Captain Robert H. Clegg, U. S. Army
Sun Prairie, WI 53590
Professor James P. Scherz
University of Wisconsin
Madison, WI 53706

A Comparison of 9-Inch, 70mm, and 35mm Cameras

Small-format cameras can obtain simultaneous color and color-infrared photos more economically than standard mapping cameras and they may be entirely adequate for environmental mapping.

Abstract: *Successful aerial photography depends on aerial cameras that provide acceptable photographs within the cost restrictions of the job. For topographic mapping where ultimate accuracy is required, only large-format mapping cameras will suffice. For mapping environmental patterns of vegetation, soils, or water pollution, 9-inch cameras often exceed accuracy and cost requirements, and small formats may be an overall better choice. In choosing the best camera for environmental mapping, relative capabilities and costs must be understood.*

This study compares resolution, photo interpretation potential, metric accuracy, and cost of 9-inch, 70mm, and 35mm cameras for obtaining simultaneous color and color-infrared photography for environmental mapping purposes.

Photographs originally were used only to provide visual pictures of some object or scene. Little effort was given to make the picture metrically correct (the position of points correct) until such cameras were used in making maps. Over the years great effort has been put into manufacturing mapping cameras that can provide as nearly perfect a perspective image as possible in order to determine the position of an object with accuracies approaching 1/10,000 of the flying height. This means that photography taken 1000 feet above the terrain can be used to measure the correct position of an object on the ground to within 0.1 feet, or approximately one inch.[1]

Such cameras, together with the manner in which error effects have been accounted for, bring credit to the technical expertise of those who develop and manufacture them. However, there is a price to pay for such perfection. Modern aerial mapping cameras are large, utilizing 9-inch film formats. Further, they are very expensive, sometimes costing more than the aircraft that carry them. Their large size allows only one camera to be used through a camera port in the floor of the aircraft; if simultaneous photography is needed, another camera port must be cut and another camera obtained.

When color and color-infrared film began to be used for mapping of environmental factors, it was common to take such photography with the 9-inch cameras which were well established for accurate topographic mapping purposes. However, for mapping of environmental factors such as the approximate boundary of a tree or grass type, a soil type, or a water pollution plume, such mapping usually requires accuracy in the tens of feet and does not require the fraction-of-a-foot accuracy necessary in topographic mapping.

For environmental mapping, it is almost always desirable to obtain simultaneous color and color-infrared photos. This requires two cameras. Most mapping aircraft are set up for one camera only and therefore two separate flights are necessary. This introduces a time lag into the monitoring as well as additional cost. Strandberg in 1963 suggested that 35mm-format cameras could be used for much environmental analysis.[2] Marlar and Rinker in 1967 indicated the economy and versatility of doing such work by using 70mm cameras.[3] Four cameras were employed in their work through one camera port. Other work has indicated that although nine lenses, four cameras, or three cameras may provide valuable additional data, two cameras utilizing color and color-infrared film adequately cover all wavelengths needed for environmental mapping. Color film which combines blue, green, and red images into one composite color photo can be used by interpreters better than the three individual black-and-white photos taken in the blue, green, and red wavelengths. Finally by projecting this color film through blue, green, and red filters, one can recreate the corresponding three black-and-white bands. A microdensitometer can also be used to obtain the intensity in any band.[4]

With color-infrared film, one is in effect creating a composite photo with green, red, and infrared images. These also can be separated by projecting the resulting photo through blue, green, and red filters. Ishaq[5] has projected 35mm film through a #27 Wratten filter onto a base map and very effectively mapped high-moisture soils which show up as dark on the infrared image which is preserved in the color-infrared film. These patterns were not visible to the interpreter until the photo was projected through this red filter, which then created in effect a black-and-white infrared photo. This technique also can be used for any other desired wavelength of photographic energy. Infrared energy (image as red on color infrared film) is especially useful in environmental work such as vegetation studies, and also water quality monitoring, because it penetrates very little into the water.[6] The blue and green images on the color film are especially useful in water quality studies because they do penetrate well into the water. Normal color film is also very valuable for photo interpretation work because it provides a true-to-life image.

The conclusion here is that two cameras, one containing color and one containing color infrared film, give the optimum combination for analysis of the environment by remote sensing. The assumption was therefore made in this study that a two-camera system was the optimum for environmental mapping.

At the University of Wisconsin, two 35mm bulk-film motorized cameras have been in use since 1970 for environmental monitoring[7] (see Figure 1). In addition to the economics of such a system, the resulting 35mm bulk color and color-infrared film is in effect microfilm and a remote sensing library has been set up for cataloging, retrieving, and viewing such film.[8] Figure 2 shows such bulk 35mm color-IR film being projected onto a rear projection screen in order to extract environmental data. This system has been very successful both in research and in teaching of environmental monitoring by remote sensing. Gustafson (1973) has very effectively used this system for mapping of aquatic weeds.[9] Although cost and data handling advantages of the 35mm format are obvious, the question always arises concerning its resolution potential and metric accuracy, especially as compared to 70mm film. Some investigators prefer to use the 9-inch format because they feel much more comfortable with its theoretically better metric accuracy and resolution, and perhaps because of the tradition of use.

Of course according to accepted theory,

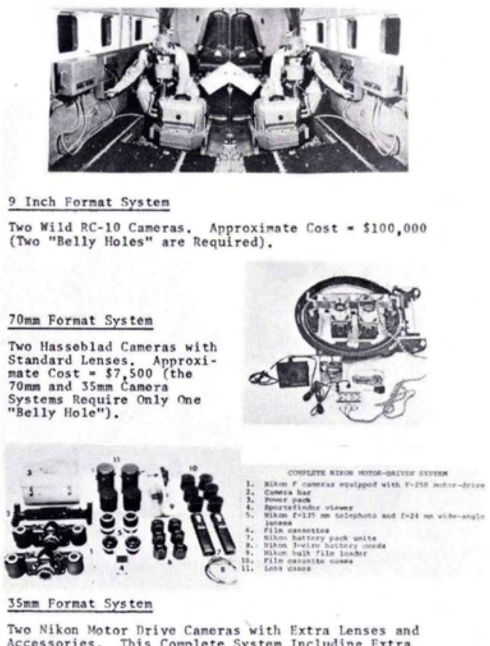

FIG. 1. Comparison of 9-inch, 70mm, and 35mm equipment for obtaining simultaneous color and color infrared photography for environmental mapping.

