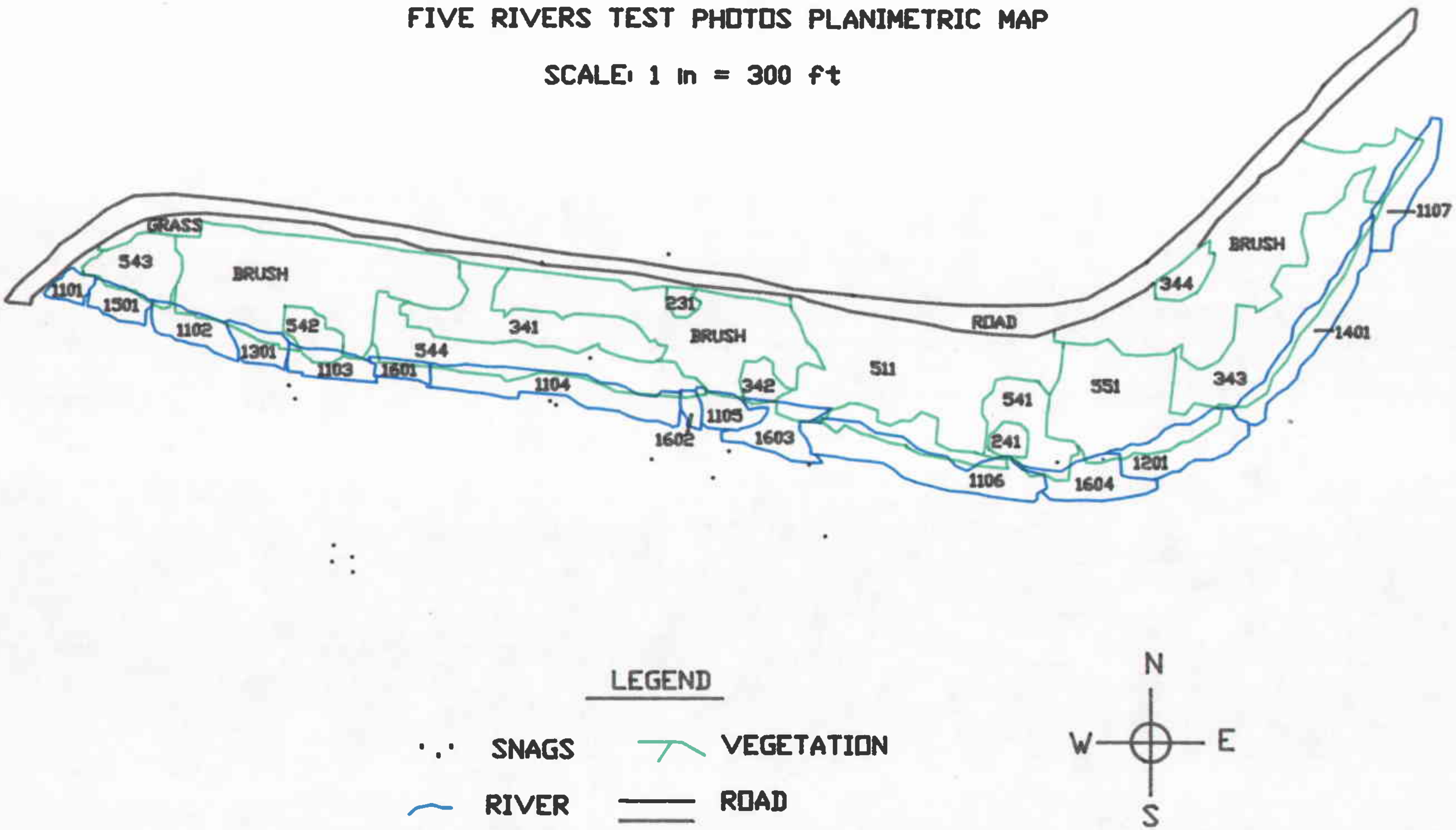
This pilot study showed the feasibility of using the AP190 in forestry applications based on the requirements of the study. Probably the most significant note was that production use of the AP190 was possible after less than a day of training.

Figure 5. Planimetric map of the Five Rivers study area. Data for the map were produced from 1:20000 CIR transparencies.

Figure 5

FIVE RIVERS TEST PHOTOS PLANIMETRIC MAP

SCALE: 1 in = 300 ft



Over the last several years, an important breakthrough in the handling of spatial data has occurred with Geographic Information Systems. This is especially important in forestry where land management decisions are ultimately based on spatial data.

One of the biggest obstacles to a GIS has been in the lack of accurate data input. The next section of this thesis will examine two aspects of error in data collection and one solution for efficient and accurate data collection and input.

The Analytical Stereoplotter as an input device to a GIS

Because GIS are data-input dependent, errors in output are directly traced to input error (or digitizing). It is estimated that digitizing takes up about 80% of the time spent in GIS application (Devine and Field, 1986). This is unavoidable in GIS. With this much time invested in the system, it becomes imperative that the digital input is done accurately and efficiently.

Data input errors may be classified as inherent and operational (Walsh et al., 1987). Inherent errors are those found in the original sources ie. maps, uncorrected aerial photos, etc. Operational errors are those produced in data capture ie, digitizing.

Every map will contain inherent error based on the nature of the source map projection, construction techniques, and data symbolization (Vitek et al., 1984). Because the accuracy of any GIS product is dependent on the inherent characteristics of the source map, positional accuracy of the source may be critical to users (Marble and Peuquet, 1983).

Operational errors may be classified as positional errors and identification errors (Newcomer and Szajgin, 1984). Positional errors are those errors in the horizontal placement of boundaries while identification errors are essentially mislabeling of areas. Additionally, Newcomer and Szajgin (1984) found that as the number of layers increase, the possibility for operational errors also increases.

A general scenario for data input is to pencil trace polygons from aerial photos, base maps, or orthophotos onto a mylar overlay. This in turn is transferred to a digitizing tablet and digitized. Finally, data must be reformatted into an acceptable GIS input format. It is not surprising that the accuracy of the data input becomes a suspect especially when done in this manner.

The PC-based analytical stereoplotter offers an economical solution to these problems. Digitizing precision is possible at levels that were previously unobtainable at reasonable costs. In addition, computer software developments allow for digital data to be directly input from aerial photography into a number of

GIS and CAD (Computer Aided Drafting) systems using the stereoplotter to emulate a direct data capture device such as a digital cursor or mouse.

Data collection directly from aerial photographs reduces the problem of inherent errors to almost non-existent since the source for projection is the ground itself. With uncorrected photo pairs, topographic displacement may account for errors of up to 30 percent in mountainous terrain (Paine, 1981). With the use of the stereoplotter, displacement and distortion in the stereo pairs are corrected through a set of rigorous mathematics.

Based on the accuracy of the AP190 (Carson, 1985, 1986), it is not unreasonable to expect accuracy of digitizing at 40 microns. At the scale of 1:24000, this translates to an error of 3.1 feet on the ground.

The only real concern then is identification errors. This can be greatly reduced by using experienced photo interpreters.

Data Transformation

At the time of this study, the university did not have access to a geographic information system. Additionally, there are at present thousands of different systems with thousands more being forecast for the coming years. With this in mind, it would not be feasible to test the data input of even a small percentage of them.

However, it should be noted that the input mode for geographic systems is essentially the same. Input is by ASCII code of x,y or x,y, and z data with some sort of attribute key. The only key difference is in the format structure of the data. The data output of the AP190 is in ASCII and contains x,y, and z data with an attribute code. Therefore, the only requirement of the data is that its format be compatible with the system it is being input to. This can be accomplished by simple programming. An example of the source code required is included for the geographic information system ARC\INFO, one of the more widely used and most powerful geographic information systems being used at the present (Appendix 2, by permission of Kevin Boston of VESTRA Resources inc., 1989).

The AP190 system has an in-house formatting structure that allows data to be automatically formatted to several applications including ARC\INFO, TERRASOFT, and DWRIS. In addition, the COPE vegetation mapping group has developed several other links to GIS including MOSS. Finally, because the ASCII output is in vector format, it eliminates the problem of resolution loss through raster format, however data may still be transferred to raster format if required.

The next section of this thesis will be concerned with the production use of the AP190 in forestry. This section will focus on a specific case study and will present the methodology developed for using the AP190 as a tool to quantitatively describe a major riparian zone in the Coast Range of central Oregon at a basin-wide scale.

A Photogrammetric Approach to Forest Mapping in the Deer Creek Watershed Basin

The condition and management of riparian zones is the number one land conservation issue in the United States (Elmore, 1987). In western Oregon, riparian zones comprise some of the most productive wildlife habitats in forested lands, characterized by high species diversity, density, and productivity (Anthony, et al., 1987). In western Washington and Oregon, approximately 359 species of vertebrates (excluding fish) utilize riparian zones for all or some of their life cycles (Brown, 1985).

The importance of riparian zones is not debatable. However, the question of maintenance and protection of riparian zones within conformance of the 1971 Oregon Forest Practices Act has generated a multi-sided conflict. Forestry practices have the potential to alter some or all of the structure and composition of the riparian zone and thereby influence the environment and structure of streams and rivers (Gregory et al., 1987).

In order to provide adequate management goals for riparian areas, a thorough understanding of the complex linkages within the systems is critical. This includes quantitative data on vegetation composition, including vegetation type, classes, and densities, riparian zone structure and geomorphology, and any additional biotic and abiotic vectors influencing the riparian zone.

Using an ecosystem analysis approach, the riparian zone may be looked at from a basin-wide perspective, both interactions from the basin and to the basin. However, basin systems can be quite large and field collection of data can be quite expensive, time consuming, and often inaccessible. To this end, aerial photography used as a quantitative tool provides an important and under-utilized source of data for riparian zone management.

COPE Project

In 1987, a cooperative research and education program, COPE (Coastal Oregon Productivity Enhancement), was formed. The overall direction of the program is to increase the multiple benefits of the forest resources of the Oregon coast range. Research is focused on multiple benefit production - the interactions of timber, wildlife, fish, water, and recreation, as they are managed together. Recognizing the importance of riparian habitat stated earlier, the fundamental research section of COPE decided to focus its efforts on riparian zone management as one its primary issues.

Management of any resource depends on an initial inventory of the resources within the system. In the case of natural resources, two types of inventory information are necessary; 1) a tabulation of the amount and condition of each category of interest and 2) the exact location of each category. With this in mind, a service/support group was formed to map and inventory the riparian zone of three major river basins in the south coast, central coast, and north coast forests of Oregon. This study focuses on the Deer Creek watershed, a basin within the Drift Creek watershed in the central coast study area.

In an earlier study (Batson, Cuplin, and Crisco, 1987), large scale (1:2000) color infra-red aerial photography was used to provide vegetation and stream information in riparian areas. Data consisted of vegetation type and subtype, width of riparian vegetation zones and acreage, riparian structure, percent ground cover of trees, shrubs, and herbaceous vegetation, percent bare soil, and density of large shrubs and trees. In addition, stream information was gathered on stream width, channel stability, bank stability, floodplain width, and stream shape.

Large-scale photography such as this is ideal for riparian zone mapping, but it is the rare exception. In application, it would be prohibitively expensive to use this scale in any large area.

Paine (1981) gives an example of a project in which full photo coverage of 480000 acres is desired. At a scale of 1:20000, this equates to a total of 458 photos for full coverage of the area at a total cost of $7248 for the project (1990 costs would be higher).

If we were to fly the same project at a scale of 1:2000, the number of photographs increases to:

$$\frac{(20000)}{(2000)} \text{ squared} = 100 \text{ times or } 45800 \text{ photos}$$

Assuming that all other costs remain the same, the total project cost increases to almost $350000.

The Five rivers test study showed that 1:20000 photography was quite adequate for vegetation mapping. An important criteria in this lies in the choice of photography. Positive transparencies allow for significant binocular enlargement (up to 8 times) without the problems of film grain associated with paper prints. At any scale, the film grain in paper prints starts to become a problem at even 2 to 3 power magnification.

Transparencies can in fact be enlarged beyond 8 power, however in forestry use, at most scales it becomes difficult for the interpreter to remain oriented to the photograph beyond 8 power magnification.

Color infra-red (modified infra-red) transparencies at a photo scale of 1:18000 were chosen for the Drift Creek watershed project. Positive transparencies provide superior resolution compared to paper prints of the same format and scale. While transparencies have the disadvantage of not being conducive to fieldwork, high quality prints can be obtained from the transparencies for field use.

In addition to film resolution quality, color infra-red photography has several key advantages to normal color, black and white, or true black and white infra-red photography (Paine, 1981). The ability of CIR to penetrate haze was of considerable importance to this project. The Drift Creek basin is strongly influenced by marine atmospheric conditions which include considerable amounts of haze.

The other key advantages of CIR especially relate to mapping riparian zones. These are: 1. CIR emphasizes water and moist areas showing more distinct boundaries. This allows the interpreter to distinguish water through very small canopy openings. With other film types, this is not always possible. 2. Conifers, hardwoods, and brush are more easily distinguished, and 3. stressed vegetation is more easily detected. This is especially important for mapping snags and broken top trees for wildlife and other purposes.

The main disadvantage of true infra-red film is the inability to distinguish detail within shadowed areas. CIR alleviates this problem by filtering out only the blue and below portion of the spectrum. This still makes use of the green through red portion of the visible spectrum. With a wider range of bands (0.5 - 0.9 microns vs. 0.7 - 0.9

microns), more detail is possible in the green to red spectrum. In addition, photography was obtained during a somewhat optimal sun angle period (mid-August near noon) which helped to reduce shadowing.

A photo scale of 1:18000 was chosen as the best alternative to economically provide full coverage of the basin. Stereo coverage of the basin comprises about 60 stereo models. At an average initial set-up time of two hours per model, the entire basin can be set up in about three to four weeks. Using a larger scale of 1:12000, the number of models increases to about 140 which would require a set-up time in excess of two months. The use of the variable magnification range of the AP190 (1x to 8x) allows photo scale enlargement to a maximum of 1:2250. Normal working conditions for forestry mapping at 1:18000 scale are usually best at 4x to 6x (1:4500 to 1:3000 scale).

Deer Creek Inventory Project Methodology

The purpose of this section is to present a procedure for stand map digitizing and to report on a mapping project using this procedure in one of the COPE study sub-basins. This project was a joint effort between the COPE wildlife team and the COPE vegetation mapping team.

The initial project and results are first presented in preliminary form. A discussion of the preliminary procedures, refinement into the final procedure used, and final results and maps follows.

The sub-basin mapping was done using 1:18000 scale color-infrared positive transparencies flown in July, 1988. The photography is identified as DRIFT CREEK 13-8 & 13-9 and DRIFT CREEK 14-4 & 14-5. Digital mapping was done using the AP190 with six-power magnification binocular attachments.

Stand typing was done according to plant community types and stand conditions as described in Management of Wildlife and Fish Habitat in Forests of Western Oregon and Washington, 1985, (ed. E.R. Brown).

The initial photointerpretive classification was first divided into one of two community types; either riparian or upland. Community types were then divided into conifer, hardwood, or conifer-hardwood mix stand types. Criteria for stand designation was 70% or greater crown closure by the predominant stand type. The conifer-hardwood mix type was used in cases where neither conifer or hardwood was predominant based on this. Stand types were then divided into stand condition classes as follows:

Stand Condition	Criteria
1. Grass-forbs	Vegetation < 2-3 ft.
2. Shrub	Vegetation < 10 ft.
3. Open sapling-pole	Trees > 10 ft. Crown cover < 60%.
4. Small saw timber	Crown cover > 60%. Trees 40-100 yrs.
5. Large saw timber	DBH > 21 in.
6. Old-growth	Snags, Broken tops present.

Table 16 shows the breakdown of acreages by stand and condition types for the sub-basin. Code numbers are used by the digitizing peripheral programs and are provided in order to access the data in ASCII format for additional analysis.

The preliminary stand map produced is shown in Figure 6. During the digitizing process, twelve larger core units were first identified at a coarse scale by stand type and condition class. Stand typing was then done within these units at a finer resolution.

Table 16. Acreage table for the Deer Creek sub-basin. Data are from 1988, 1:18000, CIR transparencies.