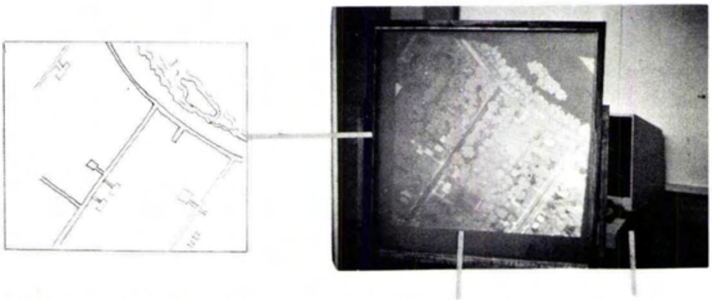

FIG. 2. Projecting a 35mm image onto a tiltable rear projection screen. The projected image is made to match the base map. Environmental detail on the photo is then traced onto the map. This figure shows bulk 35mm film being projected by a Kodak Recordak Motormatic microfilm viewer which has the screen removed. If the 35mm film is made into slides, these can be projected by standard slide projectors.

metric accuracy, resolution, and photo interpretation ability should be superior on the 9-inch format compared to the 70mm format, and better on the 70mm format than on the 35mm format. But the question is "How much better?" Also, are the theoretical differences in resolution, metric accuracy, and interpretation ability really significant when compared to the difference in cost and ease of use?

To answer these questions, an area of environmental interest was photographed with simultaneous 35mm, 70mm, and 9-inch photography taken from various altitudes, and the resulting photography was compared concerning resolution, photo interpretation potential, metric accuracy, and cost. This paper describes the investigation.

The site chosen was near Madison, Wisconsin in a marshy and wooded area where a new highway was proposed. The Wisconsin Department of Transportation* was interested in testing the University of Wisconsin's bulkfilm 35mm and color-infrared photography system in this area as a means of mapping the environment and monitoring its change. They suggested the study to University of Wisconsin personnel and all agreed that it was an ideal site.

The main environmental elements of interest for this study were soils, vegetation, and water. Experts from the state agencies (Wisconsin Department of Transportation and Department of Natural Resources) agreed to analyze the different-sized-format photography concerning photo interpretation potential for soils and vegetation mapping. Resolution panels were laid out and photographed with each camera. Engineering Services of the Wisconsin Department of Transportation already had mapped part of this area by conventional photogrammetric mapping techniques, and this map helped provide the base control for metric accuracy studies.

The area was flown with a DC3 which had the capability of providing 9-inch, 70mm, and 35mm photography simultaneously. The focal lengths for the 70mm and 35mm cameras were chosen so that approximately the same area was covered by each camera (see Figure 3). The resulting photos were then enlarged and rectified in the same enlarger to bring them to a common scale for the metric accuracy comparison (see Figure 4). The photos were viewed stereoscopically for the photo interpretation tests and resolution studies.

Details of these studies and the cost comparisons follow in this paper.

Research Specifications and Field Work

The research area selected for this project was the Mud Lake area south of Madison, Wisconsin. The study area extends 4,000 feet in the north-south direction and 14,000 feet in the east-west direction. Most of the area is marsh with swamp vegetation and sandy soils. The topography is predominantly flat with the lake in the center. The western sector is under cultivation while the eastern sector contains a petroleum tank farm. U. S. Highway 12/18, which is the south Madison beltline, provides the northern border of the study area.

The flight plan included one flight line

* Engineering Services Section of Wisc. Dept. of Transportation (Vern Schultz, Director).

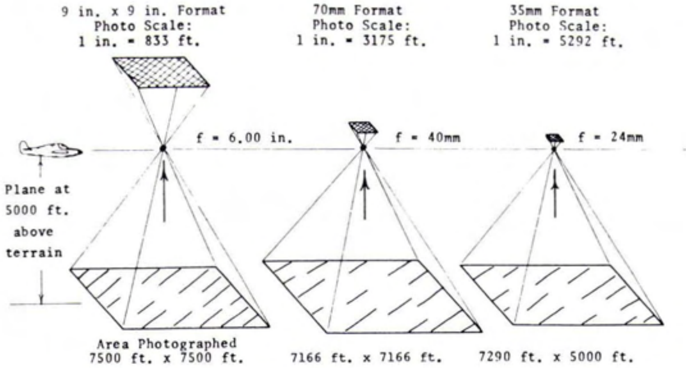

FIG. 3. Acquiring the 9-inch, 70mm, and 35mm photography for comparison. The above sketch shows the photo scales and the areas covered for a flying height of 5000 feet above terrain. The area of coverage for all three formats is approximately the same due to the proper choice of focal lengths of lenses used on the 70mm and 35mm cameras.

from east to west centered over the research area. These flights were flown at 1000 feet, 3000 feet, and 5000 feet above terrain.The speed of the DC3 aircraft was 130 knots. A Nikon F motorized camera with a 24mm lens was used to take the 35mm photography. A Hasselblad M/EL camera with a 40mm wide-angle lens, was used for the 70mm photography, and the Fairchild 224 camera with a (Bausch and Lomb Metrogon) 6-inch focal length lens was used for the 9-inch format photography. The films used were Color Infrared 2443 transparency for the 35mm imagery, Ektachrome MS transparency for the 70mm photographs, and Aerochrome Infrared transparency for the 9-inch photos. Identical film in all three cameras would have been preferred but was not available at the time of the flight.