Code	Community	Stand	Condition	Acreage	Percent
4200	RIPARIAN	HARDWOOD	SHRUB	4.67	0.6
4300	RIPARIAN	HARDWOOD	SAP-POLE	7.17	0.9
4400	RIPARIAN	HARDWOOD	SM. SAW	31.97	4.2
4500	RIPARIAN	HARDWOOD	LG. SAW	14.46	1.9
5600	RIPARIAN	CONIFER	OLD-GROWTH	3.16	0.4
7500	RIPARIAN	MIX	LG. SAW	1.42	0.2
8400	UPLAND	HARDWOOD	SM. SAW	21.36	2.8
9100	UPLAND	CONIFER	GR. FORB	55.64	7.2
9200	UPLAND	CONIFER	SHRUB	51.35	6.7
9300	UPLAND	CONIFER	SAP-POLE	199.06	25.9
9400	UPLAND	CONIFER	SM. SAW	18.87	2.5
9500	UPLAND	CONIFER	LG. SAW	111.78	14.5
10200	UPLAND	MIX	SHRUB	1.24	0.2
10300	UPLAND	MIX	SAP-POLE	0.58	0.1
10400	UPLAND	MIX	SM. SAW	15.55	2.0
10500	UPLAND	MIX	LG. SAW	230.70	30.0
11001	NON-VEG.	PARKING	ASPHALT	0.64	0.1

SUB-BASIN ACREAGE TOTAL 769.62

The preliminary procedure was subsequently modified to reflect the subjectivity involved in both vegetation mapping and photo interpretation. Three concerns are addressed here.

Criterion for the initial digitizing was merely the discernability of areas on the photos. Using the magnified optics, areas digitized with the AP190 turned out in some cases to be less than 0.4 acres in size for some open areas. However, in stands of large trees or heavy canopy closure, areas of less than two acres were not reasonable to interpret. Therefore, all acreages of less than two acres were dropped from consideration.

The second decision involved the uncertainty of defining riparian from upland. The initial mapping used the criteria of vegetation change as an indicator of zone change. While this is a valid criteria, photo interpretation was limited to the upper story and the true zone change may be reflected by vegetation change in the understory with or without upper story change. Therefore, the riparian and upland categories were dropped. However, since the digital data are GIS compatible, the riparian/upland designation may be added at a later date using ground surveyed data and\or user-defined criteria.

Figure 6. The preliminary stand map for the Deer Creek sub-basin produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

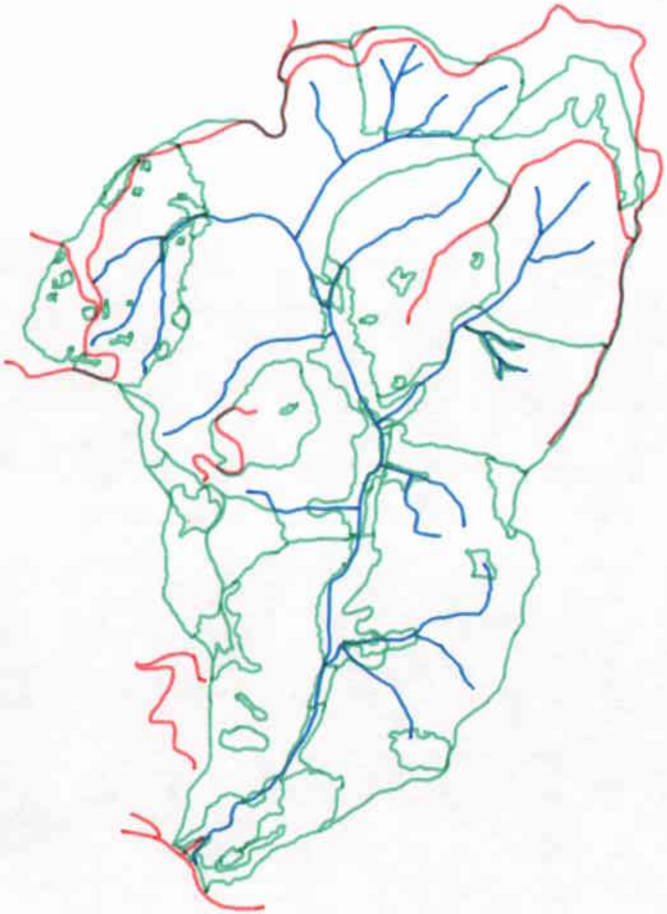


Figure 6

DEER CREEK

PRELIMINARY STAND MAP

SCALE: 1 in = 2000 ft

N

W E

S

LEGEND

VEGETATION LAYER

TRIBUTARIES

ROAD SYSTEM

The final decision was to eliminate selected categories from the condition classes. For all useful purposes, the term old-growth hardwood is not practical therefore this class was dropped. In addition, at the grass-forb level, it was not possible to discern hardwood and conifer on the scale photography used. Therefore, all grass-forb areas were designated as hardwood/conifer mix. This should better reflect true ground conditions as they exist.

Table 17 shows the final coding scheme adopted after final modifications discussed. The four digit code numbers are divided into three sections and may be read as follows. The first digit of the code denotes the stand type. The second digit denotes the condition class, and the last two digits denote the polygon number. For example, the number 5306 would represent the sixth polygon of stand type conifer in condition class sapling-pole.

Table 17. Modified coding scheme adopted for stand mapping.

Code Number	Type	Condition
1000's	Basin Boundary	-
1100's	Sub-basin Boundary	-
2000's	Drainages	-
6000's	Roads	-
3000's	Grasslands	Grass\forb
4200's	Hardwoods	Shrub
4300's	Hardwoods	Sapling-pole
4400's	Hardwoods	Small Saw
4500's	Hardwoods	Large Saw
5200's	Conifers	Shrub
5300's	Conifers	Sapling-pole
5400's	Conifers	Small Saw
5500's	Conifers	Large Saw
5600's	Conifers	Old-growth
7100's	Con\hard mix	Grass\forb
7200's	Con\hard mix	Shrub
7300's	Con\hard mix	Sapling-pole
7400's	Con\hard mix	Small Saw
7500's	Con\hard mix	Large Saw
7600's	Con\hard mix	Old-growth

With these modifications , the final maps and tables are presented. Table 18 shows the acreages for the sub-basin by stand and condition. Because the effects of edge are becoming increasngly identified as an important factor in wildlife habitat the total distance of edge has been added, community types have been eliminated, and drainages have been overlaid. Figure 7 and Table 19 show the drainages for the sub-basin as denoted by stream order and distance. Stream ordering is based on Horton's system of classification. The final maps are shown in Figures 8-12.

The maps have been separated into one stand condition map, one vegetation type map and three stand condition maps based on vegetation types.

Table 18. Acreage table for the Deer Creek sub-basin produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

CODE	STAND	CONDITION	ACREAGE	%	EDGE (ft.)	%
4300	HARDWOOD	SAP-POLE	5.1	0.7	4709.0	3.5
4400	HARDWOOD	SM. SAW	51.2	6.7	21718.6	16.3
4500	HARDWOOD	LG. SAW	14.1	1.8	5485.9	4.1
5200	CONIFER	SHRUB	48.1	6.2	6426.5	4.8
5300	CONIFER	SAP-POLE	210.6	27.4	26020.1	19.6
5400	CONIFER	SM. SAW	18.9	2.5	8761.5	6.6
5500	CONIFER	LG. SAW	114.2	14.8	14273.7	10.7
5600	CONIFER	OLD-GROWTH	4.6	0.6	2982.0	2.2
7100	MIX	GRASS-FORB	54.0	7.0	9529.0	7.2
7400	MIX	SM.SAW	14.8	1.9	5026.9	3.8
7500	MIX	LG. SAW	234.1	30.4	28061.7	21.1
				100.0		100.0

SUB-BASIN TOTALS

	ACREAGE	%	EDGE (ft.)	%
Conifer Stands	396.4	51.5	58463.8	44.0
Hardwood Stands	70.4	9.1	31913.5	24.0
Conifer\Hardwood Stands ..	302.9	39.4	42617.6	32.0
	769.6	100.0	132994.9	100.0

Table 19. Deer creek drainage system inventory produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

Stream Order	Number of Tributaries	Total Distance (ft.)	% of Basin
1	23	20984.9	56
2	7	6090.5	16
3	2	4912.2	13
4	1	5394.5	14
Totals	33	37382.1	100

Figure 7. The Deer Creek drainage system by stream order produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

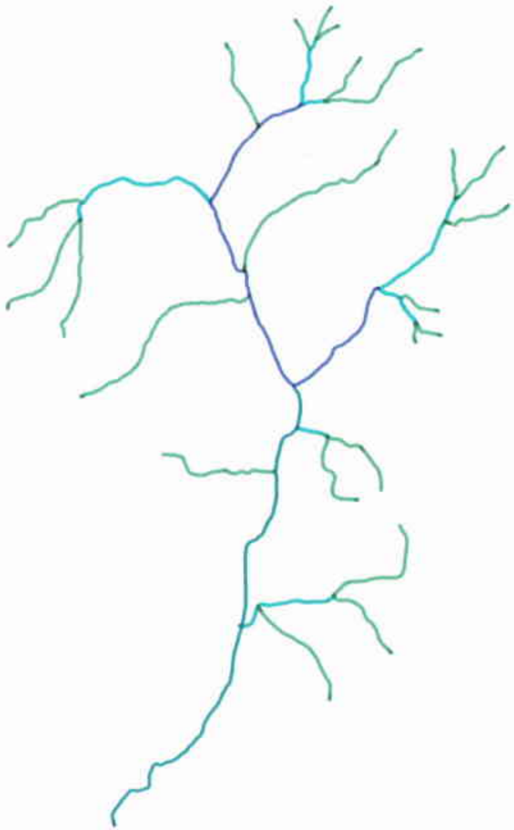
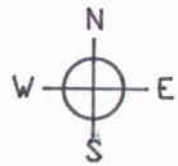


Figure 7

DEER CREEK

SUB-BASIN DRAINAGE MAP

SCALE: 1 in = 2000 ft



LEGEND

1ST ORDER

2ND ORDER

3RD ORDER

4TH ORDER

Figure 8. Deer Creek vegetation type stand map produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

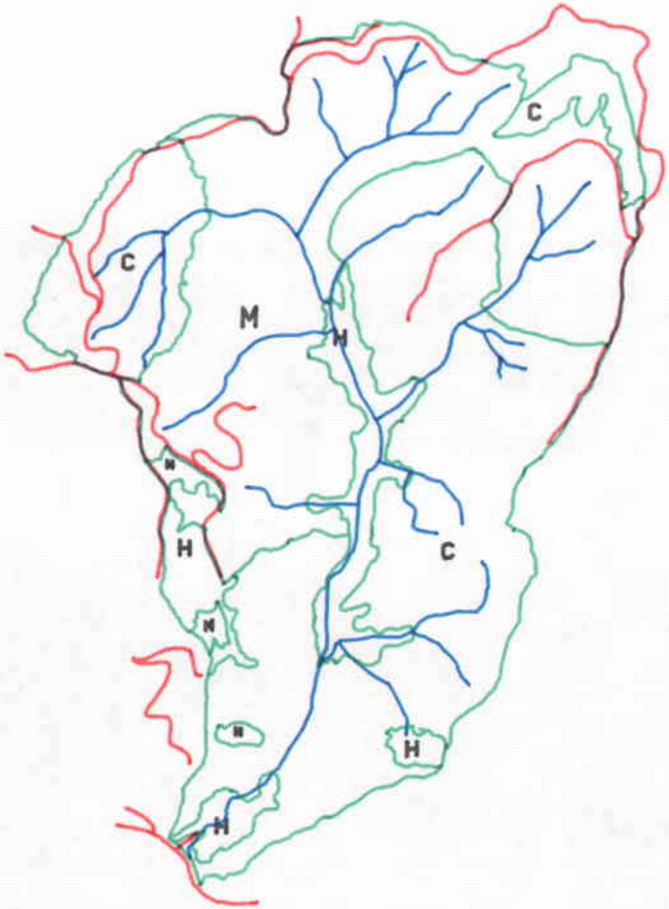
Figure 8

DEER CREEK SUB-BASIN

DRIFT CREEK WATERSHED

VEGETATION TYPE STAND MAP

SCALE: 1 in = 2000 ft



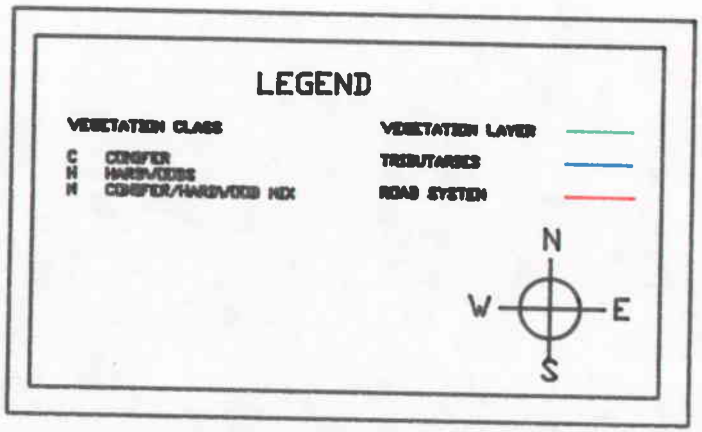


Figure 9. Deer Creek stand condition map produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

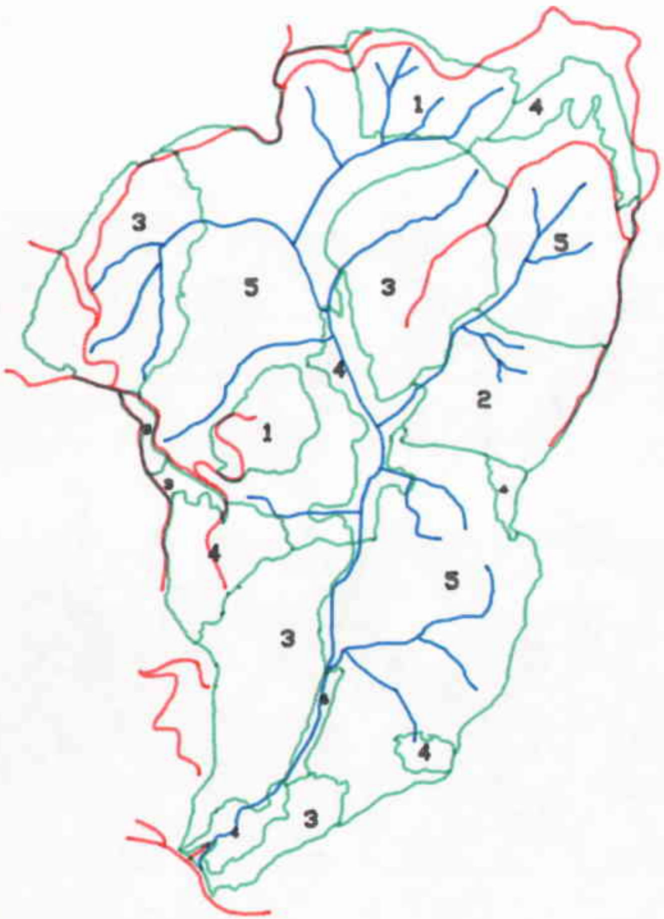
Figure 9

DEER CREEK SUB-BASIN

DRIFT CREEK WATERSHED

CONDITION CLASS MAP

SCALE: 1 in = 2000 ft



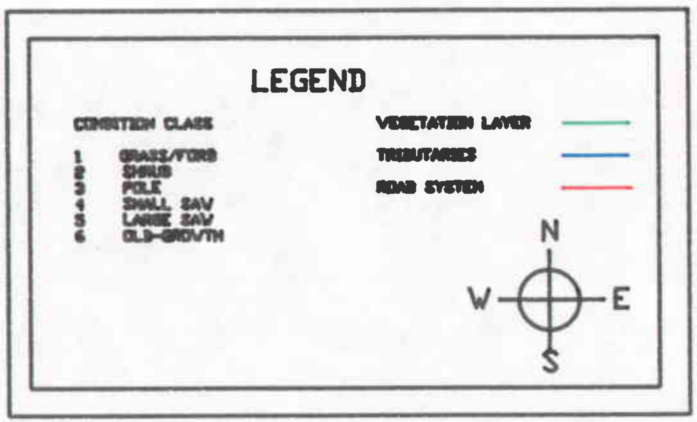


Figure 10. Deer Creek conifer stand condition map produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