With these format and focal length combinations the area coverage on each format is nearly equal as indicated in Figure 3. The scales are therefore markedly different (see Table 1). It was necessary to equalize the scales for the metric accuracy comparison. Figure 4 depicts the rectification-enlarging process used to match the scales of the three formats. For the resolution comparison, resolution panels were placed in the petroleum tank farm area in the easternmost part of the study area (see Figure 5). These white cloth panels were of 15 feet square, 12 feet square, 9 feet square, 6 feet square, 3 feet square, and 1 foot square sizes.

Ground control was required for the metric accuracy comparison. Although the area was mapped at a scale of 1-inch-equals-50-feet by the Wisconsin Department of Transportation,

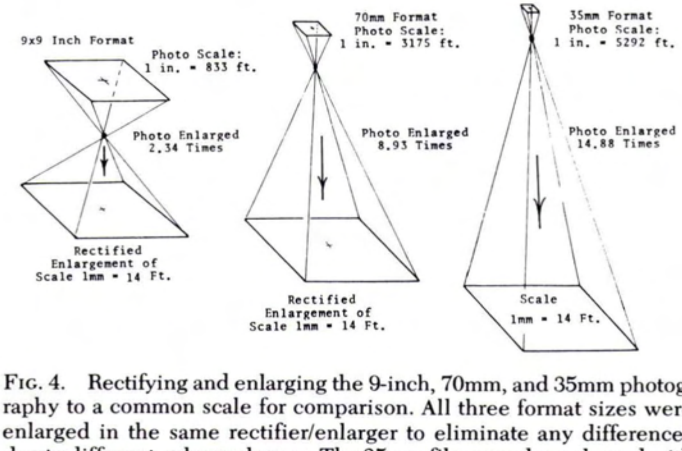

FIG. 4. Rectifying and enlarging the 9-inch, 70mm, and 35mm photography to a common scale for comparison. All three format sizes were enlarged in the same rectifier/enlarger to eliminate any differences due to different enlarger lenses. The 35mm film was also enlarged with standard slide projectors.

TABLE 1. PHOTOGRAPHIC DATA FOR THE THREE FORMATS FLOWN.

	35mm	70mm	9inch
Camera:	Nikon F	Hasselblad M/EL	Fairchild 224
Lens:	24mm	40mm Wide Angle	6-Inch
Format:	36mm×24mm	55mm×55mm	9in.×9in.
Films:	Color IR 2443 transparency	Ektachrome MS transparency	Aerochrome IR transparency
		Photo Scales	
Flying Heights			
1000 ft	lin.=1064ft	lin.=637ft	lin.=167ft
3000 ft	lin.=3191ft	lin.=1911ft	lin.=500ft
5000 ft	lin.=5292ft	lin.=3175ft	lin.=833ft
		Area Covered by One Exposure (ft)	
Flying Heights			
1000 ft	1511×1000	1433×1433	1503×1503
3000 ft	4531×3000	4299×4299	4500×4500
5000 ft	7290×5000	7166×7166	7500×7500

there was no existing control within the study area other than the plotted features on the map. A field check was conducted to determine the map's reliability. Several points on the map were chosen and the distances between them were measured on the ground with a DM-60 Cubitape. The distances between these same points were then measured on the original Cronaflex map with a glass scale. The map distances were scaled to the ground distance. Discrepancies then were calculated between the known ground distances and distances calculated from the map. The mean discrepancy between the map and the field check was found to be 0.78 feet, well within allowable map compilation error. When compared to the lengths of lines measured this resulted in a mean discrepancy of 0.12 percent (which is a 1.2-foot error in a thousand feet). The accuracy of the map was considered to be sufficient for the metric accuracy comparison. The map was used as a base in the rectification process.

RESOLUTION COMPARISON

Resolution, or sharpness, of a photographic image is dependent on the camera lens, the format of the photographs, the type of emulsion, and the shape and contrast of the target. It is of interest to know what size of photographed object can be seen from various flying heights on the different formats. The purpose of this comparison was to show the resolution differences between 35mm, 70mm, and 9-inch formats. The shape and contrast of the targets were the same for each format in this study. The flying heights were the same and the format-to-focal-length ratio was as near the same as possible.

An important consideration in comparing the resolution of the different formats is the format-to-focal-length ratios used to take the photography. The ratio of format-to-focal-length can be used to determine whether a lens is normal, wide-angle, or telephoto. These ratios for the 35mm, 70mm, and 9-inch photography must be nearly equal in this study. If the format-to-focal-length ratios are

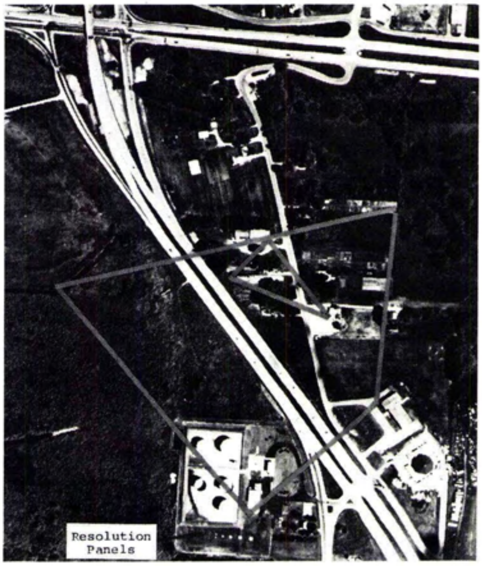

FIG. 5. 9-inch photograph showing the area on which the resolution and metric comparisons were made. The smaller control triangle demarks the base map controlled area. The quadrilateral shows the controlled area derived from the 9-inch photograph.

equal, approximately the same area will be covered by each photo.