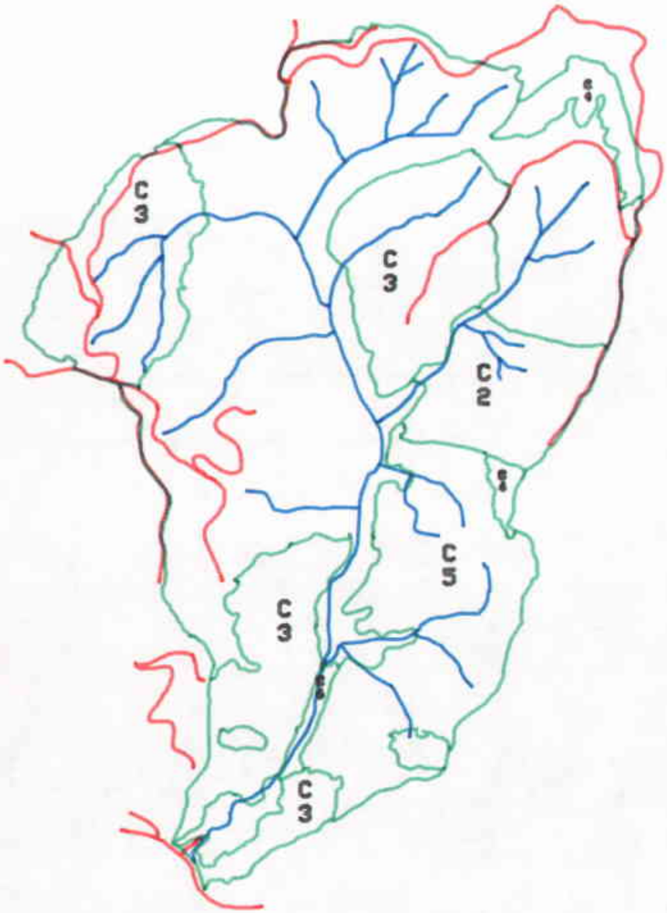


Figure 10

DEER CREEK SUB-BASIN

DRIFT CREEK WATERSHED

CONIFER STAND MAP

SCALE: 1 in = 2000 ft

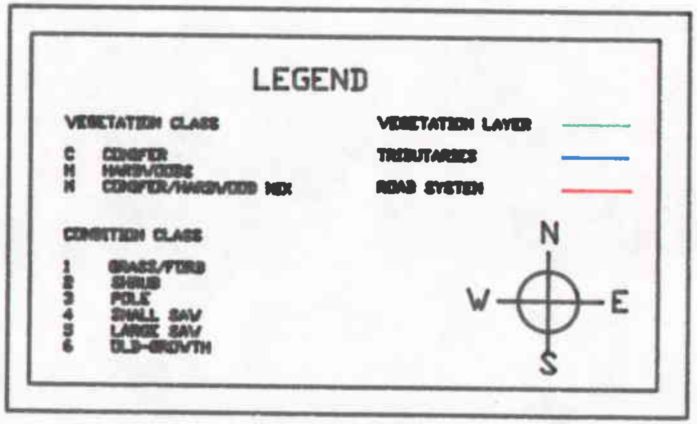


Figure 11. Deer Creek hardwood stand condition map produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

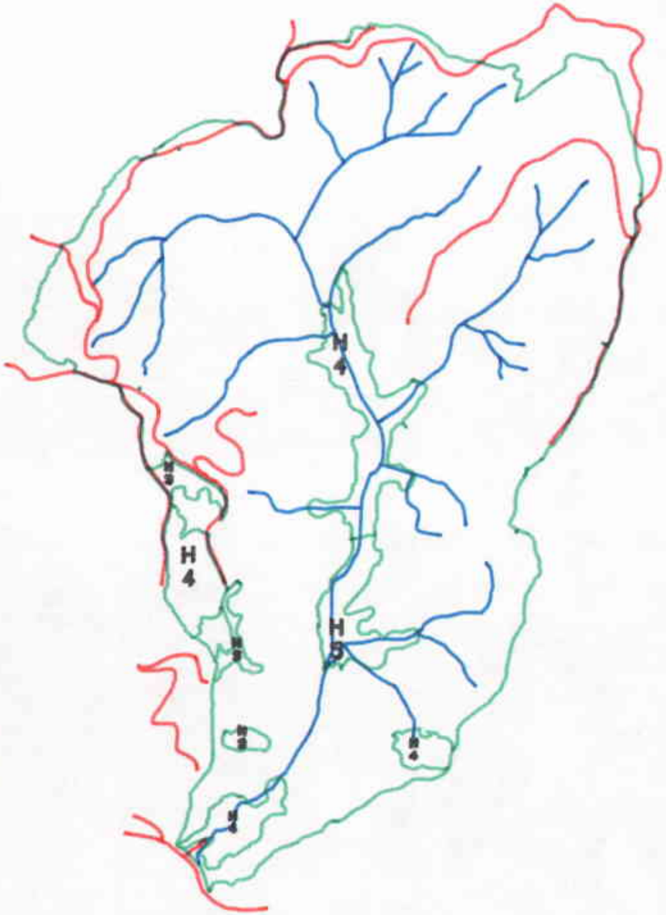
Figure 11

DEER CREEK SUB-BASIN

DRIFT CREEK WATERSHED

HARDWOOD STAND MAP

SCALE: 1 in = 2000 ft



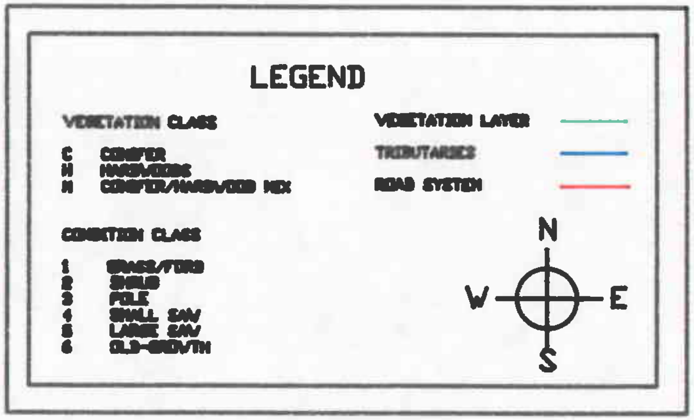


Figure 12. Deer Creek conifer-hardwood mix stand condition map produced from digital data acquired from 1:18000 scale CIR transparencies using the AP190.

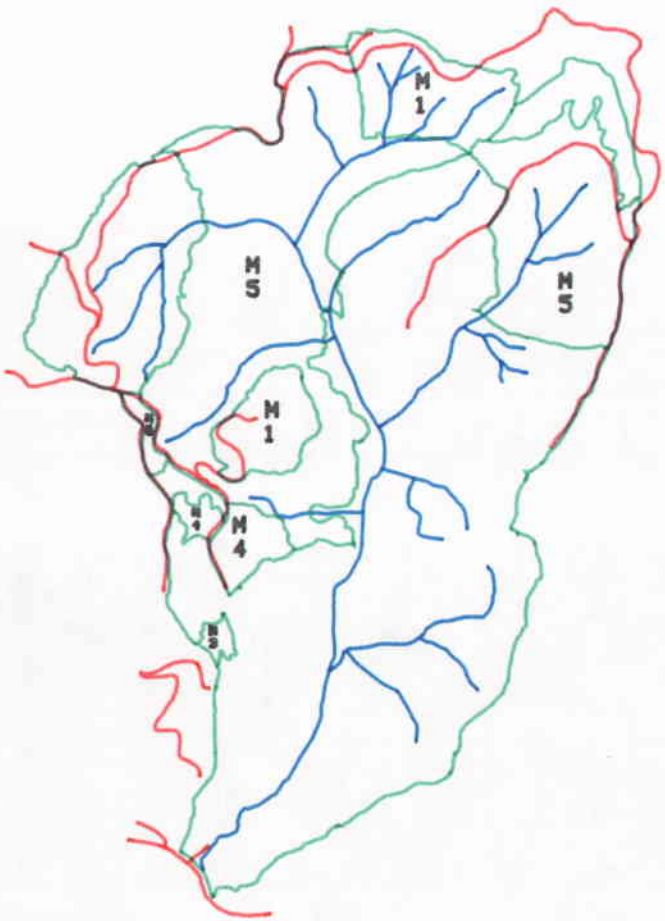
Figure 12

DEER CREEK SUB-BASIN

DRIFT CREEK WATERSHED

CONIFER / HARDWOOD MIX STAND MAP

SCALE: 1 in = 2000 ft



LEGEND

VEGETATION CLASS

C CONIFER
H HARDWOODS
M CONIFER/HARDWOOD MIX

CONDITION CLASS

1 GRASS/FORB
2 SHRUB
3 POLE
4 SMALL SAW
5 LARGE SAW
6 OLD-GROWTH

VEGETATION LAYER

TRIBUTARIES

ROAD SYSTEM

N
W E
S

One area in which forestry, both managers and field personnel, can greatly benefit is in the use of historical aerial photography. Analytical photogrammetry provides the means to geometrically link photography of different scales and time to a common scale. With this in mind, historical photos become a valuable source for accurate data collection from the past; in essence, a time machine.

The next section of this thesis will focus on the use of historical photos to measure small changes in forest openings over time; Patch Dynamics.

Forest Patch Dynamics: The Use of Aerial Photography as a Tool in Quantifying Vegetation Changes in Naturally Disturbed Areas

In most biological systems other factors besides individual growth and death contribute to dynamics. foremost among these factors are natural disturbances (White, 1979).

Natural disturbances within the forest are one of the principal factors contributing to stand dynamics, resulting in small-area openings (patches) at varying stages of succession. Most disturbances produce heterogeneous and patchy effects; these effects may themselves depend on the state of the community prior to the disturbance (Pickett and White, 1985).

Disturbances can play different roles in affecting ecosystems at both spatial and temporal scales. However, the most obvious role is in the deflection of a community from some otherwise predictable successional path (Park, 1980; Spurr, 1964).

Management of land tends to rely upon this predictability of ecosystem response, in particular with regards to human activities. However, the existence of natural change, whether consisting of cyclic replacements or successional trajectories, complicates the testing of hypotheses about human activities and impacts in these systems (Pickett and White, 1985).

"Failure to recognize the importance of disturbance has led to two kinds of frequent misinterpretation in field ecology: (a) extrapolation of events measured during disturbance-free years to predict future system states, and (b) use of a plot scale that integrates different kinds of patches. In fact, variance generated by patch dynamics is likely to be one of the most important constraints on nonexperimental sampling strategies, although this factor has seldom been considered in designing or carrying out a field sampling project." (Pickett and White,1985).

Because of the time scales involved in ecosystem response, it is rare to find studies which follow vegetation change for more than a few years (Hibbs, 1983; Park, 1980). This problem may be partially alleviated by using the analytical stereoplotter as a tool for quantification of certain various ecological parameters over longer periods than have been attempted in the past.

Study Objective

The primary objectives of this study are: 1) to focus on definitional considerations and biological aspects of forest patches, 2) to integrate the analytical stereoplotter as a tool in studying the dynamics of forest patches over time, and 3) to document changes in forest patch area and dimensions over time for a specific study site.

Aerial photography presently exists for most of the United States and many foreign countries as well (Paine, 1981). In fact, many areas have been repeatedly photographed over long periods of time. By using photogrammetric techniques on available photography, it may be possible to quantify vegetation changes in disturbance regimes over longer periods of time than previously studied. In addition, studies using aerial photography can be done at a considerable savings in both time and money.

Aerial photography is not intended to replace actual field measurements, but rather, as Avery (1968, 1978) points out, "... to complement, improve, or reduce field work". The key is to recognize and understand both the benefits and limitations of aerial photography and to use these in an integrative approach with field work to obtain an efficient system-management strategy.

To use aerial photography as a tool in dealing with patches and patch dynamics, the following criteria were necessary:

A. A definition of patch and patch dynamics was required.

B. A definition and identification of the operating disturbance mechanism was required.

C. A patch must be discernible and measurable on the aerial photograph at the scale being utilized. Both, minimum and maximum sizes must be defined.

D. Specifications of the photography should be explicit in order to maximize precision while minimizing error. Additionally, interpretation should be done by persons trained in measurement and interpretation techniques.

A. Definition of Patch and Patch Dynamics

In defining patch and patch dynamics, the definitions of Pickett and White (1985) were considered as follows:

1. "Patch" implies a relatively discrete spatial pattern, but does not establish any constraint on patch size, internal homogeneity, or discreteness.

2. "Patch implies a relationship of one patch to another in space and to the surrounding, unaffected or less affected matrix.

3. "Patch dynamics" emphasizes patch change.

Particular definitions of "patch" will always be relative to the system at hand. But within a particular system, community structure and behavior will vary locally and in a relatively patch-wise manner (Pickett and White, 1985).

It is important to differentiate between patch dynamics and the concept of shifting mosaics as proposed by Bormann and Likens (1979). The shifting mosaic idea requires a uniformity of patch distribution in time and space such that an overall landscape equilibrium of patches applies (Bormann and Likens, 1979; Pickett and

White, 1985). Patch dynamics, on the other hand neither requires nor mandates this uniformity but rather focuses on the uniqueness of each disturbance and looks to comparisons from that viewpoint.

"Patch dynamics" is preferred for more general situations in which such an equilibrium has not been demonstrated and for situations in which patch scale is large relative to the scale of the relevant landscape. further, environmental fluctuation, which may cause a shift in the disturbance regime, occurs on time scales similar to those of disturbances operating in the same systems (see Neilson and Wullstein,1983). Equilibrium landscapes would therefore seem to be the exception rather than the rule.

B. Definition and Identification of the Operating Disturbance Mechanism

Ecosystems are complex both spatially and temporally. In addition, the spatial and temporal parameters are integrated and any discussion of the system must account for this. In defining disturbances, Allen and Starr (1982) suggest that the definition must be explicitly defined from relevant community dimensions.

Another problem is that disturbances can be classified as being either environmental fluctuations or destructive events (Neilson and Wullstein, 1983). To simplify this matter, the definition of Pickett and White

(1985) will be used:

"A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment."

This holds well as an all purpose definition, but it is suggested here that the term may be further classified into three categories: (a) disturbances that are naturally occurring, either autogenically or allogenically, (b) disturbances that are human-induced or the direct cause of human activities, and (c) disturbances that are naturally occurring as a secondary result of human activities.

This last category is an inherently difficult one to work with. The rationale for categorization of events of this nature has the potential problem of subjectivity and bias. For example, logging activities may be responsible for an adjacent stand to be exposed to increased susceptibility to windthrow during a large storm event. However, should windthrow occur, the difficulty lies in the questioning of whether windthrow might have occurred anyway as a result of the intensity of the storm event regardless of the logging activities.

Human-induced disturbances are also difficult to work with and have problems of being selective and highly variable in terms of severity. Examples may include prescribed burning and thinning operations which may cause a departure of significant magnitude from what may be termed natural stand dynamics.

Both of these categories are of genuine importance and deserve research attention. However, these are beyond the scope of this study. Therefore, disturbance will be defined in this study as following the definition of Pickett and White (1985) given earlier and additionally encompassing only naturally-occurring events.

C. Patch Dimensions

Patch size plays a significant role in the magnitude of environmental fluctuation within the opening. Geiger (1965) reported that for small openings, decreases in patch size resulted in increases in humidity, decreases in wind speed, and fairly constant temperatures compared to the surrounding stand. Opening size was quantified by a D/H ratio, where D is the average diameter of the opening and H is the mean height of the surrounding stand. Light levels have been shown to increase as patch size increases up to a maximum area of D/H = apprx. 2.0 (Berry, 1964; Minckler and Woerheide 1965; Minckler et al, 1973). In addition, patch shape and orientation can be important in determining the microclimate of an opening and the surrounding stand perimeter (Tomanek, 1960).

The most important recovery processes involved in patch dynamics are lateral extension growth and sapling height growth (Runkle, 1985). Several studies on lateral growth (Trimble and Tryon, 1966; Phares and Williams, 1971; Erdmann et al., 1975; and Hibbs, 1982) have reported average rates of lateral growth to range from 4 to 14 cm./yr. with maximum rates of 20 to 26 cm./yr. Because the rate of lateral growth is dependent upon the rate of sapling height growth and gap size, it is proportionately more important to smaller gaps than to larger ones (Runkle, 1985).