It was not possible to obtain exactly equal format-to-focal-length ratios for the three camera systems used, but the available equipment provided ratios close enough to make the study acceptable. With the available lenses, the following ratios were established:

$$\frac{\text{35mm format (36mm actual)}}{\text{24mm focal length lens.}} = 1.50 \text{ ratio}$$

$$\frac{\text{70mm format (55mm actual)}}{\text{40mm focal length lens}} = 1.375 \text{ ratio}$$

$$\frac{\text{9-inch format}}{\text{6-inch focal length lens}} = 1.50 \text{ ratio}$$

With these ratios, the object size relationships on the different formats are indicated in Table 2.

TABLE 2. OBJECT SIZE DIFFERENCES FOR THE THREE FORMATS RELATIVE SIZE TO OBJECT ON X FORMAT.

X Format	35mm	70mm	9 inch
35mm	1 times	1.67 times	6.33 times
70mm	.6 times	1 time	3.8 times
9 in	.158 times	.263 times	1 time

As indicated, an object on the 35mm- and 70mm-format photos is considerably smaller than on the 9-inch photos (if the format-to-focal-length ratios are equal). The question is, to what extent does this difference in size affect the photo interpreters' ability to discern environmental detail when he views the images under magnification and how does this ability vary with the flying height of the aircraft? The resolution study attempts to answer these questions for varying flying heights up to 5000 feet above terrain.

The resolution analysis consisted of merely viewing each image and seeing which panels were visible, and indicating how sharp they appeared on each format for the various flying heights. Each exposure was studied on the University of Wisconsin's Fairchild Multi-Sensor Viewer under six-power magnification. The results are given in Table 3.

To differentiate resolution of the panels the following descriptive terms were used to establish degrees of clarity (Figure 6 illustrates the appearance of the panels related to these terms).

S = SHARP—no distortion or fuzziness, corners are acute
C = CLEAR—fuzziness is minimal, corners are not acute
B = BLURRED—fuzziness dominates, corners are not acute
NV = NOT VISIBLE—panels can not be seen at all

1000-FEET FLYING HEIGHT

Table 3 shows that at a flying height of 1000 feet there is little difference between the formats with respect to the resolution quality of the panels. On the 9-inch format the 6-foot-square panel and the 3-foot-square panels were resolved one degree sharper than on either the 35mm or 70mm formats.

3000-FEET FLYING HEIGHT

At 3000 feet, the 35mm and 70mm formats were nearly the same with the 70mm format resolving the 15-foot-square panel one degree sharper than on the 35mm format. The 9-inch format was substantially better than both the 35mm and 70mm formats. It was one degree sharper on 4 of the 6 panels when compared to the 35mm format, and better on 3 panels when compared to the 70mm format.

5000-FEET FLYING HEIGHT

At the 5000-foot flying height, the resolution of the panels on the 35mm and 70mm formats deteriorated and the 9-inch format

TABLE 3. RESOLUTION COMPARISON FOR THE THREE FORMATS (APPEARANCE OF PANEL UNDER 6× MAGNIFICATION). FORMAT /FLYING HEIGHTS (FT).

Panel	35mm Format			70mm Format			9-inch Format		
Size	1000	3000	5000	1000	3000	5000	1000	3000	5000
15ftsq	S	C	B	S	S	C	S	S	S
12ftsq	S	C	B	S	C	B	S	S	S
9ftsq	S	C	B	S	C	B	S	S	C
6ftsq	C	B	B	C	B	B	S	C	C
3ftsq	B	B	B	B	B	B	C	B	B
1ftsq	B	B	NV	B	B	B	B	B	B

S = Sharp; C = Clear; B = Blurred; NV = Not Visible

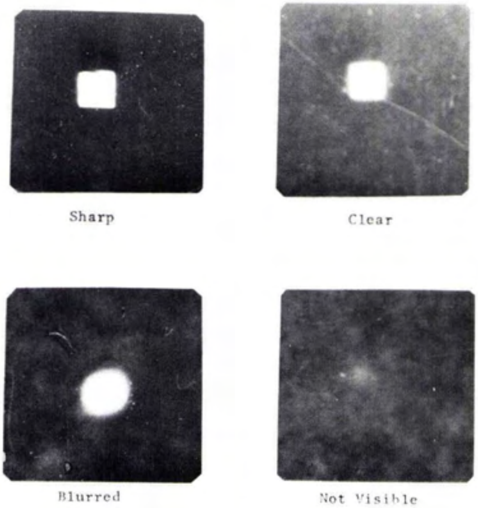

FIG. 6. Illustration of terms used to describe the resolution panels as they appeared to the individual viewing the 9-inch, 70mm, and 35mm photography.

was far superior to both of the smaller formats. This is illustrated in Figure 7.

Generally, the smaller formats are adequate with respect to resolution when using flying heights of 3000 feet or less, and there appears to be little difference between the 35mm and 70mm formats. At flying heights above the 3000-foot level, the 9-inch format is far superior.

AIRPHOTO INTERPRETATION COMPARISON

The second parameter to be tested was the ease or convenience of photo interpretation with the three formats. This comparison was geared specifically to vegetation and soils interpretation for mapping purposes. The objective of the comparison was to ascertain whether the smaller formats could provide image quality so that an interpreter can identify objects of interest as well on the 35mm and 70mm format as he can on the 9-inch format.

The aid of three soils experts and four vegetation experts was solicited. The experts individually viewed one set of stereo pairs of each format of the same general area. The stereo pairs were viewed under 4.5 magnification with the Delft Scanning Stereoscopes and the Fairchild Multi-Sensor Viewer. A cloth cover was placed over the stereoscopes so that the interpreter could not see which format he was viewing. He then judged each format. A list of criteria related to his particular field of expertise was provided as an aid to look for specific identification features.

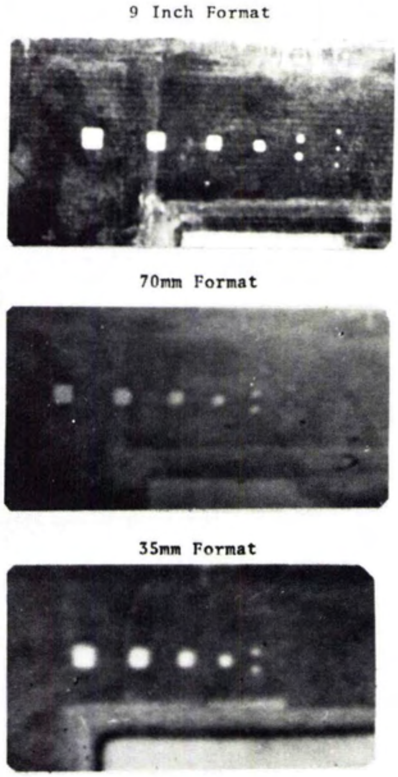

FIG. 7. Resolution panels from the 9-inch, 70mm, and 35mm formats, enlarged to a common scale of about one millimeter equals five feet. To make these prints, the 9-inch, 70mm, and 35mm photos were enlarged approximately 6.6 times, 25 times, and 42 times respectively.

The flying heights of all formats were 3000 feet. Unfortunately, no 70mm infrared false-color film was available, so normal color was used. Other qualifying aspects of this comparison were that the stereo model did not provide the identical coverage in each format (because all three cameras were not exactly synchronized). Also, two types of stereoscopes were used.

The criteria for soils interpretation included ability to interpret soil moisture, texture, color, vegetation cover, soil patterns, degree of erosion and drainage, the surrounding terrain, the land-use of the area, and the soil location and boundary. For vegetation interpretation, criteria included vegetation patterns and colors, canopy texture, shadows, branch patterns, vegetation shape and density, crown formation, and vegetation size and texture.

Before the results of the tests were known, when the vegetation experts were interviewed and asked their preference of format size, they mentioned that the small area covered per photo with smaller-format photography was restrictive. This preconceived notion was dispelled when the photos were uncovered and the area coverage was shown to be nearly the same on all the formats. It was pointed out that the same area coverage can be obtained by the smaller formats as by the 9-inch format if the correct format-to-focal-length ratio is used. This image can then be enlarged. Only one of the vegetation experts was able to correctly identify the three formats prior to the photos being uncovered. When the results of this test were tabulated, all four experts had picked the 35mm format as their first preference. They said that this format provided good color rendition and resolution. From the opinions of the four knowledgeable individuals who viewed the formats, it appears that the smaller formats can in fact provide acceptable results for vegetation mapping.

The three soils experts, on the other hand, all preferred the 9-inch format for mapping soil boundary locations. In each case they selected the 9-inch format as superior to the smaller formats for their work. When asked why, they stated that the sharper resolution was the determining factor. Further, they said, that for soils-mapping work the 9-inch format was much more convenient than the smaller formats, which must be enlarged. The soil boundaries stood out much clearer on the 9-inch formats than on the 35mm or 70mm formats. None of the soils experts correctly identified the concealed formats.

The vegetation experts were—

1. Alan Ek, Professor, Department of Forestry, University of Wisconsin.
2. Arlyn Linde, Vegetation Analysis Staff, Wisconsin Department of Natural Resources.
3. Don Thompson, Vegetation Analysis Staff, Wisconsin Department of Natural Resources.
4. Alan Rusch, Vegetation Analysis Staff, Wisconsin Department of Natural Resources.

The soils experts included:

1. Ralph Kiefer, Professor, Department of Civil and Environmental Engineering, University of Wisconsin.
2. James Elliott, Materials Section, District One, Division of Highways, Wisconsin Department of Transportation.
3. Richard Robinson, Central Office, Soils Unit, Division of Highways, Wisconsin Department of Transportation.

TABLE 4. PHOTO INTERPRETATION CAPABILITY OF THE THREE FORMAT SIZES (SUMMARY OF INTERPRETERS EVALUATION) RATINGS (1ST, 2ND, 3RD) ASSIGNED BY THE EXPERTS.

	Vegetation Experts				Soil Experts		
Format	1	2	3	4	1	2	3
9-in	2nd	3rd	3rd	3rd	1st	1st	1st
70mm	3rd	2nd	2nd	2nd	2nd	2nd	2nd
35mm	1st	1st	1st	1st	3rd	3rd	3rd

METRIC ACCURACY COMPARISON

The objective of the metric accuracy comparison was to determine the relative accuracy of the formats in locating objects of mapping purposes. Four tests were conducted in order to provide a comprehensive analysis between the 35mm, 70mm, and 9-inch formats.

The procedure involved obtaining a base map and using it as control in rectifying and enlarging the three formats to the same scale. Measurements were then taken on the rectified photos. The discrepancies between the measured distances and the base map distances provided the relative accuracy of the three formats. With these accuracy results, one can ascertain which format will meet his mapping accuracy needs.