Another important aspect of patch dynamics related to gap size is gap shape. Collins et al. (1985) reported that gap shape can determine the impact of an opening of a given area. Long, narrow gaps will have much less influence on the understory than will more isodiametric gaps.

Consideration of the effects of size and shape alone would result in an oversimplification of the processes integral to the system. Additional thought must be given to those variables which influence the overall environment of the opening as well as those variables affecting the internal processes of the system.

The effects of size and shape can be modified by topography, steepness and aspect of slopes, canopy height, and orientation (Collins et al., 1985). Topography can have an impact on retention and availability of water and nutrients as well as the rates of litter accumulation. Steepness and aspect of slopes can have an effect on the path and duration of insolation at the site, (which will additionally affect plant water relations). Minimal changes in site temperature can modify the dynamics of the system considerably by altering maintenance respiration response of the vegetation (Waring, 1986). In addition, orientation will be a determinant of the overall environment.

Additional concerns must address those factors internal to the system which are disrupted through disturbance. Removal of canopy vegetation can modify surface temperatures as well as alter the moisture input to the system. This includes the loss of the transpiration and canopy interception variables plus increases in surface evaporation. Nutrient balances are modified as a result of disruption to the input of organic matter, (ie. seasonal inputs of litterfall), and changes in decomposition rates of existing organic matter. Additionally, surface and subsurface organisms responsible for decomposition of organic matter will be affected by the change in microclimate conditions.

Finally, in considering forest patch dimensions in an ecosystem approach, consideration must be given to the wildlife component. Wildlife will utilize, (or fail to utilize), patches for forage, shelter, or reproduction (Karr and Freemark, 1985). The pattern of utilization will additionally influence the dynamics of the system.

In keeping with the discussion on patch dimensions, and with the objectives of this study, the following guidelines for study site selection were based on the criteria that a) Patch maximum dimensions will be a function of biological criteria and b) That patch minimum dimensions will be a function of aerial photographic interpretation criteria.

Because definitional dimensions of patches are based upon biological criteria, minimum size dimensions can be as small as that area covered by a single organism. However, an opening of less than about 5 meters across is generally not considered a patch or gap (Brokaw, 1982). Additionally, because this study seeks to integrate photogrammetric techniques, biological criteria for minimum size are superseded by minimum requirements as a function of photo quality, film type, and scale of the photography.

No minimum size limits could be found in the literature. However, it may be inferred that the smaller the area being measured, the larger the magnitude of any error.

Because patch size and shape are significant to patch dynamics, and in keeping within the scope of this study, the patch chosen was confined to an opening that was approximately isodiametric in shape and having a D/H ratio of approximately 2.0. In addition, the study site had to be well discernible on the various scales of photography being used. The study site chosen met these criteria.

Study Site

The forest patch chosen is located in the Oregon State University's McDonald-Dunn Research Forest properties. It was a part of an earlier study and is identified as study site four. The forest is located on the eastern edge of the Coast Range northwest of Corvallis, Oregon.

The elevation of the forest ranges from 300 to 2178 feet. Annual precipitation ranges from forty to sixty inches, mostly as rain. Snow occurs mostly above 1500 feet in elevation from November through March.

The parent material is derived from the Siletz River volcanics, a basalt formation. This formation is the foundation for the ridges and underlies most of the valleys.

The dominant tree species is Douglas-fir (Pseudotsuga menziesii) with occasional grand fir (Abies grandis) and several hardwood species including big leaf maple (Acer macrophyllum), Oregon white oak (Quercus garryana), and red alder (Alnus rubra) (Research Forest Properties, 1982-1983).

D. Photographic Specifications

It would be optimal to have all of the photographs through time of the area at identical scales and film types, but this is not realistic. However, it is possible to acquire photography over time and bridge to a common scale. Using standard photogrammetric techniques, photography from different times, different scales, and different specifications (focal length, film format, film type, etc.) may be bridged to common control points and the resulting data brought to a common scale. For this study, data were collected and control bridged in this manner.

Black and white aerial photography of McDonald Forest was used for the time period of 1948 to 1986 as follows:

Photography Date	Stereopair ID	Average PSR
1948	DFJ-4D-138 & DFJ-4D-139	20000
1954	OSC 2-4 & OSC 2-5	12000
1965	MF 5-13 & MF 5-14	12000
1972	OSU-72-511 2-4 & 2-5	12000
1986	41-001-071 & 41-001-072	12000

Control for the five dates of photography was bridged from 1:31000 black and white paper prints that were controlled from USGS 7 1/2 minute quadrangle sheets. Computer digitizing was done using the Carto AP190 analytical stereoplotter.

The study site was located on each stereo pair of photographs. Both the exterior boundary, as defined by vegetation crowns, and any vegetation existing within the boundary were digitized. Patch acreage and edge length were calculated from the digital data (Tables 20 and 21) and planimetric maps were produced for each stereo pair date (Figures 15 to 19).

Table 20 and figure 13 show a steady decline from 1948 in the patch opening of 0.17 acres per year for the 38 year time span. Using this figure as a predictor, the patch would be expected to close off completely in about 17 years or about the year 2003.

Table 21 and figure 14 show the changes in the perimeter over the 38 year time span. This change is due mostly to the interior vegetation causing fragmenting of the area as a whole and then eventually closing off the smaller areas. This is especially evident between 1965 and 1986 (Figures 17 to 19). By 1972 the patch had been fragmented into four smaller areas and by 1986, two of these areas had completely closed off.

The traditional role of the analytical stereoplotter has been as a tool in the engineering sciences. This study shows that the role has been a narrow one that should be expanded into the environmental and biological sciences. The study on site four demonstrates a number of important aspects along this line. Foremost of these is the application of the analytical stereoplotter to quantitatively define ecosystem changes over longer periods of time than normally attempted. In addition, data from sources of different formats and scales may be brought together into an accurate common base for analysis.

The use of the stereoplotter for historical mapping and analysis is certainly not limited to patch analysis. Most types of larger scale ecosystem response can be analyzed in this same manner. For example, stream channel morphology, landscape pattern and development, fire history, etc. are all large-scale responses that are well suited to the stereoplotter.

Table 20. Changes in area for study site four over 38 years. Data are from five dates of aerial photography.

YEAR	ACRES	CHANGE IN ACRES	# YEARS	CHANGE/YEAR IN ACRES
1948	9.30			
		- 0.93	6	- 0.15
1954	8.37			
		- 2.23	11	- 0.20
1965	6.14			
		- 1.02	7	- 0.15
1972	5.12			
		- 2.23	14	- 0.16
1986	2.89			
Totals		- 6.41	38	- 0.17

Table 21. Changes in perimeter for study site four over 38 years. Data are from five dates of aerial photography. Perimeter data are in feet.

YEAR	PERIMETER	CHANGE IN PERIMETER	# YEARS	CHANGE/YEAR IN PERIMETER
1948	6178.0			
		+ 3193.6	6	+ 532.3
1954	9371.6			
		+ 902.9	11	+ 82.1
1965	10274.5			
		+ 1557.3	7	+ 222.5
1972	11831.8			
		- 5723.5	14	- 408.8
1986	6108.3			
Totals		-69.7	38	428.1

Figure 13. Changes in area for study site four over 38 years. Data are from five dates of aerial photography.

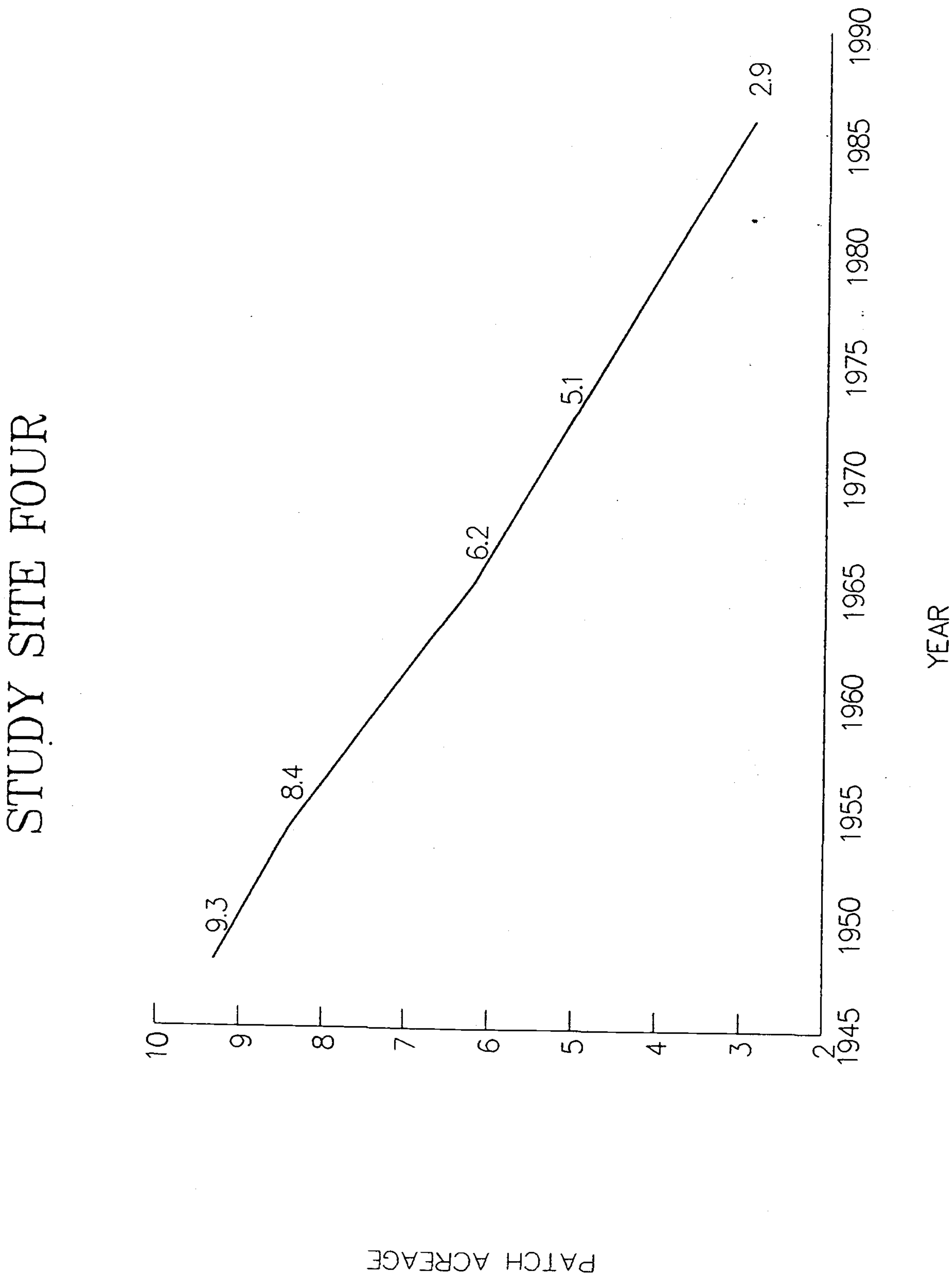


Figure 14. Changes in perimeter for study site four over 38 years. Data are from five dates of aerial photography.

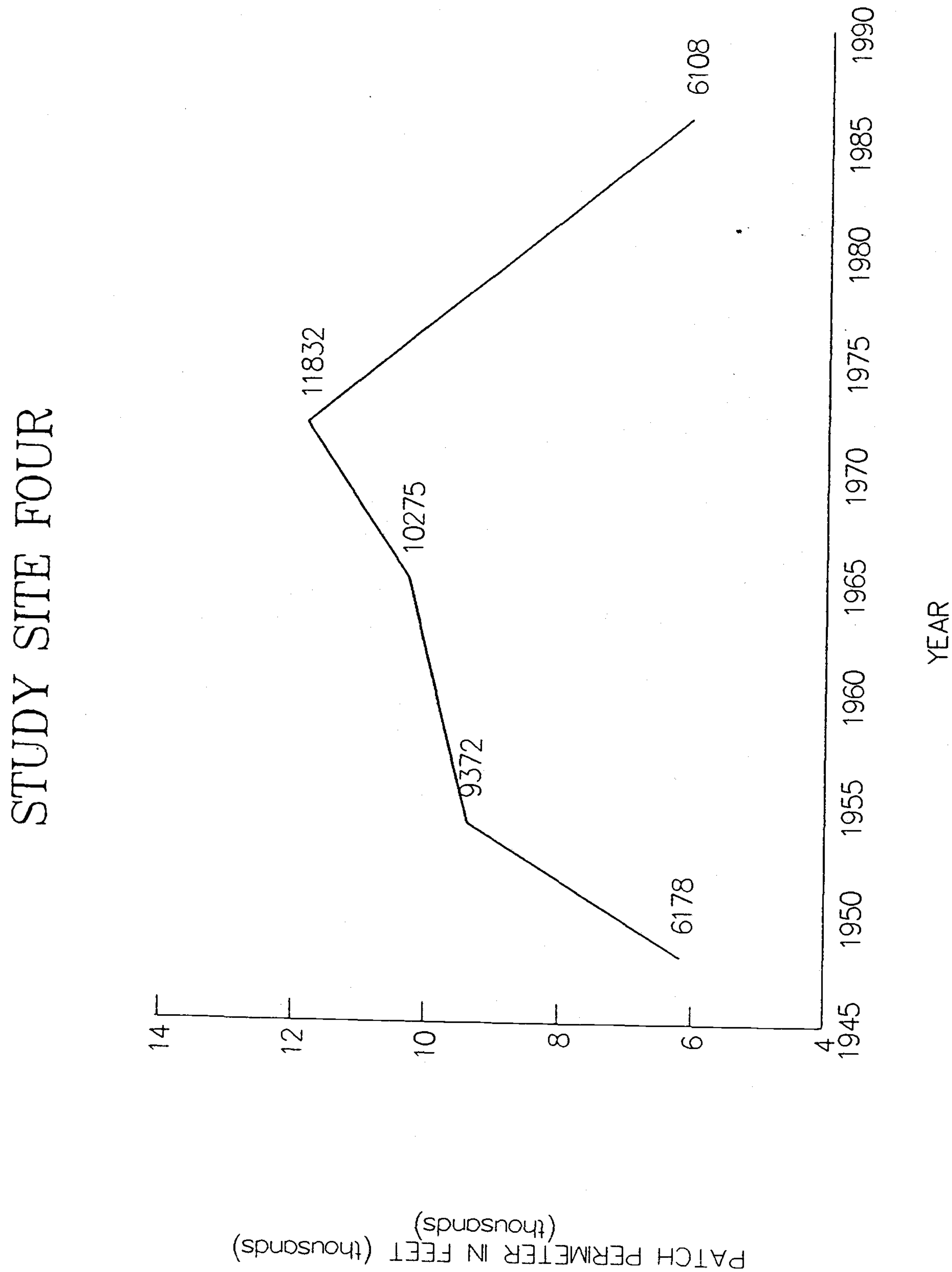


Figure 15. Planimetric map of study site four in 1948.