A base map of the research area was first field checked and the photos then enlarged and rectified to match it. The objective of the rectifying and enlarging process was to remove the tilt error in the photographs and bring them to a desired scale. The process requires at least three control points, but usually at least four control points were used. The base map, with selected control points indicated, was placed on an easel. The negative or transparency was then placed in the rectifier-enlarger projector, and the photographic image was projected onto the base map. The scales of the projected image and map were made to coincide by enlarging or reducing the projected photograph. This was done by changing the distance between the projecting lens and the easel. The easel was then tilted and rotated so as to align control points on the base map to their image points on the projected photograph. Thus, average scale of the enlarged image matched that of the base map. When sharp focus was achieved, an exposure was made resulting in a rectified photograph. This procedure was followed with each of the formats. The work was done by the Wisconsin Department of Transportation which has had several years experience in operating the rectifying enlarger. The resulting rectified photos are approximately vertical photos and are all of the same scale (see Figure 4). The errors due to relief displacement still exist in the enlarged photo as well as errors due to focal plane flatness and lens distortion and accidental error due to the enlarger operator.[1] The original photos used were those taken from a flying height of 5000 feet above terrain. Accidental operator error should be expected in all rectification processes. In this case, the error was 1 percent in the 35mm and 9-inch formats and 1.6 percent in the 70mm format. This error was determined by measuring the lengths on the enlargements and the same lengths on the base map for three control points. These three control points created the control triangle shown in Figure 5. A mean scale factor was thus determined for each photo enlargement.

TEST I. The purpose of Test I was to determine the discrepancy between about 30 selected distances on the base map and those distances on the rectified enlargements. These 30 lines were all within the control triangle (Figure 5). The measured distances from the enlargements were adjusted by the mean scale factor described above. The adjusted length was then subtracted from the measured length of the lines on the field-checked base map. Table 5 shows the resulting discrepancies for the three formats. Surprisingly, the 35mm camera system provided the least error (an error of 1.39 percent).

TEST II. To supplement and attempt to verify the conclusion of Test I, Test II was undertaken. In Test II, a scale factor was established for each of the 30 lines. An error analysis was then run on these 30 scales. Table 6 shows the results of this test. Again the 35mm format provided the least error, this error being 1.49 percent

The test lines used in these first two tests were restricted to only a small portion of the format with all lines within the control triangle (see Figure 5). Test lines were not located on the perimeters of the format. By comparing enlargements it was obvious that greater error existed on the perimeters of the formats outside of the control triangle. The results of Tests I and II do indicate that within a small area of tight control, spaced within 600 feet, the smaller formats can provide just as good an accuracy in locating points as the 9-inch format photography.

TEST III. Because of the obvious error around the perimeters of the rectified photos, Test III was undertaken. In Test III, the 9-inch projection was used as base control and the 35mm and 70mm images were enlarged and compared to it. The 9-inch projection was used as a base because no map control existed on the perimeter of the photo area. The 9-inch enlargement was placed into the rectifier-enlarger and projected onto a Cronaflex base sheet. Four points were selected and plotted for control on the outer edges of the projected image. About 30 other points for comparison studies were plotted on the base sheet. The 35mm and 70mm format photographs were then rectified to both three and four control points derived from the 9-inch photographs. The 30 comparison

TABLE 5. RESULTS OF TEST I. DETERMINING DISCREPANCIES BETWEEN ADJUSTED PHOTO DISTANCES AND BASE MAP DISTANCES FOR 30 LINES WITHIN THE CONTROL TRIANGLE.

Format	Mean Discrepancies Of Measured Lines*	Standard Dev.	% Error**
9 in	0.355mm	0.445mm	1.77%
70mm	0.397mm	0.500mm	1.97%
35mm	0.286mm	0.342mm	1.39%

Scale of Enlargements: 1mm = 14 ft.

* Mean Discrepancy = Mean Difference in Length of Adjusted Lines on Enlargement Compared to Base Map.

** % Error = (Mean Discrepancy/Mean Length of Lines) × 100.

TABLE 6. RESULTS OF TEST II. ANALYZING SCALES OF 30 TEST LINES ON THE ENLARGEMENTS (TEST LINES ARE INSIDE OF THE CONTROL TRIANGLE).

Format	Average Scale	Discrepancy of Scale Factors				
		Mean* MM	Standard Deviation MM	Max "+" MM	Max "−" MM	%** MM
9 in	1.039	0.016	0.023	+0.046	−0.067	1.54
70mm	0.992	0.020	0.025	+0.057	−0.046	2.02
35mm	1.009	0.015	0.019	+0.058	−0.027	1.49

* Mean Discrepancy = Mean Difference in Scales Between Average Scale and Individual Scale Factors.

** % Discrepancy = (Mean Discrepancy/Mean Length of lines) × 100 points were plotted and the discrepancies in their locations were measured. Table 7 provides the comparison results which are in line with accepted theory of the accuracies of smaller format camera systems. It was found that the 70mm format provided better results than the 35mm format. It is interesting to note the differences between the discrepancies with respect to whether three or four control points were used in the rectifying process and whether the test points lie within or outside the controlled area. Points within the controlled area, on enlargements rectified with four control points, yielded the best accuracies. Ground positions of points located with the 70mm format were about 6.5 feet from the point's location as determined by the 9-inch format. The 35mm format was in error by about 11 feet, assuming the 9-inch format point locations were correct. Most environmental mapping requirements are in the neighborhood of tens of feet. This accuracy can be met easily with the smaller formats.

TABLE 7. RESULTS OF TEST III SMALL FORMAT PROJECTED IMAGES COMPARED TO 9-INCH BASE ENLARGEMENT.

Format	Test Points Inside Control Area		Test Points Outside Control Area		All Points In & Outside Control Area	
	Mean mm	SD mm	Mean mm	SD mm	Mean mm	SD mm
Rectification Using Three Control Points						
70mm	2.07	1.13	4.70	1.56	3.00	1.8
Rectification Using Four Control Points						
70mm	2.00	0.75	3.00	1.58	2.22	1.06
35mm	4.71	3.87	3.54	1.61	3.86	2.45

Scale = 1mm on Base Sheet = 3.2 Ft. on the Ground

TEST IV. Field personnel compiling vegetation and soils maps don't always have available sophisticated rectifying equipment; therefore, an additional comparison was conducted projecting a mounted 35mm slide onto the base map using a standard carousel type 35mm slide projector. The image was displayed on an upright easel screen mounted on a table with a rotating top. Figure 2 illustrates the process using a 35mm micro-film viewer. The image was rectified using three control points located on the outer edges of the format, and test points were plotted on the base sheet. Table 8 provides the results, which indicate that a point can be located within 8 feet of its correct position (correct position as derived from the 9-inch format photo).

The results of Test IV are superior to those of Test III. This is partly explained by the fact that the original exposure was used in Test IV as opposed to a reproduced enlarged transparency in which the resolution had deteriorated.

The results of these four tests indicate that small formats can provide metric accuracy of tolerable limits for vegetation, soils, and other environmental mapping. The tests using the field-checked base map conclude that points within a small controlled area will be located as accurately with the smaller formats as with the 9-inch format. The tests using 5000 foot photography and the 9-inch photo as a base and locating the control on the perimeter of the photo show that points can be located to within about ten feet with the smaller formats (assuming the points located with the 9-inch photographs are correct). As indicated from the results of Test IV, using a slide projector to transfer environmental data yields as accurate results as with a rectifier-enlarger. This information is helpful to those conducting small scale research where large facilities and sophisticated equipment are not available.

Errors inherent in photographic analysis do qualify the findings of these tests. As previously indicated there was about 1 percent error between the base map and the rectified 9-inch photographs. The base map also has an error of about 0.1 percent as compared to ground control. The points included both topographic and planimetric features, and relief displacement will distort the results. Because of deterioration in resolution of the smaller formats, point locations may not be

TABLE 8. RESULTS OF TEST IV POINT LOCATION DISCREPANCIES WHEN A SLIDE PROJECTOR PROJECTED A 35MM SLIDE ONTO THE 9-INCH BASE ENLARGEMENT.

Format	Test Points Outside Control Area		Test Points Inside Control Area		All Points	
	Mean	SD	Mean	SD	Mean	SD
35mm	1.91mm	1.38mm	0.825mm	0.52mm	1.61mm	1.19mm

Scale: 1mm equals 5 feet.
3 Control Points were used in the Rectification Process.

exact. Control points used in the rectification process in every case were not sharp and distinct points; therefore, coincidence in rectification may be an error. Measuring errors and paper and film shrinkage also contribute to errors in this comparison.

Cost Analysis

Based on the assumption that to do optimum environmental mapping, simultaneous photography with color and color infrared film is required, the costs of such 9-inch, 70mm, and 35mm camera systems were analyzed. A two-camera system was investigated for each format. With the 9-inch camera system only one focal length lens was considered. This had 6-inch lenses which could be classified a "normal" focal length lens. For the 70mm and 35mm formats, however, the costs of not only normal focal length lenses but also wide angle and telephoto lenses were included. For a two-camera system for the 9-inch format a relatively large aircraft with two camera ports is required while the 70mm and 35mm camera systems a smaller aircraft with one "camera port" will suffice. The difference in initial cost and cost of operation of the different types of aircraft, although very important, is not included in the analysis.

The different format photos can be handled and viewed by various methods. These different means of transferring the photo data onto the base map will be discussed but no actual dollar values will be attached to the different systems. Generally speaking, the projection systems for the larger format sizes are more expensive.

Nine × Nine Inch Formats

For simultaneous photography with the 9-inch format, two cameras are required. The cost figures given are for a Wild RC 10 camera system:

Two Camera Cost	$ 60,000
Two Lenses	30,000
Two Filters	3,000
Intervalometer	8,000
Total Cost	$101,000

Cost per simultaneous exposure on color and color IR film:

2× Film	$ 1.37
2× Development	1.36
2× Transparency	8.38
2× Prints	6.40
Total Cost	$17.51

The advantage of the 9-inch system is that it gives greater resolution. The lenses are specifically designed to eliminate lens distortion. Focal plane flatness is assured by a vacuum sucking the film flat against the focal plane. The disadvantage of the system is the high cost of equipment and high operational costs. A large aircraft is required to carry the two cameras. Viewing for photo interpretation can be done with conventional stereoscopes, and stereoplotters. Transfer of environmental data to a base map can be accomplished with a zoom transfer scope, a sketchmaster, a 9-by-9-inch rectifying enlarger, or by tracing onto a piece of transparent material laid directly over the photo and then enlarging this transparency to match the scale of a base map. Nine-inch photography can be obtained by contract from aerial photography firms but differential film costs alone can pay for the small format system. For example, an aerial photography mission of one flight line requiring 100 color and 100 color infrared exposures could cost from $2500 to $3000. Most firms do not have two 9-inch format cameras, making simultaneous coverage unlikely. Although numerous variables affect the costs, one can see the cost savings involved with smaller format systems.

70mm System

The cost analysis is made for a two-camera Hasselblad system of the type described by Malar and Rinker but with two cameras instead of four:

Cost of Cameras—2 Hasselblad	$1,500
Lens:	4,000
2× normal	
2× wide angle	
2× telephoto	
Filters	25 ea.
Intervalometer	112
Other aerial accessory equipment (Bulk magazine, cassettes, batteries, bulk film loader, case, command unit, recharge unit)	1,800
Total Cost	$ 7,500

Cost per simultaneous pair of color and color IR photos:

2× film	$ 0.15
2× development	0.42
2× transparency	1.64
2× print	0.64
Total cost	$ 2.85

The advantage of the 70mm system is that the resolution is still quite good. Film in color and color IR is readily available. The disadvantage of this system is that the film is not held flat in the focal plane and that the lenses are made primarily for image sharpness rather than for metric accuracy. The photos can be viewed in 3D with zoom stereoscopes. Environmental data can be transferred from the photo to a base map with a zoom transfer scope, or with a rectifying enlarger or a strip film projector. Although 70mm strip film projectors are made, they are not very common. The 70mm film can be cut and mounted onto 2-inch slides to use with 2-inch slide projectors which are obtainable but are not extremely popular. With any of the projection methods the image can be projected to match a transparent base map mounted on a rear projector screen. When the projected image is made to match the scale of the base map, the environmental data on the projected image can then be traced onto the base map.