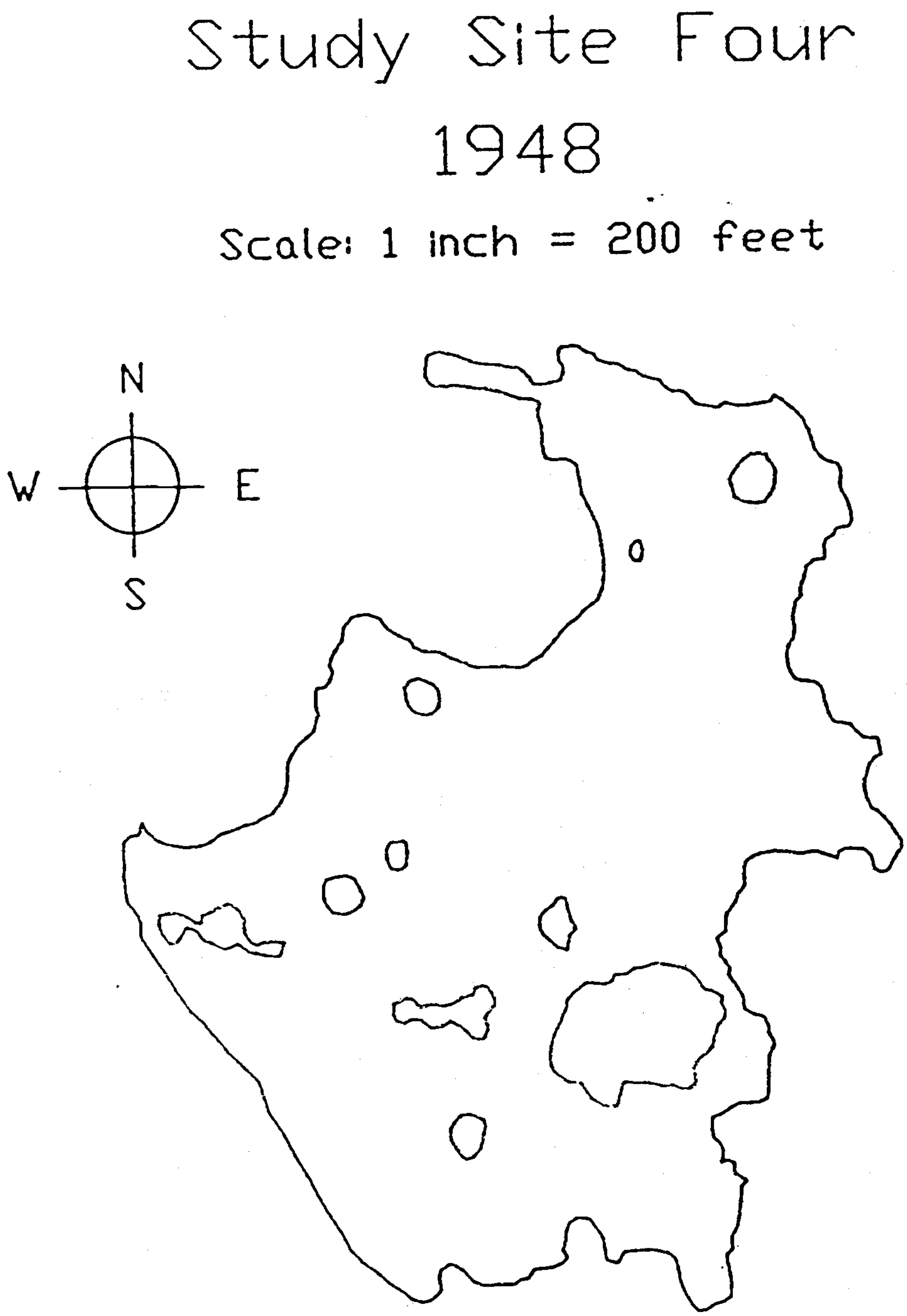


Figure 16. Planimetric map of study site four in 1954.

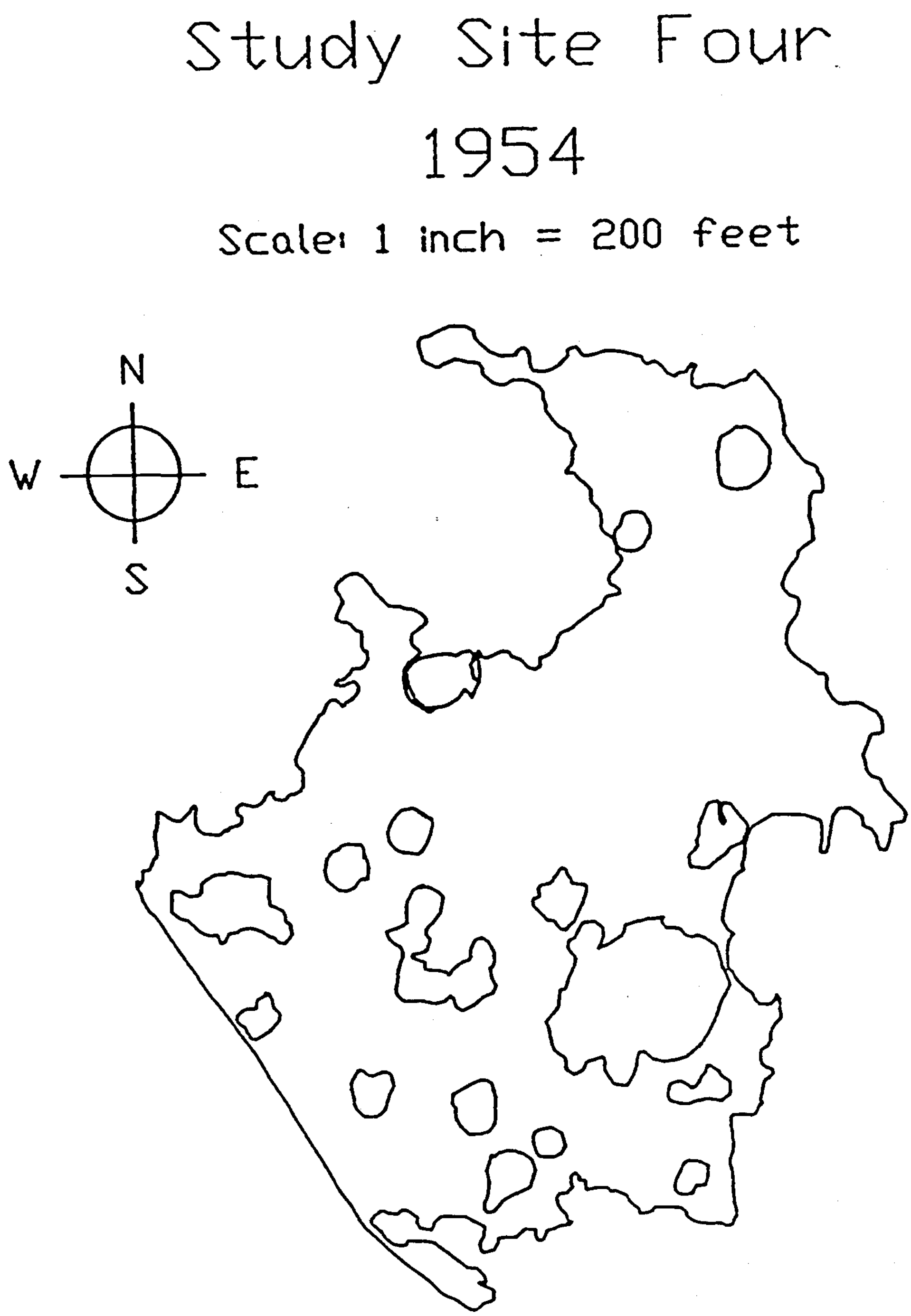


Figure 17. Planimetric map of study site four in 1965.

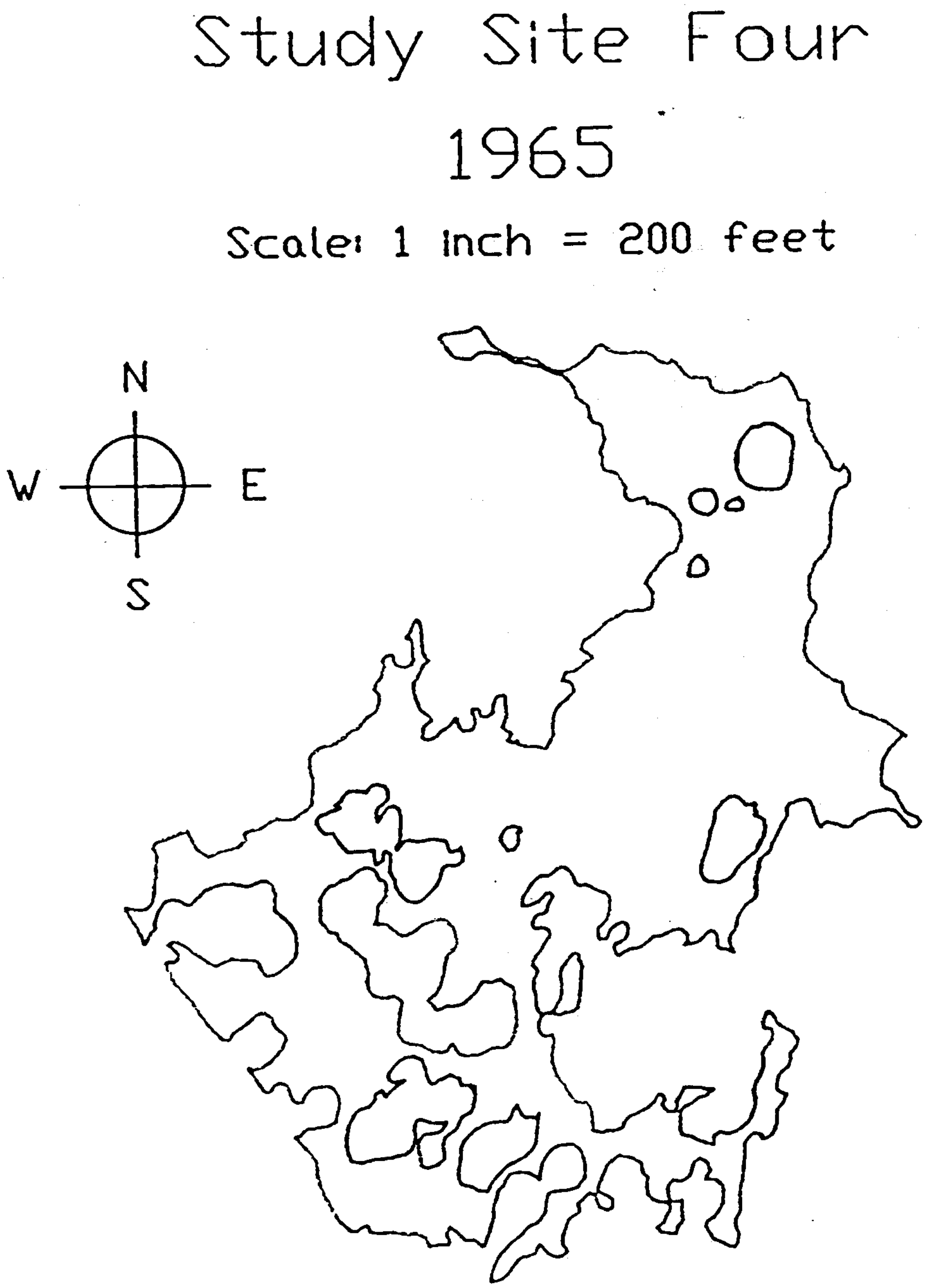


Figure 18. Planimetric map of study site four in 1972.

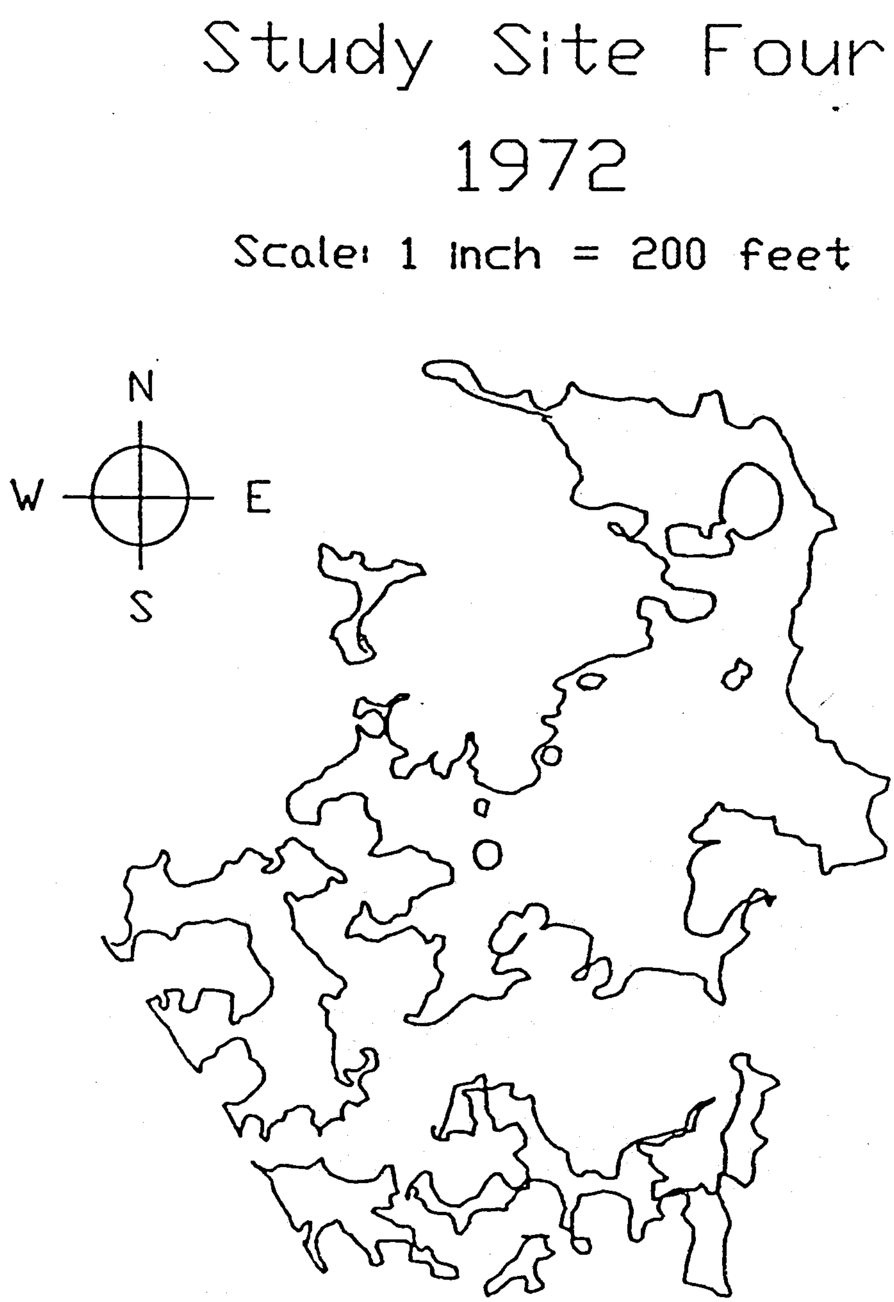
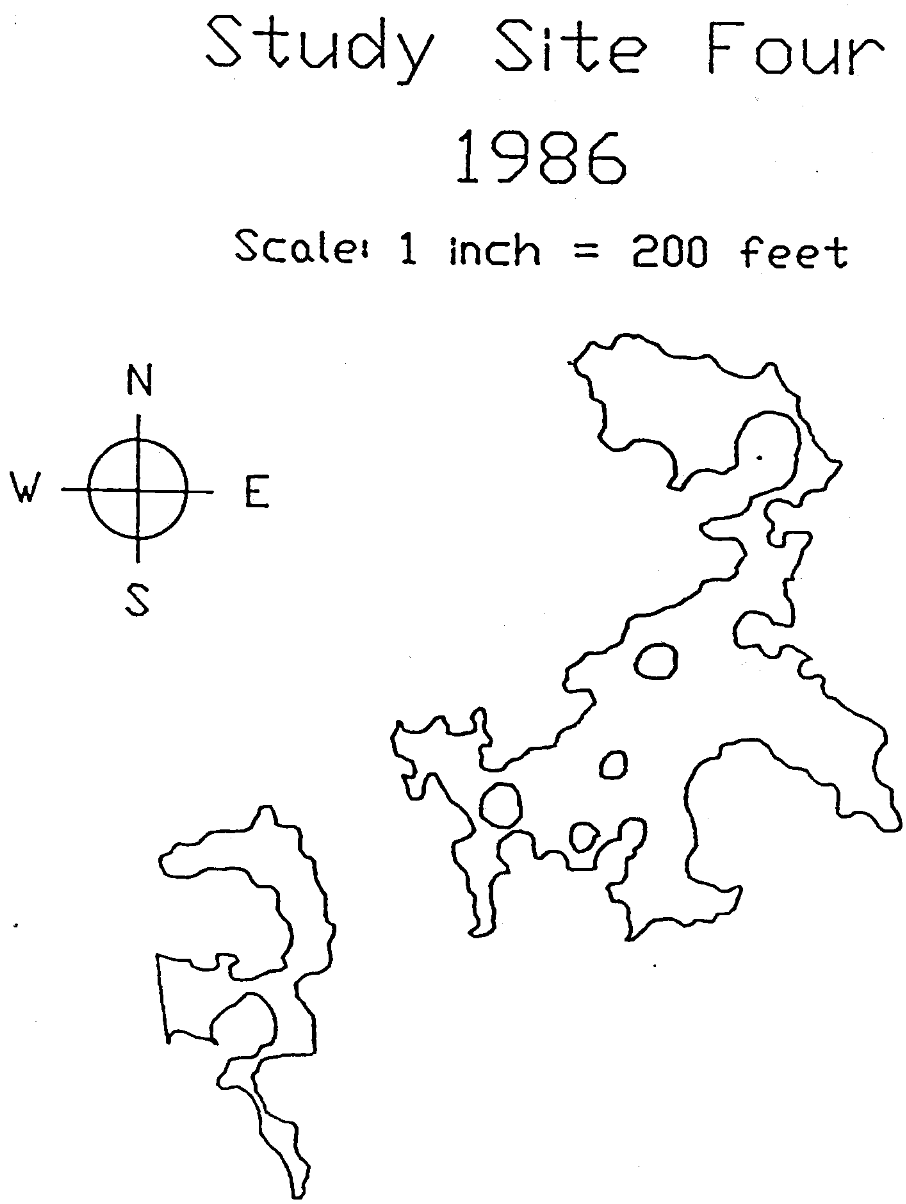


Figure 19. Planimetric map of study site four in 1986.