35mm Format

The cost analysis on the 35mm system is made for the Nikon F2 camera. Robot and Canon cameras were also investigated.

Cost of Camera	
2 Nikon Motormetric	$ 2,400
Lenses:	1,900
2× normal	
2× wide angle	
2× telephoto	
Filters	12 ea.
Intervalometer	300
Other aerial accessory equipment (Bulk magazine, cassettes, batteries, bulk film loader, recharge unit, etc.)	1,800
Total Cost	$ 6,000

Cost per simultaneous pair of color and color infrared photos:

2× film	$ 0.04
2× development	0.22
2× transparencies	0.18
2× print	0.36
Total Cost	$ 0.80

The advantages of this system are that it is the least expensive in equipment and operation, the lightest in weight, and the most versatile. Also a two-camera bank can be hand held.[7] Various focal length lenses can be put on easily and quickly exchanged. The 35mm format is the universal format not only for microfilm but also for commercial moving picture film. Most film acquisition, processing and production is readily accomplished. The developed film can be handled like standard microfilm and viewed in a variety of 35mm viewers and projectors.

Another important aspect of the 35mm system is that it can be used to photograph at close range a data sheet at the beginning of each project or during flight so later on the film is not mis-identified. This is similar to what is done in the movie industry at the beginning of each set, or in microfilming at the beginning of each new series of articles.

The disadvantage of this format is that, like the 70mm format, the lenses are primarily designed for image sharpness rather than metric accuracy. There is no vacuum to assure focal plane flatness. The 35mm format has poorer resolution than the larger formats. Also at this stage of operation little 35mm color infrared film is sold in bulk and it must be specially ordered in large quantities from the factory.

Although overlapping 35mm photos can be viewed in 3D by some zoom stereoscopes, 35mm film is primarily viewed non-stereoscopically on 35mm microfilm readers. Two such viewers side by side can be nicely used to view both color and color infrared film.[7] With the 35mm Kodak Motormatic Microfilm Viewer the viewing screen can be taken off and the image can be projected directly onto a rear projection screen which can be moved to different distances from the viewer and tilted so that the projected image can be matched to the base map (see Figure 2). The environmental data can then be traced onto the base map. This is similar to the rectification process except that the desirable data is manually transferred and no photographic enlargement is made. If desired the film can also be copied with 35mm slide copiers or made into 35mm slides and projected in the same way.

Conclusion

The objective of this investigation was to analyze 9-inch, 70mm, and 35mm format photography with respect to resolution quality, photo interpretation capability, metric accuracy, and cost. The application in mind was for environmental mapping. For such work it was assumed that both color and color infrared photography was highly desirable and that a two-camera system was the best method for obtaining the required photography.

For the analysis an area of environmental interest to the Wisconsin State agencies was flown at different flying heights with 9-inch, 70mm, and 35mm photography. The area had a variety of soils, vegetation, and water types.

Resolution panels and ground control were also located in the area.

The results of these investigations indicate that small format camera systems can in fact play a key role in environmental mapping. The resolution comparison showed the superior quality of the 9-inch format at higher flying heights. At flying heights of about 1000 feet the resolution of the three formats seemed equally satisfactory. Both the 35mm and 70mm camera systems provided nearly the same resolution quality at each flying height tested. The air-photo interpretation comparison revealed that for soils mapping the smaller formats were less desirable while for the vegetation mapping comparison the smaller formats were preferred. The metric accuracy tests using a rectifier-enlarger showed that within small tightly controlled areas the smaller formats provided just as accurate point locations as the 9-inch format. However, when control is on the perimeter of the photograph, errors of about 10 feet can be expected with the smaller formats at flying heights of 5000 feet. The 35mm images were also projected utilizing a slide projector, and metric accuracy results were better than with the rectifying enlarger.

Costs analyses were made for 9-inch, 70mm, and 35mm camera systems capable of obtaining simultaneous color and color infrared photography. The costs of such systems are about $100,000 for the 9-inch format, with the standard lenses; and $7,500 and $6,000 respectively for the 70mm and 35mm systems including auxiliary lenses. Without the auxiliary lenses these small format systems can cost as little as $3,500. The cost of film and processing is about nine times greater with the 9-inch system. The savings in cost of photos alone between the 9-inch and the smaller format systems will pay for the smaller format systems within only several hundred to a few thousand photographs.

An additional factor that requires consideration is the convenience of use of the different format systems. For stereo viewing the 9-inch format is preferrable with the 70mm more desirable than the 35mm format. However, for filing, indexing, retrieving, projecting, and simultaneous viewing of different frames, the 35mm is preferred. A marked advantage of the 35mm format over the 70mm format is its compatibility with 35mm microfilm viewing and film handling equipment. The 70mm viewing equipment is expensive and difficult to procure. For projecting onto a base map for transferring environmental data the 35mm format equipment is easily obtained and easy to use. Both the 70mm and 35mm camera systems are light weight, versatile, and easy to operate and emplace for aerial application. A variety of lenses can be obtained and easily changed during aerial operations.

The results of this comparison provide a relative quality and cost standard of the three camera systems, providing the user a basis from which to make sound decisions. The accuracy requirement of environmental mapping is in the magnitude of tens of feet. Small format systems can provide such an accuracy, and their initial and operating costs are about 1/10 the cost of 9-inch mapping camera systems. For those engaged in environmental mapping it is recommended that they closely look at the small format camera systems, specifically the 35mm system, to ascertain which system can provide their mapping needs at the least cost.

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