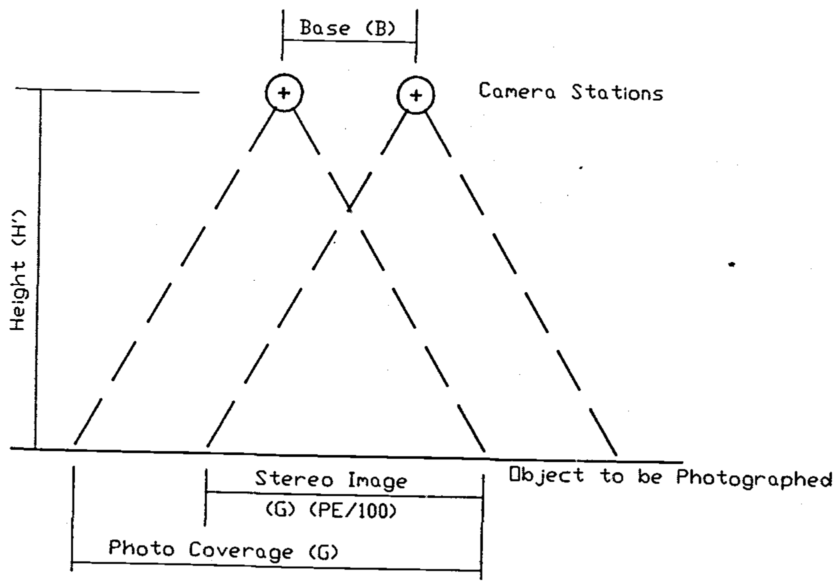
The Use of the Analytical Stereoplotter for Terrestrial Photogrammetry in Forestry

One area that offers a lot of promise is the application of terrestrial photogrammetry to forestry. Acquisition of photography is relatively quick and inexpensive. In addition, high levels of accuracy and precision are possible by using the analytical stereoplotter combined with close range terrestrial photography.

Terrestrial photography differs from aerial photography only in the rotations of the three axes, x,y, and z. The mathematics remain the same. For terrestrial photos, the air base of the stereopair becomes horizontal to the subject as opposed to vertical with aerial stereopairs. The average flying height becomes depth which equals the distance from the camera to the subject.

The important relationship revolves around the base to height ratio (B/H'). Large B/H' ratios denote low 'flying' height (short depth) and large values for x parallax. This condition favors higher accuracy in analytical measurements provided the human eye can keep the image in a stereoscopic mode. The relationship is shown in Figure 20.

Figure 20. The base to height relationship for terrestrial photogrammetry.



The mathematical relationships are as follows (from Wolf, 1983):

EQN 1. $B = G - G\ (PE/100)$

$B = G\ (1 - PE/100)$

EQN 2. $H'/G = f/d$

$H' = (f/d)\ G$

EQN 3. $B/H' = 1 - (PE/100)\ d/f$

Where:

B = Airbase or groundbase
H' = Flying height or depth
G = Total ground coverage of the photo
f = Focal length of camera
d = Format of the camera (film)
PE = Percent endlap

While a higher B/H′ ratio would be preferable for the human eye, a lower B/H′ ratio is preferable for machine operation. This is because the machine optics rely on image correlation based solely on geometric dissimilarities while the human eye introduces image interpretation which is aided by larger parallax values up to a certain point.

From equation 3, it can be seen that the ratio of B to H′ is constant for any camera-lens combination and constant flying height. This assumes a fixed percent endlap which is the usual case (ie 60%). In other words, if a specific base to height ratio is desired, then the choice of camera or lens becomes dependent upon the other, assuming a constant H′.

It should be noted that the ratio of B to H′ can be modified by the principle of convergent photography. By reducing the internal angle from the parallel of one or both cameras, the effect is to increase the stero image and thus increase parallax. This in turn increases accuracy in measurements. However, Karara (1980) indicates that this angle reduction should not be in excess of 7 percent.

The AP190 is somewhat unique in its ability to work with terrestrial photography. First, the instrument's design permits various formats of photography from 9" x 9" downward to 35 mm (prints or transparencies). Second, the software for interior orientation has a frame-edge option for photo center location. This removes the requirement for fiducial marks and allows the use of a simple 35 mm camera for photogrammetric work.

Of the two remaining orientations, the relative orientation procedure is not affected by the change to terrestrial format. However, absolute orientation of terrestrial photography requires the positioning of targets with known x,y, and z coordinates (remembering the rotations) for scale control.

Two hypothetical examples using this terrestrial approach follow. The first example involves a project to stereophotograph a chip pile in a mill yard for volume that is approximately 300 feet in width and fairly symmetrical in shape. This is usually done with vertical photography, however the option remains for terrestrial photography to be used in the event that vertical photography is not readily obtainable, (ie weather not permitting or aircraft not available). The second example is to stereophotograph individual standing trees for taper. The base area of coverage is approximately 40 feet. All calculations were made from a computer program developed by the author for terrestrial photogrammetry applications and answers reflect rounding.

Example 1. Stereophotography of a chip pile.

1. Camera format = 35 mm
2. Lens format = 50mm
3. The object of interest has a base of 300 ft.
4. 60% overlap required (Optimal overlap).

$$G\,(PE/100) = 300 \text{ ft.}$$
$$G = 300 \text{ ft.}(100/60)$$
$$= 500 \text{ ft.}$$

$$f = 50mm = 50mm(1"/25.4mm) = 1.97"$$

$$d = 35mm = 35mm(1"/25.4mm) = 1.38"$$

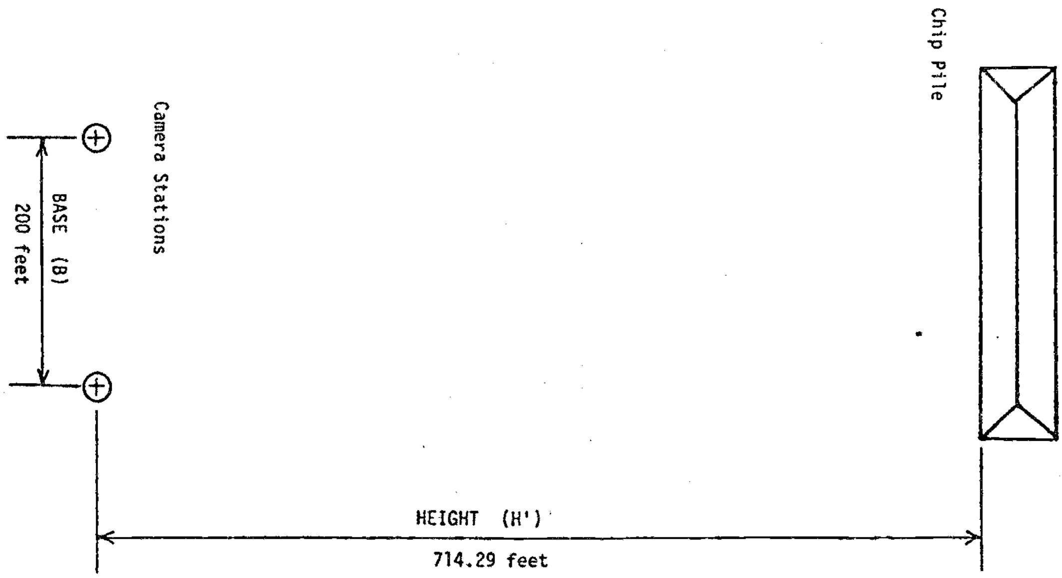
$$H' = (1.97/1.38)\ 500 \text{ ft.}$$
$$= 714.29 \text{ ft.}$$

$$B = 1 - (PE/100)\ (H')$$
$$= 1 - (60/100)\ (500')$$
$$= 200.00'$$

$$B/H' = 0.28$$

Figure 21 shows the on-ground camera set-up for this example. In this case, the low B/H′ ratio may be adequate for the type of calculations involved. However, the relationship may be altered to change the values of B and H′ by using different focal length lenses.

Figure 21. The camera set-up for the chip pile example. Lens format is 50mm.



In the above example, changing the focal length to 35mm while maintaining the camera at 35mm will result in the following:

$$f = 35\text{mm} = 1.38"$$

$$H' = (1.38/1.38)\ 500 \text{ ft.}$$
$$= 500 \text{ ft.}$$

$$B = 500 \text{ ft.}\ (1 - 60/100)$$
$$= 500 \text{ ft.}\ (0.40)$$
$$= 200 \text{ ft.}$$

$$B/H' = 0.40$$

On the other hand, by keeping the lens at 50mm, we could alter the B/H ratio by changing to a 2 1/2 inch format camera. This would result in the following:

$$f = 50mm = 1.97''$$

$$\begin{aligned} H' &= (1.97/2.50)\ 500\ \text{ft.} \\ &= 393.7\ \text{ft.} \end{aligned}$$

$$\begin{aligned} B &= 393.7\ \text{ft.}\ (1- 60/100) \\ &= 393.7\ \text{ft.}\ ((0.40) \\ &= 200\ \text{ft.} \end{aligned}$$

$$B/H' = 0.51$$

Example 2. Stereophotography of an individual tree.

1. Camera format = 35mm
2. Lens format = 50mm
2. The object of interest has a base of 40 ft.
3. 60% overlap required (Optimal overlap).

$$\begin{aligned} G\ (PE/100) &= 40\ \text{ft.} \\ G &= 40\ \text{ft.}(60/100) \\ &= 66.67\ \text{ft.} \end{aligned}$$

$$f = 50mm = 50mm(1''/25.4mm) = 1.97''$$

$$d = 35mm = 35mm(1''/25.4mm) = 1.38''$$

$$\begin{aligned} H' &= (1.97/1.38)\ 66.67\ \text{ft.} \\ &= 95.24'\ \text{ft.} \end{aligned}$$

$$\begin{aligned} B &= 1 - (PE/100)\ (H') \\ &= 1 - (60/100)\ (23.80') \\ &= 26.67'\ \text{ft.} \end{aligned}$$

$$B/H' = 0.28$$

In this case a problem exists with the model set-up as proposed. The calculations show that the total ground area being photographed is 66.67 feet. However, the tree is 150 feet tall. In order to make this work, we need to refer to the equation for total ground area to recalculate the base of the object.

G = (100/PE) Base of the object

Base of the object = G (PE/100)

In order to photograph the entire tree, G must at least equal the height of the tree.

$$\text{Therefore, } B = 150'(60/100)$$
$$B = 90'$$

Inserting this into the equation gives the following:

$$G\ (PE/100) = 90\text{ ft.}$$
$$G = 90\text{ ft.}(100/60)$$
$$= 150\text{ ft.}$$

$$f = 50\text{mm} = 50\text{mm}(1''/25.4\text{mm}) = 1.97''$$

$$d = 35\text{mm} = 35\text{mm}(1''/25.4\text{mm}) = 1.38''$$

$$H' = (1.97/1.38)\ 150\text{ ft.}$$
$$= 214.29'\text{ ft.}$$

$$B = 1 - (PE/100)\ (H')$$
$$= 1 - (60/100)\ (214.29')$$
$$= 60\text{ ft.}$$

$$B/H' = 0.28$$

For this example, it might be preferable to have a larger B/H' ratio for higher accuracy. In this case, changing the focal length to 35mm will give the following:

$$G = 150\text{ ft.}$$

$$f = 35\text{mm} = 1.38''$$

$$H' = (1.38/1.38)\ 150\text{ ft.}$$
$$= 150\text{ ft.}$$

$$B = 150\text{ ft.}\ (1 - 60/100)$$
$$= 150\text{ ft.}\ (0.40)$$
$$= 60\text{ ft.}$$

$$B/H' = 0.40$$

Going one step further by changing the focal length to 28mm will give the following:

$$G = 150 \text{ ft.}$$

$$f = 28\text{mm} = 1.10''$$

$$\begin{aligned} H' &= (1.10/1.38)\ 150 \text{ ft.} \\ &= 120 \text{ ft.} \end{aligned}$$

$$\begin{aligned} B &= 150 \text{ ft. } (1- 60/100) \\ &= 150 \text{ ft. } (0.40) \\ &= 60 \text{ ft.} \end{aligned}$$

$$B/H' = 0.50$$

In the tree example, the choice of B/H′ ratio is going to be most likely limited by visible space in the forest. For example, the use of a 50mm lens would require a visible space of about 215 feet. Even with the 28mm lens, a visible space of about 150 feet minimum will be needed.

In most instances, the more acceptable solution would be to go to the shortest possible focal length. However, certain problems appear with lenses as focal length is decreased. Three areas of concern here are a) focal length, b) f/stop, and c) aperature opening. These can be expressed as follows:

$$\text{aperature opening} = \frac{\text{focal length}}{\text{f/stop}}$$

The aperature opening is the physical opening in the diaphragm of the lens that allows light to pass through the lens to the film plane. The f/stop is a number indicating the capacity of the lens to permit light to pass through.

From a technical point, as focal length decreases it becomes neccessary to reduce the f/stop in order to keep the aperature opening constant. Commercially, this is not an option as f/stops generally are not below 1.4 for the best lenses. More appropriate is to accept the change in apperature opening as focal length decreases. However, as focal length decreases, and f/stop remains constant, it becomes increasingly more difficult to maintain a wide enough apperature opening which may be necessary in a project such as this. The "slower" the lens, the longer the exposure time required due to the decrease in light reaching the lens. From a purely economical point, as the lens size decreases, the price of the lens increases dramatically.

Table 22 illustrates the advantages and disadvantages of the different size lenses (same f/stop) and the effects on B, H′, and the ratio of B/H′. The choice of lens size is based on the available lenses for a Nikon FE 35mm format camera. Lens availability is from a local commercial dealer. Lenses below 28mm require about 4 weeks for special order delivery.

Table 22. Effects of different size lenses on B, H′, and B/H′ using a 35mm format.

Focal Length	Lens Cost	Calculated B	Calculated H′	Calculated B/H′
50mm	$ 100+	60.0′	214.3′	0.28
35mm	$ 200+	60.0′	150.0′	0.40
28mm	$ 250+	60.0′	120.0′	0.50
24mm	$ 442	60.0′	102.9′	0.58
20mm	$ 635	60.0′	85.7′	0.70
18mm	$ 1200	60.0′	77.1′	0.78
15mm	$ 2000	60.0′	64.3′	0.93

Table 23 illustrates the advantages and disadvantages of the different sizes of lenses and the effects on B, H′, and the ratio of B/H′ using a 2 1/2 inch format. The choice of lens size is based on the available lenses for a Hassalblad 2 1/2 inch (63.5mm) format camera. Cost of these lenses was not obtained, however the costs are higher than for a comparable 35mm format lens.

Table 23. Effects of different size lenses on B, H′, and B/H′ using a 2 1/2 inch format.

Focal Length	Lens Cost	Calculated B	Calculated H′	Calculated B/H′
50mm	-	60.0′	118.1′	0.51
35mm	-	60.0′	82.7′	0.73
28mm	-	60.0′	66.1′	0.91
24mm	-	60.0′	56.7′	1.06

In example 1, the optimum solution may be to use the 28mm lens with the 35mm format. This format camera is fairly common and the costs of a 28mm lens are certainly reasonable and this allows a B/H′ of 0.50.

In example 2 however, it may be best to go to either a 35mm or 28mm lens on the 2 1/2 inch format camera. In this case, the visible space will be the restriction. If the 2 1/2 inch camera is available, the increase in costs for the lens may not be that significant.

Finally, in these examples the expected maximum errors due to operator measurments using the AP190 can be calculated. Assuming a maximum measurement error of 40 microns, the accuracy of the measurements is calculated as:

$$(0.039527)\ \frac{(H'\ \text{ft.})}{(f\ \text{mm})}$$

The constant in the first part of the equation, 0.039527, is the result of reducing 40 microns to feet units. The second part of the equation is also a constant for any camera format regardless of the lens size. Referring back to equation 2,

$$H' = (f/d)G$$

and substituting this in the equation above, H′ will only change with a change in camera format (d).

For the chip pile example with the 35mm format, the expected maximum error is about 0.56 feet in object units or about 6.7 inches. Changing to the 2 1/2 inch format reduces the expected error to about 3.7 inches.

For the tree example, an expected error for the 35 mm format is about 2.0 inches. Again, the 2 1/2 inch format reduces this down to about 1.1 inches. Traditional tree taper studies rely on data from trees that are cut down for measurements. The use of the analytical stereoplotter could be a promising area for accurate and non-destructive tree taper studies.

Conclusions

The purpose of this thesis has been threefold. In the first section, the potential for errors in measurements taken directly from photographs has been demonstrated. In many cases, the traditional methods of measurement may be adequate where high orders of accuracy are not required and object location is in close proximity to the nadir of the photograph. However, where accurate planimetric data are required, the use of the traditional methods should not be considered.

The second section of the thesis describes a new generation analytical stereoplotter, the Carto AP190. The AP190 provides a relatively low-cost, high accuracy alternative to the traditional methods of photogrammetry. The accuracy of the instrument is shown to be well within any accuracy constraints for the forestry profession. In preliminary testing, the AP190 was shown to be suitable for forest mapping applications and the use of the instrument as an accurate input device for a GIS.

The final section of the thesis concentrated on three examples of the use of the AP190 in forestry applications. In the Deer Creek example, a methodology and approach to utilizing the AP190 as a tool for the forest vegetation inventory analysis of a watershed basin was presented.

This methodology has since been successfully adapted to various other projects including the study of three complete river basins in coastal Oregon.

The patch analysis study presented a current literature review of forest patch dynamics in order to define the use of the AP190 in studying the change in a biological system over long periods of time. The AP190 was used to provide accurate data for the area from several dates of photography and bring each set of data to a common scale for analysis of the change in the area over time.

The last example presented the AP190 as a tool in a more specialized area of photogrammetry using terrestrial photography. Because terrestrial photography has much more latitude in adjusting base to height ratios and lens to object distances as opposed to aerial photography, the potential for high accuracy measurements exists from nothing more elaborate than slides or prints from a standard 35 mm camera.

The AP190 was originally intended as an analytical instrument for forest engineering applications. However, this was not covered in the thesis. Forest engineering applications of the AP190 have been adequately presented in the literature (Carson, 1987; Reutebuch, 1988;) and are additionally well beyond the scope of this thesis. However, new investigations are currently under way and will be reported as they develop.

The PC-based analytical stereoplotter is beginning to find wide use in the forestry profession in the United States. In addition, the PNW Research branch of the U. S. Forest Service in Seattle, Washington and the College of Forestry at Oregon State University are continuing research into the development and application of the AP190 for forestry use.

The PC-based analytical stereoplotter was described earlier as bringing in a new era in photogrammetry. In a like manner, the use of the PC-based analytical stereoplotter may help to bring in a new era in forestry.

References

Allen, T.F.H. and T.B. Starr. 1982. Hierarchy: Perspectives for Ecological Complexity. University of Chicago Press. Chicago, Illinois.

Anthony, R.G., E.C. Meslow, and D.S. deCalesta, 1987. The Role of Riparian Zones for Wildlife in Western Oregon. What We Know and Don't Know. In: Managing Oregon's Riparian Zone for Timber, Fish, and Wildlife. NCASI Tech. Bull. No. 514. New York. 4 pages.

Avery, T.E. 1968. Interpretation of Aerial Photographs. Burgess pub. co. Minneapolis, Minn. 324 pages.

Avery, T.E. 1978. Forester's Guide to Aerial Photo Interpretation. U.S.D.A. Handbook no. 308. Washington D.C. 42 pages.

Batson F.T., P.E. Cuplin, and W.A. Crisco. 1987. The Use of Aerial Photos to Monitor Riparian Areas. BLM Technical Reference 1737-2. Service Center, Denver, Colorado. 13 pages.

Berry, A.B. 1964. Effect of Strip Width on Proportion of Daily Light Reaching the Ground. For. Chron. 40, 130-131.

Bormann, F.H. and G.E. Likens. 1979. Pattern and process in a Forested Ecosystem. Springer Verlag. Berlin, Germany.

Born, C.J., B. Makarovic, and E. Speakman. 1980. Plotting Machines with Mechanical or Optical Trains. In: Manual of Photogrammetry. 4th edition. American Society of Photogrammetry. Virginia. 1056 pages.

Boston, K. 1989. Unpublished. Source Code for ARC\INFO Conversion of AP190 ASCII Files.

Brokaw, N.V.L. 1982. The Definition of Treefall Gap and Its Effect on Measures of Forest Dynamics. Biotropica. 14, 158-160.

Brown, E.R. 1985. Management of Wildlife and Fish Habitats in Forests of Western Oregon and Washington. ed. E.R. Brown. USDA Forest Service, Publication no. R6-F&WL-192-1985. Portland, Ore.

Carson, W.W. 1987. Development of an Inexpensive Analytical Plotter. Photogrammetric Record, 12(69): 303 - 306.

Carson, W.W. 1986. An Inexpensive Analytical Photogrammetric Instrument. Norway Mapping. National Report, 18th FIG Congress - Toronto, Canada. pp 24 - 26.

Carson, W.W. 1985. An Accuracy Test of a New Stereoscopic Instrument. Kart og Plan. 2 - 1985: 227 - 233.

Cimerman, VJ. and Z. Tomasegovic. 1970. Atlas of Photogrammetric Instruments. Elsevier Publishing Co. New York. 216 pages.

Collins, B.S., K.P. Dunne, and S.T.A. Pickett. 1985. Responses of Forest Herbs to Canopy Gaps. In: The Ecology of Natural Disturbance and Patch Dynamics. ed. by Pickett and White. Academic Press Inc. London, England. 472 pages.

Devine, H.A. and R.C. Field, 1986. The Gist of GIS. Journal of Forestry. 84(8). pp 17-22.

Elmore, W. 1987. The Role of Riparian Zones for Wildlife in Eastern Oregon. What We Know and Don't Know. In: Managing Oregon's Riparian Zone for Timber, Fish, and Wildlife. NCASI Tech. Bull. No. 514. New York. 4 pages.

Erdmann, G.G., R.M. Godman, and R.R. Oberg. 1975. Crown Release Accelerates Diameter Growth and Crown Development of Yellow Birch Samplings. U.S. For. Serv., Res. Paper. NC NC-117.

Friedman, J.S., J.B. Case, U.V. Helava, G. Konecny, and H.M. Allen. 1980. Automation of the Photogrammetric Process. In: Manual of Photogrammetry. 4th edition. American Society of Photogrammetry. Virginia. 1056 pages.

Geiger, R. 1965. The Climate Near the Ground. Harvard Univ. Press. Cambridge, Mass. Trans. from Das Klima der Bodennahen Luftschicht.

Gregory S.V., G.A. Lamberti, D.C. Erman, K.V. Koski, M.L. Murphy, and J.R. Sedell, 1987. Influence of Forest Practices on Aquatic Production. In: Streamside Management: Forestry and Fishery Interactions. ed. E.O. Salo and T.W. Cundy. Univ. of Washington. Seattle, Wash. Pages 235 - 255.

Hibbs, D.E. 1983. Forty Years of Forest Succession in Central New England. Ecology. 64(6), 1394-1401.

Horton, R.E. 1945. Erosional Development of Streams and Their Drainages. Geologic Society of American Bulletin 56. pages 275-370.

Karr, J.R. and K.E. Freemark. 1985. Disturbance and Vertebrates: An Integrative Perspective. In: The Ecology of Natural Disturbance and Patch Dynamics. ed. by Pickett and White. Academic Press Inc. London, England. 472 pages.

Karara, H.M. ed. 1980. Non-Topographic Photogrammetry. In: Manual of Photogrammetry. 4th edition. American Society of Photogrammetry. Virginia. 1056 pages.

Konecny, G. 1980. How the Analytical Plotter Works and Differs From the Analog Plotter. Proceedings of the Analytical Plotter Symposium and Workshop. The American Society of Photogrammetry. Virginia. 459 pages.

Lachowski, H.M. 1986. Study of Quality of Aerial Photography.Engineering Field Notes. vol. 18. USDA Forest Service. Wash. D.C. 61 - 72.

Lyon, Duane. 1959. Basic Metrical Photogrammetry. John S. Swift Co. St. Louis, Mo.

Marble, D.F., and D.J. Peuquet. 1983. Geographic Information Systems and Remote Sensing: Manual of Remote Sensing, 2nd ed. Falls Church, Va. American Society of Photogrammetry. pp. 923-958.

Merritt E.L. 1958. Analytical Photogrammetry. Pitman Publishing Co. New York. 242 pages.

Minckler, L.S. and J.D. Woerheide. 1965. Reproduction of Hardwoods 10 Years After Cutting as Affected by Site and Opening Size. J. For. 63, 103-107.

Minckler, L.S., J.D. Woerheide, and R.C. Schlesinger. 1973. Light Soil Moisture and Tree Reproduction in Hardwood Forest Openings. USDA For. Serv., NC For. Exp. Sta. Res. Paper. NC-89.

Moffitt, F. H. and E. M. Mikhail. Photogrammetry. Harper and Row. Cambridge, Mass. 648 pages.

Neilson, R.P. and L.H. Wullstein. 1983. Biogeography of two southwest American oaks in relation to atmospheric dynamics. J. of Biogeography. 10, 275-297.

Newcomer, J.A. and J. Szajgin. 1984. Accumulation of Thematic Map Error in Digital Overlay Analysis. The American Cartographer, 11(1): 58-62.

Paine, D.P. 1981. Aerial Photography and Image Interpretation for Resource Management. John Wiley and Sons. New York. 571 pages.

Park, C.C. 1980. Ecology and Environmental Management: A Geographic Perspective. Dawson Westview Press. Kent, England. 272 pages.

Phares, R.E. and R.D. Williams. 1971. Crown Release Promotes Faster Diameter Growth of Pole-Size Black Walnut. Res. Note NC U.S. For. Serv. NC-124.

Pickett, S.T.A. and P.S. White, ed. 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press Inc. London, England. 472 pages.

Reutebuch, S.E. 1987a. PC-Based Analytical Stereoplotter for Use in Forest Service Field Offices. Paper presented at the 1987 American Society of Photogrammetry and Remote Sensing Fall Convention. Reno, Nevada. 11 pp.

Reutebuch, S.E. 1987b. Analytical Stereoplotter Specifications. unpublished technical report. USDA Forest Service. PNW Research Station. Seattle, Washington.

Reutebuch, S.E. and R.D. Shea. 1988. A Method to Control Large-Scale Aerial Photos When Surveyed Ground Control is Unavailable. Unpublished Report.

Runkle, J.R. 1985. Disturbance Regimes in Temperate Forests. In: The Ecology of Natural Disturbance and Patch Dynamics. ed. by. Pickett and White. Academic Press Inc. London, England. 472 pages.

Spurr, S.H. 1964. Forest Ecology. Ronald Press Co. N.Y. 352 pages.

Steger, T.D. 1986. Topographic Maps. (Place of publication unknown), U.S. Department of Interior, Geologic Survey. Leaflet. 27 pages.

Thompson, M.M. and H. Gruner. 1980. Foundations of Photogrammetry. In: Manual of Photogrammetry. 4th edition. American Society of Photogrammetry. Virginia. 1056 pages.

Tomanek, J. 1960. Mikroklimatische Verhaltnisse in Lochhiebe. Verh. Ganzstaatl. Bioklimatol. Konf., 2nd, Tschechoslowak. Acad. d. Wiss., Prague 1958 pp.297-313.

Trimble G.R. and E.H. Tryon. 1966. Crown Encroachment into Openings Cut in Appalachian Hardwood Stands. J. For. 62, 104-108.

Twito, R.H. and C.N. Mann. 1979. Determining Average Yarding Distance. Gen. Tech. Report PNW-79. USDA Pacific Northwest For. and Range Exp. Sta. 29 pages.

Valentine, W.H. 1986. Potential for Engineering Cost Savings with Analytical Photogrammetry. Engineering Field Notes. vol 18. USDA Forest Service. Wash. D.C. 29 - 38.

Vitek, J.D., S.J. Walsh, and M.S. Gregory. 1984. Accuracy in Geographic Information Systems: An Assessment of Inherent and Operational Errors, Proceedings, PECORA IX symposium. pp. 296-302.

Walsh, S.J., D.R. Lightfoot, and D.R. Butler. 1987. Assesment of Inherent and Operational Errors in Geographic Information Systems. Proceedings, American Society for Photogrammetry and Remote Sensing - American Congress on Surveying and Mapping, Baltimore, Ma.,5: 24-35.

Waring, R.H. and W.H. Schlesinger. 1986. Forest Ecosystems: Concepts and Management. Academic Press Inc. Orlando, Florida. 340 pages.

White, P.S. 1979. Pattern, process, and Natural Disturbance in Vegetation. Bot. Rev. 45, 229-299.

Wolf, P.R. 1983. Elements of Photogrammetry. McGraw-Hill Inc. New York. 628 pages.

Appendices

APPENDIX 1

Technical specifications for analytical stereoplotters. From "Automated Methods for Using Aerial Photography in the Logging Systems / Transportation Planning Process". (FSL, Seattle, RWU 4703, Forest Engineering Systems).

ANALYTICAL STEREOPLOTTER--Technical Specifications

The following is a list of the specifications that an instrument should have in order to be well suited for typical forestry applications.

1--SOFTWARE COMPATIBILITY

Compatible with MS-DOS and ANSI 77 FORTRAN

All software supplied with the instrument must be written in ANSI 77 FORTRAN and be executable, without modification, on the IBM-AT compatible microcomputer under the MS-DOS 2.11 operating system. This microcomputer and operating system are supplied via government contract. The instrument must be compatible with this microcomputer

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2--HARDWARE COMPATIBILITY

RS-232C Interface

The instrument must communicate with the IBM-AT compatible microcomputer via a standard RS-232 interface.

3--OPTICS

1X to 8X viewing magnification (approximate)

Viewing magnification must be easily interchangable from approximately 1X to 8X. In many of logging and transportation planning applications, the planner must be able to view a large portion of the stereo model (at 1X magnification) to formulate overall system patterns and then switch to a higher magnification to take specific measurements of discrete features within the planning area. This capability to switch from low to high magnification can be met by either a zoom capability or a set of 8X binocular optics that the planner can use at will to view details.

4--PHOTO FORMAT SIZE

Format sizes ranging from 35mm X 35mm to 230mm X 230mm

The instrument must be capable of handling both aerial and terrestrial photography ranging in size from 35mm to standard 9" X 9" aerial photos (230mm X 230mm). The instrument will be used for working involving both traditional aerial photography produced using 9" X 9" metric cameras and terrestrial photography using 35mm and 70mm non-metric cameras.

5--ACCESS TO PHOTOS DURING OPERATION

Allows the user to sketch on the photos while mounted in the instrument

In most of the planning activities for which photos are used, the planner must be able to mark features and sketch boundaries on the photos while the photos are mounted in the instrument and being viewed stereoscopically.

6--PHOTO MEDIUMS

Paper prints and transparencies of photos

The instrument must be capable of accepting paper prints and transparencies of photos. For all of the traditional aerial photo uses, paper prints of the photos will be used with the instrument. In many of the terrestrial photography applications, the user will use the negatives from 35mm or 70mm photos to make measurements.

7--EASE OF OPERATION

One week training period

The instrument must be simple enough to use so that a resource specialist, who is familar with the use of a mirror stereoscope, can effectively operate the instrument after a one week training session.

8--PHOTO ORIENTATION

Software routines for interior, relative, and absolute orientation

The instrument must be supplied with analytical orientation routines that enable the user to perform interior, relative, and absolute orientation. The software should also include a routine that allows the user to re-set a model by using previously determined orientation parameters and stored control data. The software must also allow the user to re-set photos simply by digitizing fiducials and reading digital orientation data from other sources such as analytical aerotriangulation programs, e.g MAPP/PAL/ALBANY.

9--MAINTENANCE

Self Calibration Routine

The instrument must be supplied with a self calibration routine that enables the user to re-calibrate the instrument in-place without the need of specialized personnel.

10--ACCURACY

20 microns in X and Y directions at photo scale

The instrument must be capable of measuring photo coordinates to within 20 microns. Working with resource photography (1:12,000), this accuracy corresponds to a 12 inch circle on the ground. At a photo scale of 1:1,000 (typical for terrestrial photos), this accuracy corresponds to a one inch circle on the ground. For all photo work to be undertaken in this study, both aerial and terrestrial, this accuracy is sufficient.

11--WORK ENVIRONMENT RESTRICTIONS

Normal Forest Service Ranger District Office environment

The instrument must not require any environmental controls in the office that are not currently met by normal heating, cooling, and humidity, lighting controls in Ranger District offices. The instrument must be compact and light enough to be installed on a 3′ X 6′ office desk.

12--AUTOMATIC Y-PARALLAX REMOVAL

Parallax free viewing of the entire model after orientation

The instrument must automatically remove y parallax throughout the entire stereo model once a single relative orientation has been performed. This feature greatly increases the ease with which the instrument can be used. It also greatly reduces the eye strain associated with stereo viewing.

Summary of Survey of Analytical Stereoplotter Manufacturers Oct 1987

The following is a list of all manufacturers of analytical stereoplotters. The Carto Instruments AP 190 is the only instrument that fully meets the specifications needed to meet project goals. For the other instruments on the list, the specification(s) that are not met by each instrument are detailed.

Each manufacturer was contacted by phone or letter. Technical specification sheets for each instrument were requested, along with current pricing information. Costs are approximate and may be outdated.

Carto Instruments AP 190 Analytical Stereoplotter
Price: $ 40,000

Carto Instruments A/S
Postbok 215
1430 Aas, Norway FAX: 011-47-9941925

The AP 190 meets all specifications.

Adam Technology MPS-2 Micro Photogrammetric System
Price: $ 39,000

E. Coyote Enterprises
One Coyote Circle
Rt. 4 Hdq. Bldg. 228
P.O. Box 1119
Mineral Wells, Texas 76067
(817) 325-0757

The MPS-2 does not meet specifications 3,4,5,6,8:

3--OPTICS

1X to 8X viewing magnification (approximate)

Viewing magnification is 7X-20X. Minimum magnification is 7X.

4--PHOTO FORMAT SIZE

Maximum format size is 70 mm X 70 mm.

5--ACCESS TO PHOTOS DURING OPERATION

The user can not sketch on the photos while mounted in the instrument.

6--PHOTO MEDIUMS

Paper prints can not be used in the instrument.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

Qasco SD-4 Analytical Stereoplotter
Price: $ 33,000

Qasco Pty Ltd.
P.O. Box 233
Baulkham Hills
NSW 2153
Australia
Phone: (02) 639-8822

Specifications not met: 1,3,5,8

1--SOFTWARE COMPATIBILITY
The software for this instrument would require modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

3--OPTICS
The optics are fixed at 6X magnification.

5--ACCESS TO THE PHOTOS
The photos are not accessable to the user during use

of the instrument.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

B&L Stereo ZTS w/ VM Module
Price: $ 33,000

Bausch & Lomb
Optical Systems Division
P.O. Box 450
Rochester, NY 14692
Phone: (716) 338-6000

Specifications not met: 5,8

5--ACCESS TO PHOTOS DURING OPERATION

The user can not sketch on the photos while mounted in the instrument.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

PHOTOGRAMMETRIC SYSTEMS APY
Price: $ 40,000

Photogrammetric Systems
8332 Russikon
Switzerland
Phone: 01 954 08 60

Specifications not met: 5,8,10,12

5--ACCESS TO PHOTOS DURING OPERATION

The user can not sketch on the photos while mounted in the instrument.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation. Many, rather than a single, relative and absolute orientation are needed to work over the entire stereo model area--see 12 below.

10--ACCURACY

Does not meet the 20 micron accuracy requirement.

12--AUTOMATIC Y-PARALLAX REMOVAL

Repeated orientations must be performed to move to different areas of the model, particularly if higher magnification optics (4X) are used.

Zeiss Stereocord G3 Analytical Stereoplotter
Price: $ 42,000+

Carl Zeiss, Inc.
One Zeiss Drive
Thornwood, NY 10594
Phone: (914) 747-1800

Specifications not met: 1,2,8,12

1--SOFTWARE COMPATIBILITY
All of the software is written in Hewlett-Packard BASIC and would require extensive modification to execute on the IBM-AT compatible microcomputer under MS-DOS.

2--HARDWARE COMPATIBILITY
This instrument communicates to the HP86 microcomputer via an HPIB interface, not an RS-232 interface.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

12--AUTOMATIC Y-PARALLAX REMOVAL
This instrument does not automatically remove y-parallax under computer control after orientation.

AMI 35/70 Analytical Stereoplotter
Price: $ 58,500

American Measuring Instruments
2400 Freedom
San Antonio, TX 78217
Phone: (512) 828-1213

Specifications not met: 1,2,3,4,5,6,8

1--SOFTWARE COMPATIBILITY
The software for this instrument would require modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

2--HARDWARE COMPATIBILITY
This instrument is only supplied with an IEEE interface. No RS-232 is offered.

3--OPTICS
The minimum magnification with this instrument is 8X.

4--PHOTO FORMAT SIZE
The maximum format size is 2.25 inches (70mm). Standard 9" X 9" photos can not be used.

5--ACCESS TO THE PHOTOS
The photos are not accessable to the user during use of the instrument.

6--PHOTO MEDIUMS
Only transparencies can be used, not paper prints.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

Galileo Digitcart Analytical StereoPlotter
Price: $ 65,000

Galileo Corp. of America
291-293 Main St.
Eastchester, NY 10709
Phone: (914) 961-6020

Specifications not met: 1,2,3,5,8

1--SOFTWARE COMPATIBILITY
The software for this instrument would require

modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

2--HARDWARE COMPATIBILITY
This instrument is only supplied with a parallel interface. No RS-232 is offered.

3--OPTICS
The minimum magnification with this instrument is 8X.

5--ACCESS TO THE PHOTOS
The photos are not accessable to the user during use of the instrument.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

OMI AP5 Analytical Stereoplotter
Price: $ 70,000

OMI Corp. of America
1319 Powhatan St.
Alexandria, Virginia 22314
Phone: (703) 549-9191

Specifications not met: 1,2,3,5,8

1--SOFTWARE COMPATIBILITY
The software for this instrument would require modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

2--HARDWARE COMPATIBILITY
This instrument requires specialized interfacing.

3--OPTICS
The minimum magnification with this instrument is 8X.

5--ACCESS TO THE PHOTOS
The photos are not accessable to the user during use of the instrument.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

Matra Traster T2 Analytical Stereoplotter
Price: $ 100,000

Matra Technology
2840-100 San Tomas Expressway
Santa Clara, CA 95051
Phone: (408) 986-9910

Specifications not met: 1,2,3,5,7,8,11

1--SOFTWARE COMPATIBILITY
The software for this instrument would require modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

2--HARDWARE COMPATIBILITY
This instrument requires specialized interfacing.

3--OPTICS
The minimum magnification with this instrument is 10.

5--ACCESS TO THE PHOTOS
The photos are not accessable to the user during use of the instrument.

7--EASE OF OPERATION
This instrument has many additional controls that are not required for this project which results in undue complexity.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

11--WORK ENVIRONMENT RESTRICTIONS
This instrument requires a large area for installation.

Kern DSR-11 Analytical Stereoplotter
Price: $ 100,000

Kern Instruments, Inc.
Geneva Road
Brewster, NY 10509
Phone: (914) 279-5095

Specifications not met: 1,2,3,7,8

1--SOFTWARE COMPATIBILITY
The software for this instrument would require

modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

2--HARDWARE COMPATIBILITY
This instrument requires specialized interfacing.

3--OPTICS
The minimum magnification with this instrument is 5X.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

7--EASE OF OPERATION
This instrument has many additional controls that are not required for this project which results in undue complexity.

APPS-VI Analytical Stereoplotter
Price: $ 100,000+

Autometric, Inc.
5205 Leesburg Pike
Suite 1308/Skyline 1
Falls Church, Virginia 22041
Phone: (703) 998-7606

Specifications not met: 1,3,5,7,8

1--SOFTWARE COMPATIBILITY
The software for this instrument would require modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

3--OPTICS
The minimum magnification with this instrument is 2.3X.

5--ACCESS TO THE PHOTOS
The photos are not accessable to the user during use of the instrument.

7--EASE OF OPERATION
This instrument has many additional controls that are not required for this project which results in undue complexity.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

Wild BC2 Analytical Stereoplotter
Price: $ 90,000+

Wild Heerbrugg, Ltd.
P.O. Drawer P
Farmingdale, NY 11735
Phone: (800) 645-9190

Specifications not met: 1,2,3,5,7,8,11

1--SOFTWARE COMPATIBILITY

The software for this instrument would require modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

2--HARDWARE COMPATIBILITY
This instrument requires specialized interfacing.

3--OPTICS
The minimum magnification with this instrument is 6X.

5--ACCESS TO THE PHOTOS
The photos are not accessable to the user during use of the instrument.

7--EASE OF OPERATION
This instrument has many additional controls that are not required for this project which results in undue complexity.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

11--WORK ENVIRONMENT RESTRICTIONS
This instrument requires a large area for installation.

Helava US-2 Analytical Stereoplotter
Price: $ 125,000+

Helava Associates, Inc
21421 Hilltop St.
Southfield, Michigan 48034
Phone: (313) 352-2644

Specifications not met: 1,2,3,5,7,8,11

1--SOFTWARE COMPATIBILITY
The software for this instrument would require modification in order to execute on the IBM-AT compatible microcomputer under MS-DOS.

2--HARDWARE COMPATIBILITY
This instrument requires specialized interfacing.

3--OPTICS
The minimum magnification with this instrument is 8X.

5--ACCESS TO THE PHOTOS
The photos are not accessable to the user during use of the instrument.

7--EASE OF OPERATION
This instrument has many additional controls that are not required for this project which results in undue complexity.

8--PHOTO ORIENTATION

Can not read digital orientation data from other stereoplotters and aerotrig programs to eliminate the need for relative and absolute orientation.

11--WORK ENVIRONMENT RESTRICTIONS
This instrument requires a large area for installation.

INSTRUMENT COMPARISON MATRIX

INSTRUMENT	SPECIFICATIONS NOT MET											
	1	2	3	4	5	6	7	8	9	10	11	12
Carto AP190	(Meets all specifications)											
Qasco SD-4	X		X		X			X				
B&L ZTS					X			X				
APY					X			X				X
Zeiss G3	X	X						X				X
AMI 35/70	X	X	X	X	X	X		X				
Digicart	X	X	X		X			X				
OMI AP5	X	X	X		X			X				
Traster T2	X	X	X		X		X	X			X	
Kern DSR-11	X	X	X				X	X				
APPS-IV	X		X		X		X	X				
Wild BC2	X	X	X		X		X	X			X	
Helava US-2	X	X	X		X		X	X			X	
Adam MPS-2			X	X	X	X		X				

Of the instruments surveyed, the Carto AP190 instrument is the only instrument available that meets all 12 technical specifications required for project work.

APPENDIX 2

Program to convert Carto AP190 object coordinate files to ARC\INFO format.

(With permission from Kevin Boston, VESTRA RESOURCES Corp. Redding Ca. 1989.)

```
C
C*****************************************************
C*    MM/DD/YY    WHO    STER              DESCRIPTION
C*    07/07/88    KDB    ----         ORIGINAL DEVELOPMENT
C*
C*****************************************************
C
      PROGRAM CARTARC
C
      CHARACTER * 47 TITLE
      CHARACTER * 20 FILEIN,FILOUT
      CHARACTER * 18 LINE2
      CHARACTER * 17 LINE1
      CHARACTER * 13 LINE3
      CHARACTER * 6 BLANK
      CHARACTER * 3 END
      CHARACTER * 2 TERM
      CHARACTER HOLD,LAY
C
      INTEGER OLDPOL,POLY,COL,INP,OUT,LAYNUM,RANGE
C
      DOUBLE PRECISION  XCOR,YCOR
C
      HOLD='Y'
      TERM='PC'
C
      TITLE='CARTO PLOT COORDINATE FILE TO ARC/INFO
     &      COVERAGE'
C
      LINE1='INPUT FILE NAME: '
      LINE2='INPUT LAYER CODE: '
      LINE3='INPUT RANGE: '
      OUT=2
      INP=1
      END='END'
C
C     WRITE TITLE USING DIRECT CURSOR CONTROL
C
      CALL CLEAR
      CALL HEADER
      IROW=5
      ICOL=17
      CALL DCA(IROW,ICOL,HOLD)
      WRITE(5,1000)TITLE
C
C     WRITE FIRST LINE AND READ INPUT FILE NAME
C
10    IROW=8
      ICOL=1
      CALL DCA(IROW,ICOL,HOLD)
      WRITE(5,1100)LINE1
```

```
      IROW=8
      ICOL=18
      CALL DCA(IROW,ICOL,HOLD)
      READ(5,1200,ERR=10)FILEIN
15    IROW=9
      ICOL=1
      CALL DCA(IROW,ICOL,HOLD)
      WRITE(5,1300)LINE2
      ICOL=19
      CALL DCA(IROW,ICOL,HOLD)
      READ(5,1400,ERR=15)LAYNUM
      IF(LAYNUM .NE. 0)THEN
         NUMLAY=NUMLAY+1
         LAY=CHAR(NUMLAY+48)
25       IROW=10
         ICOL=1
         CALL DCA(IROW,ICOL,HOLD)
         WRITE(5,1500)LINE3
         ICOL=14
         CALL DCA(IROW,ICOL,HOLD)
         READ(5,1400,ERR=25)RANGE

         COL=INDEX(FILEIN,'.')
C
         FILOUT=FILEIN(1:COL-1)//'-'//LAY//'.OUT'
C
C           OPEN INPUT FILE - FILEIN AND OUTPUT FILE -
          FILOUT
C
         OPEN(UNIT=INP,FILE=FILEIN,STATUS='UNKNOWN',
     1   ACCESS='SEQUENTIAL',FORM='FORMATTED')
         OPEN(UNIT=OUT,FILE=FILOUT,STATUS='UNKNOWN',
     1   ACCESS='SEQUENTIAL',FORM='FORMATTED')
C
         ICOUNT=0
20       READ(INP,2000,END=30)POLY,XCOR,YCOR
         IF(POLY   .GE.   LAYNUM   .AND.   POLY   .LE.
         LAYNUM+RANGE)THEN
            ICOUNT=ICOUNT+1
            IF(ICOUNT .EQ. 1)THEN
               WRITE(OUT,3000)POLY
               WRITE(OUT,3100)XCOR,YCOR
               OLDPOL=POLY
            END IF
            IF(OLDPOL .NE. POLY)THEN
               WRITE(OUT,4000)
               WRITE(OUT,3000)POLY
               WRITE(OUT,3100)XCOR,YCOR
               OLDPOL=POLY
```

```
                ELSE
                   IF(ICOUNT .GT. 1)THEN
                      WRITE(OUT,3100)XCOR,YCOR
                   END IF
                END IF
             END IF
             GOTO 20
C
C            AT END OF INPUT FILE INPUT FINAL TWO END
C
30           CLOSE(INP,STATUS='KEEP')
             WRITE(OUT,4000)
             WRITE(OUT,4000)
             CLOSE(OUT,STATUS='KEEP')
          END IF
          IF(LAYNUM .NE. 0)THEN
             GOTO 15
          END IF
1000      FORMAT(A47)
1100      FORMAT(A17)
1200      FORMAT(A20)
1300      FORMAT(A18)
1400      FORMAT(I5)
1500      FORMAT(A13)
2000      FORMAT(1X,I9,2X,F11.3,2X,F10.3)
3000      FORMAT(1X,I9)
3100      FORMAT(1X,F11.3,',',F10.3,5X)
3200      FORMAT(1X,A3)
4000      FORMAT(1X,'END')
          END
```